

World day for safety and health at work

2023

Edited by

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World day for safety and health at work 2023

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Psychosocial ergonomics of the workplace of medical staff during the COVID-19 pandemic in three risk's dimensions: working hours, violence and the use of psychoactive drugs—a prospective pilot study

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Introduction: Workplace ergonomics should also be considered in the context of psychosocial factors affecting the worker, which have a real impact on occupational risk. The present study examined psychosocial risk factors in medical personnel in three domains: working hours, violence and substance abuse.

Methods: The purpose of the present study is to assess the current state of psychosocial ergonomics of medical personnels by measuring occupational risks in the domains of: working hours, violence and psychoactive substance abuse. The survey is consisted of two parts: socio-demographic information of participants and participants' assessments of psychosocial risk factors.

Results: In more than half of the respondents (52%), increased risk was identified in the domain of working hours. Nearly half of the respondents (49.6%) have an identified high risk in the domain of violence, and more than half of the respondents (52%) are at high risk in the domain of psychoactive substance abuse.

Discussion: Our findings show that the present psychosocial ergonomics of the Polish health system must be improved. The COVID-19 pandemic has been a compelling test to assess the current state. Our findings highlighted the fact that HCWs often worked overtime and that many cases of workplace violence and substance abuse were reported.

KEYWORDS

ergonomics, medical staff, occupational risk, workplace, occupational environment

1. Introduction

Poor psychosocial ergonomics at work should be considered a safety hazard because it has a negative impact on the mental health of workers. In many instances, the ergonomics of the workplace is poor in health care. Adverse ergonomics can be detrimental to the mental health of health care workers (HCWs). Given the high and unavoidable work stress of HCWs, it is

important to reduce stress from imperfect work ergonomics to improve the mental health of workers. To assess the psychosocial ergonomics of HCWs, we investigated psychosocial risk factors in three domains: hours of work, experience of workplace violence, and substance abuse.

We considered working hours as a major factor, since the long and exhausting working shifts of HCWs make them more exposed to stresses caused by imperfect work workplace ergonomics (1–4).

Workplace violence against medical personnel has a negative effect on workers mental health, exert psychological pressure on them, and can result in workplace absenteeism, job resignation (5–8). Workplace violence is complex problem which can impact different practitioners and can be caused by various risk factors including, high demand for health services, shortages of HCWs, long waiting times for health services, limited interpersonal trust, unrealistic patient expectations, and medical errors (9, 10).

There have been concerns about substance abuse, including alcohol, nicotine, and particularly psychoactive drugs that can alter the cognitive treatment, mood, and emotions of health care workers (11, 12). Predisposing factors associated with substances abuse among HCWs are complex and includes, dealing with pain and death of patients, workload, mental and physical exhaustion, low salaries, as well as access to psychotropic drugs (13). Since substance abuse among health care workers is a mechanism for coping with stress at work, the measurement of the extent of substance abuse among health care workers is an indicator of ergonomics in the workplace (14).

While many medical workers have faced unfavourable psychosocial ergonomics at work, the SARS-CoV-2 epidemic has exacerbated the problem. Factors such as fear of infection, forced overtime work, fatigue, and family isolation affected the mental health of medical workers during the outbreak which might engender risky behaviors such as substance use (15–17).

To understand the preparedness of our healthcare ergonomics in relation to epidemics, we evaluated occupational risks in the domains of which are outcomes of poor workplace psychosocial ergonomics: working hours, work place violence experience, and abuse of psychoactive drugs.

2. Materials and methods

2.1. Participants and settings

The survey was conducted between November 1, 2021 and December 31, 2021 during the COVID-19 pandemic. The survey was conducted in an online format, by using the electronic survey platform www.webankieta.pl.

The survey was distributed to medical staff of the Wrocław University of Medical Sciences including physicians, dentists, nurses, midwives, paramedics, and physiotherapists. Potential participants were given a link to the survey through their medical groups and social media. Completion of the survey was voluntary and data was collected anonymously. Participants could withdraw anytime. An IP address filtering (a numerical identifier given to a network interface) was used to avoid collecting duplicate responses from a participant.

The inclusion criterion for this study was being an active healthcare provider at the time of the survey, i.e., November–December 2021, during the COVID-19 pandemic. There were 143 potential participants in this study. From all, 18 surveyees submitted their response incomplete which were excluded from statistical analysis.

2.2. Research tool

The survey consists of two parts:

- a) socio-demographic information about participants.
- b) Participants' assessments of psychosocial risk factors.

The psychosocial risk factors section goes over three major themes, and each theme consists of 15 questions which are adopted from the European Commission's guide to health and safety risks in the healthcare sector (18):

- a) Working hours.
- b) Violence.
- c) Abuse of psychoactive substances.

Surveyees chose either “applicable” or “not applicable” in response to psychosocial risk factors' questions. We used the aggregated scores to assess the severity of psychosocial risks. The risk levels were defined as follows:

- a) No risk (1–5 marked answers “applicable”)—the need to take action on individual elements.
- b) Increased risk (6–10 marked “applicable” answers)—structural and control analyses are recommended.
- c) High risk (11–15 marked “applicable” answers)—need for urgent structural and control analyses.

For the purposes of this study, the following definition of “external” workplace violence was adopted: insults, threats, and physical or psychological aggression from people outside the organization, including customers (patients), which is directed against the person doing the work and threatens his or her health, safety or well-being - including those with racial or sexual motivation (18).

2.3. Ethical considerations

The study was carried out in accordance with the tenets of the Declaration of Helsinki and guidelines of Good Clinical Practice (World Medical Association, 2013).

Written information about the study was provided as an introduction to the survey, with an emphasis on the voluntary and anonymous nature of participation and its guaranteed confidentiality. By answering the questionnaire, participants gave their consent to participate in the study. The research project was approved by the independent Bioethics Committee at the Wrocław Medical University (No. KB-613/2021).

2.4. Statistical analysis

In the study, the analysis of quantitative variables (i.e., expressed by number) was carried out by calculating the mean, standard deviation, median and quartiles. The analysis of qualitative variables (i.e., not expressed by number) was carried out by calculating the number and percentage of occurrences of each value. Comparison of the values of quantitative variables in the two groups was performed using the Mann–Whitney test. Comparison of the values of quantitative variables in three or more groups was performed using

TABLE 1 Socio-demographic characteristics of the study sample (*N* =125).

Parameter		Total (<i>N</i> =125)
Sex	Female	68 (54.40%)
	Male	57 (45.60%)
Age (years)	Mean (SD)	32.11 (7.65)
	Median (quartiles)	30 (26–36)
	Range	23–60
Marital status	Single	34 (27.20%)
	In relation to	91 (72.80%)
Residence ^a	Country	27 (21.60%)
	City up to 50,000 inhabitants	18 (14.40%)
	City of 50,000–150,000 inhabitants	16 (12.80%)
	City of 150,000–500,000 inhabitants	23 (18.40%)
	City with more than 500,000 inhabitants	41 (32.80%)
Occupational group	Physiotherapist	5 (4.00%)
	Physician/dentist	24 (19.20%)
	Nurse	39 (31.20%)
	Midwife	5 (4.00%)
	Paramedic	51 (40.80%)
	Other	1 (0.80%)
Education	Secondary education	6 (4.80%)
	Bachelor's degree	44 (35.20%)
	Master's degree/medical doctor/dentist	68 (54.40%)
	PhD	7 (5.60%)
Seniority	Less than a year	6 (4.80%)
	1–5 years	72 (57.60%)
	6–10 years	19 (15.20%)
	11–15 years	12 (9.60%)
	16–20 years	7 (5.60%)
	More than 20 years	9 (7.20%)
Weekly working hours	20–39 h	18 (14.40%)
	40–59 h	57 (45.60%)
	60–79 h	38 (30.40%)
	80–99 h	9 (7.20%)
	100 h and more	3 (2.40%)
Place of employment	Hospital	86 (68.80%)
	Long-term care facilities	2 (1.60%)
	Primary health care	1 (0.80%)
	Others	36 (28.80%)
Works in shifts	No	24 (19.20%)
	Yes	101 (80.80%)

(Continued)

TABLE 1 (Continued)

Type of hospital ward	Surgical	46 (36.80%)
	Non-surgical	25 (20.00%)
	Not applicable	54 (43.20%)
Working in more than one place	No	53 (42.40%)
	Yes	72 (57.60%)

^aThe adopted classification of place of residence is based on the population of each territorial unit, characteristic of Poland.

the Kruskal–Wallis test. When statistically significant differences were detected, post-hoc analysis was performed with Dunn's test to identify statistically significantly different groups. Multivariate analysis of the effect of multiple variables on a quantitative variable was performed using linear regression. The results are presented in the form of regression model parameter values with 95% confidence intervals. The analysis assumed a significance level of 0.05. So, all *p*-values below 0.05 were interpreted as indicating significant relationships. The analysis was performed in the R program, version 3.6.1 (R Core Team, 2019) (19).

3. Results

The study group was gender-diverse: 68 (54.4%) women and 57 (45.6%) men. The average age of the participants was 32.1 years. The study group included 51 paramedics (40.8%), 39 (31.2%) nurses and 24 (19.2%) doctors. The remaining participants were 11 (8.8%). The socio-demographic data of the sample are presented in [Table 1](#).

Based on the results, risk was identified for the three domains studied: hours of work, violence and substance abuse ([Table 2](#)). More than half of the subjects (52%) were identified as having an increased risk in the domain of working hours, which may mean that they work too much, in shift work, and this may directly affect the level of fatigue and work capacity. Close to half of those surveyed (49.6%) are at high risk of violence. More and more people working in the health care system are victims of patient abuse—this includes verbal and physical abuse. During the COVID-19 pandemic, this phenomenon has grown. Over half of respondents (52%) are at high risk of addiction. Based on the responses we can see that medical staff have easy access to psychoactive medicines - the prescriptions and the medicines themselves. Excessive workload, mental strain and physical fatigue can be predictors of the use of such stimulants, which of course can translate directly or indirectly into the safety of the patient and other medical personnel.

3.1. Bivariate analysis

A univariate analysis was performed to calculate the determinants of risk. The results of the analysis are as follows.

The risk in the domain of experiencing workplace violence is significantly higher in paramedics than in other professional groups. Additionally, nurses and midwives have experienced higher workplace violence than in representatives of “other” professions ([Table 3](#)). Paramedics are on the front line when it comes to contact with patients in hospital emergency departments or at the scene of an

accident/patient's home. Very often, patients waiting for their turn in a hospital emergency department become impatient and aggressive. Similar situations occur at the scene of an ambulance call. It also turns out that the odds of experiencing workplace violence is significantly higher in men than in women (Table 4).

We examined the relationship between highest educational attainment and experiencing workplace violence. The results show that the chance is significantly higher in those with a bachelor's or master's degree than in those with a high school education. This may be due to the fact that people with higher education tend to work in several places, such as paramedics and doctors. Medical workers with bachelor degree are the top risk of experiencing workplace violence and abusing substances (Table 5), taking into account that most, paramedics make up of a great majority of staff with bachelor degrees.

The study also examined the impact of weekly workload by using numbers of hours devoted to professional work. It found that the risk in the domain of violence is significantly higher in the group working 40–59 or 80 or more hours/week than in the group working 20–39 h/week. Additionally, the risk is significantly higher in the group working 60–79 h/week than in the group working less than 60 h/week (Table 6). Which can be deduced from the result that the high working hours is associated with the higher risk of experiencing violence,

which can be associated with a higher likelihood of contact with a violent patient.

Working extra hours, experiencing work violences, and substance abuse are significantly higher among shift workers and those HCWs who work in more than one place (Tables 7, 8).

3.2. Multivariate analyses

Multivariate analyses were performed on variables that had a significant effect on a given risk domain in univariate analyses or were close to significance (i.e., had $p < 0.1$) and occupational group, which is the main variable of this analysis.

3.2.1. Risk score in the domain: working hours

The multivariate linear regression model showed that the significant ($p < 0.05$) independent predictors of risk in working hours domain are (Table 9):

- Bachelor's degree: the regression parameter is 5.023, so it raises the risk by an average of 5.023 points relative to secondary education;
- Master's degree/doctor/dentist: the regression parameter is 4.545, so it raises the risk by an average of 4.545 points relative to secondary education;
- Weekly working hours of 80 h or more: the regression parameter is 2.263, so it raises the risk by 2.263 points on average relative to working less than 40 h/week;
- Working in shifts: the regression parameter is 2.099, so it raises the risk by 2.099 points on average;
- Working in more than one place: the regression parameter is 1.936, so it raises the risk by 1.936 points on average.

3.2.2. Risk score in the domain: violence

An analogous analysis to that for working hours domain was conducted for violence domain (Table 10). The multivariate linear regression model showed that the significant ($p < 0.05$) independent predictors of risk in this domain are:

TABLE 2 Risk level results for each domain.

Risk domain	Risk level		
	No risk	Increased risk	High risk
Working hours	36 (28.80%)	65 (52.00%)	24 (19.20%)
Violence	18 (14.40%)	45 (36.00%)	62 (49.60%)
Abuse of psychoactive substances	20 (16.00%)	40 (32.00%)	65 (52.00%)

TABLE 3 Influence of occupational groups on the risk scores in three domains: working hours, violence and abuse of psychoactive substances.

Risk domain	Occupational group	N	Mean	SD	Median	Min	Max	Q1	Q3	p
Working hours	Nurse/midwife	44	8.14	3.27	9.0	2	14	4.75	10.25	$p = 0.531$
	Physician/dentist	24	6.96	3.50	8.5	1	12	3.75	10.00	
	Paramedic	51	7.55	2.97	8.0	2	14	5.50	9.50	
	Other	6	7.50	2.51	7.0	5	12	6.00	8.00	
Violence	Nurse/midwife—A	44	9.25	3.71	10.0	0	14	7.75	12.25	$p = 0.002^*$ C > B, A, D A > D
	Physician/dentist—B	24	9.29	2.97	10.0	2	15	7.75	12.00	
	Paramedic—C	51	10.94	2.64	12.0	3	15	9.50	13.00	
	Other—D	6	4.00	5.18	3.0	0	14	0.75	3.75	
Abuse of psychoactive substances	Nurse/midwife	44	9.02	3.93	10.0	0	14	7.00	12.00	$p = 0.55$
	Physician/dentist	24	9.58	4.40	11.5	0	14	7.75	12.25	
	Paramedic	51	9.47	3.40	11.0	0	14	8.00	12.00	
	Other	6	8.50	2.95	9.0	4	11	7.00	11.00	

p, Kruskal–Wallis test + post-hoc analysis (Dunn's test); SD, standard deviation; Q1, lower quartile; Q3, upper quartile.

*Statistically significant difference ($p < 0.05$).

TABLE 4 Influence of sex on the risk scores in three domains: working hours, violence and abuse of psychoactive substances.

Risk domain	Sex	N	Mean	SD	Median	Min	Max	Q1	Q3	p
Working hours	Female	68	7.85	3.28	9.0	2	14	4.00	10.00	$p = 0.219$
	Male	57	7.39	3.02	8.0	1	14	5.00	9.00	
Violence	Female	68	8.81	3.86	9.0	0	15	7.00	12.00	$p = 0.003^a$
	Male	57	10.75	2.82	12.0	3	14	10.00	12.00	
Abuse of psychoactive substances	Female	68	9.29	3.94	11.0	0	14	7.75	12.00	$p = 0.688$
	Male	57	9.28	3.53	11.0	0	14	8.00	12.00	

p, Mann–Whitney test; SD, standard deviation; Q1, lower quartile; Q3, upper quartile.

^aStatistically significant difference ($p < 0.05$).

TABLE 5 Influence of education on the risk scores in three domains: working hours, violence and abuse of psychoactive substances.

Risk domain	Education	N	Mean	SD	Median	Min	Max	Q1	Q3	p
Working hours	Secondary education—A	6	4.00	2.19	4.0	2	8	2.50	4.00	$p = 0.015^a$ B, C > A
	Bachelor's degree—B	44	8.34	3.06	8.0	2	14	6.00	11.00	
	Master's degree/ medical doctor/ dentist—C	68	7.62	3.15	8.0	1	14	5.00	10.00	
	PhD—D	7	6.57	2.51	8.0	2	8	6.00	8.00	
Violence	Secondary education—A	6	7.50	4.72	8.0	0	14	5.75	9.50	$p = 0.026^a$ B > D
	Bachelor's degree—B	44	10.57	3.11	12.0	1	15	9.00	13.00	
	Master's degree/ medical doctor/ dentist—C	68	9.66	3.44	10.0	0	15	8.00	12.00	
	PhD—D	7	6.43	4.20	6.0	2	12	3.00	9.50	
Abuse of psychoactive substances	Secondary education—A	6	4.00	3.52	2.0	1	9	2.00	6.50	$p = 0.009^a$ B, C > A
	Bachelor's degree—B	44	9.82	3.25	11.0	3	14	8.00	12.00	
	Master's degree/ medical doctor/ dentist—C	68	9.63	3.56	11.0	0	14	8.00	12.00	
	PhD—D	7	7.14	5.11	8.0	0	12	4.00	11.00	

p, Kruskal–Wallis test + post-hoc analysis (Dunn's test); SD, standard deviation; Q1, lower quartile; Q3, upper quartile.

^aStatistically significant difference ($p < 0.05$).

- Bachelor's degree: the regression parameter is 3.538, so it raises the risk by an average of 3.538 points relative to secondary education;

- Master's degree/doctor/dentist: the regression parameter is 3.235, so it raises the risk by an average of 3.235 points relative to secondary education;

- Job tenure of 6–10 years: the regression parameter is 3.257, so it raises the risk by an average of 3.257 points relative to tenure of less than 1 year;

- Seniority 11–15 years: the regression parameter is 3.542, so it raises the risk by an average of 3.542 points relative to seniority of less than a year;

- Weekly working hours 40–59 h: the regression parameter is 1.674, so it raises the risk by 1.674 points on average relative to working less than 40 h/week;

- Weekly working time of 60–79 h: the regression parameter is 4.001, so it raises the risk by an average of 4.001 points relative to working less than 40 h/week;

- Weekly working hours of 80 h or more: the regression parameter is 3.667, so it raises the risk by an average of 3.667 points relative to working less than 40 h/week;

- Shift work: the regression parameter is 3.098, so it raises the risk by an average of 3.098 points.

TABLE 6 Influence of weekly working hours on the risk scores in three domains: working hours, violence and abuse of psychoactive substances.

Risk domain	Weekly working hours	N	Mean	SD	Median	Min	Max	Q1	Q3	p
Working hours	20–39 h	18	5.67	3.56	3.5	2	12	3.00	9.00	$p = 0.065$
	40–59 h	57	8.12	2.61	8.0	1	13	7.00	10.00	
	60–79 h	38	7.68	3.04	8.0	2	14	5.00	10.00	
	80 h and more	12	8.17	4.37	7.5	2	14	4.00	12.25	
Violence	20–39 h—A	18	6.22	3.73	6.5	0	14	3.25	8.75	$p < 0.001^a$
	40–59 h—B	57	9.12	3.38	10.0	0	15	8.00	11.00	D, B > A C > B, A
	60–79 h—C	38	11.89	2.01	12.0	6	15	11.25	13.00	
	80 h and more—D	12	10.67	3.11	12.0	5	14	8.00	13.25	
Abuse of psychoactive substances	20–39 h	18	8.28	4.86	10.5	0	13	4.50	12.50	$p = 0.287$
	40–59 h	57	9.98	3.30	11.0	0	14	8.00	12.00	
	60–79 h	38	9.26	3.27	10.0	0	13	8.00	11.00	
	80 h and more	12	7.58	4.81	8.5	0	13	2.00	11.25	

p, Kruskal–Wallis test + post-hoc analysis (Dunn's test); SD, standard deviation; Q1, lower quartile; Q3, upper quartile.

^aStatistically significant difference ($p < 0.05$).

TABLE 7 Influence of shift work on the risk scores in three domains: working hours, violence and abuse of psychoactive substances.

Risk domain	Shift work	N	Mean	SD	Median	Min	Max	Q1	Q3	p
Working hours	No	24	5.79	2.83	5.5	2	12	3.75	8	$p = 0.001^a$
	Yes	101	8.08	3.08	8.0	1	14	6.00	10	
Violence	No	24	6.25	4.46	6.5	0	14	2.75	9	$p < 0.001^a$
	Yes	101	10.51	2.75	11.0	3	15	9.00	13	
Abuse of psychoactive substances	No	24	7.08	4.90	7.0	0	13	3.25	12	$p = 0.021^a$
	Yes	101	9.81	3.23	11.0	0	14	8.00	12	

p, Mann–Whitney test; SD, standard deviation; Q1, lower quartile; Q3, upper quartile.

^aStatistically significant difference ($p < 0.05$).

3.2.3. Risk score in the domain: abuse of psychoactive substances

The last risk domain analyzed was psychoactive drug abuse. A multivariate linear regression model showed that significant ($p < 0.05$) independent predictors of risk in this domain are:

- Practicing a medical/dental profession: the regression parameter is 2.11, so it raises the risk by an average of 2.11 points relative to that of a nurse/midwife;
- Bachelor's degree: the regression parameter is 5.358, so it raises the risk by an average of 5.358 points relative to secondary education;
- Master's degree/doctor/dentist: the regression parameter is 5.217, so it raises the risk by an average of 5.217 points relative to secondary education;
- shift work: the regression parameter is 3.681, so it raises the risk by 3.681 points on average.
- Working in more than one place: the regression parameter is 1.87, so it raises the risk by 1.87 points on average.

4. Discussion

Healthcare system is fraught with many psychosocial risk factors. It is important to improve psychosocial ergonomics of the healthcare system to increase the preparedness for high demand situations like pandemics. Poor psychosocial risk factors has detrimental consequences on patient safety and workers mental health. In this study we measured outcomes of current healthcare system ergonomics on HCWs during COVID-19 pandemic in three dimensions of risk factors from the psychosocial group (see Table 11).

The labor system adopted in Poland (governed by the Labor Code) assumes that in the case of contract work, an employee works 7 h 25 min each day (for 5 days a week), or comes on duty for 12 h—which in the weekly calculation is supposed to give 40 h of work. In the case of employees who are employed on contractual agreements (running a sole proprietorship) it is different, because they can work more than 40 h a week—the labor code does not apply to them. The

TABLE 8 Influence of working on more than one place on the risk scores in three domains: working hours, violence and abuse of psychoactive substances.

Risk domain	Working in more than one place	N	Mean	SD	Median	Min	Max	Q1	Q3	p
Working hours	No	53	6.47	2.80	6	2	12	4.00	8	$p < 0.001^a$
	Yes	72	8.50	3.15	9	1	14	7.00	11	
Violence	No	53	9.38	3.15	10	1	15	8.00	12	$p = 0.108$
	Yes	72	9.93	3.83	11	0	15	8.00	13	
Abuse of psychoactive substances	No	53	8.34	3.87	9	0	14	6.00	11	$p = 0.006^a$
	Yes	72	9.99	3.52	11	0	14	8.00	12	

p, Mann–Whitney test; SD, standard deviation; Q1, lower quartile; Q3, upper quartile.

^aStatistically significant difference ($p < 0.05$).

TABLE 9 Multivariate analysis—working hours domain.

Feature	Parameter	95% CI	p
Occupational group	Nurse/midwife	Ref.	
	Physician/dentist	−0.342	−1.932 1.248 0.674
	Paramedic	−0.05	−1.499 1.399 0.946
	Other	1.161	−1.785 4.106 0.442
Education	Secondary education	Ref.	
	Bachelor's degree	5.023	2.434 7.613 <0.001 ^a
	Master's degree/medical doctor/dentist	4.545	1.939 7.152 0.001 ^a
	PhD	3.296	0.016 6.576 0.051
Weekly working hours	20–39 h	Ref.	
	40–59 h	0.973	−0.625 2.571 0.235
	60–79 h	0.696	−0.936 2.328 0.405
	80 h and more	2.263	0.088 4.438 0.044 ^a
Workplace	Hospital	Ref.	
	Other	−1.106	−2.555 0.342 0.137
Shift work	No	Ref.	
	Yes	2.099	0.42 3.778 0.016 ^a
Working in more than one place	No	Ref.	
	Yes	1.936	0.913 2.958 <0.001 ^a

p, multivariate linear regression.

^aRelationship statistically significant ($p < 0.05$).

WHO is warning that long working hours contribute to deaths from stroke and ischemic heart disease. This mode of work is classified as high occupational risk (20). Medical personnel often work more than 40 h a week in Poland. In addition, they work shifts (80.8% of the

respondents), and more than half of the respondents take on additional work (57.6%). This practice is common in many countries around the world, as confirmed by numerous scientific reports and reports (21, 22). More than half of those surveyed were found to have elevated hourly occupational risks. It should be noted that the results obtained in the study showed a higher occupational risk in the **domain** of working hours for those with higher than secondary education. A similar relationship was shown in a study conducted in medical workers in the Brazilian health care system (23). In Australia, on the other hand, medical students—young doctors—are working shorter hours than they were a few years ago. This has resulted in better patient safety and higher workers satisfaction (24). Working beyond the norm among medical personnel is nothing new. It is the result of many factors—including unsatisfactory salaries, staff shortages and attempts to “patch up” schedules. However, this is a special professional group, burdened with great responsibility for the health and lives of patients. Fatigue caused by overwork can have disastrous nipples, and this should not be forgotten.

Violence in the healthcare system is increasing. Upset patients, stresses of illness or loss of loved ones are among risk factors. Emergency department workers including doctors, nurses and paramedics are the most vulnerable group to work violences (25). This is a special field of medicine where the level of aggression from patients is high. Our study shows that HCWs with higher education and a high working hour are at higher risk of experiencing violence. Additionally, Shift workers are at the risk of experiencing violence by medical staff (26). Violence reported during night shift mor than day shifts, when workloads are higher, and less staff are available. A study of Chinese hospitals found that shift work is associated with the experience of violence (for example: verbal violence from patients, physical and psychological violence from patients and their families) by medical staff and doctors were more susceptible to experiencing non-physical violences (26). The problem of violence experienced by medical staff is very serious. In addition to the obvious issues like experiencing physical recognition from the patient, one must remember the psychological trauma, which can be profound and which can lead to a wave of departure from the profession. It is also necessary to look for answers as to why patients are violent - it is not always due to their condition. Often this aggression arises from a malfunctioning health care system, waiting too long for help and powerlessness. Policymakers need to keep this in mind as they put their medics on the front lines.

TABLE 10 Multivariate analysis—violence domain.

Feature		Parameter	95% CI		p
Occupational group	Nurse/midwife	Ref.			
	Physician/dentist	1.378	−0.163	2.92	0.083
	Paramedic	1.073	−0.183	2.329	0.097
	Other	−1.378	−4.155	1.398	0.333
Sex	Female	Ref.			
	Male	0.294	−0.824	1.413	0.607
Education	Secondary education	Ref.			
	Bachelor's degree	3.538	1.021	6.054	0.007 ^a
	Master's degree/medical doctor/dentist	3.235	0.697	5.773	0.014 ^a
	PhD	0.884	−2.2	3.969	0.575
	Less than a year	Ref.			
Seniority	1–5 years	1.935	−0.299	4.17	0.093
	6–10 years	3.257	0.83	5.684	0.01 ^a
	11–15 years	3.542	0.837	6.246	0.012 ^a
	16–20 years	1.402	−1.738	4.542	0.384
	More than 20 years	2.907	−0.397	6.212	0.087
	20–39 h	Ref.			
Weekly working hours	40–59 h	1.674	0.2	3.147	0.028 ^a
	60–79 h	4.001	2.46	5.542	<0.001 ^a
	80 h and more	3.667	1.572	5.762	0.001 ^a
	Shift work	Ref.			
Shift work	No	Ref.			
	Yes	3.098	1.278	4.918	0.001 ^a

p, multivariate linear regression.

^aRelationship statistically significant ($p < 0.05$).

The psychophysical burden on medical personnel can make them to use substances as coping mechanism (27). A detailed multivariate analysis showed that doctors are more likely to use psychoactive drugs than nurses. In addition, higher education or shift work and working in more than one place are associated with higher substance abuse. That the problem is so important is evidenced by statistics—about 20% of nursing staff have a problem with psychoactive drug abuse (28). A study in India found that more than 30% of resident doctors have a problem with psychoactive drug abuse (29). Substance abuse by medical personnel can also have many underpinnings and is the product of many factors. Working with patients and fighting for their health and life is very physically and mentally exhausting. Lack of alternatives to cope with such a heavy workload can result in a desire

TABLE 11 Multivariate analysis—abuse of psychoactive substances domain.

Feature		Parameter	95% CI		p
Occupational group	Nurse/midwife	Ref.			
	Physician/dentist	2.11	0.236	3.984	0.029 ^a
	Paramedic	0.677	−0.719	2.072	0.344
	Other	2.641	−0.73	6.012	0.127
Education	Secondary education	Ref.			
	Bachelor's degree	5.358	2.56	8.156	<0.001 ^a
	Master's degree/medical doctor/dentist	5.217	2.397	8.037	<0.001 ^a
	PhD	2.822	−0.965	6.61	0.147
Shift work	No	Ref.			
	Yes	3.681	1.754	5.607	<0.001 ^a
Working in more than one place	No	Ref.			
	Yes	1.87	0.661	3.08	0.003 ^a

p, multivariate linear regression.

^aRelationship statistically significant ($p < 0.05$).

to turn to intoxicating substances. Once again, the role of prevention should be noted - it is also crucial in the middle of the work.

The results of our own research as well as demographic forecasts indicate that, with the current shortage of medical personnel, it is necessary to take multifaceted measures. One such task—for which employers are responsible—is the prevention of occupational risk reduction. Without the active participation of employers, managers and universities training future medics, it will not be possible to meet the growing expectations for nurses or doctors. This is a space to be exploited by public health specialists, who can develop and implement programs in the field of prevention of coping with stress, occupational burnout. Much of the responsibility lies with the employer, as he is the one who must see the need for such action—unless there are legal provisions in the public space forcing such action.

5. Conclusion

We carried out this study by investigating the HCWs of one of the most prestigious medical hospitals in Poland. Our findings show that the present psychosocial ergonomics of the Polish health system must be improved. The COVID-19 pandemic has been a compelling test to assess the current state. Our findings highlighted the fact that HCWs often worked overtime and that many cases of workplace violence and substance abuse were reported. This outcome may be used by health facilities, including hospitals and clinics, as a guideline to identify domains where intervention is required to address occupational risks. Medical personnel are an occupational group for whom preventive

programmes should be devoted to improving ergonomics in the workplace. The lack of action in the above-mentioned domain is likely to increase the shortage of medical staff in the future, precisely because of inadequate work ergonomics.

5.1. Study limitation

The study has several limitations that must be taken into account when transposing the results and conclusions. First of all, it is important to emphasize the fact that the study group is not homogeneous, and consists of representatives of different medical professions, in varying numbers. When relating the results to individual professional groups, this should be taken into account, and inferences should be made with great caution. As the survey was conducted online and the survey link was distributed to professional groups, it is not possible to determine the return rate.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The study was carried out in accordance with the tenets of the Declaration of Helsinki and guidelines of Good Clinical Practices (World Medical Association, 2013). The study was fully anonymous and voluntary. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

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LR and AK: conceptualization. LR: methodology, software, formal analysis, and supervision. LR and HS: validation. PG: investigation. LR and PG: resources. LR, IW, and HS: data curation and writing—original draft preparation. LR, AK, and HS: writing—review and editing. LR and AH-S: visualization and project administration. LR, IW, AK, and PG: funding acquisition. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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Influence of communication determinants on safety commitment in a high-risk workplace: a systematic literature review of four communication dimensions

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Health, safety, and environment (HSE) are critical aspects of any industry, particularly in high-risk environments, such as the oil and gas industry. Continuous accident reports indicate the requirement for the effective implementation of safety rules, regulations, and practices. This systematic literature review examines the relationship between safety communication and safety commitment in high-risk workplaces, specifically focusing on the oil and gas industry. The review comprises 1,439 articles from 2004 to 2023, retrieved from the Scopus and Web of Science databases following the PRISMA comprehensive guidelines. This study considers safety communication, communication climate, and communication satisfaction to evaluate their influence on safety commitment under occupational health and safety. This study identifies safety commitment issues and their underlying factors, discussing measures for preventing and reducing accidents and incidents and highlighting preventive measures for future research. It also signifies the variables influencing accident and incident rates. The research underscores the importance of communication dimensions and the need for workers to possess adequate skills, knowledge, and attitudes regarding occupational safety and health procedures. Moreover, the study contributes to the industrial and academic domains by improving organizational safety commitment, promoting a safety culture, and developing effective communication strategies. Furthermore, practitioners may benefit from this comprehensive overview in developing, evaluating, and enhancing occupational safety.

KEYWORDS

safety communication, safety commitment, communication climate, communication satisfaction, occupational safety, high-risk workplace, occupational accidents, occupational injuries

1. Introduction

For decades, the oil and gas industry has been considered a highly effective industry for accelerating the world's economies (1). Malaysia has Asia-Pacific's third and fourth-highest gas and oil reserves, respectively (2). Therefore, the contribution from these industries accounts for approximately 20% of GDP in the Malaysian economy (3). Despite implemented safety

measures, oil and gas operations are reportedly significantly challenging and dangerous globally, whether onshore or offshore (4), raising concerns regarding highly hazardous and risky processes and associated activities in the oil and gas industry. These incidents and perilous circumstances occur due to ineffective communication and negligence of defined rules, regulations, and commitment to safety (5). Though the deployment of rules, regulations, and technology has drastically improved safety measures, oil and gas industry incidents are still significantly higher than in other industries and can trigger a catastrophic impact, leading to a high rate of occupational injuries and accidents, as reported by numerous studies (6, 7). Therefore, ensuring a safe working environment is of utmost importance.

Workplace safety is associated with active communication to minimize the rate of accidents and improve safety in the workplace. It is also deduced that the antecedent of accidents is unsafe behavior, which is partly ascribed to the organization's safety systems (8). According to International Labor Organization (ILO) global statistics reports, nearly 2.78 million fatalities are reported annually. Poor and inefficient safety systems, management practices, and human error are among the causes of the reported incidents. Such consequences are alarming and necessitate a focus on improving the workplace to reduce workplace accidents, injuries, and fatalities, which also accrue costs to the organization in terms of medical, health, death, equipment damage, production loss, and increased insurance costs (9–13).

Moreover, the Social Security Organization - SOCSO (2018–2019) has expressed dissatisfaction with the oil and gas sector's Health, Safety, and Environment (HSE). The most viable indicator of workplace safety is the number of fatalities and injuries that have occurred; therefore, most companies endeavor to achieve 'zero lost time injury' (LTI). Despite such preferences to ensure workplace safety the oversight occurs, which lead towards hazards (14–16). These incidents are heavily interlinked with communication and human error, highlighting the importance of effective communication in the workplace to avoid incidents (17).

The Malaysian Occupational Safety and Health Act (OSHA) was passed on the 25th February 1994. It has significantly improved the health and safety of working environments in Malaysia and influenced oil and gas organizations to comply to avoid unpleasant incidents and near-misses (18–20). Despite the ILO and the Malaysian OSHA-1994, the frequency of incidents indicates that acceptable safety measures against risks are not being provided. These risks are associated with safety performance, which comparatively exists due to a lack of safety leadership, safety commitment, and safety communication (19, 21). A safe workplace is facilitated by the employees' and employers' strong support and commitment to safety. Numerous studies report ineffective communication to be a significant factor in triggering accidents (18, 19, 22, 23).

Although the rate of accidents has decreased globally compared to previous years due to safety precautions and HSE implementation, including the technological advances of equipment and machinery, the human factor has significantly contributed to accidents in the workplace. Figures 1, 2 present a trend analysis of the occupational accident and fatality rate in Malaysia from 2004 to 2021, and Figure 3 presents a comparative analysis of the occupational injury and fatality rates of different countries. The statistical evidence indicates that approximately 80–90% of incidents are derived from human factors (25). These factors are not limited to human and machine contact but extend to various factors involving individuals, organizations, and

working environments (26). Therefore, safety communication is considered a significant factor in reducing accidents caused by human factors and improving the workplace (27). However, the SOCSO produced the latest report claiming that in 2021, a total of 61,447 accident cases were reported, of which, 36,794 were industrial accidents, with almost 700 reported deaths in Malaysia alone. However, According to worldwide evidence, 2 million fatalities have been reported relating to accidents and diseases caused by the workplace. In total, 270 and 160 million occupational accidents and illnesses occur yearly, respectively (28, 29). Workplace safety remains challenging and it is needed to avoid accidents effectively and improve safety performances (30).

Unsafe working conditions generate serious health issues and affect employees' well-being, negatively impacting their productivity and organizational performance (31). Human behavior is anticipated to be dynamic and complex (32); therefore, their capacity to understand, comply with, and perform according to the procedures and standards of safety contributes significantly to achieving success across high-risk industries (33–35). Organizations should consider effective communication and the efficient administration of OSHA practices to improve work performance in high-risk environments and promote positive working environments. Therefore, effective communication is of utmost importance to ensure positive working behavior (36).

However, communication barriers pose a significant challenge in promoting safety in an organization (37, 38); ensuring credibility, impact, and clarity remain vital to safety communication (39). Safety communication comprises a broad spectrum, from entry to board level, and is believed to be an essential factor connected with unsafe behavior (40). The unsafe behavior of employees may ultimately expose them to work-related accidents or injuries due to a lack of safety awareness. Therefore, safety communication also ensures employees' behavior is monitored so that they are less likely to exhibit unsafe behavior (41, 42). Several barriers hinder effective communication, including lack of information, knowledge, and attention; the existence of prejudice; different perceptions; selective listening; and a lack of clear reporting of official information (16, 43). Therefore, effective communication is critical to ensure safe operations and avoid disasters at oil and gas plants.

There is a surfeit of existing research evidence supporting the theory that work-related safety behavior could be improved by effective communication, which directly correlates with the significant association between communication and safe behavior (8–10, 16, 27, 39, 40, 44–46). Some recent studies have investigated the relationship between commitment and communication to constitute the impact of safety communications, leader and worker roles, and organizational climate in the oil and gas industry (46, 47). Most studies have revealed that the safety communication and climate of an organization are crucial antecedents of safety commitment.

The existing studies have highlighted the communication issue, indicating numerous complexities in several communication domains (mentioned in Table 1). However, these studies have limited dimensions and highlight the issues instead of emphasizing the root causes. Henceforth, there is a need to further investigate, identify, and imply how the four dimensions of communication affect safety and assist in preventing disasters at high-risk workplaces to reduce the high rate of accidents, injuries, and fatalities causing physical and mental health, and investment loss.

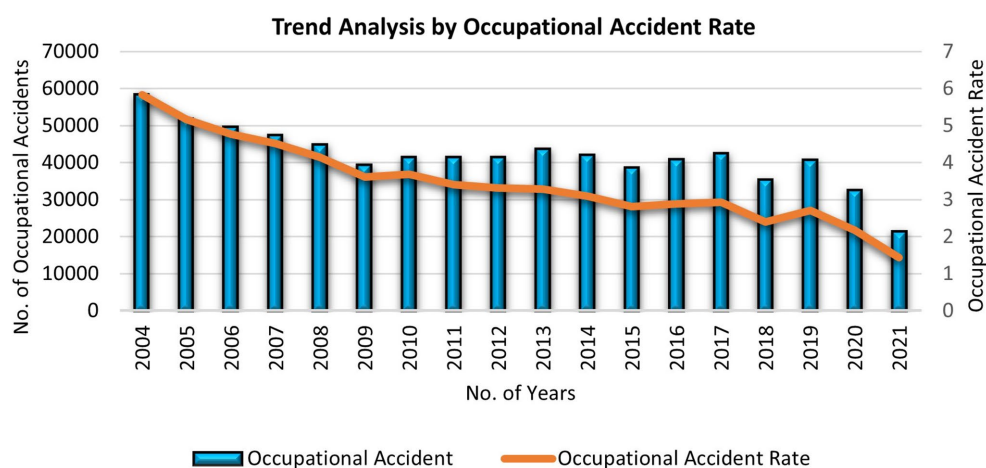


FIGURE 1

Trend analysis by occupational accident rate published by the Department of Statistics Malaysia for 2021 (24).

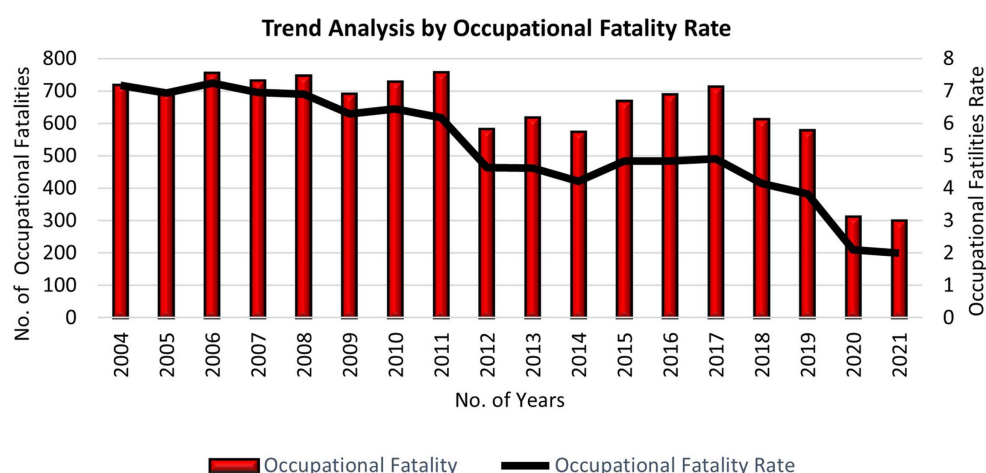


FIGURE 2

Trend analysis by occupational fatality rate published by the Department of Statistics Malaysia for 2021 (24).

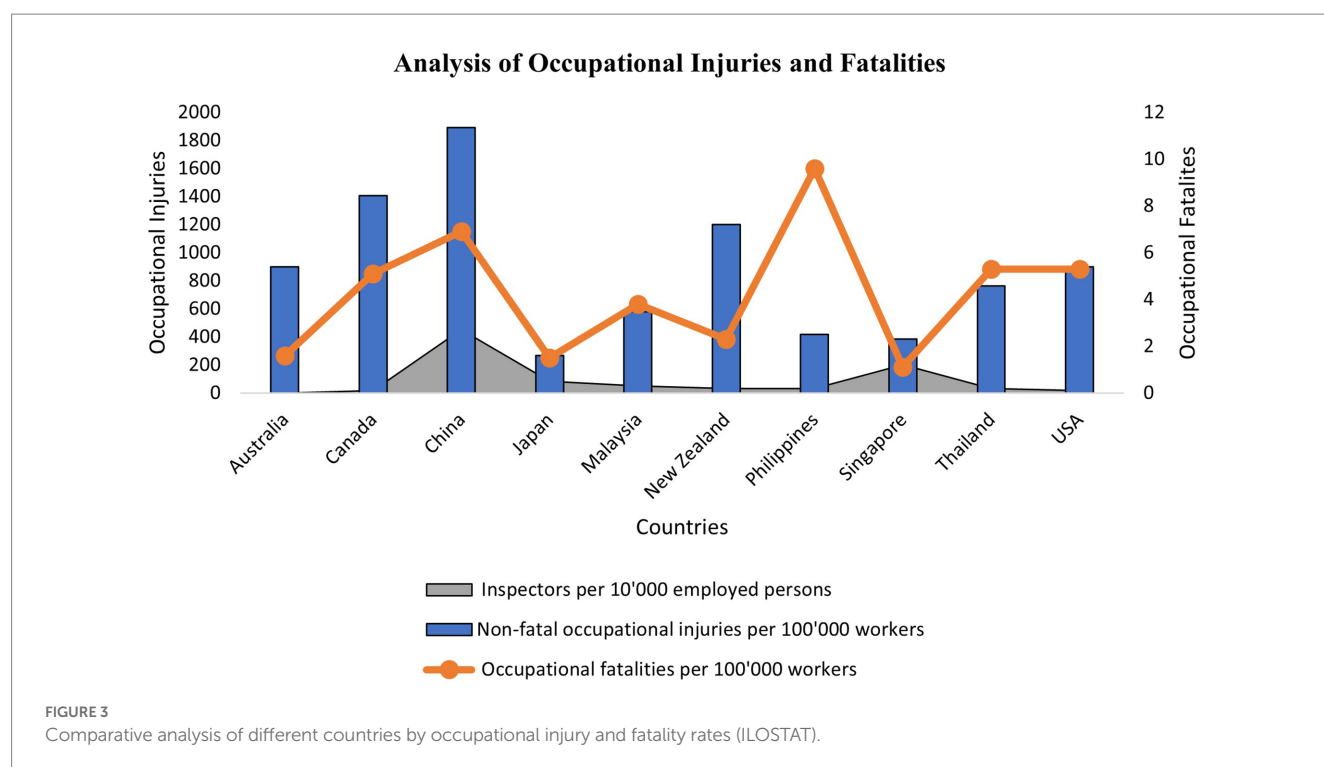
Therefore, the current study presents a systematic literature review based on four communication dimensions after examining the past studies. The proposed study focuses on highlighting safety issues and identifying communication gaps in high-risk workplace environments, especially in the oil and gas industry. Furthermore, this study also investigates and formulates research questions regarding how safety communication, communication satisfaction, and communication climate influence safety commitment. The deductions of these research questions will assist in avoiding disasters in a high-risk workplace environment, specifically focusing on oil and gas processing plants in Malaysia.

2. Methodology

The methodology adopted in this research is based on a systematic review to evaluate the literature regarding safety communication, communication climate, communication

satisfaction, and safety commitment to explore the findings and highlight existing research gaps for future studies in the context of occupational health and safety. As per the Preferred Reporting Item for Systematic Reviews (PRISMA) 2020, systematic literature is based on explicit, systematic procedures for gathering and synthesizing data from research that covers a specific area of study. Though most literature reviews are part of a broader perspective of study, they can be a stand-alone piece of work (83).

This type of study combines the results of other investigations to create a logical and comprehensive argument for a specific research issue (84). To define a future research agenda based on the existing gaps, a review article's main objective is to critically analyze the literature in a particular research area, subject, or field, identifying significant theories, key constructs, and empirical methods and setting unaddressed research questions (85). Systematic research reviews have gained popularity in research trends because of the data and information that they can provide. In conducting and directing this systematic review, the protocols suggested by Page et al. (84)



suggested protocols were used as a reference. A five-step strategy, which consists of the following points, has been proposed (86).

- (i) Framing review questions
- (ii) Identifying appropriate works
- (iii) Evaluating the quality of studies
- (iv) Synthesizing the evidence
- (v) Interpreting the results

PRISMA guides comprehensive and systematic research regarding the term “safety communication” and its influence on safety commitment, safety performance, and outcomes. This study follows the main three simple review steps:

- (i) Developing review questions
- (ii) Identifying appropriate literature
- (iii) Synthesizing the relevant forms of works

The current study was conducted from November 2022 to March 2023. This study includes three primary aspects, namely, the oil and gas industry (population), the practice of safety management (context), and safety metrics (interest), to achieve the study's objective and answer the research questions.

2.1. Resources

This study uses two major databases to conduct a systematic review, namely, Scopus and the Web of Science, due to their strength and inclusion of more than 334 disciplines and areas of research, including occupational health and safety studies. However, it should be kept in mind that no database, not even Scopus or Web of Science, is comprehensive and flawless.

2.2. Research question formulation

The formulation of the research question is considered the first step in a systematic review; it should be formulated and stated clearly before the study is started (86). PICO, which stands for Population, Intervention, Comparison, and Outcome, can often be used to identify the key components that must be addressed to fully formulate the review question. The main objective of this review is to examine the impact of safety communication on safety commitment in high-risk work environments within the oil and gas industry. Specifically, the study focuses on three primary aspects: the population involved (oil and gas industry), the intervention being studied (safety communication practices), and the context and outcome of the research (influence on safety commitment). The comparison aspect is not included in this study, as the main emphasis is on understanding how safety communication practices influence safety commitment in the high-risk workplace setting (87). Therefore, the following three research questions were devised for the purpose of this study:

RQ1: How does safety communication impact safety commitment in a high-risk work environment?

RQ2: How does communication satisfaction influence safety commitment in high-risk work environments?

RQ3: How does communication climate impact safety commitment in high-risk work environments?

2.3. Systematic searching strategies

Based on PRISMA, there are three main methods in the systematic searching strategy process, namely, identification, screening, and eligibility (83, 88).

TABLE 1 Analysis of themes and sub-themes for safety communication.

Reference and country	Safety communication				Occupational health and safety						Safety performance				Safety commitment			
	CC	CS	CM	CE	SP	SI	Sin	SR	S	SB	OA	OF	NM	LT	SM	SK	SC	SP
(7) Italy								x			x						x	
(25) UK	x			x											x			
(48) Malaysia				x		x	x		x		x	x		x			x	
(31) Iran					x									x				
(34) Australia						x	x		x		x	x	x	x	x			x
(49) Malaysia	x			x	x				x	x	x		x			x		x
(50) Malaysia				x	x	x			x		x			x		x	x	x
(51) Norway											x						x	x
(52) China				x	x			x				x			x		x	x
(53) Indonesia			x				x				x	x		x				
(54) Norway									x		x			x				
(55) USA				x	x											x		
(56) USA	x							x										x
(57) Australia				x											x			x
(58) Brazil	x		x															
(59) France		x			x												x	
(60) Malaysia	x			x						x						x		x
(61) Norway	x				x	x		x										x
(62) Malaysia	x		x															
(63) Egypt	x	x													x	x		
(64) Brunei						x		x				x		x				
(65) Indonesia	x			x	x										x		x	
(66) Nigeria	x																	
(67) Albania	x	x	x												x	x		x
(68) Columbia	x	x	x							x								
(69) Australia	x			x	x										x		x	
(70) Croatia	x		x	x	x										x			
(71) Malaysia						x	x				x	x	x	x		x		x
(72) Israel				x		x					x				x	x	x	
(73) Malaysia										x	x	x		x	x		x	x
(74) Ghana				x	x	x					x			x	x	x		x
(75) China					x		x		x		x			x	x	x	x	
(76) UAE					x	x		x				x		x		x	x	
(77) Norway				x			x	x				x						
(78) Singapore						x	x					x	x					x
(79) Bahrain												x		x		x		
(80) Iran										x								
(81) USA	x			x				x								x		
(82) UK								x		x	x							

Safety Communication	Occupational Health and Safety	Safety Outcome	Safety Commitment
CC: Communication Climate	SP: Safety Policy	OA: Occupational Accidents	SM: Safety Motivation
CS: Communication Satisfaction	SI: Safety Issues	OF: Occupational Fatal Accidents	SK: Safety Knowledge
CM: Communication Mechanism	Sin: Safety Indicator	NM: Near Misses	SC: Safety Compliance
CE: Communication Effectiveness	SR: Safety Rules and Regulation	LT: Lost Time Injuries	SP: Safety Participation
	S: Strategies		
	SB: Safety Benchmark		

TABLE 2 Search strings followed for literature extraction from the Web of Science and Scopus.

Data base	Search string
Web of Science	TOPIC: ("safety communication" OR "effective safety communication" OR "effectiveness of safety communication" OR "impact of safety communication" OR "effect of safety communication" OR "occupational safety and health" OR "OHS performance" OR "safety indicators outcome" OR "leading indicator" OR "lagging indicator") Refined by: TOPIC ("effective communication management" OR "communication management practice" OR "safety commitment" OR "safety programs" OR "communication climate" OR "communication satisfaction") AND FINAL TOPIC: ("industries" OR "oil" OR "gas" OR "petrochemical" OR "oil and gas sector" OR "high-risk work environment" OR "hazardous workplace").
Scopus	TITLE-ABS-KEY ("safety communication" OR "effective safety communication" OR "effectiveness of safety communication" OR "impact of safety communication" OR "effect of safety communication" OR "occupational safety and health" OR "OHS performance" OR "safety indicators outcome" OR "leading indicator" OR "lagging indicator") AND ("effective communication management" OR "communication management practice" OR "safety commitment" OR "safety programs" OR "communication climate" OR "communication satisfaction") AND ("industries" OR "oil" OR "gas" OR "petrochemical" OR "oil and gas sector" OR "high-risk work environment" OR "hazardous workplace").

2.3.1. Identification

Identification is a search method that uses the study's primary keywords, i.e., communication, occupational health, and safety, which were developed based on the research question (89). The search process used synonyms, associated keywords, and variants to give users more options for choosing databases when searching for further relevant articles for the review. The identification procedures were based on prior research, keywords proposed by guidelines, and keywords suggested by experts. In this study, entire search strings were constructed using an enriched existing term from the Scopus and Web of Science databases. A total of 1,439 articles were found during a search of these two databases from Dec 2022 to March 2023 that was limited to published papers from 2004 to 2023. Table 2 provides details about the databases and search strings considered.

2.3.2. Screening

The objective of the initial screening was to remove duplicate articles. A total of 17 duplicate articles were removed from the chosen articles. According to the numerous inclusion and exclusion criteria developed by the researchers, 1,088 publications were removed during the first stage, and 334 articles were reviewed during the second stage. The researcher decided to only focus on journal sources and article document types (research articles) because they act as the main sources of empirical data for determining the first criterion, which was the type of literature. As a result, this study did not include any conference papers, book chapters, reviews, conference reviews, notes, abstract reports, business pieces, brief surveys, retracted works, conference proceedings, trade journals, book series, books, or book chapters. Second, all non-English publications were removed from the search, and only English-language articles were prioritized to avoid misinterpretation and translation issues. Furthermore, 20 years (between 2004 and 2023) was selected as an appropriate time frame for tracking the development of research and related publications. These standards led to the elimination of 1,088 articles in total to achieve the objective of the study. Table 3 outlines the criteria for inclusion and exclusion of articles.

2.3.3. Eligibility

Eligibility involved individually reviewing the relevant articles to ensure that all the remaining research articles met the research criteria after the screening process. This process was completed by reviewing the article's title, abstracts, and keywords, which were used for literature coding. Based on the unnecessary or irrelevant information

mentioned in the title, abstract, and keywords, the article was analyzed to aid in coding. The coding process identifies study methods and findings portions. During this process, the following information was collected and included in the database:

- (i) Title of the paper
- (ii) Publication year of each paper
- (iii) Region or country (this information is regarding the location of the research article and is not related to the author's origin)
- (iv) Research area and field
- (v) Population of the research (profession)
- (vi) Safety communication context and concept

A standard procedure was adopted based on PRISMA 2020 (presented in Figure 4) to reduce the chances of biases and to ensure the quality of the literature review. The exclusion criteria included studies conducted in non-high-risk work industries, not related to safety communication, irrelevant to the health and safety field, and published as a book chapter. After the assessment of quality, a total of 254 articles were removed and 90 were selected.

2.3.4. Data abstraction and analysis

This study used an integrative review method, which analyses and synthesizes different research methodologies (qualitative, quantitative, and mixed methods) together, to reduce biases and ensure all data can be gathered by converting one kind of data into the other, i.e., qualitizing quantitative data or quantitating qualitative data (90). The data were acquired based on qualitative analysis in this study. The process of developing relevant themes and sub-themes was carried out based on thematic analysis. Data collection was the first step in the theme creation process. To find statements or information that addressed the study questions, the authors carefully read through a group of 40 publications during this phase. The authors employed a coding approach to create meaningful groupings based on the nature of the data in the second stage after that examination. In other words, by discovering themes, concepts, or ideas for more connected and related data, the second stage turned raw data into usable data (91).

As a result, the authors noted any discrepancies in the themes that emerged. The authors also reviewed the results to address any disparities in the theme-generating process. The developed themes and sub-themes were then modified as necessary to maintain consistency.

TABLE 3 Criteria for articles inclusion and exclusion.

Criteria	Inclusion	Exclusion
Timeline of publication	2004- March 2023	2003 and before
Types of documents	Articles (research on empirical data and review)	Conference papers, book chapters, book series, conference reviews, books, short surveys, notes, reports, etc.
Language	English	Non-English
Discipline of the study	Safety communication practice in industries Measurement of safety indicators Safety outcomes	Research methodology/Process system. Not relevant in terms of safety communication. Not related to the high-risk workplace environment.

2.3.5. Inclusion and exclusion criteria

After setting the research questions, we set the limitations for article selection based on the inclusion and exclusion criteria. The inclusion and exclusion criteria for the study were developed on the principles of systematic review protocols and PRISMA 2020 guidelines. These criteria are described in the following section.

2.3.5.1. Inclusion criteria

The inclusion criteria for selecting articles in our study included articles published between 2004 and March 2023. We considered articles based on empirical data and review studies, ensuring a comprehensive examination of the topic. The language requirement was English to facilitate a thorough understanding and analysis of the content. Our focus was on safety communication practices within various industries, examining how organizations communicate and promote safety within their workforce. Furthermore, we prioritized articles that investigate the measurement of safety indicators, allowing us to assess the effectiveness of these practices. Finally, we considered articles that explore the impact of safety communication on safety outcomes, as this provides valuable insights into the overall effectiveness of these practices. By adhering to these inclusion criteria, we aimed to provide a comprehensive and insightful analysis of safety communication in industries.

Moreover, the inclusion criteria of the study also included quality appraisal, where two experts with 15–20 years of experience as an auditor from health and safety backgrounds were selected. The selected articles were sent to the experts for quality assessment to ensure the high quality of the content. The remaining publications were divided into three categories: high, medium, and low. Articles in the high and medium groups were selected for review. The papers were classified when both experts were satisfied with the quality and ranking. This methodology produced 12 with a high ranking, 28 with a medium ranking, and 50 that were considered low-ranking articles. As a result, low-ranking articles were excluded, and the remaining 40 articles were considered suitable for further examination.

2.3.5.2. Exclusion criteria

The exclusion criteria for our study ensured that we focused on the most relevant and rigorous research in the field of safety communication. We excluded articles published before 2003 to ensure

we captured the most recent advancements and insights in the field. Additionally, we excluded conference papers, book chapters, book series, conference reviews, books, short surveys, notes, reports, and similar publications to maintain a high standard of scholarly research. Non-English articles were also excluded to ensure consistency in our analysis and interpretation. We excluded articles that primarily focus on research methodology or process systems rather than the specific topic of safety communication. We also excluded the articles that were selected as low-ranking after quality appraisal.

Furthermore, the content of each article was then carefully assessed to determine its relevance to the topic of safety communication in industries, measurement of safety indicators, and safety outcomes. Articles that did not address these specific areas or were not related to the high-risk workplace environment were excluded from further analysis. By applying these exclusion criteria, we aimed to maintain a focused and comprehensive analysis of safety communication in the context of high-risk workplaces.

3. Results

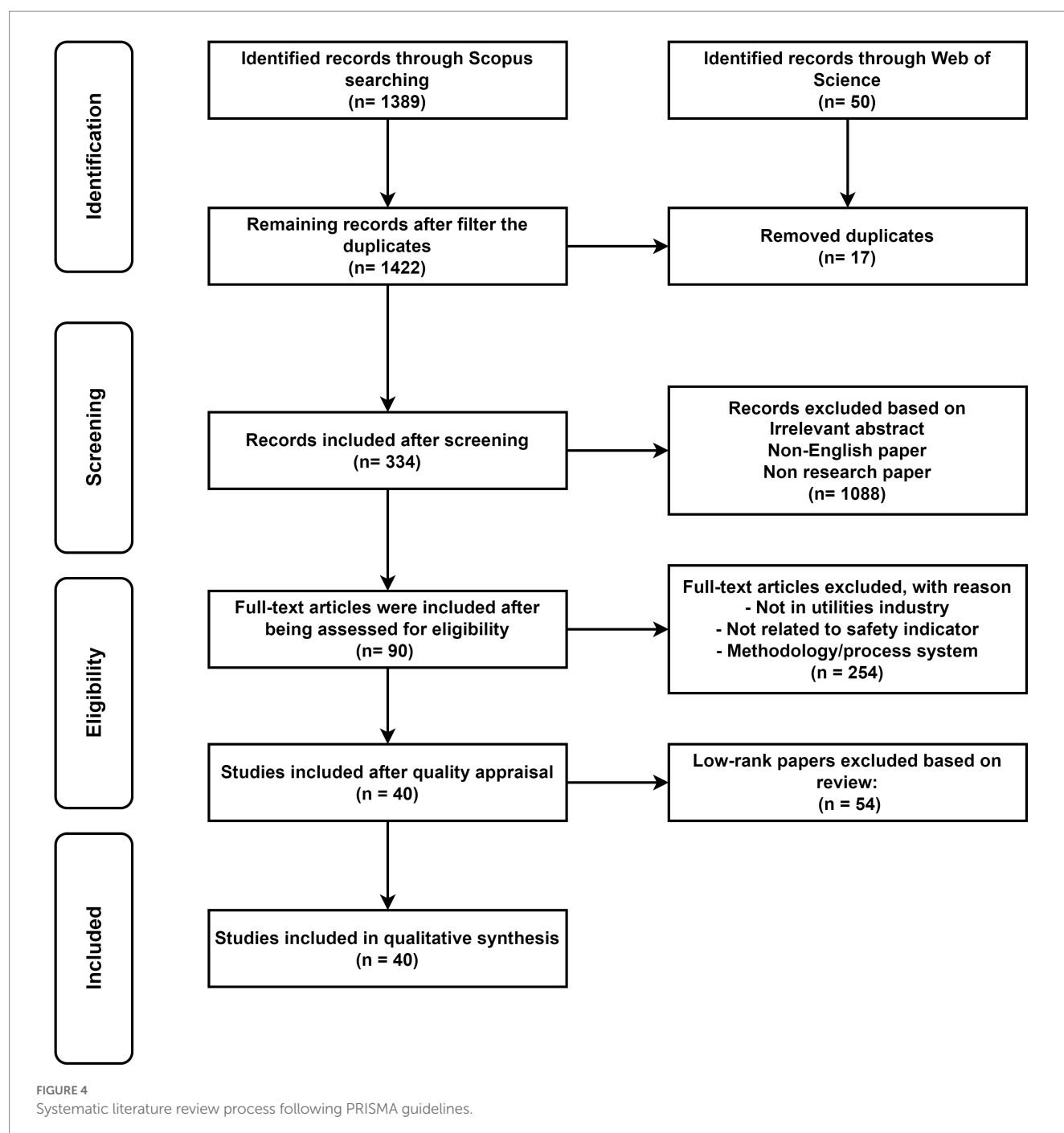
The literature review resulted in four main themes and 18 sub-themes related to factors impacting safety communication and commitment in high-risk work environments. As shown in [Table 1](#), the four main themes comprise safety communication (four sub-themes), occupational safety and health (six sub-themes), safety commitment (four sub-themes), and safety performance (four sub-themes). The results proposed a systematic analysis of the factors impacting safety communication on safety commitment in a high-risk work environment.

3.1. Background and findings of the reviewed studies

An analysis led to the development of a total of four main themes, namely, safety communication, occupational health and safety management system, safety commitment, and safety outcomes. Following this categorization, the study procedures were followed for each of the themes that had been created, developing themes, ideas, or thoughts that were related to one another within the main subject as a sub-theme. This process resulted in 16 sub-themes. The data were categorized into four main indicators. There were four sub-themes in safety communication (communication climate, communication satisfaction, communication mechanism, and communication effectiveness), four in occupational health and safety management system (organizational policy, strategy, indicator, continual improvement), four in safety outcome (occupational accidents, occupational fatal accidents, near misses, and lost time injuries), and four in safety commitment (safety motivation, safety knowledge, safety compliance, and safety participation). The main themes and subthemes are presented in [Table 1](#).

3.2. Years of publishing of selected articles

According to the literature, most of the articles on safety communication in the oil and gas industry were published in



2022, with seven articles (15%) and six articles (15%) respectively published in 2019–2021. The distribution of articles fluctuated during the study period, with only one article being published in 2004 and 2008, and the number of publications increased in 2013. However, this study was conducted from December 2022 to March 2023 and the researchers were not able to include articles that were published during these months. None of the articles were published in 2009–2012, except one, which was published in 2011. The fluctuation in publications indicates that researchers are directing their attention towards positive actions and proactively addressing safety communication issues to potentially minimize

highlighting of occupational health and safety (OHS) accidents and injuries. Figure 5 presents the number of publications in the literature related to safety communication in different years.

3.3. Publication by origin/country

The countries where the highest number of studies were conducted were Malaysia, with seven articles (18%); Nigeria, with three articles (8%); and Norway, with three articles (8%), followed by China, Iran, the U.S., Australia, Bahrain, and Indonesia, each

with two articles (5%). Most of the countries published one article only, including Brazil, Italy, the UK, Saudi Arabia, France, Egypt, Brunei, Albania, Israel, Croatia, Columbia, Singapore, and the UAE. Figure 6 presents a glimpse of the published articles in different countries.

3.4. Publication by field and methods

In 1970, the U.S. Congress enacted the U.S. Occupational Safety and Health Act of 1970 (OSHA) in the United States. Since then, governments and organizations have put a lot of effort into the development of OSHA around the world. The implementation of OSHA is broad and has diversified into all industries and various job roles and positions. As a result of categorizing the relevant publications, we can see that the studies involving safety competencies in OHS were conducted in five main fields of work, as shown in Figure 7. There were 14 research works conducted in the safety management field, mostly in Malaysia. The development of safety communication research in the high-risk work environment field shows the importance of equipping the young workforce with core competencies before they join the occupational world. The remaining studies were conducted in other fields of work, namely, construction, process safety, safety management, manufacturing, and oil and gas. These four areas were the main implementation of OSHA in most regions. The oil and gas, construction, and manufacturing fields are old industries that are known for their high-risk tasks involving workers and machines. For the process safety field, the OHS risk is also high because this field consists of the chemical and petrochemical industry, which needs a strong, competent workforce. Most of the people who participated in these studies were members of safety management teams, workers, and construction supervisors. Hence, most of the studies applied a quantitative approach, accounting for 75%, while qualitative studies accounted for 20%, and a mixed method approach was adopted by only 5% of studies. It is worth mentioning that the most prevalent methodologies used in these studies are case study, accounting for 52%; critical review, accounting for 28%; and theoretical, accounting for 20%.

3.5. Themes and sub-themes of the study

This section discusses the four proposed main themes, namely, safety communication, occupational safety and health, safety performance, and safety commitment, which, between them, have 18 sub-themes (see Table 1).

3.5.1. Safety communication

The safety of workers is crucial for all high-risk organizations, including in the oil and gas industry. One of the most critical factors associated with unsafe behavior is safety communication. “Safety communication is an appropriate knowledge exchange concerning internal safety matters. It enhances the efficiency of the safety management system.” An effective form of communication would help ensure safe workplace behavior. Safety communication guides workers to reduce unsafe incidents, strengthen their motivation, and commit themselves to safety in the workplace. Safety communication procedures also assist workers in improving safety practices in the workplace. Several studies have reported that a lack of safety communication is a significant factor in creating conflict and confusion regarding rules and procedures among workers in an organization (92). In this study, 23 articles (57%) from past studies were found to focus on safety communication, specifically in related sub-dimensions, impacting organizational safety performance and reducing accident and injury rates. Most highlighted variables that is communication climate and effective communication were the most prevalent and relevant approaches in this context, being the focus of 16 papers (40%), followed by communication mechanism, which was the focus of 7 papers (17%), and communication satisfaction, as the focus of 4 (10%).

3.5.1.1. Communication climate

The communication climate, in terms of organizational perspective, can be defined as “a relatively enduring quality of the organizational environment which is experienced by its members that could encourage or discourage the communication process” (93). The organizational communication climate plays a pivotal role in the success of an organization due to the relationship it creates between leaders and members. The effectiveness of

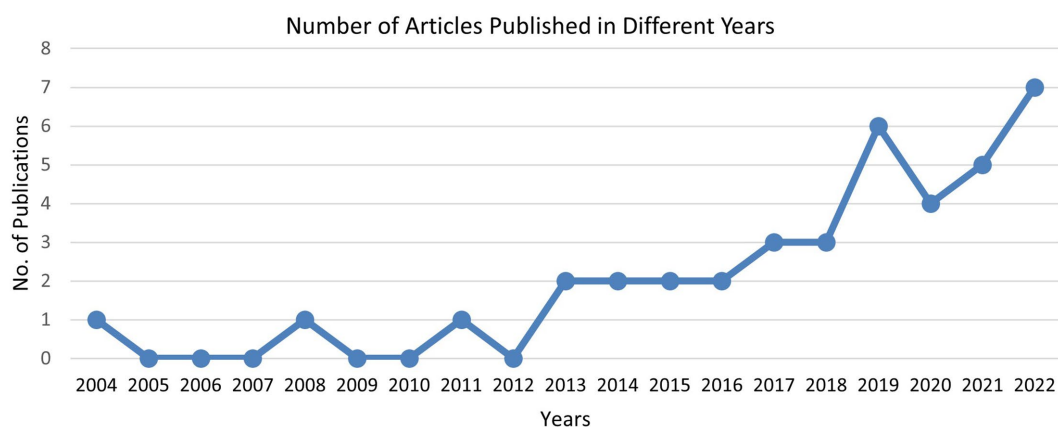


FIGURE 5
Number of articles published in different years on safety communication.

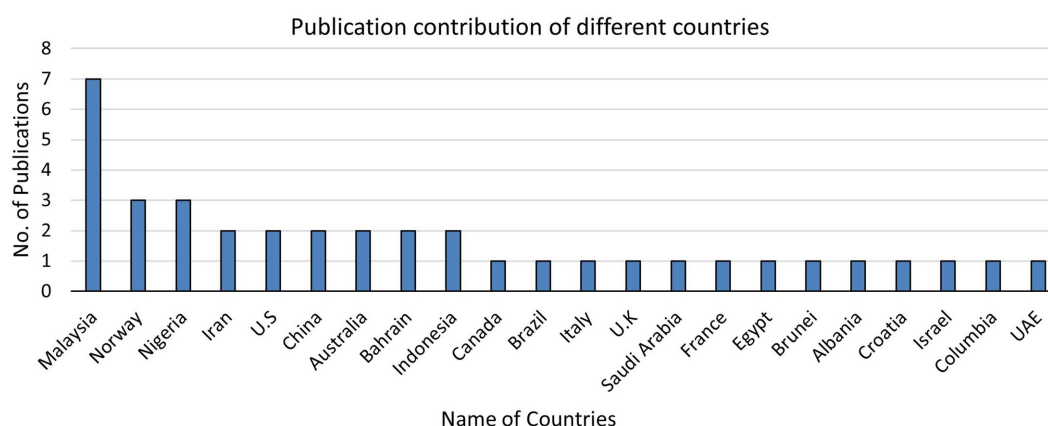


FIGURE 6
Publication contribution of different countries.

communication between leaders and members nurtures the organization and it significantly impacts the act of following safety measures.

The communication climate is dominant and essential to a workplace as it contributes to the efficiency and success of an organization. The organizational communication climate influences the workplace atmosphere either by encouraging or discouraging both horizontal and vertical communication modes across all levels of employees. Supportive environments motivate effective participation, prompt and healthy exchange of information, and productive conflict resolution. An effective communication climate needs active and efficient management of conflicts (60, 93–96). Moreover, the internal climate positively impacts the correlation of organization leaders with other organization members. A study by (56), conducted in the United States, revealed that supportive communication from senior management with employees encourages symmetrical communication in the workplace; hence, balanced communication is required to create and promote the appropriate communication mechanism in the organizational climate.

Additionally, positive internal communication is crucial in public relations; organizations gain positive outcomes, such as workers' involvement, commitment, and performance (56). Symmetrical internal communication is significant for an organization as it has greater potential to enhance personnel creativity. Researchers (97) have argued that workers' perspectives regarding a symmetrical communication climate and systems are highly influenced by transformational leadership behavior (e.g., trained leadership style, authentic leadership). A symmetrical communication climate, two-way communication, and an open environment can foster and encourage personnel's active communication within their organization. It can be concluded that these factors influence their feedback-seeking behavior FSB (78, 98). Pragmatic research has shown that symmetrical internal communication is a contributing factor in achieving organizational visions and goals by involving individuals from different sectors and improving results of individuals to follow the safety precautions and develop sense of belonging, such as corporate empowerment identification, trust, and the relationship between employee and organization (56, 99).

3.5.1.2. Effective communication

One-way communication and feedback are not enough for effective communication (100). Morning meetings, toolbox discussions, safety walks, and workshops are thought to stimulate conversations and contribute to openness and trust within an organization. Employee communication is critical for carrying out safety procedures. As a result, the organization should adopt safety measures, such as enabling two-way communication with employees, especially within multicultural workforces (101). This entails creating a safety information system that collects, analyzes, and disseminates data from accidents and near misses, as well as performing proactive checks on the system's vital signs on a regular basis (102). Furthermore, organizational management may be successful to communicate the effective rules and regulations to their employees to reduce accident and injuries (103). As a result, techniques and resources, such as leading indicators and flexible communication channels, are needed to facilitate the efficient exchange of information among individuals (100). Accidents and unsafe conditions are expected to be reported on a regular basis, resulting in early problem resolution before employees are harmed, and results are expected to be communicated on a regular basis (104). However, when combined with frequent interaction with safety communication, employees' dependability and positive outcomes should increase rather than decrease (105).

3.5.1.3. Communication mechanism

Communication is considered essential for giving feedback on how employees perform their tasks and for providing knowledge and information according to the organization's vision regarding reducing safety issues and hazards. It motivates, provides a direction, and illuminates possibilities for improvement and collective growth (106, 107). Verbal communication is commonly used for the delivery of the safety information. According to leaders, it is of utmost importance to provide employees with clear information regarding the need for safety rules and procedures and find the reasons behind why certain rules and regulations usually face conflict. Through the proper channel of communication, employees receive instruction regarding safety procedures and standards, and they ensure they are understood before beginning operational tasks (108). Communication mechanisms are

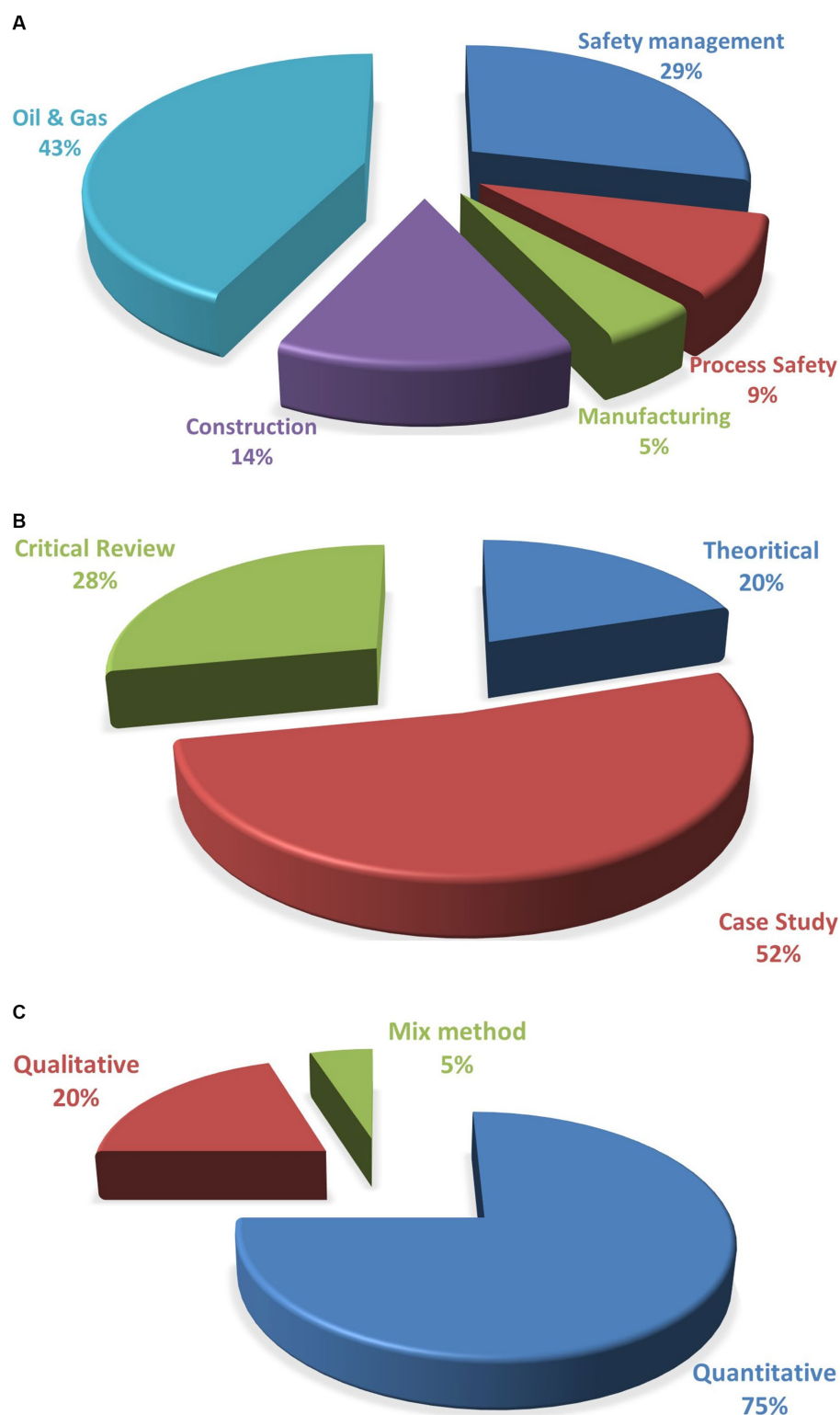


FIGURE 7

(A) Distribution of publications with reference to study areas. (B) Distribution of publications with reference to study methodologies. (C) Distribution of publications with reference to study category methods.

key tools used by management to deliver the objectives and visions of an organization.

Organizational communication commonly shares information about function and relationship structure among workers. This flow

of information has limitations, such as the horizontal and vertical flow of information (109, 110) stated that organizational communication significantly affects employees' performance. It improves their efficacy and effectiveness, in which top-down communication could impact

capabilities and roles and workforce in decision-making, enhance productivity, and motivate workers to demonstrate more competent and effective performance. However, bottom-up communication assists in maintaining a supportive and vertical structure for awareness, thus empowering a balanced work environment to achieve worker efficacy and effectiveness. In addition, organizational communication is intended to encourage informal communication and bottom-up efforts. The importance of consistent and up-to-date communication and effective tools for putting plans into action has been emphasized. Safety briefings, newsletters, information displays, films, safety days and events, monthly safety themes, and mobile applications are among the media and methods used to achieve safety communication and reduce accident rates (100). Furthermore, through monthly lessons learned and documented, the organization may communicate to its employees summaries of all accidents and process failures (including all first aid and near-miss events) (111). A poor safety and health culture, on the other hand, may lead to weaknesses because poor communication causes difficulties for employees in the workplace (101).

3.5.1.4. Communication satisfaction

Communication satisfaction encompasses personal and individual satisfaction with multiple aspects of communication in interpersonal, group, and organizational contexts (112, 113). As per (70), communication satisfaction is generally deemed an affective reaction achieved by fulfilling an expectation during an exchange of information and implies a satisfying experience. Previously, communication satisfaction has been considered a unidimensional construct; however, various researchers (114, 115) have proven that it has multiple dimensions.

The theory of communication satisfaction was initially proposed to describe the relationship between communication and job satisfaction. Considered the most successful research framework for organizational communication (70, 116). Communication satisfaction includes the following constructs: communication climate, communication with management and subordinates, corporate contribution, horizontal and informal communication, media quality, organizational perceptions, and individual feedback (117). The organization should share all of its visions and values clearly with employees as it makes them feel more valued and motivated toward organizational commitment.

Organizational communication has multiple dimensions, including informational and relational dimensions (113, 118, 119). Informational communication satisfaction refers to satisfaction in an organizational context and exchanging information with team members, supervisors, and others concerned. Informational communication satisfaction relies on communication climate, managerial perceptions, and organizational integration. Relational communication satisfaction highlights satisfaction with the relationship between supervisors, subordinates, and all other organizational members in the workplace. It also refers to employees' and supervisors' perceptions and attitudes among corporate members (113).

3.5.2. Occupational safety and health

The objective of OHS management is to provide and maintain a standard procedure for improving safety performance to prevent workplace hazards and injuries. It is a systematic mechanism to determine which methods are required to be implemented. Unsafe

working conditions generate serious health issues and affect employees' well-being, negatively impacting their productivity and organizational performance (31). Human behavior is anticipated to be dynamic and complex (32); therefore, their capacity to understand, comply, and perform according to the procedures and standards of safety contributes significantly to achieving success across high-risk industries (35, 120). Organizations should consider effective communication and efficient administration of OSHA practices to improve work performance in high-risk environments and promote positive working environments. Therefore, effective communication is of utmost importance to ensure positive working behavior (36). In total, 14 articles (35%) were based on occupational health and safety management system, specifically through effective safety communication, 10 (25%) articles were published on safety issues, 7 articles focused on safety indicators (17.5%), 6 papers highlighted the benchmark in the context of high-risk work environment (15%), organizational strategy was mentioned in 6 studies (15%), and the topic of safety rules and regulation was addressed in 10 articles (25%).

3.5.2.1. Safety policy

A control component that prevents accidents from occurring is always present in organizations' senior management, such as a safety policy and goals (103). According to organization management, companies follow a consistent safety policy throughout their operations. The importance of safety-related policies and programs is understandable because such rules and procedures typically provide immediate and visible proof of management's commitment to safety. Organizational safety policies that are ignored or regularly violated send an unclear message about the importance of safety. It is also worth noting that most organizational policies include all aspects of the occupational safety and health management system, in addition to enforcement and discipline (102, 108). It is necessary to monitor and evaluate operational hazards by implementing relevant safety policies to protect and safeguard personnel and proactively prevent risks and accidents in the workplace. Safety indicators play a significant role in decreasing hazards and accident prevention. Safety indicators are used as operational variables in the oil and gas industry to monitor safety performance (35, 119, 120).

In Malaysia's oil and gas industry, safety policies used to measure and monitor offshore processes are derived from generic-specific safety indicators published by the American Petroleum Institute and the International Association of Oil and Gas Producers (IAOG). The oil and gas sector remains a high-risk work environment with a high hazard and accident rate. There is growing concern that safety policies are not implemented correctly, resulting in fatalities, injuries, and incidents in the workplace (74, 121). A healthy and safe work environment requires safety policies and procedures. Due to the lack of appropriate safety policies, personnel experience safety issues, such as mental and physical disability, danger to life, property damage, and negative impacts on productivity and other colleagues (122). The significant components that cause these accidents are a lack of communication, negligence, and shortcomings in ensuring occupational health and safety in the workplace. Table 4 provides a description of different safety policies implemented in different countries.

3.5.2.2. Safety issues

The oil and gas industry is the most hazardous in the world. Even though operational safety procedures and standards with various

TABLE 4 Description of different safety policies implemented in different countries.

References	Country	Safety Policies	Description
(123)	South Africa	OSHA	The safety policy of South Africa is adopted from the Occupational Health and Safety Act (OSHA). Its prime objectives and vision are to provide occupational safety for employees and health and safety for those who operate machinery and plant; to develop an advisory council for safety and health in the workplace.
(2)	Malaysia	HSE 2006	The Malaysian Oil and Gas industry adopts the HSE 2006 safety policy. That comprises a wide range of safety indicators that measure causes of accidents/ incidents or injuries and take responsibility for preventing accidents. Such accidents include but are not limited to fire, burnout, explosion, oil spills, gas release, or other conditions, which could result in illness or injury to personnel.
(124)	Indonesia	Regulation 79–2014	The Director-General of Oil and Gas (DGOG) monitors and implements policies and objectives associated with health and safety issues. Indonesia adopts safety policies from Government Regulation 79 of 2014 for the oil and gas sector. The government has stipulated that energy policy is to be implemented from 2014 to 2050.
(125)	Saudi Arab	OSHA	Saudi Arabia adopts the occupational safety policy from US OSHA standards and the American Society of Safety Engineers (ASSE). In the Jeddah refinery, multiple departments are responsible for maintaining employees' health and safety, such as the Loss Prevent Department (LPD), Environment Protection Department (EPD), and the Occupational Medical Department (OMD). These all are working under Saudi Aramco Medical Services Organization.
(126)	U.K., Brazil, Mexico, and Australia	Regulation 2005	Brazil implements three safety policies, Safety Case, Barrier Management, and Research and Development, to maintain and establish a healthy and safe work environment for their employees in oil and gas organizations. The safety case approach is adopted from the UK's offshore installation Regulation 2005. Under the safety case, operators are responsible for predicting safety issues, such as burns, escape, and fire risk, and fulfilling safety requirements at the workplace.

effective programs are already implemented in Malaysia, incidents, hazards, and injuries still occur (125, 127). The high-risk work activities related to the oil and gas sector and minor incidents that become natural disasters make safety issues crucial in this field. Hazards in the oil and gas sector are always a reason for safety measures. It was identified that personnel in high-risk work environments suffer from work-related safety issues, including injuries, such as cuts, burns, contusions, and lacerations of the legs, hands, fingers, and eyes (128). The reasons for the occurrence of catastrophic events include poor infrastructure, lack of funding for safety systems, unqualified occupational health professionals, inappropriate occupational hazards and injury monitoring and evaluating mechanisms, and a lack of available data regarding health and safety; these are the most common safety issues in oil and gas industry (129). Along with these safety issues, employees face the most hazardous accidents and injuries that occur in the workplace. Table 5 provides a description of safety issues experienced in the oil and gas sector worldwide.

3.5.2.3. Strategies

Safe operational practices are necessary for safe production at the workplace, primarily focusing on unsafe situations, where there is no established standard procedure for carrying out a specific task or where the legal mechanism is lacking for safely completing the task (132). Implementing a compelling communication vision in delivery systems might be achieved by an organization by establishing uniform standards and processes. Accident and injury rates can be reduced by establishing process checklists, standardizing care procedures, and removing pointless variance where practical (104). Standard mechanisms ensure that organizational tasks are completed safely and effectively and can contribute to a better and safer work environment (133). A control system must also be in place for an organization to operate safely.

To ensure that these control systems are being used and are sufficient to handle the constantly changing working environment, they must be evaluated and monitored regularly. Their goal is to pinpoint the situations where a deficiency in the monitoring and reporting of present controls results in workplace hazards or injuries (132, 134).

3.5.2.4. Safety rules and regulations

To protect the workers and safeguard the operational facilities of the oil and gas industry, several international and national organizations have enforced international and national rules to overcome health, safety, and environmental challenges. Accidents happen despite safety policies, rules and regulations, acts, laws, and training. In Malaysia, concerns related to oil and gas encouraged the enactment of the Petroleum Act of 1984 for transportation safety measures. The Act regulates the storage, transportation, and utilization of petroleum products. Another subsidiary regulation (Regulations of 1985) relating to petroleum safety measures was introduced for pipeline transport under the same Act (2, 135).

The Petroleum mining ACT was introduced in 1984 but had limited safety implications for offshore operations. To overcome the limitations and resolve safety concerns, another Act, namely the Factory and Machinery Act (FMA), was introduced in 1967, which provides the safety, health, and welfare governance of the workers along with the inspection and registration of machinery to ensure safe working environments. Therefore, offshore oil and gas platforms are subject to the FMA (135). Still, the ACT had certain shortcomings, which were fulfilled after introducing the Occupational Safety and health act (OSHA) in 1994. The OSHA promotes a safe and healthy work environment, including onshore and offshore installations. The OSHA ensures the safety of operations by mandating a safety committee that performs risk assessment and helps provide safety measures to prevent accidents and hazards (136, 137). Table 6

TABLE 5 A brief description of safety issues experienced in the oil and gas sector worldwide.

References	Year	Country	Safety issues
(2)	2017	Malaysia	The process of safety issues includes a set of various reasons; leakage and spillage, fire, and explosion are the most frequent causes of severe consequences. Such accidents are caused by misinterpretation of knowledge and communication issues.
(45, 121)	2013, 2018	Malaysia	A lack of training and guidance exposes people to dangerous chemicals because appropriate safety measures are not taken immediately. A lack of safety culture was identified as the leading cause of negligence and hazardous situations in organizations.
(129)	2020	Ghana	A lack of health and safety policies, untrained and underqualified employees, and poor infrastructure.
(52)	2022	China	Sets of safety performance factors that impact industries, including management and worker factors.
(53)	2020	Indonesia	Poor communication, the employees or people involved consider themselves fit for duty. Accidents occur due to a lack of information or knowledge, appropriate training, leader supervision, and implementation of occupational safety and health regulations.
(130)	2011	Iraq	Insufficient tools, poor technology, poor organizational management, lack of precautions, lack of adequate services, employee disregard of safety regulations, and inadequate training are factors that trigger unsafe behavior.
(131)	2019	Iran	Technological advances have excelled in high-risk involvements, the negligence of which forms the basis of catastrophe.
(74)	2019	UAE	In past studies, fatal accidents have occurred in the UAE oil and gas industry with different safety issues, including explosions, exposure to chemical equipment, and inspection of high-heating products (boiler), which are the leading causes of loss of workforce.

provides a brief overview of the different safety rules and regulations introduced by different countries to improve workplace safety.

3.5.2.5. Safety benchmark

The benchmarking process compares similar entities that need to improve in cost, quality, and performance. It refers to the idea of pursuing continuous performance improvement (CPI) by studying the top strategies used by competitors (142). A quality audit notifies auditors of performance gaps compared to the expected criteria. The benchmarks are often set based on performance targets, while the audit criteria are specified. Usually, surveys, audits, interviews, or industry standards are used to establish the measurements of the benchmarking process. Organizations identify performance gaps, select action items, and conduct follow-up studies to improve underperforming processes. Benchmarking strategies have been employed extensively in the O&G sector, just like in other industrial sectors.

3.5.2.6. Safety indicator

When one or more leading indicators point to a missing or ineffective part of the safety program, interventions or adaptive mitigation measures can be implemented to strengthen the safety program and improve safety performance outcomes. The leading indicator measures a system, condition, or behavior that predicts future performance. In contrast, effective leading indicators should anticipate a change in performance, whether for the better or worse. A literature theoretical framework included three categories of safety performance indicators: result, monitor, and derive indicators. Result indicators measure the overall outcomes and conditions of a system like TRIR. Monitor indicators, such as work and safety motivation or hazard recognition, show the organization's potential and capacity to conduct safety procedures. Derive indicators, such as safety leadership and strategic management, measure how well safety management operations are carried out. Using this theoretical framework, the authors stated that monitor and drive indicators are leading indicators. They control system activities and organizational dynamics, whereas

outcome indicators lag because they result from various elements. The oil and gas industry usually gauges its safety performance using lagging indicators, such as the total recordable incident rate TRIR and the severity rate S.R. of the Occupational Safety and Health Administration (OSHA). Lagging indicators are metrics that relate to injury or loss events in the past. Lagging indicators highlight and respond promptly to hazards and accidents, and lagging indicators of safety performance are based on prior safety performance results (71, 143, 144). Table 7 assists in deciding the proactive metrics concerning their measurement, highlighting the leading and lagging indicators.

3.5.3. Safety performance

The rate of occupational injuries/accidents and hazards requires every worker's participation. Commitment to unsafe Acts and unsafe conditions could enhance workplace safety if every individual adhered to the organizational safety rules and was eager to strengthen safety performance (57). Similarly, (121) revealed positive safety performance-maintained safety measures, procedures, and rules derived from regular communication between supervisors and employees. Some accidents are impossible to prevent in high-risk working environments due to the nature of certain operations and processes. Though industries are now strictly adhering to safety precautions for health, safety, and the environment, incidents are still reported worldwide, to which the oil and gas industry contributes the majority. According to worldwide evidence, 2 million fatalities are reported relating to accidents and diseases caused by the workplace. A total of 270 and 160 million occupational accidents and illnesses occur annually (28, 29). Workplace safety remains challenging and it is necessary to avoid accidents effectively and improve safety performances (38).

3.5.3.1. Occupational accidents

Occupational accidents result in injuries requiring medical attention (145). Reducing occupational accidents is perceived as the goal or outcome of an organization's safety efforts. Occupational accidents result from many factors, including unsafe behavior, (which

TABLE 6 Brief overview of the different safety rules and regulations introduced by different countries to improve workplace safety.

Rules and regulations	Details	Country	Source
OSHA 1994	Mandates the establishment of a safety committee, employing safety officers, measuring chemical health risks at facilities with organizational incidents hazards, monitoring of organizational hygiene and medical surveillance of personnel, and all other safety mechanisms.	Malaysia	(136)
FMA 1967	Controls factories concerning matters relating to the safety, health, and welfare of persons therein.	Malaysia	(135)
ACT 1984	Consolidates the safety-related laws regarding transportation, storage, and utilization of petroleum and matters relating to it.	Malaysia	(2), (135)
Act 1974	Mandates the safeguarding of work-related health, safety, and welfare.	Malaysia and Singapore	(76)
2009 regulations	For operators considering safety cases, validation, and accident notification about offshore facilities.	Australia	(137)
Workplace Safety and Health Act (2009)	Provides a framework to protect all workers' health, safety, and welfare concerning the workplace and work activities. International Labour Organization	Brunei	(131)
Act 2003/Law-11,970	Covers Indonesia's paramount health and safety laws, focuses on their prevention, and ensures the implementation of safety measures.	Indonesia	(138)
Factory Act 1951 and OSHL 2019	Concerns the implementation of employee safety and health in the workplace.	Myanmar	(136, 139)
Republic Act (2006)	Established for occupational safety, health, and welfare.	Singapore	(140)
BSEE (2010)	The United States established the Bureau of Safety and Environmental Enforcement (BSEE) to respond to the Deepwater Horizon explosion in 2010; it strictly follows offshore safety and environmental protection rules and regulations.	United States	(141)

is a direct trigger factor, with it intends to highlight different level of injuries) in most organizational injury rates (124). Occupational accidents can also be measured by recordable injuries resulting in lost time, recordable injuries requiring medical treatment, and incident rates based on severity and frequency (60). This is vital in a high-risk work environment, specifically in the oil and gas industry, where disasters and accidents can occur if the information is not communicated adequately among workers. Negligence and information blocks could result in disasters and accidents.

3.5.3.2. Occupational fatalities accidents

ILO global statistics report nearly 2.78 million annual fatalities. Poor and inefficient safety systems, management practices, human error, etc. were the causes of the reported incidents. Such consequences are alarming, and improving the workplace to reduce workplace accidents, injuries, and fatalities is necessary. Furthermore, such safety issues in the workplace need to be identified and addressed appropriately to mitigate risks in the workplace because they also accrue costs to the organization in terms of medical, health, death, incapacitation, equipment damage, production loss, and increased insurance costs (9–12). The fatality rate due to workplace accidents among oil and gas employees is seven (7) times higher than in other industries. As a result, companies in this sector must provide a safe working environment to reduce the risks of operational hazards.

3.5.3.3. Lost time injury

There are two methods for reporting lost time: lost time injuries (the subset of work-related injuries that result in 'lost time' due to work absence) and lost time injury frequency rate [the number of lost time work-related injuries (fatalities and failed workday cases) per one million work hours (146, 147)]. Some companies, however, calculate lost time injury frequency rates according to the Occupational Health

and Safety Administration guidelines, which use 200,000 h as the denominator (147).

3.5.3.4. Near misses

Analyzing the literature has revealed two main approaches to a near-miss definition. The first (traditional approach) considers a near miss to be any event that occurs but does not cause any harm. Sometimes, it may only cause minor property damage. The second (proactive approach) includes events and potentially hazardous situations, such as unsafe acts and conditions. Some recent studies have outlined the main features of the first approach by analyzing it. In a review, the concept of precursors was critically examined (80), who attempted to clarify the definition of a near miss by analyzing a generic accident sequence. A near miss is defined in this framework as a precursor to an accident in which the accident sequence has been prevented, although the accident could have taken place.

3.5.4. Safety commitment

Safety commitment is a crucial component of safety practice to ensure that safety in the organization is successfully achieved, especially in the oil and gas industries, which face high incident rates. Thus, safety commitment is the involvement of an individual in safety activities to improve workplace safety and can reduce the costs to organizations and any loss of workforce (77, 148, 149). Numerous studies have found that if organizations follow safety rules and procedures and conduct regular safety training, and if management shows commitment, attention, and interest in safety issues, they are likely to have a lower rate of injuries and accidents (99, 150, 151). Various researchers (152, 153) have highlighted that safety rules and feedback have a positive relationship with safety management related to management's commitment to safety in the workplace. According to (121, 154), fostering workplace safety and

TABLE 7 Proactive metrics concerning their measurement, highlighting the leading and lagging indicators.

Proactive metrics	Measurements	Indicators
Safety training programs	Number of training sessions conducted. Percentage of employees trained. Number of safety violations pre- and post-training. TRAR and SR pre- and post-training.	Leading
Safety meetings	Frequency of safety meetings held. Participation rates of employees and management. Number of safety concerns raised and addressed. TRAR and SR pre- and post-meetings.	Leading
Job hazard analysis	Number of job hazard analyses completed. Number of corrective actions taken. Number of incidents prevented. TRAR and SR pre- and post-hazard analyses.	Lagging
Safety audits and inspection	Frequency of safety audits and inspections. Number of safety violations identified. Number of corrective actions taken. TRAR and SR pre- and post-audits/inspections.	Leading/ Lagging
Safety communication plans	Effectiveness of safety communication strategies. Employee feedback on safety communication. Number of safety incidents prevented. TRAR and SR pre- and post-communication plans.	Leading
Near-miss reporting system	Number of near misses reported. Percentage of near misses investigated and addressed. Number of incidents prevented through near-miss reporting. TRAR and SR pre- and post-near-miss reporting.	Leading/ Lagging
Management commitment to safety	Demonstrated commitment from upper management. Allocation of resources to safety initiatives. Employee perception of management commitment to safety. TRAR and SR pre- and post-commitment to safety.	Leading/ Lagging
Employee involvement in safety	Employee participation in safety programs. Employee feedback on safety policies and procedures. Employee suggestions for safety improvements. TRAR and SR pre- and post-employee involvement.	Lagging
Safety risk assessments	Number of risk assessments completed. Number of high-risk activities identified. Number of mitigating actions implemented. TRAR and SR pre- and post-risk assessments.	Lagging
Safety leadership	Demonstrated safety leadership from managers and supervisors. Employee perception of safety leadership. Number of safety initiatives led by safety leaders. TRAR and SR pre- and post-safety leadership.	Leading
Safety culture assessments	Employee perception of safety culture. Number of safety culture initiatives implemented. Number of safety culture improvements observed. TRAR and SR pre- and post-safety culture assessments.	Leading
Safety incentive programs	Employee participation in safety incentive programs. Number of safety-related achievements recognized. Number of safety incidents prevented through incentive programs. TRAR and SR pre- and post-incentive programs.	Leading
Safety checklists	Number of safety checklists completed. Number of safety issues identified. Number of corrective actions taken. TRAR and SR pre- and post-checklists	Lagging
Contractor management	Number of safety assessments completed for contractors. Number of safety requirements communicated to contractors. Number of safety incidents involving contractors. TRAR and SR pre- and post-contractor management.	Leading
Safety equipment inspections	Frequency of safety equipment inspections. Number of safety equipment issues identified. Number of corrective actions taken. TRAR and SR pre- and post-equipment inspections.	Lagging
Emergency preparedness	Effectiveness of emergency response plans. Number of emergency drills and exercises conducted. Number of emergency incidents prevented or mitigated. TRAR and SR pre- and post-emergency preparedness.	Leading
TRAR	Total Recordable Accident Rate (TRAR) is a safety performance indicator that measures the number of work-related accidents and injuries within a specific timeframe per a certain number of hours worked. It provides a standardized measure to assess the overall safety performance of an organization or workplace. $TRAR = (\text{Number of Recordable Accidents} / \text{Total Hours Worked}) \times 100,000$	
Safety readiness (SR)	SR, or Safety Readiness, is a proactive safety measure that refers to the preparedness and state of readiness within an organization or individual to effectively manage safety risks and respond to potential hazards. It encompasses a range of activities and practices aimed at preventing accidents and promoting a safe working environment	
Pre- and post training	Pre- and Post-Training measures refer to proactive safety measures taken before and after training sessions to enhance the effectiveness of safety training programs and maximize their impact on improving workplace safety. These measures aim to ensure that employees receive relevant and comprehensive training, retain the knowledge and skills acquired, and apply them effectively in their work environment.	

executing safety practices in the workplace is difficult without management commitment to safety, which shows that the management of safety is an essential element in ensuring effective and efficient safety practices in an organization. A total of 13 previous studies (32%) highlighted the characteristics related to safety motivation, specifically in high-risk work environments. Most of the authors focused on and discussed the sub-theme of safety participation, which was the focus of 15 articles (38%),

followed by safety knowledge, as the focus of 14 articles (35%), and safety compliance, as the focus of 13 articles (32%).

3.5.4.1. Safety participation

Safety participation is a system that develops an overall participant environment, although it does not directly affect an individual's safety (41, 155). A safe work environment requires participation in safety committees, reporting on unsafe situations,

decision-making, suggestions for enhancing security, and motivating guide co-workers involved in dangerous acts. Safety participation refers to supporting employee behavior and creating an environment to support safety as well as procedures for helping co-workers, involvement in voluntary safety activities, taking safety initiatives, promoting safety-related principles, and implementing safety in the workplace.

3.5.4.2. Safety knowledge

Safety knowledge is based on the degree of workers' knowledge regarding the organization's safety system, practices, and procedures. Employee work performance is determined according to their understanding, motivation, and skill; thus, workers perform their duties safely by following safety measures to enhance these three factors. Organizations must conduct frequent, comprehensive, and systematic health and safety training programs to improve employees' knowledge (129). Workers' knowledge related to performing their jobs safely, how to use safety equipment and standard operating procedures, how to maintain or improve safety and health in the workplace, how to reduce the risk of accidents and incidents in the workplace, the associated hazards and necessary precautions, and how to report potential hazards noticed in the workplace are the six items of the safety knowledge scale (156).

3.5.4.3. Safety compliance

A significant relationship between accident involvement and unsafe behavior is understood to be based on actions, participation in risks, violating rules, and unsafe behavior. These create a highly hazardous situation for an individual, eventually leading to critical accidental events. Lack of safety knowledge leads to safety rules being ignored and failure to use appropriate protective personal equipment. The previously mentioned examples are called safety compliance, which develops only one aspect of safe behavior (157, 158). Safety compliance implies workers' behavior in relation to safety procedures and policies for achieving work safety standards, such as obeying rules regarding the use of personal equipment, performing operational duties safely, complying with safety rules and regulations, and following appropriate procedures (8). The oil and gas industry is highly regulated with safety standards and procedures. Occupational safety rules within the oil and gas industry completely rely on safety, and virtually operational tasks are processed by rules and regulations. Therefore, a high level of compliance requires a high level of safety preconditions.

3.5.4.4. Safety motivation

Safety motivation, or the desire to participate in safety practice that will enhance one's skills and improve safety behavior, is another proximal antecedent of safety performance (145, 156). The necessity of maintaining safe and effective practices, making an effort to improve personal safety, and reducing the risk of workplace accidents and incidents are used as a scale to measure safety motivation (107). The safety climate was found to be significantly correlated with safety knowledge and motivation in meta-analysis studies, both of which are associated with predicting safety performance, which indirectly affects accidents and injuries (145, 159). Improvements in information and training that promote safe behavior can improve worker health and safety (88, 160).

3.6. Main findings

To summarize, the findings of this study provide valuable insights into the themes of safety communication, occupational health and safety, safety performance, and safety commitment within high-risk industries, particularly the oil and gas sector. These themes encompass 18 sub-themes that were identified through an extensive analysis of the literature. The major findings and their implications are discussed as follows.

Safety communication emerged as a critical factor in ensuring the well-being of workers in high-risk organizations. Effective safety communication practices were found to enhance the efficiency of the safety management system and guide workers in reducing unsafe incidents. A lack of safety communication was identified as a significant factor in conflict and confusion among workers regarding safety rules and procedures. The sub-themes of communication climate, effective communication, communication mechanism, and communication satisfaction were highlighted in the literature, emphasizing their relevance in organizational safety performance. The presence of a supportive communication climate, characterized by open and two-way communication, was found to promote symmetrical communication within the organization. Transformational leadership behavior was identified as a key influencer of workers' perspectives on communication climate, highlighting the importance of leadership in fostering effective communication. It can be concluded that symmetrical internal communication contributes to achieving organizational goals and establishing a strong relationship between employees and the organization.

Occupational health and safety management was identified as a crucial aspect of maintaining workplace safety and preventing hazards and injuries. Safety policies, safety issues, safety strategies, safety rules and regulations, safety benchmarking, and safety indicators were among the sub-themes explored in this area. Safety policies were found to play a vital role in demonstrating management's commitment to safety and in setting clear guidelines and procedures. Safety issues, including hazards and injuries, were identified as ongoing challenges in the oil and gas industry, indicating the need for continued efforts to address these concerns. Strategies such as process standardization and control systems were emphasized as essential for maintaining a safe working environment. Compliance with safety rules and regulations was identified as a critical factor in protecting workers and preventing accidents. Safety benchmarking and safety indicators were recognized as valuable tools for monitoring and improving safety performance.

Safety performance, including occupational accidents, occupational fatalities, lost time injuries, and near misses, was a key area of focus in the literature. The study revealed the importance of understanding the factors contributing to occupational accidents and the need for effective safety measures to prevent such incidents. Occupational fatalities and lost time injuries were identified as significant concerns, emphasizing the need for comprehensive safety systems and management commitment. The concept of near misses was explored, highlighting its potential as a proactive indicator of potential accidents and the importance of reporting and addressing near misses to prevent future incidents.

Safety commitment was identified as a critical component of safety practice and performance. The sub-themes of safety

participation, safety knowledge, safety compliance, and safety motivation were examined in this context. Active participation in safety activities, knowledge of safety practices and procedures, compliance with safety rules, and motivation to prioritize safety were all found to contribute to a positive safety culture and improved safety outcomes. Management commitment to safety was identified as a crucial factor in fostering a safe working environment and encouraging employee involvement in safety practices.

Overall, this study provides comprehensive insights into the themes of safety communication, occupational health and safety, safety performance, and safety commitment within high-risk industries. The findings underscore the importance of effective communication, robust safety management systems, and a strong safety culture in ensuring the well-being of workers and preventing accidents and injuries. The identified sub-themes offer valuable avenues for further research and provide practical implications for organizations seeking to enhance their safety practices and performance in high-risk workplaces.

4. Discussion

The purpose of this study was to conduct a comprehensive literature review on the impact of organizational variables on effective safety communication, communication climate, communication satisfaction, and commitment to safety. The findings of the reviewed articles revealed that organizations are influenced by various factors in their pursuit of creating a healthy and safe work environment. The study considered two databases and identified 40 articles relevant to the impact of effective safety communication. From the extracted literature, the study identified four main themes, namely, occupational health and safety, safety communication, safety performance, and safety commitment, which collectively contribute to achieving the organizational goals and visions of a safe workplace.

Safety communication was highlighted as a critical aspect of safety management systems in the oil and gas industry. It involves the exchange of information among workers, supervisors, managers, and stakeholders regarding safety policies, procedures, and regulations. Different forms of safety communication were identified, such as safety meetings, alerts, training sessions, reports, audits, and feedback mechanisms. Effective safety communication enables workers to identify and report hazards, take corrective actions, and learn from safety incidents, ultimately preventing future occurrences (28, 50, 57, 161, 162).

The communication climate within an organization plays a crucial role in safety communication. A positive communication climate, characterized by open and honest communication, mutual respect, and trust, fosters effective safety communication. In such an environment, workers are more likely to speak up about safety concerns, ask questions, and offer suggestions for improving safety practices. Establishing a positive communication climate encourages collaboration and problem-solving among workers, leading to enhanced safety outcomes (41, 93, 97).

Communication satisfaction also emerged as a significant factor in safety communication. When workers feel satisfied with the communication they receive from supervisors, colleagues, and stakeholders, they are more likely to engage in safety communication. Satisfied workers are more inclined to report safety incidents and

hazards, offer suggestions for improvement, and adhere to safety procedures and regulations. Therefore, organizations should strive to ensure that workers receive clear, timely, and supportive communication, which positively impacts safety performance (63, 67, 113, 163, 164).

To facilitate effective safety communication, the study highlighted the importance of having an appropriate communication mechanism in place. Workers need access to tools and channels that enable them to report incidents, receive safety information, and communicate with colleagues and supervisors. Various mechanisms were identified, including safety manuals, meetings, committees, hotlines, suggestion boxes, training, and inspections. Employing the right communication mechanisms enhances safety communication and improves overall safety performance (63, 70, 164, 165).

Communication effectiveness (C.E) in safety communication refers to the degree to which safety information is communicated accurately, clearly, and in a timely manner to all relevant stakeholders in the oil and gas industry. Effective safety communication ensures that workers are aware of safety hazards, understand safety procedures and regulations, and can take appropriate measures to prevent accidents and incidents. Communication effectiveness is crucial to the success of safety communication in the oil and gas industry. Effective safety communication ensures that safety information is accurately and clearly communicated to all relevant stakeholders, enabling workers to understand safety procedures and regulations, identify safety hazards, and take appropriate measures to prevent accidents and incidents (72, 113, 117, 163, 166, 167).

Occupational health and safety (OHS) management systems were found to be crucial in creating a safe work environment. These systems encompass the development and implementation of rules, regulations, and policies that promote workplace health and safety. Effective safety policies motivate employees and managers to perform their duties in accordance with safety procedures, reducing the occurrence of unsafe conditions and acts. Organizations should allocate appropriate resources to ensure the successful implementation of safety measures and prioritize safety within their budget evaluations (49, 168–176).

Safety commitment, as a subset of safety management strategies, was identified as a key factor in influencing safety performance. Top management plays a vital role in motivating and influencing workers' safety performance through their commitment to safety. Transformational leadership was highlighted as an effective leadership style that influences safe employee behavior, contributing to high safety performance. Organizational support, open communication climates, and management involvement in decision-making processes all contribute to a supportive safety environment that fosters safety participation and compliance (177–182).

Safety performance indicators, including occupational accidents, lost time injuries, fatalities, near misses, and occupational diseases, provide measurable insights into organizational safety performance. The severity of an occupational accident is determined by its impact on property damage and injuries. Analyzing incidents helps uncover underlying factors, such as deficiencies in OHS activities and programs, and individual unsafe behaviors that trigger accidents. Organizations should monitor leading safety indicators and utilize appropriate tools and technology to identify and address safety issues proactively (145, 183).

To conclude, this comprehensive literature review emphasizes the significance of organizational variables in effective safety communication and the creation of a healthy and safe work

environment. By understanding and addressing factors such as communication climate, communication satisfaction, communication mechanisms, and safety commitment, organizations can improve safety performance and prevent accidents and injuries.

4.1. Practical relevance

The findings of this study hold significant practical relevance for safety practitioners operating in high-risk workplace environments. By highlighting the importance of safety communication, occupational health and safety management, safety performance, and safety commitment, the study provides valuable insights that can inform and guide the practices of safety professionals.

Firstly, the emphasis on safety communication underscores the need for safety practitioners to prioritize effective communication strategies within their organizations. By promoting a supportive communication climate, implementing effective communication practices, establishing clear communication mechanisms, and fostering communication satisfaction, safety practitioners can enhance the flow of safety-related information, reduce conflicts and confusion, and ultimately improve safety outcomes. The study's findings provide guidance on key areas of focus for safety communication initiatives, enabling practitioners to develop targeted and impactful communication strategies that address the specific needs of their organizations.

Secondly, the exploration of occupational health and safety management highlights the importance of implementing comprehensive safety policies, addressing safety issues, devising effective safety strategies, ensuring compliance with safety rules and regulations, benchmarking safety performance, and utilizing safety indicators. Safety practitioners can utilize these findings to assess and strengthen their organization's safety management systems. By adopting standardized safety policies, identifying and mitigating safety issues, implementing effective safety strategies, and staying up to date with relevant safety regulations, practitioners can contribute to creating a safer working environment. Furthermore, the study's insights on safety benchmarking and safety indicators offer practical tools for safety practitioners to monitor and evaluate safety performance, identify areas for improvement, and drive continuous safety enhancement initiatives.

Moreover, the study's examination of safety performance provides safety practitioners with valuable information on occupational accidents, fatalities, lost time injuries, and near misses. By understanding the factors contributing to these incidents, safety practitioners can develop targeted prevention strategies, improve safety training and procedures, and implement proactive measures to identify and address potential hazards. The findings emphasize the importance of management commitment, employee participation, safety knowledge, and safety motivation in achieving positive safety performance. Safety practitioners can leverage these insights to design and implement comprehensive safety programs, enhance safety training initiatives, and foster a safety culture that encourages active involvement and prioritization of safety.

Lastly, the study's focus on safety commitment underscores the critical role of management in creating a safe working environment. Safety practitioners can use this knowledge to advocate management support and commitment to safety initiatives, ensuring that safety practices and procedures are effectively implemented and adhered to throughout the organization. By promoting safety participation, enhancing safety knowledge, fostering safety compliance, and

encouraging safety motivation, safety practitioners can drive a culture of safety commitment among employees, leading to improved safety performance and reduced risks.

5. Limitations and challenges

This study is based on thematic analysis results; the selected review articles on the practice of safety communication in the high-risk workplace is still moderate and has only increased in recent years. Most papers are published in the construction industry rather than other high-risk industries, such as oil and gas, mining, and manufacturing. Furthermore, most of the articles were removed during the screening process because the focus area was the oil and gas industry, indicating a gap and the need for further investigation and research in these industries. Since OHS reporting methods and procedures depend on industries and the nature of work, further research is required to focus on and identify OHS performance measures and indicators that are more promising and can assist an organization in effectively implementing them (183). Future research is required in a wide range of oil and gas industries, which may have more OHS procedures and standards due to the use of benchmarking tools or adapting across safety communication activities.

Based on the current research, most of the selected review papers focused on occupational accidents and injuries. All were supported by (124), who identified that most organizations provide detailed information about occupational injuries. Thus, focus should be applied to all levels and types of accidents, despite the level of loss or damage, such as occupational accidents, fatalities, near misses, and lost time injuries. Minor accidents that do not have severe outcomes or that do not damage property and equipment still require attention as they can cause future incidents. Future research should consider a lack of effective communication, safety communication, and commitment towards safety as safety outcomes as the root causes of fatal occupational accidents, occupational accidents, lost time injuries, and near misses. Thus, the researcher should also highlight the positive outcomes of high safety standards in the workplace, such as economic increase, productivity, and profit increase.

Despite the abovementioned limitations, the results of this systematic review could draw a framework relevant to developing strategies regarding effective safety communication and safety commitment research and to organizations seeking to improve the safety behavior of workers in the oil and gas industry. These findings are also relevant to other high-risk industries, where safety procedures, rules, and regulations constitute a major concern for maintaining safety.

6. Conclusion

This study is based on a systematic review, emphasizing the importance of the variables that influence the reduction of accident and injury rates through effective communication and commitment to safety. In an organizational context, the minimum rate of incidents vision focused on the occupational health and safety environment. Most organizations and policymakers implement this vision efficiently along with strategies and programs related to occupational health and safety. Various scholars have experiences associated with OHS from different backgrounds, giving insight into its effective use and success from a theoretical perspective and in practice. The countries where the

highest number of studies were conducted were Malaysia, with seven articles (18%); Nigeria, with three articles (8%); and Norway, with three articles (8%), followed by China, Iran, the U.S., Australia, Bahrain, and Indonesia, each with two articles (5%). Most of the countries published one article only, including Canada, Brazil, Italy, the UK, Saudi Arabia, France, Egypt, Brunei, Albania, Israel, Croatia, Columbia, Singapore, and the UAE.

This study's systematic review emphasizes the importance of the variables that influence the reduction of accident and injury rates through effective communication and safety commitment. The findings shed light on various dimensions of safety communication, occupational health and safety management, safety performance, and safety commitment, providing valuable insights for both the industrial and academic realms.

One significant implication of this study is the development of strategies to promote a safety culture and address communication barriers. The findings highlight the need for interventions that enhance communication skills and techniques at both macro and micro levels. Safety practitioners can leverage these insights to design communication management strategies that foster a culture of safety and overcome obstacles in safety communication.

Moreover, this study also reveals several gaps and potential areas for future research. One such area is the exploration of safe behavior as an influencing variable on safety principles. Future studies could conduct in-depth qualitative analyses to provide a comprehensive understanding of safe behavior and its impact on organizational safety. Additionally, future research could employ specific systematic review methodologies, incorporating appropriate searching techniques such as reference searching, citation tracking, snowballing, and expert input, to further enhance the research synthesis in this field.

Furthermore, the study highlights the need to adapt to new challenges and hazards in the context of the 4th Industrial Revolution and the global impact of events like the COVID-19 pandemic. Future studies should focus on developing new strategies that ensure the sustainability of safety in the face of emerging challenges. This includes strengthening safety competencies among designers, engineers, and workers to maintain a safe working environment.

Practitioners can derive practical leads from this study to improve organizational commitment to safety, devise strategies to overcome communication barriers, foster a safety culture, and enhance communication skills and techniques. The comprehensive overview of the elements and their relationship with negative safety outcomes and performance provides practitioners with valuable insights for developing and evaluating interventions aimed at improving occupational safety.

In conclusion, this study not only presents significant findings on the importance of communication and safety commitment in occupational safety but also offers valuable directions for future research. By focusing on the development of effective communication strategies for safety commitment and addressing the identified

research gaps, researchers can contribute to advancing the field and promoting a safer and healthier working environment.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

JZ, SN, and AI contributed to the design and implementation of the study. JZ conducted the detailed analysis and manuscript drafting. SN contributed to assessing the study quality and management of the study. SN and AI were involved in supervision and manuscript revisions. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Exploring the relationships among safety leadership, safety climate, psychological contract of safety, risk perception, safety compliance, and safety outcomes

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Background: Recently, two types of safety compliance behaviors including deep compliance and surface compliance were differentiated. The current study aimed to investigate the relationships among safety leadership, safety climate, psychological contract of safety (PCS), risk perception, and deep compliance and surface compliance behavior of workers. In addition, the effects of both deep and surface compliance on safety outcomes were considered.

Methods: Workers' perceptions in terms of safety leadership, safety climate, PCS, risk perception, deep compliance, and surface compliance were measured by appropriate questionnaires. Three questions were asked to measure undesired safety outcomes. Structural equation modeling and correlation analysis were applied to examine the research model and relationships among variables.

Results and discussion: The results of the current study showed that deep compliance was positively predicted by safety leadership, safety climate, and PCS and negatively predicted by risk perception. Surface compliance was positively predicted by safety leadership and safety climate and negatively predicted by risk perception. Surface compliance is not significantly predicted by PCS. With regard to the adverse safety outcomes, the results showed that both deep and surface compliance were negatively associated with adverse safety outcomes, however, deep compliance had a stronger negative correlation with adverse safety outcomes than surface compliance.

KEYWORDS

safety leadership, safety climate, psychological contract of safety, deep compliance, surface compliance

1. Introduction

Steel manufacturing is a risky workplace and safety is an important concern in steel-manufacturing industries. Workers in the steel-manufacturing context face many types of risks which are related to the nature of the job and working environment. Heavy work tasks, hot and noisy environments, crushing injuries, and burns are some of the work-related stressors experienced by metalworkers (1).

Workers' unsafe behavior appears to be a key factor in work-related accidents in high-risk industries. Workplace accidents impose a large direct cost and indirect damage such as injuries and psychological costs for employees (2). In addition, a lack of compliance with safety rules and procedures is identified as a central contributory factor to work-related accidents in accident investigations (3).

Previous studies have shown that safety leadership, perceived safety obligations, perceived safety climate level, and risk perception impact workers' safety behavior (2, 4, 5).

Safety leadership plays a key role in supporting safety in workplace settings. Leader-Member Exchange and transformational leadership can affect workers' safety participation behaviors and their voluntary participation in safety-related activities (6). Clarke (7) suggested that safety leadership is important in ensuring compliance with safety rules and regulations. Also, leader behaviors affect subordinates' safety behaviors. Safety leadership has an important influence on shaping workers' perceptions regarding the importance of safety in the workplace. Two aspects of safety leadership including transactional leadership and transformational leadership have been proven to be effective in workers' safety compliance. Transactional leaders clarify expectations, roles, and task requirements and recognize the actions subordinates must take to achieve outcomes to fulfill leader expectations and achieve outcomes (7, 8). This type of leadership is important in ensuring compliance with safety regulations and rules. Transformational leaders as intellectually stimulating leaders help subordinates develop new ways of problem solving. Transformational leadership is positively associated with employees' safety participation and their perceived safety climate (7).

Safety climate refers to the employees' shared perceptions regarding an organization's policies, practices, and procedures in relation to safety issues that demonstrate the priority of safety (9–12). Previous studies have suggested the positive relationship between safety leadership and safety climate (7), safety climate and psychological contract of safety (5), and safety climate and safety compliance (13). Safety climate has a significant negative association with risk perception (14).

Psychological contract theory is developed based on social exchange theory and considers a perceived exchange relationship between an employer/supervisor and an employee. A psychological contract of safety (PCS) suggested the beliefs of employees about reciprocal safety obligations in the workplace. Empirical evidence revealed that perceived employer/ supervisor safety obligations can positively influence employees' safety behavior and PCS can be a key factor in describing how employees attach meaning to employer/ supervisor behavior in their workplace. Perceived employer/supervisor breach or fulfillment of the psychological contract of safety has also been examined in the domain of leader-member exchange studies (4, 5, 15).

The extent of employees' exposure to danger while working is defined as workplace risks and the employees' subjective judgment of the risk is referred to risk perception (16, 17). Risk perception is associated with the employees' assessment regarding the probability and severity of the undesired effects occurring (such as accidents and injuries) (18). The link between risk perception and safety behavior is confirmed in the previous finding concerning the

influence of risk perception on safety behavior (2). In recent years, the importance of leaders in enhancing workers' safety behaviors was mentioned by safety researchers. Safety leadership can also influence the level of workers' perceived risk. There is a negative link between risk perception and safety leadership (18).

Safety behaviors are related to some activities ensuring that the workplace is free from harm or physical threat. Based on job performance theory and regarding the task and contextual work performance, two components of safety behavior are distinguished in the previous studies that include safety compliance and safety participation. Safety compliance is associated with some behaviors such as doing work in a safe manner and adhering to safety rules and procedures. Safety participation involves behaviors like workers' voluntary participation in safety activities and putting efforts into enhancing safety in the workplace settings (19). Hu et al. (20) found that perceived organizational support for safety and perceived supervisor support for safety can impacts compliance with safety procedures and perceived ease of use and perceived usefulness are some antecedents of safety compliance. The traditional perspective in safety science supposes that compliance behavior is a unidimensional construct. Recently, Hu et al. (21) distinguished two forms of compliance behaviors including surface compliance and deep compliance based on the concepts of surface and deep acting with regard to the emotional labor literature. Workers engage in surface compliance behaviors with the aim of meeting organizational requirements and direct their effort and attention toward illustrating compliance. Workers engage in deep compliance behaviors with the aims of maintaining workplace safety and investing the effort needed for enacting risk management strategies expected to achieve desired organizational safety outcomes. It is found that surface compliance was negatively associated with management commitment to safety, positively associated with punishment climate, and also positively related to undesired safety outcomes (accident, injury, and near miss). Safety outcomes is defined as an event or results of employees' safety performance and commonly refers to accidents, injuries, and near misses. It was found that deep compliance was negatively associated with undesired safety outcomes. Employees exhibiting deep compliance invest sufficient effort into achieving desired safety goals (21, 22).

1.1. Objectives and hypotheses

The current study aimed to investigate the relationships among safety leadership, safety climate, psychological contract of safety, risk perception, and two types of safety compliance behavior including deep compliance and surface compliance. In addition, the effects of both deep and surface compliance on safety outcomes (accidents, injuries, and near misses) were taken into account. Figure 1 presents the hypothesized model of the current study. We hypothesize that:

H1a: Safety leadership significantly influences deep compliance.

H1b: Safety climate significantly influences deep compliance.

H1c: Psychological contract of safety significantly influences deep compliance.

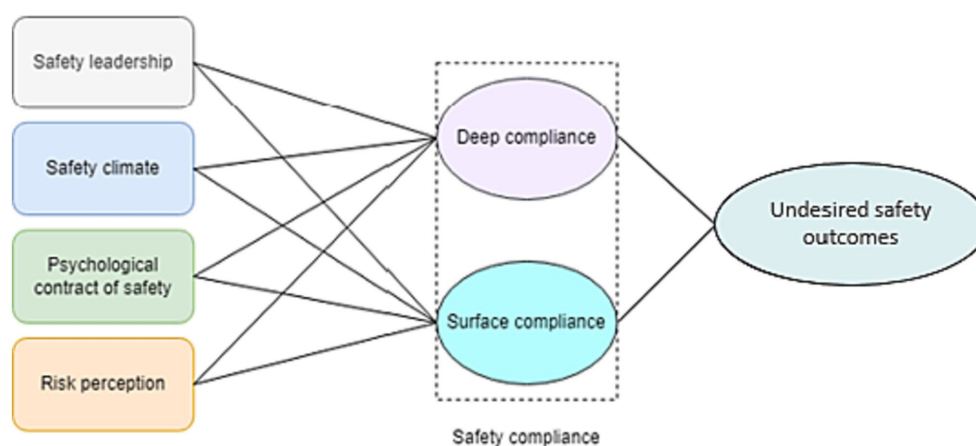


FIGURE 1
Research model.

H1d: Risk perception is negatively related to deep compliance.

H2a: Safety leadership significantly influences surface compliance.

H2b: Safety climate significantly influences surface compliance.

H2c: Psychological contract of safety significantly influences surface compliance.

H2d: Risk perception is negatively related to surface compliance.

H3a: Deep compliance is negatively related to undesired (adverse) safety outcomes.

H3b: Surface compliance is negatively related to undesired safety outcomes.

Workers' perceptions in terms of safety leadership were measured using 10 items adapted from Avolio et al. (23) and Fernández-Muñiz et al. (24). Example items are "The managers/supervisors recognize workers' achievement to safety goals," and "The managers/supervisors clarify rewards for compliance with safety procedures." The Cronbach alpha for this sample was 0.74.

Safety climate was assessed by three items developed by Neal and Griffin (19). An example item is "Safety is given a high priority by management." The Cronbach alpha for this sample was 0.81.

PCS was assessed by 12 items adapted from Newaz et al. (5). Example items are "My manager/supervisor meets their obligation to listen to employee safety concerns" and "My manager/supervisor meets their obligation to set a good example for safety behavior." The Cronbach alpha for this sample was 0.82.

Risk perception was measured by 3 items adopted from Oah et al. (18). An example item is "In my workplace, the chances of being involved in an accident are quite large." The Cronbach alpha for this sample was 0.76.

Deep compliance was measured by 5 items adopted from Hu et al. (21). Example items are "I tried to be safe by carrying out each step of the procedure with my full attention" and "I tried to work safely by foreseeing how my actions could impact safety."

Surface safety compliance behavior was assessed by 3 items adapted from Neal and Griffin (19). An example item is "I use the correct safety procedures for carrying out my job." The Cronbach alpha for this sample was 0.80.

For measuring undesired safety outcomes, participants were asked to answer the questions about the history of accidents, injuries, and near misses over the past 12 months (21). Three questions were asked. An example item is "How many work-related accidents have you been involved in over the past 12 months?"

2. Method

2.1. Participants

Cross-sectional survey data were gathered from 250 workers of a steel-manufacturing company in Iran. A total of 205 workers answered the survey. All of them were male. Among study workers, about 61% were in the age range of 41–50 years, 24% were in the age range of 31–40 years, and 10% were in the age range of 51–60 years. Approximately, 56% of them had 16–20 years of work experience and 28% had more than 20 years of work experience. About 44% of workers had a Bachelor of Science degree and 6% had a Master of Science degree.

2.2. Measures

Items were measured using a five-point Likert scale (1 = strongly disagree and 5 = strongly agree).

2.3. Data analysis

Statistical package for social science (SPSS 20) and analysis of moment structure software (AMOS 24) were employed for data analysis. Structural equation modeling (SEM) was applied for

examining the research model and relationships among the observed and latent variables. To test the overall fit of the model, fit indexes such as χ^2 ratio (< 3), CFI (comparative fit index) (> 0.90), and RMSEA (root mean square error of approximation) (< 0.08) were employed. To examine the correlations among the variables, the Spearman correlation coefficient was applied.

3. Results

The results of correlation coefficient analysis demonstrate significant positive correlations between employees' deep compliance and safety leadership ($r = 0.16, p < 0.01$), safety climate ($r = 0.27, p < 0.01$), and PCS ($r = 0.17, p < 0.01$). Also, significant negative correlation was observed between deep compliance and risk perception ($r = -0.19, p < 0.01$) and deep compliance and undesired safety outcome (accidents, injuries, and near misses) ($r = -0.15, p < 0.01$). Significant positive correlations were observed between surface compliance and safety leadership ($r = 0.13, p < 0.01$) and between surface compliance and safety climate ($r = 0.23, p < 0.01$). Furthermore, negative correlations were observed between surface compliance and risk perception ($r = -0.15, p < 0.01$) and between surface compliance and undesired safety outcomes ($r = -0.10, p < 0.05$). Moreover, there was a significant positive relationship between employees' deep compliance and surface compliance ($r = 0.37, p < 0.01$) (Table 1).

The results of SEM analysis for testing the proposed model suggested that the proposed model has a very good fit to the data in the current study (Chi-square/df = 1.23, CFI = 0.96, and RMSEA = 0.04). Figure 2 illustrates the significance of safety leadership ($\beta = 0.30, p < 0.01$), safety climate ($\beta = 0.35, p < 0.001$), and PCS ($\beta = 0.24, p < 0.001$) in predicting employees' deep compliance. Both deep compliance ($\beta = -0.20, p < 0.001$) and surface compliance ($\beta = -0.12, p < 0.001$) were negatively related to risk perception (Figure 2). Based on the results, hypotheses H1a to H1d, H2a, H2b, H2d, H3a, and H3b were supported by these findings in that safety leadership, safety climate, and psychological contract of safety have significant positive influences on deep compliance, safety leadership and safety climate have significant positive influences on surface compliance, and risk perception has

a negative significant influence on both deep compliance and surface compliance. Among all hypotheses, H2c was not supported. That is, the psychological contract of safety had no significant impact on surface compliance. In addition, both deep ($\beta = -0.20, p < 0.001$), and surface compliance ($\beta = -0.13, p < 0.001$), were negatively associated with undesired safety outcomes (Figure 3), however, deep compliance had a stronger negative correlation with adverse safety outcomes than surface compliance.

4. Discussion

The previous study differentiated two different forms of safety compliance behavior including deep and surface compliance regarding complying with safety procedures. Moreover, it is suggested that surface compliance increases the risks of adverse safety outcomes and deep compliance reduces the risk of undesired safety events (21). The current study was conducted to assess the relationships among safety leadership, safety climate, psychological contract of safety, risk perception, and two forms of safety compliance behavior including deep compliance and surface compliance. In addition, the effects of both deep and surface compliance on safety outcomes were considered.

The results of this study indicated that both forms of safety compliance behavior are positively predicted by safety leadership and safety climate. Clarke (13) showed that safety leadership has significant effects on safety compliance and a perceived safety climate mediates the relationship between safety leadership and safety compliance. Furthermore, Pilbeam et al. (25) indicated that safety leadership practices can affect organizational safety compliance. Leaders' safety behavior is an influential factor in shaping worker safety performance (safety compliance and safety participation) and may ensure compliance with safety procedures (6).

Hu et al. (21) reported a negative association between surface compliance and management commitments to safety (as a dimension of safety climate). The findings of the current study differ from their findings. In the current study, safety climate is significantly associated with both deep compliance and surface

TABLE 1 Correlations among variables.

Variable	1	2	3	4	5	6	7	8	9	10
1. Age	–									
2. Work experience	0.47**	–								
3. Education level	0.08	0.21**	–							
4. Safety leadership	0.09	0.17**	0.10	–						
5. Safety climate	0.03	0.07	0.03	0.57**	–					
6. PCS	0.08	0.12	0.15**	0.66**	0.58**	–				
7. Risk perception	0.23**	0.17*	0.11	–0.12**	–0.18**	–0.16**	–			
8. Deep compliance	0.05	0.07	0.10	0.16**	0.27**	0.17**	–0.19**	–		
9. Surface compliance	0.05	0.11	–0.15*	0.13**	0.23**	0.10	–0.15**	0.37**	–	
10. Safety outcomes	–0.10	–0.13	–0.02	–0.12*	–0.14*	–0.11	–0.25**	–0.15*	–0.10	–

**Correlation is significant at the 0.01 level; *Correlation is significant at the 0.05 level; and PCS is psychological contract of safety.

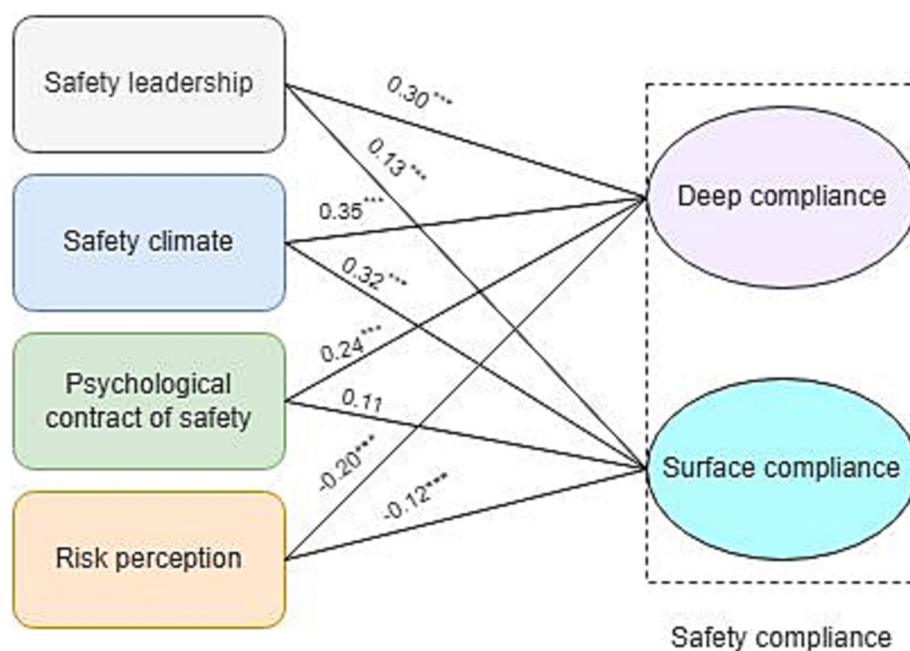


FIGURE 2
Results of the proposed model. ***Correlation is significant at the 0.001 level.

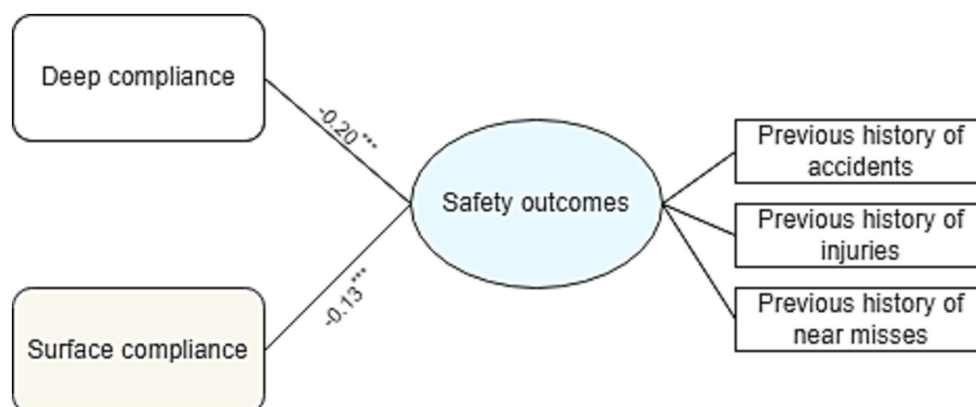


FIGURE 3
Effects of two forms of safety compliance behavior on undesired safety outcomes. ***Correlation is significant at the 0.001 level.

compliance. A possible explanation for this might be the impact of context. The study of Hu et al. (21) was done in different organizations and various occupational backgrounds while the current one was conducted in a single industry having a defined framework of safety procedures and rules for occupational groups in the company and workers are familiar with company safety policy and workplace practices.

It is suggested that the intention of workers to engage in deep compliance is associated with maintaining workplace safety and reducing the efforts needed for effective risk management strategies to achieve desired organizational safety outcomes and the intention of workers to engage in surface compliance is related to meet the requirements of the organization and direct efforts

toward demonstrating compliance (21). This study revealed that both deep and surface compliance are important in complying with safety procedures. Although deep compliance tended to correlate most strongly with safety leadership and safety climate, both deep and surface compliance required attention for accomplishing desired safety outcomes, as demonstrated by Yeo and Frederiks (26).

Deep compliance is positively predicted by PCS but this is not so for surface compliance. Deep compliance refers to mindful awareness and careful application of safety procedures and contains a four-stage psychological process encompassing health and risk awareness, perceived utility, behavioral adaption, and integration. Surface compliance indicates compliance with

minimal effort (27). As mentioned by Walker (28), one important factor in employee safety obligations is compliance with safety. Following safety rules, complying with safety procedures considering risks and hazards, and proper use of work equipment are essential for employee safety obligations. In addition, setting a good example for safe behavior and providing details about safety procedures are some influential items in PCS (5).

Deep compliance is related to changes in the awareness and perceptions of workers (27). PCS can influence the perception of employees and can predict workers' safety perception and safety behavior (5). Given that deep compliance affects the awareness and perceptions of employees and consistent with previous findings (27), in the current study, a significant positive relationship was reported between deep compliance and PCS. Conversely, no significant relationship was found for surface compliance and PCS.

Risk perception had significant negative relationships with both deep compliance and surface compliance. Results of previous studies showed negative correlation coefficients among risk perception, safety compliance, and safety participation. Xia et al. (2) suggested a negative correlation between safety compliance and risk perception ($r = -0.234^{**}$, $p < 0.01$). It was found that risk perception as a job hindrance can affect construction workers' safety behavior and can result in reduced safety motivation and subsequently reduced levels of safety compliance and safety participation behaviors. In addition, as demonstrated by Oah et al. (18), safety climate of organizations and safety leadership were negatively related to risk perception.

In this study, both deep and surface compliance were negatively correlated with undesired safety outcomes. Some parts of the current results differ from those found by Hu et al. (21). Although consistent results were obtained for deep compliance (negative relationship between deep compliance and undesired safety outcomes in both studies), the results were different regarding surface compliance.

In the current study, surface compliance was negatively related to undesired safety outcomes. In the study conducted by Hu et al. (21), positive associations were reported between surface compliance and undesired safety outcomes ($r = 0.16^{*}$, $p < 0.05$). Safety compliance is considered an observable safety behavior that can have positive impacts on organizational safety results. Deep compliance can be translated to desired safety outcomes considering the levels of safety knowledge and expertise of workers. It can be effective in reducing occupational risks when workers are skilled enough in carrying out the procedures properly (21). In the current study, more than 99% of study workers had more than 5 years of work experience and more than 95% of them had >11 years of work experience. The difference between the results for surface compliance may be due to the mentioned issue. Moreover, empirical evidence has shown that safety compliance had a significant negative relationship with occupational injuries (13).

Both deep compliance and surface compliance show the attempts of employees to meet the organizational safety goals such as compliance with safety rules and procedures but deep compliance and surface compliance differ regarding underlying intentions and strategies and deep compliance is correlated with better safety outcomes (21).

5. Practical implications

The current study has important implications for employees, safety professionals, and managers in high-risk organizations. Workers should comply with safety procedures in high-levels of cognitive activities that are required to reach desired safety outcomes (21). Supervisors and safety professionals in high-risk industries should differentiate deep and surface compliance and their different contributions to safety.

Leaders' behaviors, safety climate levels in organizations, and psychological contract of safety might affect workers' safety compliance. Although the importance of safety leadership on safety compliance behavior has been well established, in the present study, the understanding about the effect of safety-related factors and risk perception on employees' deep compliance and surface compliance was extended.

Organizations should motivate their workers to engage in deep compliance to carry out the safety procedures appropriately. In addition, given that surface compliance is often a prerequisite for deep compliance, it should also need to be taken into consideration. In terms of PCS, the results highlight the effects of mutual safety obligations between supervisors and employees on employees' deep compliance. PCS also has a significant impact on safety outcomes. Risk perception has a hindrance feature for workers (29) and negatively affect both deep compliance and surface compliance. Managers and safety professionals in high-risk industries should consider appropriate measures in terms of reducing the levels of risk in these industries.

6. Conclusion and future research

The results of the current study support positive roles of safety-related factors such as safety leadership, safety climate, and PCS in predicting deep compliance with safety procedures. These findings can help organizations to manage factors influencing employees' deep compliance with safety procedures. Also, it is found that risk perception can negatively affect both deep compliance and surface compliance. Both deep compliance and surface compliance were negatively associated with undesired safety outcomes.

A number of limitations need to be noted regarding this study. First, a full range of factors influencing deep compliance and surface compliance in terms of complying with safety procedures was not regarded in the current study. Second, the data were based on self-reports of employees. Future studies can investigate the effects of other factors such as workers' intentions and motivations and the specific dimensions of safety related factors such as safety leadership and safety climate and can also use objective assessments for safety outcomes (21).

Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Ethics statement

The studies involving humans were approved by the Tabriz University of Medical Sciences. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

LO and GM: conception and drafting the work. HK: acquisition. CP: drafting the work. SM: statistical analysis. All authors contributed to manuscript revision, read, and approved the submitted version.

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Ergonomic risk management process for safety and health at work

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Purpose: The paper aims to provide the main principles and practical aspects of the model, to present the process of identifying, determining the level, as well as assessing and managing occupational and ergonomic risks.

Methods: To conduct the research, as well as to identify the influence of various dangerous factors related to the working posture, pace, rhythm of work performance, equipment and individual characteristics of the employee's health condition, methods of complex analysis and synthesis, formal and dialectical logic are used to study the essence of the concept of occupational and ergonomic risks. Additionally, induction and deduction methods are used to examine the cause-and-effect relationships between dangers, dangerous factors, dangerous event, and the severity of consequences to determine the level of occupational and ergonomic risks based on the improved bow-tie model. The proposed approach effectiveness is tested based on the assessment of occupational and ergonomic risks of forest workers (loggers) with the participation of five experts to identify dangerous factors and develop precautionary measures.

Results: An algorithm for managing occupational and ergonomic risks has been developed, consisting of eleven steps, which can be divided into three steps: preparatory, main and documented. It has been determined that occupational and ergonomic risk is the probability of a dangerous event occurring due to employee's physical overload and its impact on the severity of damage to the employee's physical health. The level of occupational and ergonomic risk management is determined taking into account the probability (frequency), intensity and duration of physical overload, as well as the employee's adaptation index to physical overload and his/her health index.

Conclusion: The novelty is the substantiation of the principles of occupational and ergonomic risk management, which are based on the bow-tie model and predict the impact on the probability and severity of consequences of a dangerous event, taking into account dangerous factors. Forms for drawing up occupational and ergonomic risk maps have been developed, in which it is necessary to consider interaction of occupational hazards and occupational-ergonomic risk – physical overload.

KEYWORDS

ergonomics, risk, safety, dangerous factors, health, disease, consequences

1. Introduction

Occupational safety and health protection is a priority area for development. New approaches are being developed and production processes and models are being updated to improve the effectiveness of occupational health and safety management systems. However, in the area of occupational safety and health, greater attention has been given to finding ways to reduce losses within organizations, leading to a constant conflict over the distribution of funding between different systems. A more promising field of activity is provided by ergonomics, which, according to clause 2.21 of ISO 26800:2011 standard, “is a scientific discipline that studies the interaction of a person and other system elements (3.5), as well as the field of activity on application of the theory, principles, data and methods of this science to ensure human well-being and optimize the whole system performance.” Thus, this allows specialists to reduce the impact of dangers and dangerous factors to increase labor productivity, which is more attractive to employers in terms of financial profits (1, 2). On the other hand, business owners face significant financial losses due to diseases or injuries to the musculoskeletal system of their employees (3). Therefore, there is a need to identify ergonomic risks and develop appropriate recommendations to preserve the health of employees (4–6).

The main factors of interest for ergonomics, as well as for occupational safety, include hygienic, anthropometric, physiological, psychophysiological and psychological factors that cause deterioration in the physical and mental health of employees (7). A significant number of them, due to limited financial and material resources in the organizations, require the introduction of a process for managing occupational and ergonomic risks, the purpose of which, inseparable from occupational safety, is not only to reduce injuries and occupational morbidity, but also the creation and protection of values, the main of which are the life and health of an employee.

To successfully implement risk management at the enterprise, it is necessary to rely first of all, on ISO 31000:2018 standard (the National Standard of Ukraine ISO 31000:2018 “Risk management. Principles and guidelines”), which defines the basic principles and essence of the risk management process (Figure 1) (8). The creation of algorithms for managing occupational and ergonomic risks of an organization is an urgent task, the solution of which will improve the effectiveness of occupational health and safety management systems, as well as stimulate innovation and contribute to the achievement of goals to reduce injuries and occupational diseases.

In order to prevent the development of the Musculoskeletal System Diseases (hereinafter – MSDs), more and more attention is paid to the assessment of occupational and ergonomic risks, as well as various factors that worsen working postures when performing production tasks. Many different methods are used for this purpose, which can be divided into three main groups: subjective judgment, systematic observation and direct observation (9–12). Each of them has its own advantages. For example, subjective judgment methods allow you to quickly assess a situation and make a decision within a limited time frame. The following methods use special checklists, such as the “RULA/REBA” method (13, 14), which are based on assessing the scores, taking into account the difficulty of uncomfortable postures when performing certain production operations. Thus, the specified methods make it possible to quantify various indicators associated with an employee’s working posture (15, 16), comparison with which



allows the evaluator to set the appropriate scores. At the same time, the total number of these scores does not allow determining the risk of an occupational disease or injury, since it evaluates only one of the ergonomic risk (ER) components: a load index comparable to the probability of occurrence of a dangerous event. However, the REBA or RULA approach lacks a second necessary component for risk assessment: the severity of consequences, which is the main disadvantage of these approaches. In addition, they also do not take into account the employee’s individual health. It is precisely the need to assess its influence that is discussed in the following works (17, 18). The authors insist that when studying ER, it is necessary to consider the compatibility of production conditions with the physiological, psychological and anthropometric properties of employees with an assessment of their health (19, 20). The need to take into account individual health when assessing ER is discussed in some publications (21, 22).

The purpose of the research is to develop the principle for managing occupational and ergonomic risks in the employee’s workplace when performing professional activities.

2. Methods

According to the European Agency for Health and Safety at Work definition of ergonomic risk (23): ergonomic risk is a risk caused by physical overload, repetitive movements or unnatural postures during work, which can lead to fatigue, mistakes, accidents, occupational diseases or musculoskeletal system disorders. Ergonomic risks are complex and multidimensional by their nature, they can affect the loss of employee’s productivity, his/her physical and psychological health. If they occur in the workplace, they can directly cause or worsen a current health condition. Different types of movements have very different impacts on occupational MSDs, and there are important factors, such as age, health condition and gender of the employee that need to be considered when managing ergonomic risks.

The general ergonomic risk is a combined risk and it consists of four possible variants:

- Occupational and ergonomic risk of a dangerous event, incident or accident;
- Occupational and ergonomic risk of occupational MSDs;
- Psychosocial ergonomic risk;
- Ergonomic risk of work performance.

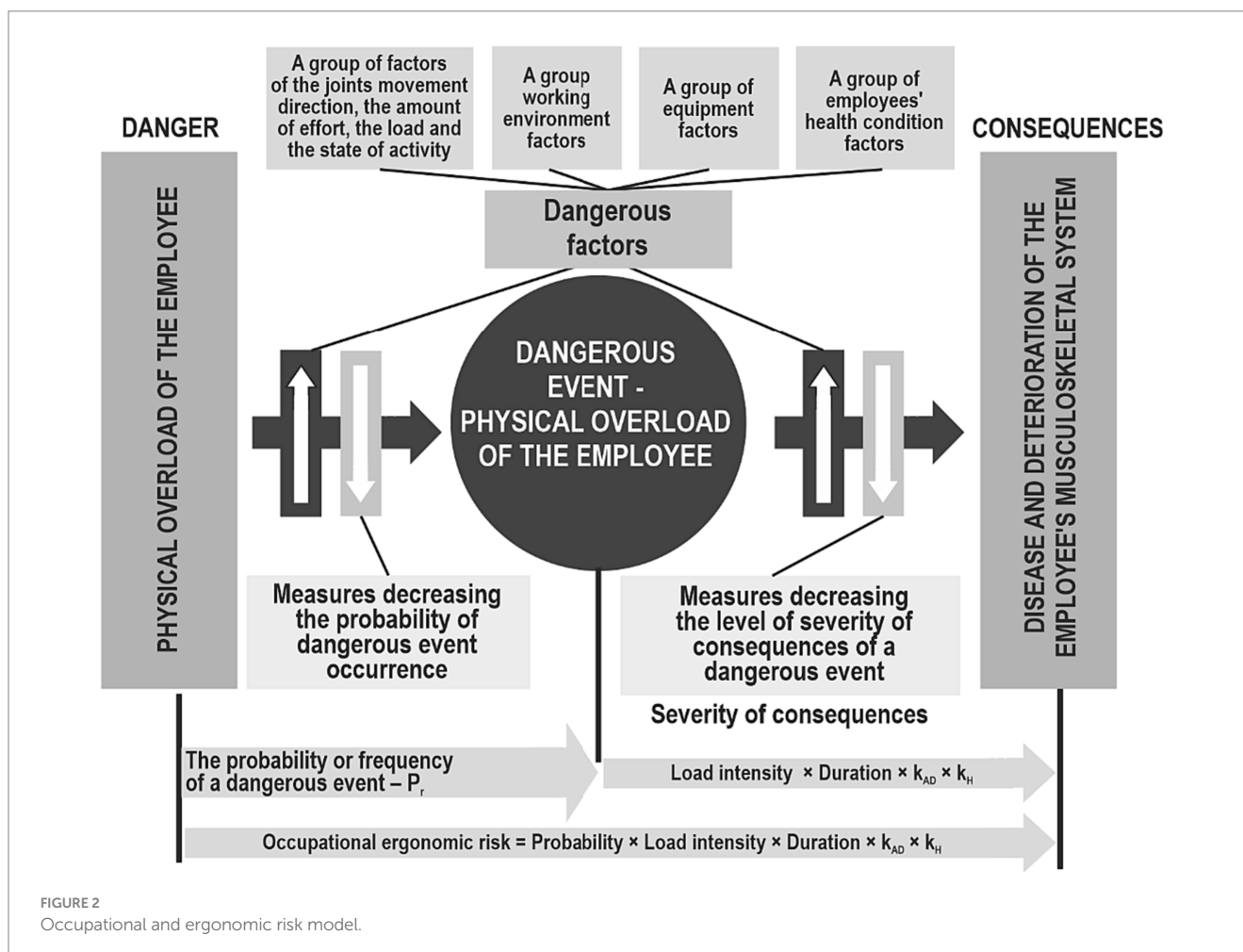
In this paper, we will consider the purely professional and ergonomic risk of occupational MSDs, taking into account the following significant dangerous factors:

- The direction of repeated movements of the joints, the magnitude of effort, the level of load and the state of activity;
- Working environment at the workplace;
- Equipment, appliances and tools at the workplace;
- Health condition of the employee (age of the employee);
- Gender of the employee.

As for the psychosocial ergonomic risk, the danger is posed by musculoskeletal system disease – this means physical overload of the employee, and a dangerous event is a physical exhaustion, while the consequences of which are the occurrence of occupational MSDs. Moreover, the increase in the probability of the dangerous event

occurrence – physical overload of employees, as well as the severity of consequences (severity of an occupational disease) is influenced by a number of different dangerous factors associated with working posture, pace, rhythm of work performance, environmental and hygienic factors, equipment and individual characteristics of the employee (7, 24). The level of health condition corresponds to the employee's adaptive capabilities to tolerate/adapt to inconveniences when performing production tasks without consequences for health. On the other hand, precautionary and protective measures should be organized at each workplace that reduce the influence of dangerous factors, which must be based on the principles of occupational and ergonomic risk management. Given the bow-tie model (25, 26), which is the best way to reveal cause-and-effect relationships between danger, a dangerous event and the severity of consequences, it is possible to obtain an appropriate idea of occupational and ergonomic risks (Figure 2).

Thus, having identified the physical overload of an employee as the main danger, which can lead to a dangerous event – physical overload under the influence of a number of dangerous factors – the main components of the occupational and ergonomic can be determined, namely: the frequency of the dangerous event occurrence by identifying the value of physical overload and the severity of consequences based on the physical health and adaptability of the employee. At the same time, given that the dangerous event occurrence depends on a group of dangerous factors, such as the direction of joint



movement, the magnitude of effort and the level of load, the severity of consequences can be expressed through the intensity and duration of the load. From this, a conclusion can be drawn about the degree of the disease severity, as well as the period of its development.

The constructed model (Figure 2) makes it possible to develop an appropriate algorithm for the process of managing occupational and ergonomic risks, which consists of eleven steps (Figure 3). It differs from the existing ones by the procedure for determining both the level of occupational and ergonomic risk from a specific dangerous factor, and the overall level of risk (taking into account all dangerous factors). This approach makes it possible to understand, from the total influence of all dangerous factors on the probability of the dangerous event occurrence, only the most important ones that require rapid response.

The first three steps related to identifying the components of occupational and ergonomic risks, dangerous factors causing employee's overload, and the procedures for their examination belong to the preparatory step, which involves the preparation of documents and process components, in particular:

- Register of dangerous occupational and ergonomic risks.
- Determining the level of occupational and ergonomic risk and its components.
- Scales of probability (frequency) of the occurrence of a dangerous event and scales of severity of the consequences from the dangerous event occurrence and their components of occupational and ergonomic risk.
- Matrices for assessing occupational and ergonomic risks.
- Forms of the maps of occupational and ergonomic risks.
- Forms of the employee's questionnaire about dangerous occupational and ergonomic factors, as well as components of occupational and ergonomic risk.

We suggest using the form given in the Table to develop a register of dangerous occupational and ergonomic factors. 1. Three groups of dangerous factors are highlighted in the form: (1) direction of joint movement, the magnitude of effort, the level of load and state of activity; (2) working environment; and (3) equipment and infrastructure. The employee's adaptation to physical overload and his/her health condition is taken into account. For each dangerous factor, it is indicated the possible level of intensity of the employee's physical overload and its duration, as well as the consequences that the employee's physical overload leads to.

After the preparatory step, we proceed to the fourth step "Determining the level of occupational ergonomic risk and its components," which can be conducted using two approaches (See Table 1).

2.1. The first approach

Determining the level of occupational and ergonomic risk and its components in the traditional way using the formula:

$$R_i = P_r \times S_{cons},$$

where, P_r is probability of physical overload; S_{cons} is severity of the consequences of physical overload.

It is recommended to use the scale of probability (frequency) of the dangerous event occurrence and the scale of severity of the consequences from the dangerous event occurrence, given in the Tables 2 and 3, respectively. The issues of constructing a scale of probability (frequency) of the dangerous event occurrence and a scale of severity of the consequences are presented in detail (27). Having a scale of probability (frequency) of the dangerous event occurrence

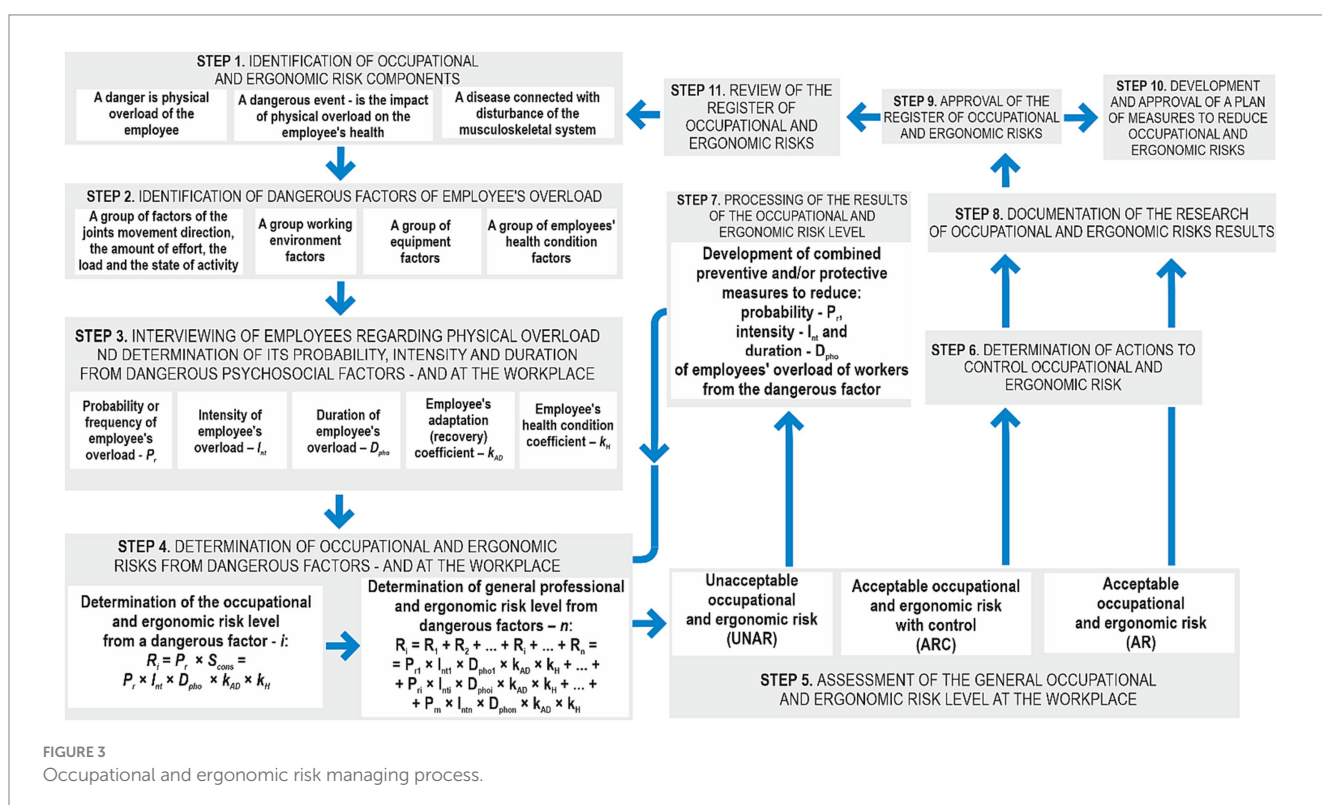


FIGURE 3
Occupational and ergonomic risk managing process.

TABLE 1 An example of the register of dangerous occupational and ergonomic factors.

No	Group name of the dangerous psychosocial factors	Dangerous factors	Consequences, MSDs
1	Group of factors in the direction of joint movement, effort magnitude, load level and activity state	1.1 Angle of the head inclination relatively to the body; 1.2 Angle of the torso inclination relatively to the workplace; 1.3 Placement of hands relatively to the body; 1.4 Rhythm and pace of work; 1.5 Dynamic loads.	Muscle pain, muscle strain, ligament rupture, disease development (arthritis, arthrosis, intervertebral hernia, bursitis, etc.), injury
2	Group of dangerous factors – working environment	2.1 Illumination; 2.2 Noise; 2.3 Vibration; 2.4 Air temperature; 2.5 Weather conditions	Deterioration of the employee's physical condition, vision, hearing, tactile sensations, development of vibration disease, manifestations of body overheating, heat stroke
3	Group of dangerous factors – equipment	3.1 Number of repetitive operations; 3.2 Number of objects under the control; 3.3 Equipment weight.	The development of fatigue, which leads to mistakes and injuries, nervous strain

TABLE 2 Frequency scale of the dangerous event occurrence.

No	Frequency level of the dangerous event occurrence	Indication	Frequency criterion for the dangerous event occurrence	Score
1	Extremely high	A	At least 1 time per hour	5
2	High	B	At least once per work shift	4
3	Medium	C	At least once per week	3
4	Low	D	At least once per month	2
5	Absent	E	Absent	1

TABLE 3 Scale of severity of consequences from the dangerous event occurrence.

No	Severity level of the dangerous event consequences	Indication	Criteria for human MSDs	Score
1	Extremely high	I	MSDs, which lead to a complete loss of working capacity, the onset of disability (disability of the 1st group)	5
2	High	II	MSDs, which lead to partial loss of working capacity (disability of the II group)	4
3	Medium	III	Average injury or illness without loss of working capacity, but with long-term treatment – more than three months and less than a year	3
4	Low	IV	Minor injury or illness without disability, with treatment lasting more than three days but less than seven days	2
5	Absent	V	No injuries or illnesses	1

(Table 2) and a scale of severity of the consequences from the dangerous event occurrence (Table 3), it is possible to construct a matrix for assessing occupational and ergonomic risks (Table 4).

In this case, the following risk acceptance criteria are used for risk assessment: unacceptable risk – more than 14 and from 14 to 25; acceptable risk with scores from 8 to 13; acceptable risk without verification is less than 8 and from 1 to 7.

2.2. The second approach

Determination of the level of occupational and ergonomic risk, as well as its components, is assumed taking into account the

probability of physical/mental overload; the severity of the consequences (determined by the intensity and duration of physical/mental overload); the index of employee's adaptability to physical/mental overload; employee's health condition:

$$R_i = P_r \times P_{pho} = P_r \times I_{nt} \times D_{pho} \times k_{AD} \times k_H \times k_G$$

where, P_r – probability of physical overload; I_{nt} – intensity of physical overload; k_{AD} – the index of employee's adaptability (recovery) to physical overload; D_{pho} – duration of physical overload; k_H – the employee's health condition index; k_G – the coefficient taking into account the employee's gender.

TABLE 4 Assessment matrix of occupational and ergonomic risks.

Assessment matrix of occupational and ergonomic risks			Scale of severity of consequences from the dangerous event occurrence				
			I	II	III	IV	V
			5 scores	4 scores	3 scores	2 scores	1 score
Frequency scale of the dangerous event occurrence	A	5 scores	25	20	15	10	5
	B	4 scores	20	16	12	8	4
	C	3 scores	15	12	9	6	3
	D	2 scores	10	8	6	4	2
	E	1 scores	5	4	3	2	1

TABLE 5 Scale of physical overload intensity.

No	Overload intensity level	Indication	Criterion for physical overload, %	Score
1	Extremely high	a	75–100	5
2	High	b	50–75	4
3	Medium	c	25–50	3
4	Low	d	1–25	2
5	Absent	e	0	1

We determine the intensity of physical overload (Table 5) and the duration of physical overload (Table 6). To create a scale of physical overload intensity, the following research recommendations are used (28, 29).

Based on the scale of physical/mental overload intensity (see Table 5) and the scale of physical overload duration (see Table 6), we construct a matrix for assessing the occupational and ergonomic risk severity depending on the intensity and duration of physical/mental overload in scores (Table 4). The indices for employee's adaptability (recovery) and the employee's health condition are determined according to Tables 7 and 8, respectively. To determine the employee's adaptability (recovery) index, any proposed methods can be used (30–33). For example, for workers performing physical work, the "Map of Adaptation Process" method (34) or the Harvard Step Test (35, 36), based on assessing heart rate or changes in blood pressure, can be used. The procedure consists of testing immediately after performing physical work and certain time after recovery (37). As a rule, this procedure can be carried out during the regular preventive examination of employees. The coefficient of the employee's physical health condition can be determined from the employee's medical history.

The gender differences should also be taken in to account through the gender index (Table 9), since there is enough research on the difference in strength and power relative to body weight between men and women (38–40).

In the fifth step, to determine the criteria for acceptability and unacceptability of risk, we consider that more than 6 scores, but less than 12 scores is an acceptable risk with verification, if the level is less than 6 scores, the risk is acceptable, if more than 12 scores, it is unacceptable.

In the sixth step, actions to control general occupational and ergonomic risks are determined if the risk is considered acceptable

during the inspection. The seventh step provides for the development of precautionary and protective measures to eliminate the risk or reduce its level to an acceptable level for general occupational ergonomic risk, the level of which is unacceptable. In the eighth step, we list all acceptable and permissible general occupational and ergonomic risks in the form of a map of occupational and ergonomic risks at the workplace. We also document unacceptable risks that will become acceptable if certain precautionary and protective measures are taken. Further, in the ninth step, enterprise managers or the responsible person must approve the register of occupational and ergonomic risks.

In the tenth step, according to the risk register, a plan for monitoring, eliminating and reducing occupational and ergonomic risks is developed and approved by the management of the enterprise (Table 10), taking into account the relevant deadlines, responsible persons and necessary resources.

In the last, the eleventh step, we anticipate the need to revise the register of occupational and ergonomic risks and the plan for monitoring, eliminating and reducing occupational and ergonomic risks at least once a year or in the event of significant changes in the work of an employee at the workplace in terms of introducing new equipment, recruiting workers of a different gender, etc. (41).

2.3. Collection and processing of data

To provide an example of determining occupational and ergonomic risk using the developed algorithm, a study of the workplace of a tree feller (logger) is conducted. This profession has been chosen because it is one of the most traumatic, which leads to disorders and diseases of the musculoskeletal system (42, 43). For example, hand vibration syndrome, carpal tunnel syndrome (44).

Based on identifying the causes of the development of the musculoskeletal system diseases among loggers, key indicators have been identified by which occupational and ergonomic risk can be assessed from published scientific literature (45–48). This list will also be refined based on surveys and observations, which are among the most common tools for identifying ergonomic risks (49, 50).

A test to determine the level of occupational and ergonomic risk of loggers was conducted at SE "Kievsky forestry" enterprise. The territory of SE "Kievsky forestry" is located in the central part of Kyiv Oblast, where broad-leaved forests (oak, hornbeam, ash, alder, and linden) predominate. The average age of loggers is 36 ± 3.1 years. The participants' work experience ranges within 5 – 11 years. All participants participate in the research voluntarily. They were

TABLE 6 Scale of physical overload duration.

No	Overload duration level	Indication	Criterion of physical overload duration	Score
1	Extremely high	1	More than a half of a year	5
2	High	2	Less than a half of a year, but more than a month	4
3	Medium	3	Less than a month, but more than a week	3
4	Low	4	No more than a week	2
5	Absent	5	Absent	1

TABLE 7 Index of the employee's adaptability (recovery).

No	Employee's adaptability	Indication	Description	Index
1	Extremely high	k_{AD1}	The employee is quickly adapted to physical overload and he/she quickly recovers	0.1–0.25
2	High	k_{AD2}	The employee is not quickly adapted to physical overload and he/she does not recover quickly	0.25–0.50
3	Medium	I_{ad3}	It is difficult for the employee to be adapted to physical overload and it is difficult to recover	0.50–0.75
4	Low	k_{AD4}	The employee does not adapt well to physical overload and he/she does not recover well	0.75–1.00
5	Absent	k_{AD5}	The employee does not adapt to physical overload and he/she does not recover	1.00

TABLE 8 The index of the employee's physical health condition.

No	Employee's health condition	Indication	Description	Coefficient
1	Extremely high	K_{H1}	The employee has no significant health problems and no chronic diseases	0.05–0.1
2	High	K_{H2}	The employee has health problems and does not have chronic diseases	0.1–0.25
3	Medium	K_{H3}	The employee has significant health problems and does not have chronic diseases	0.25–0.50
4	Low	K_{H4}	The employee has poor health and one chronic disease unrelated to MSDs	0.50–0.75
5	Absent	K_{H5}	The employee is constantly sick, has significant health problems and more than one chronic disease related to MSDs	0.75–1.00

TABLE 9 Employee's gender index.

No	Employee's gender index	Indication	Employee's gender index score
1	Male	K_{Gmale}	1.0
2	Female	$K_{Gfemale}$	2.0

previously introduced to the testing program and control indicators, determined during the experiment.

The work of a logger involves felling trees, cutting branches, and sometimes it becomes necessary to clean the chainsaw, as well as other additional equipment, from dirt and wood debris; removing and washing the chain, cleaning the carburetor mesh and the fan; technical maintenance of the hydraulic felling wedge and other auxiliary tools. To fell, cut trees and trim branches, fellers use a Stihl MS 362 two-stroke mechanical chainsaw with a power of 3.4 kW and a weight of 5.9 kg.

To assess the working posture, a sample of photographs of production operations of felling trees, clearing trees of branches and twigs is used (Figure 4). To photograph the working postures of workers, a camera with a resolution of 1,024 × 768 pixels (Canon EOS R10 RF-S 18-45 IS STM) is used. The photographs were taken at a distance of one meter so that the lens captured the worker's entire body in profile. All working movements of workers were photographed to determine ergonomic risk.

To set the pace and rhythm of work, when monitoring the performance of their work, count the number of movements per unit of time, determined by the task nature (felling trees or cutting branches). In this case, a scale from 1 to 5 is used, where 1 is not a high speed of work performance, and 5 is a very high speed of work performance (33, 51).

To assess the occupational and ergonomic risk of a logger, a team of five volunteer experts was formed with higher education in occupational safety and health. Experts have at least six years of experience working at forestry enterprises in the field of occupational safety. Each of the experts, after inspecting the logger's workplace, observing his work and conducting a survey, is asked to determine the appropriate scores presented in Tables 6–8 regarding the probability of physical overload, the intensity of physical load and its duration. The scores set for each dangerous factor are averaged and entered into the appropriate table for further calculations.

The employee's health indicators and adaptability index to overload have not been determined in this research for ethical reasons, but the proposed algorithm provides such an opportunity, which will make it possible in the future to select precautionary and protective measures taking into account the individual capabilities of the employee.

Score calculations and measurement discrepancy determinations are made using Microsoft Excel 2016. Outliers are tested using Z-scores, and all values are within ≤ 2 , $p < 0.05$.

TABLE 10 Form of plan for control, elimination and reduction of occupational and ergonomic risks.

No	Occupational and ergonomic risk is not acceptable	A measure to control, eliminate or reduce the risk	Execution period	Resources	Responsible person
1	Uncomfortable working posture	Anticipate the need to revise the technology of production operations, identify working positions with minimal ergonomic risk, provide ergonomic hand tools, and a procedure for automating production operations	Term from month to a half of a year	Making a change in the production technology involves financial costs within the developed budget	Production manager

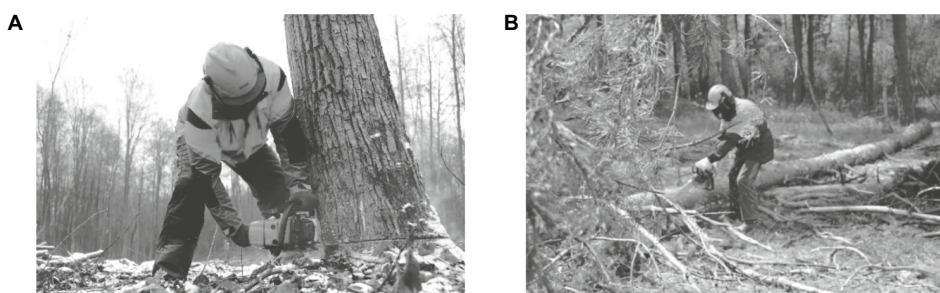


FIGURE 4

Basic production operations of the wood production technological process: (A) – felling trees; (B) – cleaning trees from branches and twigs.

3. Research results

Based on field observations and a survey of loggers, dangerous factors characteristic of the SE “Kievsky forestry” enterprise have been determined. Table 11 shows the averaged data on the probability of physical overload, as well as the physical load intensity and its duration.

It has been revealed that the most influential dangerous factors are the group that characterizes the direction of joint movement, the magnitude of effort, the level of load and state of activity. This includes directly an uncomfortable working posture, which arises due to the need to cut as low as possible at an angle to the trunk of 90°, a significant pace and rhythm of work (the tree must be felled as soon as possible, up to 320 s). Dynamic loads also occur when clearing a tree from branches positioned at different angles on the trunk (52). Also, when cutting trees, the terrain and weather conditions (snow, rain, wind, fog) influence the process (53). The results of processing scores from specified indicators, rounded for the convenience of their analysis and setting the risk level, are given in Table 12. Also, if an unacceptable level of risk is set, appropriate measures are provided to improve the logger’s safety. It should be noted that in order to maintain high labor productivity of the logger, preference is given to measures to change cutting technology, the use of various devices that reduce the number of dangerous working postures, as well as the elimination of equipment that increases the manifestation of negative health consequences.

An analysis of the research results shows that the logger is exposed to several significant dangerous factors: an uncomfortable working posture, which, together with rather dangerous equipment, leads to the risk of developing the occupational MSDs. This requires, first of

all, a reduction in the intensity and duration of the employee’s physical load, which will reduce the severity of the health consequences. Of course, it is necessary to consider the employee’s adaptability – recovery and the current state of his physical health (54). At the same time, constant exposure to dangerous factors from production equipment and the environment can reduce these opportunities due to the need to use a certain amount of energy to adapt to uncomfortable working conditions (55, 56).

4. Discussion

A distinctive peculiarity of the proposed approach to determining the level of occupational and ergonomic risk from the known ones is the calculation of the adaptability to physical loads and the state of health of the employee. On the one hand, thanks to this approach, it is possible to individually take into account the distribution of work, embodying the well-known TILE principle (Task, Individual, Load, and Environment) (57) to reduce MSDs. On the other hand, it can be used to provide employees with an appropriate level of workload, which will help avoid injuries to employees with low physical strength and musculoskeletal system chronic diseases.

From a methodological point of view, the proposed process allows for the assessment of occupational and ergonomic risk. That is, ergonomic risks associated with working posture, load, and equipment are assessed taking into account occupational hazards related to the organization of the production process, the impact of working conditions, etc. In addition, the proposed method takes into account the influence of the employee’s individual parameters, which makes it possible to make targeted management decisions on health

TABLE 11 Logger observation of dangerous ergonomic factors and occupational ergonomic risk components (employee questionnaire).

No	Group of dangerous factors	Dangerous factors		Physical overload			Physical overload consequences
		Name	Indication	Probability, Pr	Intensity, Int	Duration, D _{pho}	
1.	Group of factors in the direction of joint movement, force magnitude, load level and activity state	Uncomfortable working posture: bent torso, outstretched arms, strain on the legs	DF ₁₁	2,6±0,4	4,6±03	4,7±0,3	Development of MSDs disease, muscle strain, tendon rupture, muscle pain, fatigue
		Working pace	DF ₁₂	2,7±0,3	3,2±0,3	4,8±0,4	
		Rhythm of work	DF ₁₃	2,6±0,4	2,6±0,3	2,8±0,3	
		Dynamic loads	DF ₁₄	4,2±0,5	3,8±0,5	4,2±0,3	Rapid loss of working capacity
2.	Group of dangerous factors – working environment	Air temperature	DF ₂₁	4,6±0,4	4,8±0,5	2,6±0,5	Overheating of the body
		Presence of wind	DF ₂₂	4,2±0,3	3,2±0,4	4,8±0,3	Fractures of limbs
		Fog	DF ₂₃	1,2±0,2	2,6±0,3	2,4±0,2	Fractures of limbs, spine
3.	Group of dangerous factors – equipment	Equipment weight	DF ₃₁	4,6±0,4	4,6±0,3	4,8±0,3	Loss of working capacity, muscle pain
		The number of repetitive movements	DF ₃₂	4,8±0,5	2,6±0,3	2,8±0,3	Loss of working capacity, muscle pain
4.	Index of employee's adaptability to overload	Tension of adaptation mechanisms	K _{AD5}	1.0			Possibility of physical health recovery
5.	Index of employee's health condition	The level of employee's individual health	k _{H5}	1.0			
6.	Employee's gender index	The employee's gender is male	k _{G1}	1.0			

No group of dange-rous factors	Assessment of the residual level of occupational and ergonomic risks, R_i	Precautionary and protective measures (PM) to reduce the unacceptable primary level of occupational and ergonomic risk, R_i	
		Indication	Content
1	AR	PM_{11}	Review and implement new cutting technology, replace manual labor with automated systems, and provide for the possibility of increasing technological breaks.
	AR	PM_{12}	
	AR	PM_{13}	
	AR	PM_{14}	
	AR		
2	AR	PM_{21}	Conduct an assessment of climatic conditions, ensure control over the prohibition of work in unsuitable conditions, and provide for the possibility of performing other work.
	AR	PM_{22}	
	AR	PM_{23}	
	AR		
3	AR	PM_{31}	Conduct an ergonomic assessment of chainsaws, select and use the most suitable one in terms of weight and other indicators.
	AR	PM_{32}	Review and implement new cutting technology, replace manual labor with automated systems
	AR		
ARC			

TABLE 12 The form and example of a map for managing occupational and ergonomic risks of a logger.

No group of dangerous factors	Dangerous factors (DF)	Determination of the occupational and ergonomic risk initial level				Assessment of the occupational and ergonomic risk level, R_i	
		Determination of severeness of consequences			Severeness of consequences, S_{cons} $S_{cons} = D_{pho} \times I_{nt} \times k_{AD} \times k_H \times k_G/5$	Occupational and ergonomic risk level, R_i (abbreviation of words Figure 3)	
		Probability (frequency), Pr	Intensity, I_{nt}	Duration, D_{pho}			
1	DF ₁₁	3	5	5	5	15	UNAR
	DF ₁₂	3	3	5	3	9	ARC
	DF ₁₃	3	2	5	2	6	AR
	DF ₁₄	2	5	4	4	8	ARC
	Group 1 general risk					66	UNAR
2	DF ₂₁	5	5	3	3	15	UNAR
	DF ₂₂	4	3	5	3	12	ARC
	DF ₂₃	1	5	2	2	2	AR
	Group 2 general risk					29	UNAR
3	DF ₃₁	5	1	5	5	25	UNAR
	DF ₃₂	5	5	3	3	15	UNAR
	Group 3 general risk					115	UNAR
General risk of all groups						205	UNAR

preservation by ensuring that the workload corresponds to the health level. Therefore, this can be considered a progress over existing tools.

The proposed process begins with an analysis of the task, individual characteristics of the employee's health, analysis of the characteristics of the production tools, working conditions, which makes it possible to clearly identify the danger and dangerous factors that lead to an increase in the probability of the dangerous event occurrence. Then appropriate methods are used to determine the occupational and ergonomic risk for each dangerous factor. By the way, these tools include, among other things, all known tools for ergonomic parameters, if they allow the evaluation scales to be combined. In this example, a 5-score scale was chosen, but it can be changed for convenience and detailing of assessments.

In general, the main difference between the implemented approach to managing occupational and ergonomic risks from the known ones is that it takes into account a number of dangerous factors: hygienic, psychophysiological and individual, which are absent in other available models. It is assumed that the greatest influence on musculoskeletal disorders is danger – especially inappropriate, uncomfortable, unnatural working posture (10, 12, 58). At the same time, it is not taken into account that the amount of risk may be further aggravated by psychosocial dangers (59) that arise from the organizational culture, psychological climate, environmental parameters, which are assessed according to hygienic principles. However, if to take into account the totality of various dangerous factors, it is possible to set this task much broader than identifying the causes of occupational MSDs. For example, as mentioned above, this may be an increase in labor productivity, taking into account the absence of injuries and the absence of occupational diseases, but is

more attractive to business owners in terms of justifying changes in the technological process, production equipment, and hand tools.

The positive result of implementing this approach is the preservation of the organization's value, primarily human potential, which is based on the appropriate and timely involvement of interested people and a structured, comprehensive approach to risk management. Hence, there is a need to develop basic principles for managing occupational and ergonomic risks. In particular, the revealed patterns between the amount of occupational and ergonomic risk and the influence of dangerous factors (intensity of joint movement, high magnitude of effort, overload and state of activity; working environment, equipment) allow us to speak about the development of a strategy aimed at eliminating problems related to the human factor. It is assumed that this will be a complex of various measures for mechanization and automation of the technological process to replace human manual labor. This requires awareness of the most important dangerous factors influencing decision-making, which entails conducting appropriate training to improve the competence of employees, thereby forming an appropriate leadership institute (60). Taken together, this will ensure a positive working environment where responsibility, motivation, training and development play an important role and are based on occupational ergonomic risk management practices.

Management of occupational and ergonomic risks is, first of all, work with people, which is related to the impact on their health of physical load, movements, working postures, organization of production, which is dictated by public interests. Therefore, to achieve real results in reducing the incidence of MSDs, it is necessary to involve employees in the process of managing occupational and

ergonomic risks. It is important that employees are involved in this process to protect human health or preserve valuables (61). In the future, there is a need to optimize the organization's activities due to the emergence of various tasks to ensure the reliability and effectiveness of the production process.

5. Conclusion

An algorithm for the process of managing occupational and ergonomic risk has been developed, consisting of eleven steps, which can be nominally divided into three steps: preparatory, main and documented. In the process of managing occupational and ergonomic risks, it is necessary to take into account the dangerous factors of physical overload that are related to work: the direction of joint movement, the magnitude of effort, the level of load and the state of activity; working environment, equipment (infrastructure); employee's adaptability to physical overload; physical condition of health and gender of the employee.

It has been determined that occupational and ergonomic risk is the probability of the dangerous event occurrence due to physical overload of an employee and its impact on the severity of damage to the employee's physical health.

The level of occupational and ergonomic risk in the process of managing occupational and ergonomic risks is determined taking into account the probability (frequency), intensity and duration of physical overload, as well as adaptability to physical overload, the health condition and the gender of the employee.

The principles of occupational and ergonomic risk management are substantiated. They are based on the bow-tie model and predict the impact on the probability and severity of the dangerous event consequences, taking into account dangerous factors: high intensity of joint movement, high magnitude of effort, overload and state of activity; working environment, equipment (infrastructure); employee's adaptability to physical overload; physical health condition and gender of the employee.

Maps of occupational and ergonomic risks have been developed, in which it is necessary to take into account the interaction of occupational hazards, as well as occupational and ergonomic dangers – physical overload.

Two approaches to assessing occupational and ergonomic risk are proposed: the first takes into account the probability (frequency), intensity and duration of physical overload, and the second takes into

account the employee's adaptability to physical overload, index of health condition and gender.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

VT: conceptualization. SC and OD: methodology. OD and OBo: validation and resources. SC: formal analysis. VT, SC, and OD: investigation. VT and OBo: writing-original draft preparation. SC and VL: writing-review and editing. OD: visualization. VT and SC: supervision. OBa: project administration. OBa and VL: funding acquisition. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Evaluation of N95 respirators on fit rate, real-time leakage, and usability among Chinese healthcare workers: study protocol of a randomized crossover trial

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Background: N95 respirators are used to limit the transmission of respiratory viruses in clinical settings. There are two to three major types of N95 available for all healthcare workers in Hong Kong. However, after the coronavirus outbreak and the consequent shortage of many commonly used respirators, several new N95 respirators were adopted temporarily in clinical settings without evaluation. Prior literature indicates that traditional N95 respirators used in hospitals in Hong Kong are not fit for Chinese people and have fit rates ranging from 50 to 60%. This study aims to investigate and compare the fit rate, real-time leakage, and mask usability of traditional and new N95 respirators among Chinese healthcare workers.

Methods: This study will employ two sequential phases. Phase 1 has a cross-sectional exploratory design used to investigate the fit rate and mask usability of three types of respirators. Phase 2 will examine the effectiveness of respiratory protection by comparing traditional and new N95 respirators by a randomized crossover trial. Eligible participants will be randomly allocated through a controlled crossover experiment to either a traditional or new respirator group ($n = 100$ in each arm) for performing standard clinical procedures. The primary outcome (real-time leakage) will be recorded at 30 s intervals during nasopharyngeal suctioning and cardiopulmonary resuscitation. The secondary outcomes are the fit rate and mask usability. After a 2 min suctioning (15 s twice) and 4 min one-person CPR, the fit rate (assessed by standard N95 fit testing) and mask usability (measured by self-reported mask usability scale) will be recorded as data of post-procedure. After 10 min rest, measurement of real-time leakage (i.e., crossover), fit test, and usability will be repeated.

Discussion: The result of real-time leakage will be a vital indicator of the respiratory protection of Chinese healthcare workers while performing prevalent clinical procedures, such as resuscitation. The fit rate and usability result will serve as an essential reference for consumable purchase policy in clinical settings.

Trial registration: ISRCTN registry: ISRCTN40115047. Retrospectively registered on May 9, 2023. <https://www.isrctn.com/ISRCTN40115047>.

KEYWORDS

N95 respirators, fit rate, real-time leakage, usability, Chinese healthcare workers, crossover trial

1 Introduction

1.1 Background and rationale

Worldwide outbreaks of different infectious diseases have caused an increased awareness of occupational protection among healthcare workers (HCWs). Therefore, the use of N95 respirators as an effective nonpharmaceutical measure to limit the spread of diseases in hospitals is recommended by the World Health Organization (WHO) and the Centre for Disease Control and Prevention (CDC) (1, 2). However, regardless of the shape and brand of such respirators, they are all generally tight-fitting half-facepiece type, and their credibility depends on fit to the wearer (3–5). For ill-fitting respirators, the average penetration by ambient aerosol was found to be 33% compared with 4% for well-fitting respirators (6). To achieve creditable occupational protection, most known authorities, such as the National Institute for Occupational Safety and Health (NIOSH), CDC, WHO, and the Hospital Authority (HA) in Hong Kong, made fit testing compulsory for wearers prior to the use of an N95 respirator (1, 3–5, 7).

N95 respirators are used to limit the transmission of respiratory viruses in clinical settings. Hospitals under the HA and private hospitals regularly provide two to three major types of N95 respirators available for all HCWs, particularly for high-risk caring procedures, such as suctioning, working in airborne precaution rooms, and resuscitation (7). Commonly used types of N95 respirators are the cup-shaped 3M 1860 (regular or small size), cup-shaped 3M 8210 (one size), and the three-panel designed 3M 1870+ (one size) (8–10). Although manufacturers claimed that all traditional 3M respirators are 86–100% fit for people (8–10), their performance when donned for Chinese people is suboptimal in terms of protection (reflected by fit rate and real-time leakage) and comfort (reflected by mask usability) compared with that of Western people (3–5, 7, 11, 12).

After the coronavirus (COVID-19) outbreak and the consequent shortage of many commonly used respirators, several new N95 respirators, such as Alpha Pro Tech N95 and NASK M0011 Professional Edition, were adopted temporarily in clinical settings without comprehensive evaluation (13, 14). NASK M0011 comprises nanofibers and has an ear-loop design with two plastic clips, which differs from the traditional melt-blown nonwoven material and head-loop design. The nanomaterial features ultra-thin, lightweight, and breathable properties, allowing wearers to use it for the whole day comfortably. Tests through respected international laboratories, such as the Nelson Laboratories, confirmed a virus filtration efficiency of >99.9%. The material for and design of NASK was officially adopted

in public hospitals on 24 April 2020 (13, 14). However, given such a considerable effect on infection control and prevention, the evaluation of reasonable fit rate, real-time leakage, and usability was not comprehensively checked. Besides, the CDC warned that donning a respirator with ear loops as the head harness is difficult to achieve an adequate fit (2).

Quantitative fit testing is a recognized method to determine whether a tight-fitting respirator fits a wearer. This method adopts an electronic device to measure the ratio of particular air particles inside and outside the breathing zone (when donned with a respirator), and the ratio (i.e., fit factor) reflects the degree of leakage (3–5). Therefore, fit rate (the overall passing rate of fit testing) would be the primary concern to determine the fit of an N95 respirator to a population. Studies on American and Canadian HCWs indicated that several brands and types of respirators developed in the West (e.g., 3M 1870 and 1860) fit 90–100% (9, 10). However, local retrospective analysis reported the fit rate of two N95 respirators (i.e., 3M 1860S and 9210) from 84 to 91 nursing staff working in intensive care units (12). The fit rate was as low as 55–69% only. Further local studies examined the fit rate of several commonly used N95 respirators among nursing students and reported a consistently low fit rate of 57.4–65.0% (3, 4). In contrast to the results of studies conducted in the West, the fit rates of respirators were lower when donned by Chinese people. These results may reveal that tight-fitting N95 respirators require a match between mask design and facial anthropometry of a given population (e.g., face length and width) (15). However, the fit rates of all newly adopted N95 respirators for Chinese HCWs are unclear, except for some of the preliminary findings indicating that locally developed respirators (i.e., NASK head-loop model) provide a better-fit rate (78.8%) after nursing procedures (11).

Most of the pre-set quantitative fit testing systems require the wearer with a donned N95 respirator to perform a series of exercises, including a static portion without body movement and a dynamic portion with normal breathing and designated movement (i.e., side-to-side, and up-and-down head movement, talking or reading a standard set of passages, grimacing, and bending over). These exercises stimulate common working activities in the clinical environment (5, 7, 9). Several local studies have challenged the reliability of real-time protection of respirators during nursing procedures based on the sole result of fit testing because performing specific procedures involved a greater range of body movement, such as changing napkin, suctioning, and nasogastric tube insertion (11, 16, 17). Real-time leakage (also named face-seal leakage) was measured by a validated portable aerosol spectrometer (17). It was found that the different particles concentration (size >0.3 μm , >0.4 μm , >1.0 μm , and >4.0 μm) inside a fit respirator significantly increased before and during suctioning and nasogastric tube insertion (15). Preliminary results suggested that the fit factor of the NASK head-loop model decreased to less than that of the traditional model (11). However, these studies did not consider testing the real-time leakage

Abbreviations: HCWs, Healthcare workers; WHO, World Health Organization; CDC, Centre for Disease Control and Prevention; NIOSH, National Institute for Occupational Safety and Health; HA, Hospital Authority; CPR, Cardiopulmonary resuscitation; MUS, Mask usability scale; ITT, Intention-to-treat; GEE, Generalized estimating equations.

of a given “fit” respirator under heaviest-duty processes, such as CPR, which is a life-saving clinical procedure, and compulsory use of N95 respirators in hospital settings (18).

Although HCWs assume some level of personal occupational risk when caring for contagious patients, numerous policies and regulations call for respiratory protection in the healthcare environment, noncompliance is unfortunately quite common (19). In general, mask usability is a concept used to reflect conditions, including discomfort, interference with occupational duties, and poor communication experienced by the wearers of N95 respirators (20). Discomfort is often associated with tight-fitting N95 respirator models, including 3 M models used in Hong Kong. Such discomfort encompasses various sensations and experiences, including facial pressure, facial heat, facial pain, labored movement of facial muscles, or skin itchiness (21, 22). Moreover, poor communication has been a concern with existing N95 respirators, as they diminish speech intelligibility in noisy clinical environments (23). During the COVID-19 outbreak, usability can also reflect the maximum duration for the extended use of a given respirator. This parameter is crucial during the pandemic because of the global shortage of personal protective equipment (24). Poor mask usability influences the compliance of N95 respirator use (19) and reduces the applicability for extended use, as some HCWs do not wear N95 respirators as indicated when performing resuscitation during the non-pandemic period.

Literature indicates that traditional N95 respirators used in hospitals in Hong Kong are not fit for Chinese people, having fit rates ranging from 50 to 65% compared with those among Western people (10, 11). Such a result poses a risk of real-time leakage during caring procedures, including suctioning, nasogastric tube insertion, and resuscitation. Our preliminary results found that real-time leakage happens during care procedures requiring moderate body movement, referring to moderate intensity of physical activity. However, the degree of real-time leakage of traditional N95 respirators during procedures requiring high body movement (e.g., CPR) remains unknown. Additionally, changes in fit factors during and after various caring procedures are also unknown. More importantly, new respirators with nanomaterials and ear-loop with clip designs have been introduced in public hospitals. Nevertheless, the fit rate, real-time leakage, and mask usability of such design have not been evaluated, which poses a threat of uncertainty to HCWs. Therefore, this study aims to investigate and compare the fit rate, real-time leakage, and mask usability of traditional and new N95 respirators among Chinese healthcare workers.

2 Objectives

2.1 Study objectives

This study aims to investigate and compare fit rate, real-time leakage, and mask usability of the traditional and new N95 respirators among Chinese healthcare workers.

2.1.1 Primary objective

To compare real-time leakage by using traditional and N95 respirators during two clinical procedures, which are nasopharyngeal suctioning and CPR.

2.1.2 Secondary objective

To investigate the fit rate and mask usability of traditional and new N95 respirators when donned by Chinese healthcare workers.

3 Research hypothesis

We hypothesize that there is no significant group difference in real-time leakage between the use of traditional and new N95 respirators among Chinese healthcare workers during two clinical procedures (i.e., nasopharyngeal suctioning and CPR). We also hypothesize that the fit rate and mask usability have no significant difference between traditional and new N95 respirators among Chinese healthcare workers.

3.1 Trial design

The study is a randomized controlled, exploratory crossover trial with two arms ($n = 100$ in each arm) to examine and compare the real-time leakage of traditional and new respirators during two standard clinical procedures (i.e., nasopharyngeal suctioning and CPR).

The study will employ two sequential phases. A cross-sectional exploratory design in phase 1 will investigate the fit rate and usability of three types of respirators (two traditional melt-blown respirators with head-loop design and one new nano-respirator with ear-loop and clips) among Chinese HCWs, which is used to identify potential participants for the next phase. A cross-sectional design is appropriate to estimate the prevalence of unfit respirators through testing in a group of large samples.

Phase 2 is a randomized controlled crossover trial with two arms: participants donned with traditional best-fit respirators (either 1860S or 1870+), and participants donned with a new respirator (made of nanomaterial and ear-loop with clip design). A best-fit respirator refers to a given respirator obtaining the highest fit factor when donned by a user. A crossover design has advantages over a parallel experiment because the participating subject will act as his or her control, and possible incomparability between “intervention” and “control groups” could be eliminated. A two-arm study can yield reliable evidence about the effectiveness of real-time protection between traditional and new respirators. Randomization is performed as block randomization with a 1:1 allocation. To protect participants’ rights, anonymity, and confidentiality, the study was designed with the ethical principles of the Declaration of Helsinki. The paper complies with the SPIRIT recommendation for study protocol (25). The overall CONSORT flowchart of the study design is shown in Figure 1.

4 Method: participants, interventions and outcomes

4.1 Study setting

This study is being conducted in Hong Kong. Participants will be approached and recruited from web promotion (40% of samples) and invited collaborators (60% of samples), including HCWs (e.g., 20% doctors and 80% nurses based on the ratio of total doctors to nurses in Hong Kong) working in non-governmental organizations and students

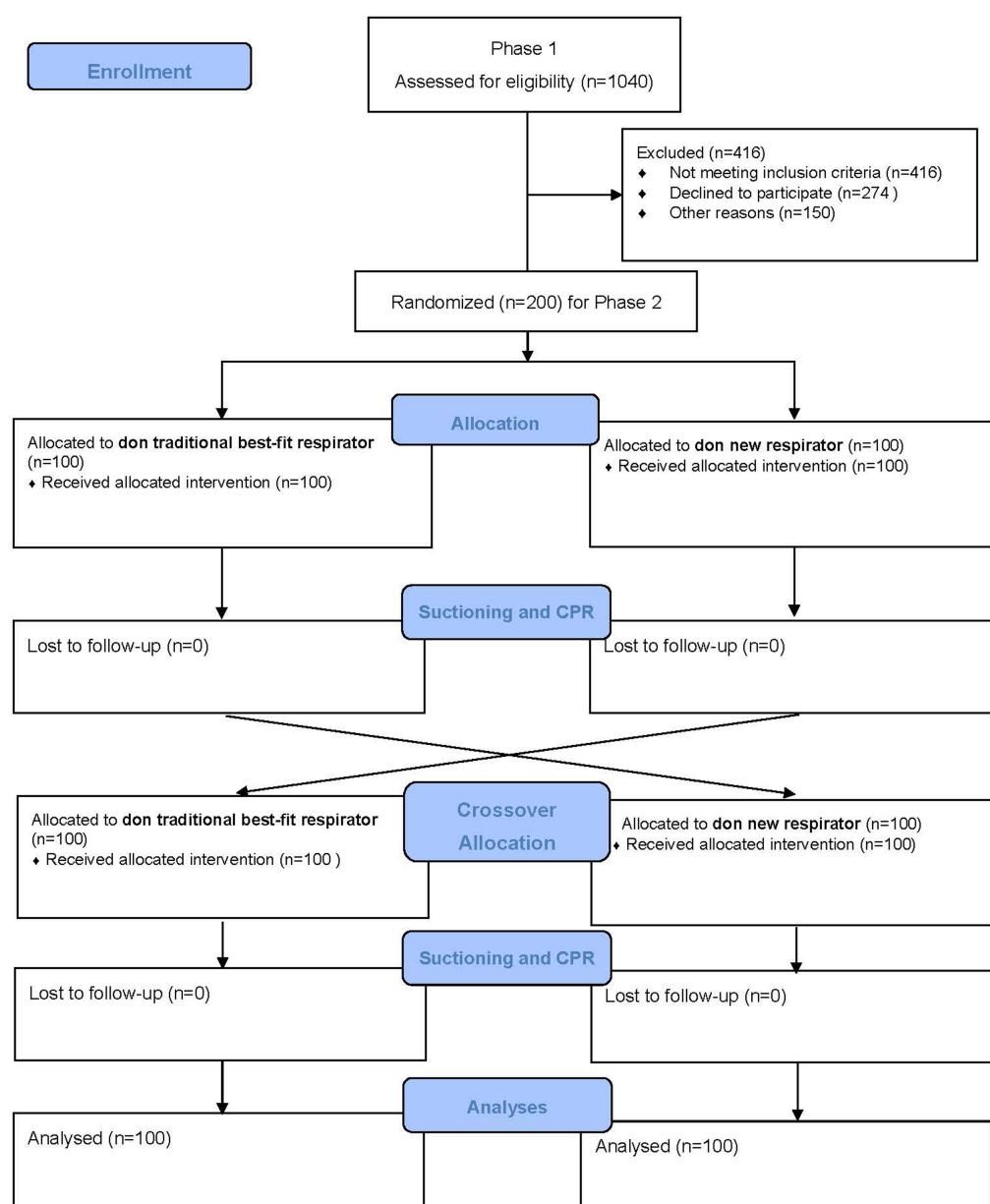


FIGURE 1
CONSORT flow diagram.

studying in healthcare disciplines in universities. These organizations provide HCWs who offer treatment and care to patients directly.

4.2 Eligibility criteria

4.2.1 Inclusion criteria

All participants must give written consent for participation following adequate explanation and sufficient understanding before being included in the study.

1. Aged 18 years or above.
2. Healthcare workers who are students or staff (with license) who provide direct care to patients.

3. Certified to perform standard CPR for delivery of basic life support or cardiovascular life support.
4. Have completed an accredited institutional training program and perform CPR in the clinical field.
5. Participants must obtain a pass of fit tests for one traditional N95 respirator (best-fit one) as well as new respirators.

4.2.2 Exclusion criteria

1. Healthcare workers with a history of chronic respiratory diseases or medical conditions (e.g., asthma, congestive heart failure, coronary heart disease, etc.).
2. Pregnant.

3. Having any musculoskeletal diseases that restrict the capacity of CPR performance.

4.3 Who will take informed consent?

A research assistant will introduce the trial to the participants by demonstration. Participants will also receive an information sheet. The participants are screened with reference to the inclusion criteria, and eligible participants are invited to join the study using a signed written consent with an explanation. The research assistant will then collect the data of fit testing and mask usability results of all three respirators (two traditional respirators and one new respirator), gender, age, and body weight, which are records required for fit testing. Participants who pass one traditional respirator and one new respirator are invited to the phase 2 study.

4.4 Additional consent provisions for collection and use of participant data and biological specimens

Not applicable.

4.5 Interventions

4.5.1 Explanation for the choice of comparators

To ensure accuracy in comparison of real-time leakage of respirators during CPR, the types of respirators are the infection-control measure serving as an independent variable. Participants receive a traditional best-fit respirator either 3M 1860S or 3M 1870+. All participants are required to don necessary personal protective equipment (assigned N95 respirators, gown, and face shield) for nasopharyngeal suctioning and CPR in the designated simulation environment. Literature indicates that respirator-donning skills, user-seal-check skills, and facial outlook influence the fit-testing results and lead to inaccurate measurement of real-time leakage (3–5). A stringent standardization N95 respirator-wearing protocol is applied (Figure 2), including tying up long hair, standardized psychomotor training on user-seal-check, and standardized psychomotor training on donning skills through video, demonstration, and return demonstration (3–5). Traditional respirators are the commonly used 3M head-loop respirators in hospitals in Hong Kong, namely the 3M cup-shaped 1860S and the three-panel-designed 1870+ (7, 8). To the best of our knowledge, these respirators have two of the highest fit rates (3, 5). Participants using these respirators are the control group. New respirators are masks made of nanomaterial and ear-loop with clip design, which have been adopted for clinical use (13). Participants using this new respirator are the intervention group. Comparison of three respirators is presented in Figure 3.

4.5.2 Intervention description

Eligible participants are randomly allocated in equal proportion to either control or intervention (traditional or new respirator group). New respirator as intervention has been

illustrated and described in Figure 3. Standard scenarios are introduced to participants in advance to reduce stress from the environment and psychological factors. Sufficient time is provided for participants to familiarize themselves with the devices and settings. Participants are required to don all necessary personal protective equipment (assigned N95 respirators, gown, and face shield) for nasopharyngeal suctioning and CPR in the designated simulation environment. Data of real-time leakage is recorded at 30 s intervals during the nasopharyngeal suctioning and CPR. After 2 min suctioning (15 s for two times) and a 4 min one-person CPR, participants donned with the tested respirator will perform fit testing and respond to mask usability, which is recorded as data of post-procedure. With a 10 min rest, participants will don another respirator and repeat the measurement of real-time leakage (i.e., crossover), fit test, and usability.

4.5.3 Criteria for discontinuing or modifying allocated interventions

Not applicable.

4.5.4 Strategies to improve adherence to interventions and scenarios

A face-to-face adherence session will take place at the designated simulated environments. This will include:

- Instruction to the standardization of N95 respirator-wearing protocol (Figure 2).
- Importance of following instructions for standard scenarios and measurements of the speed and depth of chest compression to ensure minimal discrepancy.
- Instruction about the duration of suctioning (i.e., two times suctioning for a maximum of 15 s each) and one-man CPR (a total of 4 min, which included two series of five cycles) (Figure 2).

4.5.5 Relevant concomitant care permitted or prohibited during the trial

Not applicable.

4.5.6 Provision of post-trial care

Participants enrolled in the study will be monitored by the principal investigator and research nurse continuously to check for problems such as discomfort in performing chest compression, allergic reaction due to the respirators.

4.6 Outcomes

4.6.1 Primary outcome measures

Real-time leakage will be measured by portable aerosol spectrometers (Grimm Model 1.109-006 and 007; Grimm Technologies, Ainring, Germany) during two selected clinical procedures. They will provide rapid measurement of particle concentration with optical sizes of 0.25–0.32 μm and different sizes from 31 channels. The system will consist of two spectrometers, the first will measure ambient air particle concentration, and the second will measure air particle concentration inside the respirator. This device will be placed on a designated table throughout the assessment. Participants will perform real-time

measurements for real-time leakage at an average of 30 s intervals while performing the standard clinical procedures. A total of eight sets of data are collected within a 4 min procedure while 4 sets of data are collected in a 2-min one. Portable aerosol spectrometers have been used to measure real-time leakage during aerosol-generating procedures and some nursing procedures, namely, open suctioning, nasogastric-tube insertion, and napkin change (15, 16).

4.6.2 Secondary outcome measures

Fit rate and mask usability will be assessed and measured.

Quantitative fit testing will be conducted with a PortaCount respirator fit-tester system (model Pro+8038/8040; TSI limited), a recognized technology for counting air particles. The overall fit factor (range = 0–200) is the ratio of the concentration of a challenge agent (ambient particles) outside the respirator to the concentration of the same agent that leaks into the respirator (26). Fit rate is the proportion of the number of fit factor > 100 among total tested samples with a given respirator. A fit exceeding 100 indicates a passing rate, meaning that a given respirator is well-fitted to the wearer (3, 4, 12, 16, 27) (Figure 4).

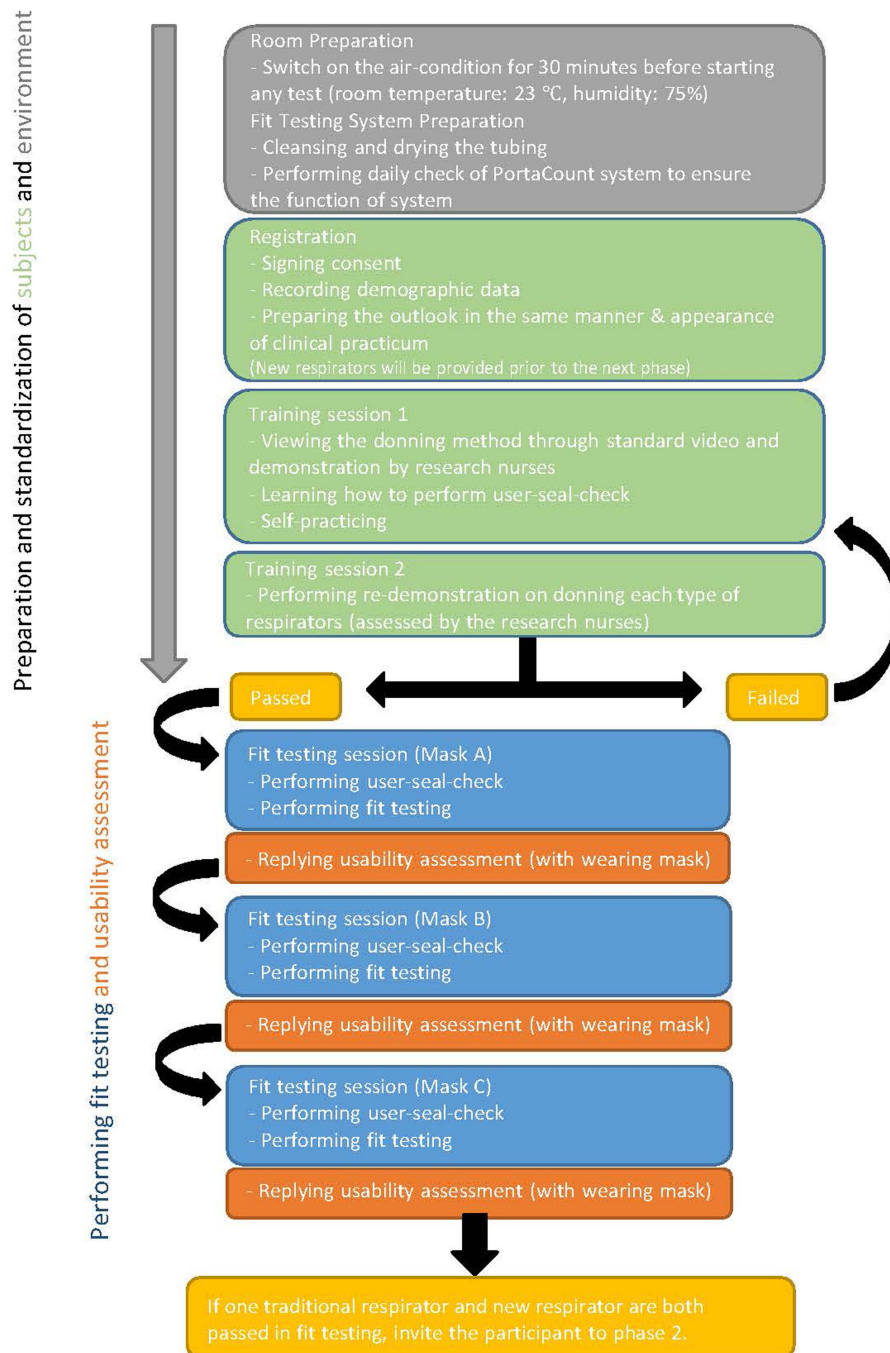


FIGURE 2 (Continued)

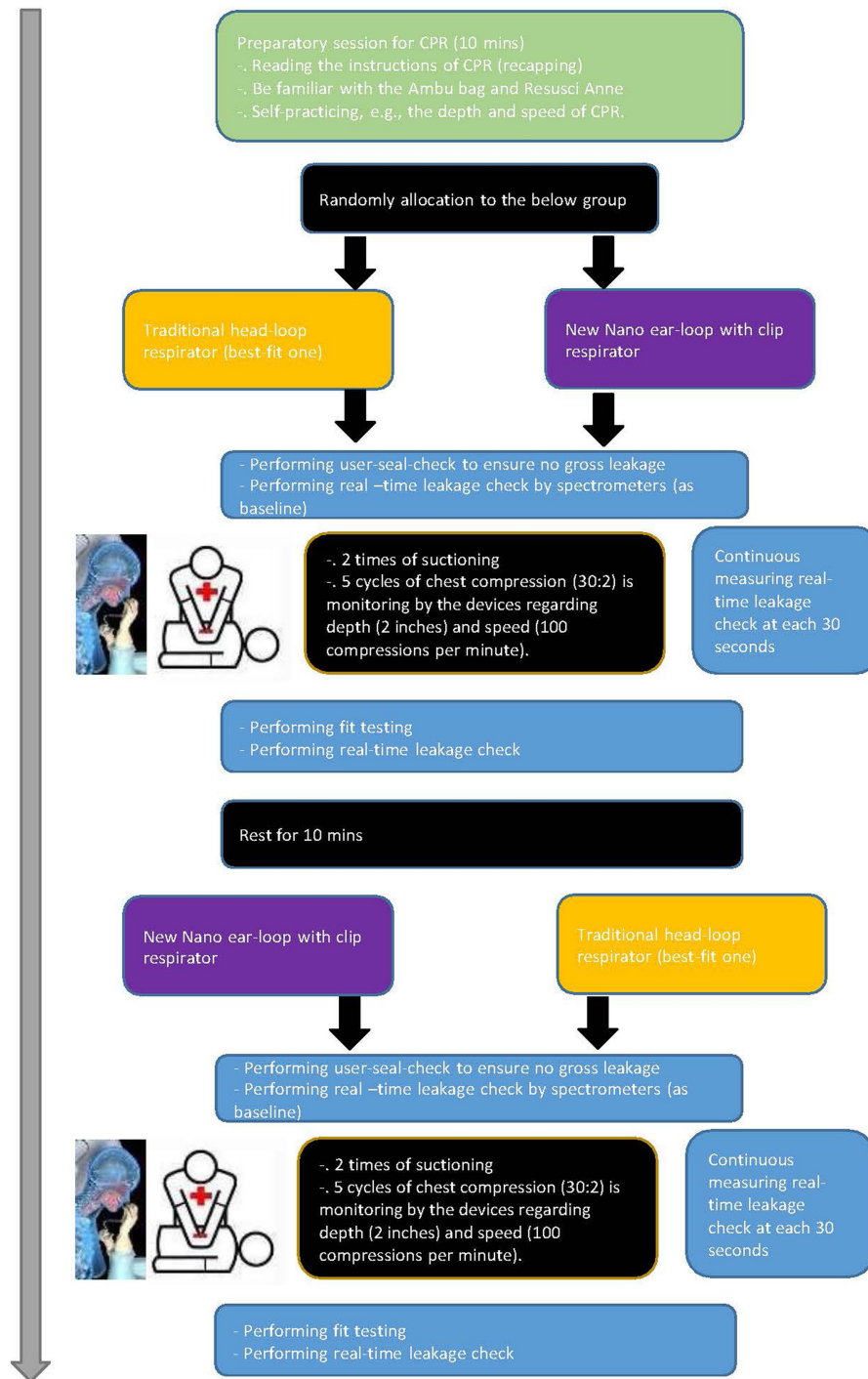


FIGURE 2
Standardization of N95 respirator-wearing protocol and the flow of crossover trial.

Mask usability will be measured by an 11-item Mask Usability Scale (MUS), which involves the wearer's feedback on tolerated heat, breathability, tightness, interference on speaking, skin itchiness, mask displacement, discomfort on the ear lobe, duration of use, interference on working efficiency, mist over glasses, and overall level of comfort (unpublished data). The MUS is rated on a six-point Likert scale, where a lower score means better usability. We have developed this scale and preliminarily used it in our previous studies (11, 16). We have also validated this scale on 283 nursing students with satisfactory

psychometric properties (Cronbach's $\alpha = 0.81\text{--}0.87$; 2-week test-retest reliability: intraclass correlation coefficient = $0.821\text{--}0.822$).

4.7 Sample size

Calculation of sample size in this study was carried out based on Cochran's formula for sampling size estimation ($N = Z^2 p(1-p)/d^2$) (28, 29), where Z is 1.96 for a 95% confidence level, p is 40%







	Traditional respirators		New respirators
Model	1860s	1870+	M0011
Outlook-Front view			
Outlook-Side view			
Filter technology	Meltblown Polypropylene	Meltblown Polypropylene	Nanomaterial
Design	Cup-shape, head-loop	3-panel, flat-fold, head-loop	4D, flat-fold, ear-loop with 2S-shape plastic clips.
Size	Small, medium, large	One-for-all size	One-for-all size
Weight (g/m ²); mean, SD	9.04356 (0.00017)	10.14386 (0.00029)	4.8795 (0.442)
Thickness (mm); mean, SD	2.506 (0.063)	1.846 (0.038)	0.5184 (0.025)
Air permeability (kPa.s/m)	0.9280 (0.0024)	1.2716 (0.0611)	1.050 (0.065)

FIGURE 3
Traditional and new N95 respirators.

for the estimated prevalence of unfit respirators (3, 4, 14), and d is 3% for an acceptable margin of error, for determining fit rate and mask usability (29). A quota sampling will be conducted to ensure that the samples include a certain proportion of students and staff (ratio of 1:2). Our previous study indicated that the medium to large effect size on group differences between traditional and new respirators can be obtained using real-time leakage (11). We will assume an effect of 0.40 to achieve a power of 80% at a 5% significance level (30). 1040 HCWs were recruited in phase 1, of which 60% of Chinese HCWs obtained a pass rate of fit testing in either traditional respirators (3, 4, 12, 14). Coupled with those who passed the fit testing for the new respirator (about 79%) as well as the 20% attrition rate, we have sufficient eligible samples to invite for the phase 2 study ($1040 \times 60\% \times 78\% \times 0.8 = 389$). A total sample size of 200 will be required for this study.

4.7.1 Participant timeline

Refer to Figure 5 for the SPIRIT figure of the participant timeline.

4.7.2 Recruitment

Recruitment takes place at the Integrative Health Center, Tung Wah College, and Squina International Center for Infection Control. These centers are well-equipped with fit testing devices and simulated clinical environments for performing CPR. The devices and facilities have been accredited and used for practical examination by the Hong Kong Nursing Council.

4.8 Assignment of interventions: allocation

4.8.1 Sequence generation

The randomization process will be conducted using computer-generated randomization by a research nurse to determine random allocation, that is the sequence of donning the respirators in this crossover design. All participants will receive an anonymous identifying number to ensure anonymity.

Participants will be randomized with equal probability (1:1 ratio). The block sizes will not be disclosed to ensure concealment.

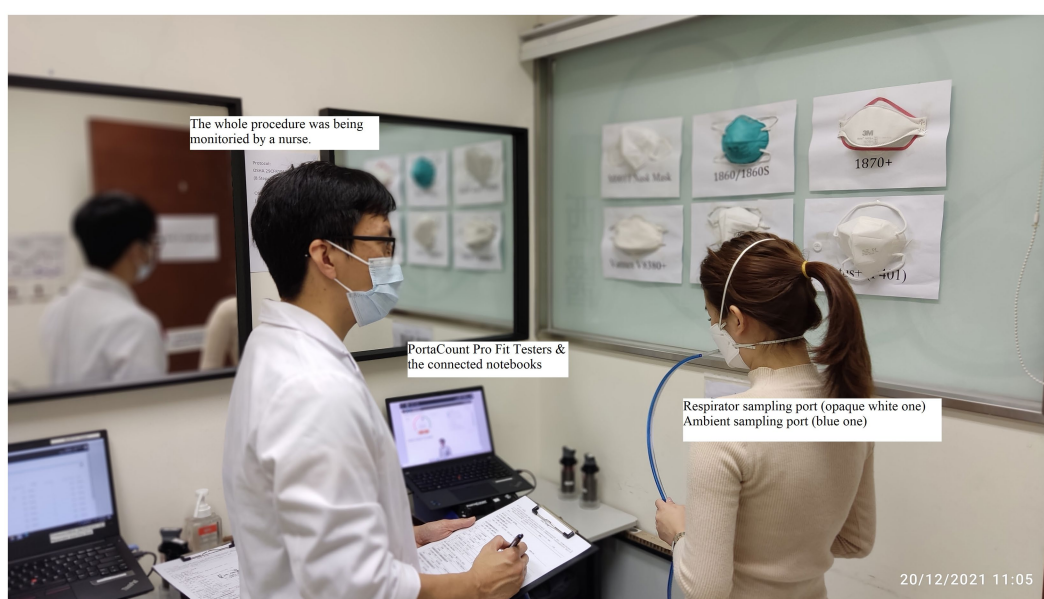


FIGURE 4
Quantitative fit testing system, tubing connection, and respirator.

4.8.2 Concealment

Participants will be randomized using sealed envelopes. Only the research nurse who generated the allocation sequence knows the order of randomization.

4.8.3 Implementation

Participants are randomly allocated to either the group using a traditional respirator or to the group using the new respirator according to an allocation sequence prepared by the research nurse before the start of the study.

4.9 Assignment of interventions: blinding

4.9.1 Who will be blinded

The research team member assigned to perform data input is blinded to the allocation sequence.

4.9.2 Procedure for unblinding if needed

Not applicable.

5 Data collection and management

5.1 Plans for assessment and collection of outcomes

The plan for the collection of outcomes is illustrated in Figure 2 and the measurements are described in the abovementioned section of “Outcomes.”

	STUDY PERIOD			
	Enrolment	Allocation	Post-allocation	
TIMEPOINT	$-t_1$	0	t_1	t_2
ENROLMENT:				
Eligibility screen	X			
Informed consent	X			
Allocation		X		
INTERVENTIONS:				
Traditional N95 respirators			X	X
New N95 respirators			X	X
ASSESSMENTS:				
Real-time leakage		X	X	X
Fit rate and mask usability		X	X	X

FIGURE 5
SPIRIT figure of participant timeline.

5.2 Plans to promote participant retention and complete follow-up

Once a participant is enrolled or randomized, the principal investigator will ensure reasonable effort to follow the participant through the study period.

Participants may withdraw from the study for any reason at any time, without consequences. Participants may also withdraw if the study sponsor or organization sponsoring the trial

terminates the study before the proposed end date. Participants who complete the trial are provided with HK\$300 (~US\$38) incentive as time compensation.

5.3 Data management

All data recorded are stored and backed up on an encrypted hard drive. Data entry and management will be completed by one of the research team members and double-checked by a minimum of one other team member. Personal identifiers will be removed upon completion of the study and stored for long-term retention of the research data. Data will be retained for at least 7 years.

5.4 Confidentiality

Participant and study-related information will be securely stored at the study site with limited access. All data collection and administrative forms will be coded to maintain participant confidentiality. Personal identifiers, such as informed consent forms will be removed from the local database and stored separately from participant information.

5.5 Plans for collection, laboratory evaluation and storage of biological specimens for genetic or molecular analysis in this trial/future use

Not applicable.

6 Statistical methods

6.1 Statistical methods for primary and secondary outcomes

Statistical Package for the Social Sciences (SPSS) version 27 will be used to perform descriptive and inferential statistical analysis. Descriptive statistics, including mean, standard deviation, percentage, and frequency, will be used to report the demographics, fit rate, and mask usability. The intention-to-treat (ITT) principle will be applied. We expect no carry-over and no period effect for this study based on previous experience. Chi-square test for categorical variables and independent sample *t*-test for continuous variables will be used to examine comparability among groups by randomization. Independent sample *t*-tests and paired *t*-tests will be used to compare real-time leakage among different groups of tested respirators during procedure, before and after procedures, respectively. Generalized estimating equations (GEE) will be used to evaluate the total real-time leakage difference in the interaction of time and cycles of chest compression. All the tests will be two-sided, and a *p*-value will be set at 0.05 for statistical significance.

6.2 Interim analyses

Interim analysis is performed by a statistician, blinded to the allocation sequence. The interim analysis is reported to the monitoring committee. The monitoring committee will discuss the results of the interim analysis with the steering committee in a joint meeting. The continuation of the trial is decided by the steering committee and will be reported to the Ethics Committee.

6.3 Methods of additional analyses (e.g., subgroup analyses)

Not applicable.

6.4 Methods in analysis to handle protocol non-adherence and any statistical methods to handle missing data

Not applicable.

6.5 Plans to give access to the full protocol, participant level-data and statistical code

Not applicable.

7 Oversight and monitoring

7.1 Composition of the coordinating centre and trial steering committee

7.1.1 Principal investigator

The principal investigator will prepare the protocol and revisions, collaborate with participating institutions to secure efficient participant recruitment and organize steering committee meetings once a month. The principal investigator is responsible for training research assistant and research nurse, and monitoring data collection procedures. Additionally, the principal investigator is responsible for the publication of study reports.

7.1.2 Steering committee

The steering committee consists of the principal investigator, co-investigators, frontline nursing officer, occupational health and aerosol protection expert, occupational health physician, and statistician. All lead investigators will be steering committee members and will have an agreement on the final protocol. The committee is responsible for participant recruitment, monitoring the trial's overall conduct, and protecting its credibility.

7.1.3 Trial management committee

This committee led by the principal investigator meets every month at the study site. The committee reviews the progress of the study, and if necessary, agrees to changes to the protocol.

7.2 Composition of the data monitoring committee, its role and reporting structure

A data monitoring committee (DMC) has been established. The study organizers are not affiliated with the DMC. During recruitment to study, interim analyses will be given to DMC in strict confidentiality. The DMC will provide guidance to the trial steering committee based on the interim evaluations.

7.3 Adverse event reporting and harms

Not applicable.

7.4 Frequency and plans for auditing trial conduct

The study is monitored by the Sponsor per the approved protocol alongside the relevant regulatory body. Monitoring occurs bi-yearly, and a review of data collection is carried out to ensure accurate and complete data reports.

7.5 Plans for communicating important protocol amendments to relevant parties (e.g., trial participants, ethical committees)

Any modification to the protocol or administrative changes that may impact the conduct of the study will require formal amendment of the protocol. This amendment will be agreed upon by the Research Fund Secretariat of Health Bureau and approved by the Ethics Committee before implementation.

7.6 Dissemination plans

Local dissemination of research findings will be to the Infection Control Branch of the HA Hospital Authority and the Centre of Health Protection of the Hong Kong SAR Government for their information and reference. The study results will be disseminated at local and international conferences and in refereed journals related to infection control and occupational health, aiming to draw worldwide attention to this real-time leakage issue and popularize the importance of facial anthropometrics in N95 respirator design.

8 Discussion

N95 respirators are used to limit the transmission of respiratory viruses in clinical settings. This randomized crossover study will serve as an essential reference for occupational safety as well as consumable purchase policy in clinical settings. The fit rate and usability result will be informative regarding which type of N95 respirators best fits most Chinese HCWs in terms of passing rate of fit testing and usability. The results of real-time leakage will be vital indicators of the respiratory protection provided to HCWs during their performance of prevalent aerosol-generating procedures, like suctioning and resuscitation. The

selection of these clinical procedures is because they are common aerosol-generating procedures in clinical settings and can represent mild to vigorous intensities of physical activity, which enriches the comprehensive understanding of leakage conditions in relation to the intensity of physical activity. If the new nano-respirator is better than the traditional one for Chinese people, this evidence will reduce the use of many different kinds of respirators and the time used for fit testing because of failed fit testing. It will also increase real-time protection during clinical procedures and enhance compliance with donning N95 respirators because of better usability. All of the above clinical implications as nonpharmaceutical interventions to limit the spread of infectious respiratory pathogens in hospitals.

It is possible that the new nano N95 respirator (i.e., NASK ear-loop design with clips) is not superior to the conventional ones. The results will inform us about what procedures require caution because of real-time leakage, which is beneficial to the occupational health of frontline HCWs. However, we know that the NASK has another N95 head-loop model, which has not yet been verified in any clinical trial. Moreover, several newly developed N95 respirators have recently been developed, such as V8380+ and V9580+, with filed patents licensed from the Hong Kong Polytechnic University. The preliminary fit rate and usability are attractive, and these respirators still need to be fully evaluated. However, these respirators haven't been fully adopted in current public clinical settings. The results could provide a good reference to inform whether we should test other potential respirators for Chinese healthcare workers.

If the new N95 respirators have a better fit rate, greater mask usability, and less real-time leakage, increasing the production of respirators for Chinese HCWs to replace all traditional models is worthy of consideration. Our findings will also provide vital insight to encourage local manufacturers to develop more N95 respirators.

Some limitations deserve discussion. Firstly, this trial does not include all available N95 respirators in the market. The focus of this trial is not to promote some respirators better than others. Instead, the risk of real-time leakage of the use of N95 respirators should be verified for the specific design (e.g., ear-loop with clips) or shape (e.g., vertical flat-fold). Secondly, this trial does not include all aerosol-generating procedures in clinical settings but two common procedures are selected to simulate a range of intensity of physical activity. Hence, the results were impossible to generalize to all aerosol-generating procedures. Lastly, the current experiment is conducted through standard scenarios in a controlled simulation environment with mannequins. It is anticipated that the results of real-time leakage may be underestimated or regarded as minimal because the on-site clinical situations in resuscitation consist of many uncontrolled factors and different involved personnel.

8.1 Trial status

The trial is completed. However, it is confirmed that the study protocol has not been changed or revised anywhere. The results related to this trial have not been disseminated. Recruitment began in November 2021 and was completed on 31 May 2023. Protocol version 1 was approved by the Ethical Committee on 3 June 2021 and 19 January 2022, respectively.

Ethics statement

The studies involving humans were approved by Hong Kong Polytechnic University Institutional Review Board Tung Wah College Research Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants will provide their written informed consent to participate in this study. Written informed consent was obtained from the individuals for the publication of any identifiable images or data included in this article.

Author contributions

SL: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. AO: Visualization, Writing – review & editing. IY: Funding acquisition, Methodology, Writing – original draft. SS: Funding acquisition, Writing – original draft. KC: Funding acquisition, Investigation, Methodology, Writing – original draft. PL: Formal analysis, Funding acquisition, Methodology, Writing – original draft. LS: Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

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Assessment of knowledge and practice of nurses regarding infection prevention and associated factors at Debre Tabor Comprehensive Specialized Hospital, Northwest Ethiopia

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Background: Healthcare-Acquired Infections have a major negative impact on the global healthcare delivery system, resulting in increased morbidity and mortality and excessive healthcare resource utilization. Infection prevention and control is the main healthcare agenda nationwide. However, it remains a challenge to achieving Sustainable Development Goals regarding healthcare issues. This study aims to assess nurses' knowledge and practice regarding infection prevention and associated factors at Debre Tabor Comprehensive Specialized Hospital, Northwest Ethiopia.

Methods: An institutional-based cross-sectional study was carried out from May 1 2021 to June 30 2021 at Debre Tabor Comprehensive Specialized Hospital, Ethiopia. A total of 219 nurses participated in this study. A stratified random sampling technique with a pre-tested structured self-administered questionnaire was used to collect data. A Multivariable logistic regression model was fitted to identify factors associated with the knowledge and practice of nurses regarding infection prevention.

Result: The current study shows that the overall knowledge and practice of nurses regarding infection prevention are 59.4% (95% CI: 53.0–65.8) and 53% (95% CI: 46.6–59.4), respectively. Educational level of diploma [AOR: 0.8, 95% CI: 0.67–0.83], years of work experience ≤ 10 [AOR: 1.7, 95% CI: 1.3–9.28], and being trained in infection prevention [AOR: 2.5 (2.3–8.0)] were found to be factors that affect the knowledge of nurses about infection prevention. Moreover, ≤ 10 years of work experience [AOR = 1.5, 95% CI: 1.2–10.1] and being trained in infection prevention [AOR = 2.2, 95% CI: 1.94–13.5] were found to be factors that affect the practice of nurses regarding infection prevention.

Conclusions and recommendations: Most nurses were knowledgeable and had good practices. However, a substantial proportion of nurses had inadequate knowledge and practice regarding infection prevention. The nurses' knowledge and practice were associated with years of work experience and status of training on infection prevention. Moreover, the education level of nurses was another predictor variable of the knowledge of nurses. Therefore, healthcare workers in

the hospital setting should adhere to the national infection prevention protocols. The policy designers should provide training for nurses on infection prevention to improve knowledge and practice in this area. Furthermore, to attain more detailed information, future research should involve a qualitative study.

KEYWORDS

hospital, infection, knowledge, nurses, practice, risk factors

Background

Infection is defined as the colonization of body tissue by bacteria and other microorganisms (1). Due to the failure to prevent infection globally, more than 400 million individuals worldwide have chronic hepatitis B virus (HBV) infection, and up to one million people may pass away from an HBV-related illness each year (2). In healthcare environments, infections can spread from Health Care Providers (HCPs) to patients, patients to HCPs, patients to patients, and HCP to HCP. Healthcare-Acquired Infections (HAI) are a major problem in the world within the healthcare delivery system (3).

According to the global estimation of the global burden of disease attributable to contaminated sharps injuries among healthcare professionals, HCWs may have contracted 16,000 HCV, 66,000 HBV, and 1,000 HIV infections worldwide in 2000 as a result of their job-related exposure to percutaneous wounds (4). The general HCAI predisposing factors are associated with characteristics of the patient, such as age, underlying disease, comorbidities, and reduced host defenses.

Infection prevention and control (IPC) is a vital, continuing requirement for safeguarding patients and healthcare workers (HCWs) against the transmission of infectious diseases in healthcare settings (5). Globally, the prevalence of HCV among 100 countries was 1%, with viremia infections in 71.1 million people (6).

An elaborative global health system has been established as a defense against both known and unknown infectious disease threats in order to slow the spread of infectious diseases. The system is made up of several formal and informal networks of organizations that work with different stakeholders; have different objectives, methods, and levels of accountability; operate at various regional scales (e.g., local, national, regional, or global); and span the public, for-profit, and non-profit sectors (1).

Existing studies have tried to assess the knowledge and practice of healthcare workers regarding infection prevention and associated factors (7–9); however, the knowledge and practice of nurses in particular, who carry out the highest burden of healthcare activities, regarding infection prevention and associated factors are not well addressed. Furthermore, less is known about the burden associated with substandard care and ineffective infection control in settings with limited resources (10–12). Therefore, this study aims to assess nurses' knowledge and practice regarding infection

prevention and associated factors at Debre Tabor Comprehensive Specialized Hospital, Northwest Ethiopia.

Method and materials

Study design and setting

The institutional-based cross-sectional study design was carried out from May 1 2021 to June 30 2021 at Debre Tabor Comprehensive Specialized Hospital Ethiopia. According to the information obtained from the Debre Tabor city administrative health department, the hospital served as a general hospital until the end of 2019 and upgraded to a Comprehensive Specialized Hospital in 2020. The hospital is organized into surgical, medical, gynecology, pediatrics, ophthalmology, emergency, and intensive care unit wards. Currently, it has a total of 125 inpatient beds in all wards and 534 staff providing health care services for a population of ~2,651,350.

All nurses working in Debre Tabor Comprehensive Specialized Hospital, providing healthcare services, and who had at least one of four possible contacts (patients, medical equipment, linens, and high-risk wastes) were eligible to be included in the study. The study excluded nurses who were on annual or maternity leave at the time the data were collected as well as those who were ill and unable to respond to the questions.

Population

All nurses working in Debre Tabor Comprehensive Specialized Hospital were the source population, while nurses working in Debre Tabor Comprehensive Specialized Hospital and providing healthcare services who had at least one of four possible contacts (patient, medical equipment, linens, and high-risk waste) were the study population.

Sample size and sampling procedure

The sample size was determined using the single population proportion formula. A previous study on the level of knowledge and practices of nurses regarding infection prevention higher proportion was considered and demonstrated that the proportion of nurses with good knowledge regarding infection prevention was 84.7% (8), with a 95% confidence level, 5% margin of error, and 10% non-response rate, which yields the final sample size of 219. A stratified random sampling technique was used to select

Abbreviations: HbsAg, Hepatitis B surface Antigen; HCWs, Healthcare Workers; IPC, Infection Prevention Practice; PI, Principal Investigator; PLWHIVA, People Living with HIV/AIDS; MOH, Ministry of Health; SPSS, Statistically Package for Social Science.

the required sample size of 219 nurses. Hospital departments were classified into six main strata with nearly the same working conditions: (1) Medical, (2) Surgical, (3) Pediatrics, (4) Gynecology, (5) Ophthalmology, and (6) Emergency and Intensive Care departments. The proportional allocation was taken from each stratum and then a simple random sampling technique was applied.

Variables and measurements

The dependent variables studied were the knowledge and practice of nurses regarding infection prevention. The independent variables were sex, job category, educational level, year of work experience, working hours, work shift, status of training, marital status, monthly income, duration status, and level of hospital previously worked in and currently working in.

Nurses' knowledge of infection prevention was assessed by 18 "yes or no" questions. A scoring system was utilized in which the respondents' correct and incorrect answers provided for the questions were allocated "1 and 0" points, respectively. Knowledge scores were summed up to give a total knowledge score for each respondent. There were two types of responses based on the total score for the knowledge questions, which ranged from 0 to 18. Respondents who scored the mean and above were knowledgeable and those who scored below the mean were not knowledgeable (13, 14).

The nurses' practice regarding infection prevention was measured by 15 items to which the responses were "yes" or "no." Similar methods were used to analyze the practice: a score of 1 was given for good practice and a score of 0 for poor practice. Hence, the range of the overall score for infection prevention practice was from 0 to 15. Respondents who scored mean and above were classified as good practice and those who scored below the mean were classified as poor practice (13, 14).

Operational definitions

- Knowledge: Nurses' understanding of infection prevention.
- Knowledgeable: Knowledge status of nurses when they scored 50% and above on the knowledge questions.
- Not knowledgeable: Nurses' status of knowledge when they scored <50% on the knowledge questions.
- Practice: The act of performing a given procedure(s) in accordance with a predetermined standard.
- Good practice: Practice level of nurses when they scored 50% and above on the practice questions.
- Poor practice: Practice level of nurses when they scored <50% on the practice questions (13, 14).

Data collection tools and procedures

The data collection tool was a three-part questionnaire involving socio-demographic variables, knowledge, and practice-related variables on infection prevention and control. Data

were gathered using a pre-tested, structured self-administered questionnaire. The data collection tool was developed by reviewing relevant literature (13, 15, 16) and by adapting the content from related studies (13, 14). The instrument for collecting data was initially written in English; it was then translated into Amharic (the local tongue) and, finally, back into English to ensure uniformity. The data collection process was conducted by four data collectors and two supervisors.

Data quality assurance and control

A day of training focused on the objectives of the study, how to get consent, maintain confidentiality, and basic data collection techniques was provided for both data collectors and supervisors.

The instruments were undergone preliminary testing to enhance reliability on 5% (11) of individuals in the total sample with traits that the target population shares and the necessary amendment was done accordingly. Questionnaires were checked for consistency and completeness. The data collection process was checked by supervisors daily and appropriate action was taken according to the findings. Alpha Cronbach values of 0.78 and 0.822 demonstrated the internal consistency of items for the knowledge and practice sections, respectively.

Data processing and analysis

Data were entered into Epidata version 4.6.0 software and STATA version 13 statistical software for analysis. The analysis was both descriptive and analytical. The descriptive analysis was presented using texts, frequency, and cross-tabulation.

A binary logistic regression model was fitted to assess the association between the dependent and independent variables, and those variables with a $p < 0.2$ were entered into a multivariable logistic regression to control the confounding effect and to estimate the independent variables of knowledge and practice regarding infection prevention. A $p < 0.05$ at a 95% confidence interval was considered statistically significant. The appropriate model goodness-of-fit was checked by the Hosmer Lemeshow test which was 91.8%, indicating that the model fitness was good. Finally, significant findings in the multivariable analysis were interpreted.

Result

Socio-demographic characteristics of nurses

A total of 219 nurses were enrolled in this study. The mean (SD) age of the nurses was 36.02 ± 14.56 . The monthly income and duration of training were 6642.2 ± 2279.29 and 4.2 ± 4.3 , respectively. The majority, 56.2% (123), were female, 37.9% belonged to the age group 41+ years, 81.7% had a bachelor's degree, and 59.4% were staff nurses by profession. Moreover, 58% and 70.3% of the nurses were married and earned a monthly

salary of 73.3 US\$–146.5 US\$ respectively. Approximately one-third (29.7%) and three-quarters (75.8%) of participants had work experience of > 10 years and were working on day shifts, respectively (Table 1).

Knowledge of the nurses regarding infection prevention

The study revealed that the overall knowledge of nurses about infection prevention was 59.4% (95% CI: 53.0–65.8). Approximately 82.6% of nurses knew about safety precautions for infection prevention and 87.7% were aware of the recommended guidelines for hand hygiene. Similarly, 86.8% and 13.2% of the study participants were aware of the IPC team and had undertaken infection prevention-related training in the past 12 months.

Moreover, 83.6% and 65.8% of nurses were aware of the availability of infection prevention guidelines in their working area and the availability of personal protective equipment (PPE) at all times, respectively. Likewise, 86.6%, 14.2%, and 18.3% of nurses were aware that disinfection prevents hospital-acquired infection, used chemical sterilization techniques for all equipment, and employed physical sterilization (heat and radiation) techniques for all equipment used, respectively. Similarly, 77.2%, 90.0%, and 85.8% of the study participants believed that all microorganisms, including spores, are destroyed by autoclaving, all equipment must be decontaminated before sterilization, and protective clothing minimizes hospital-acquired infection, respectively (Table 2).

The practice of the nurses regarding infection prevention

In this study, 53% (95% CI: 46.6–59.4) of nurses were found to have good practice. Moreover, approximately three-quarters (76.7%) of nurses responded that they wash their hands with soap and water after taking a sample and 182 (83.1%) responded that they wash their hands immediately after contact with body fluids and contaminated items.

Furthermore, 166 (75.8%), 206 (94.1%), and 182 (83.2%) nurses reported that they discard sharp materials in a safety box, wear goggles to protect their eyes during procedures, and wear a mask during sputum sample collection and processing, respectively.

On the contrary, 84 (38.4%) and 26 (11.9%) of nurses reported that they recap needles before disposal and do not wear gowns properly for every procedure, respectively. Wearing an apron, covering wounds and cuts on the skin before starting work, being vaccinated against common pathogens, and eating or drinking in the work area were 48.4%, 68.5%, 17.8%, and 48.8%, respectively.

However, 49 (22.4%), 168 (76.7%), and 180 (82.2%) of the study participants responded that they had been exposed to needle-stick injury, soak contaminated medical equipment in 0.5% chlorine solution, and separate wastes infectious and noninfectious, respectively (Table 3).

TABLE 1 Socio-demographic characteristics of nurses at Debre Tabor Comprehensive Specialized Hospital, Northwest Ethiopia, 2021 ($n = 219$).

Variables	Frequency	Percentage (%)
Age (in years)		
20–25	24	11
26–30	52	23.7
31–40	60	27.4
41+	83	37.9
Sex		
Male	96	43.8
Female	123	56.2
Religion		
Orthodox Christian	179	81.7
Protestant	16	7.3
Muslim	24	11
Educational level		
Diploma	29	13.2
Bachelor	178	81.3
Masters and above	12	5.5
Job category		
Supervisor nurse	27	12.3
In charge nurse	62	28.3
Staff nurse	130	59.4
Marital status		
Never married	127	58
Married	70	32
Divorced	22	10
Monthly income		
73.3–146.5 (US\$)	154	70.3
146.5+ (US\$)	65	29.7
Work experience (in years)		
≤10	154	70.3
>10	65	29.7
Work shift		
Day	166	75.8
Night	53	24.2
Trained in infection prevention		
Yes	27	12.3
No	192	87.7
Duration of training (in days)		
1–5	16	7.3
>5	11	5
Currently working in		
OPD	73	33.3
Triage	14	6.4
Ward	132	60.3

TABLE 2 Knowledge of the nurses regarding infection prevention at Debre Tabor Comprehensive Specialized Hospital, Northwest Ethiopia, 2021 ($n = 219$).

Variables	Frequency	Percentage (%)
Knowing about safety precautions		
Yes	181	82.6
No	38	17.4
Presence IPC team		
Yes	190	86.8
No	29	13.2
Trained in infection prevention in the past 12 months		
Yes	29	13.2
No	190	86.8
Availability of infection prevention guidelines in the work area		
Yes	183	83.6
No	36	16.4
Availability of PPE at all times		
Yes	144	65.8
No	75	34.2
Availability of water for 24 h		
Yes	106	48.4
No	113	51.6
Knowing the impact of HCAs on clinical outcomes		
Yes	184	84
No	35	16
Knowing disinfection prevents hospital-acquired infection		
Yes	194	88.6
No	25	11.4
Chemical sterilization technique used for all equipment		
Yes	31	14.2
No	188	85.8
Believe that all microorganisms including spores are destroyed by autoclaving		
Yes	169	77.2
No	50	22.8
All equipment needs decontamination before sterilization		
Yes	199	90.9
No	20	9.1
Protective clothing minimizes hospital-acquired infection		
Yes	188	85.8
No	31	14.2
Proper handling of working equipment decreases the risk of contamination		
Yes	202	92.2

(Continued)

TABLE 2 (Continued)

Variables	Frequency	Percentage (%)
No	17	7.8
Vaccinated for HBV		
Yes	19	8.7
No	200	91.3
Presence of a system for reporting accidental exposure to blood and body fluids		
Yes	179	81.7
No	40	18.3
Know to take PEP while exposed to body fluid or needle-stick injuries of HIV-infected patients		
Yes	193	88.1
No	26	11.9

Factors associated with knowledge of nurses about infection prevention

In the bivariable analysis, age, sex, educational level, years of work experience, work shift, and ever having been trained on infection prevention were the predictor variables associated with the knowledge of nurses about infection prevention.

However, only education level, years of work experience, and status of training on infection prevention were factors associated with the knowledge of nurses about infection prevention in the multivariable logistics regression analysis.

Nurses with an educational level of diploma were 20% less knowledgeable than nurses with a master's or above [AOR = 0.8, 95% CI: 1.7–8.3, $P = 0.04$]. Moreover, nurses with ≤ 10 years of work experience were 1.7 times more likely to be knowledgeable compared to nurses with > 10 years of work experience [AOR = 1.7, 95% CI: 1.3–9.3, $P = 0.002$]. Similarly, nurses who had ever been trained on infection prevention were 2.5 times more knowledgeable than those who had never [AOR = 2.5, 95% CI: 2.3–8.0, $P = 0.03$] (Table 4).

Factors associated with the practice of the nurses regarding infection prevention

In the bivariable logistics regression analysis, sex, education level, years of work experience, work shift, and status of training on infection prevention were factors that were significantly associated with nurses' practice regarding infection prevention, whereas only years of work experience and status of training on infection prevention were significantly associated with the infection prevention practice of nurses in the multivariable analysis.

Nurses with work experience of ≤ 10 years had 1.5 good than nurses who had a work experience of > 10 years [AOR = 1.5, 95% CI: 1.2–10.1, $P = 0.003$]. Moreover, nurses who had been trained on infection prevention had 2.2 times better practice than

TABLE 3 Practice of the nurses regarding infection prevention at Debre Tabor Comprehensive Specialized Hospital, Northwest Ethiopia, 2021 ($n = 219$).

Variables	Frequency	Percentage (%)
Washing hands with soap and water after taking a sample		
Yes	168	76.7
No	51	23.3
Washing hands immediately after coming into contact with blood, body fluids, or contaminated items		
Yes	182	83.1
No	37	16.9
Discard sharp materials in a safety box		
Yes	166	75.8
No	53	24.2
Discard needles in the sharps bin		
Yes	168	76.7
No	51	23.3
Wear goggles to protect your eyes during procedures that generate a spray of blood or body fluids		
Yes	206	94.1
No	13	5.9
Wear a mask during sputum sample collection and processing		
Yes	182	83.1
No	37	16.9
Recap needles before disposal		
Yes	84	38.4
No	135	61.6
Wear a gown properly for every procedure		
Yes	193	88.1
No	26	11.9
Wear an apron when blood or body fluid splash is expected		
Yes	106	48.4
No	113	51.6
Cover wounds and cuts on the skin before starting work		
Yes	150	68.5
No	69	31.5
Vaccinated for common pathogens		
Yes	39	17.8
No	180	82.2
Eat or drink in your work area		
Yes	85	38.8
No	134	61.2
Exposure to needle-stick injury		
Yes	49	22.4

(Continued)

TABLE 3 (Continued)

Variables	Frequency	Percentage (%)
No	170	77.6
Soak contaminated medical equipment in 0.5% chlorine solution		
For 10 min	168	76.7
For 1 h	39	17.8
For 24 h	12	5.5
Separation of waste into infectious and non-infectious		
Yes	180	82.2
No	39	17.8

those who had not [AOR = 2.2, 95% CI: 1.94–13.5, $P = 0.04$] (Table 5).

Discussion

This study revealed that 59.4% (95% CI: 53.0–65.8) of nurses were knowledgeable about infection prevention. In this study, it is indicated that a substantial proportion of respondents (40.6%) in the hospital had inadequate knowledge about infection prevention, whereas 53% (95% CI: 46.6–59.4) of nurses had good practice in infection prevention.

The knowledge of nurses about infection prevention in the current study was higher than similar studies conducted in Amhara regional state referral hospitals, Addis Ababa, and Eastern Ethiopia, which reported that 40.7%, 46.3%, and 47.7% of the nurses were knowledgeable, respectively (17–19), but lower compared with a similar study conducted in Wolaita Sodo, Afar, Debre Markos, and Bahir Dar, where the overall knowledge of nurses about infection prevention was 99.3%, 65.9%, 84.7%, and 74.5%, respectively (8, 20–22). This difference might be due to differences in the provision of training provided for nurses and the previous experience of nurses.

Another possible justification for this difference might be the differences in socioeconomic status, study setting, and sample size and the use of different data collection tools.

However, this finding is similar to studies conducted in Dubti referral hospitals and Zambia, where the overall knowledge of nurses was reported to be 48.4% and 48.88%, respectively (23, 24). A possible reason for the similarity between the current study, Dubti referral hospital, and Zambia might be the use of a similar study design (cross-sectional) and study population (nurses).

Moreover, in this study, the practice of nurses regarding infection prevention was higher compared with the Gamo Gofa zone, Ethiopia, which reported that the overall practice of nurses regarding infection prevention was 39.9% (25), but lower compared with studies conducted in Addis Ababa, Dessie, Nigeria, Yemen, and Saudi Arabia, where the practice of nurses regarding infection prevention was reported to be 66.1%, 77%, 77.9%, 71%, and 92.1%, respectively (26–29). Possible reasons for this discrepancy might be the time gap and the improper supply of PPE, including disinfectants, in the study areas.

TABLE 4 Factors associated with knowledge of the nurses regarding infection prevention at Debre Tabor Comprehensive Specialized Hospital, Northwest Ethiopia, 2021 ($n = 219$).

Variables	Knowledge of infection prevention		COR (95% CI)	AOR (95% CI)	P-value
	Yes	No			
Age (in years)					
20–25	20	4	4.37 (1.24–9.53)*	4.0 (0.86–9.35) 1.6 (0.9–6.0)	0.3
26–30	3	22	1.5 (0.6–8.0)	1.8 (0.9–6.0)	1.08
31–40	50	10	1.65 (0.7–10.0)	1	0.5
41+	43	40	1		
Sex					
Male	69	58	2.3 (1.56–3.99)*	2.2 (0.52–7.87)	1.4
Female	54	151	1	1	
Educational level					
Diploma	20	9	0.56 (0.6–0.93)*	0.8 (0.67–0.83)**	0.04
BSc	96	82	0.72 (0.77–14.0)	0.8 (0.75–12.0)	0.9
MSc and above	10	2	1	1	
Work experience (in years)					
≤10	36	54	1.89 (1.8–12.0)*	1.7 (1.3–9.28)**	0.002
>10	69	60	1	1	
Work shift					
Day shift	100	54	0.67 (0.7–0.89)*	0.9 (0.09–11.0)	1.6
Night shift	16	49	1	1	
Trained in infection prevention					
Yes	100	66	2.1 (1.5–10.3)*	2.5 (2.3–8.0)**	0.03
No	16	37	1	1	

AOR, Adjusted Odds Ratio; COR, Crude Odds Ratio; CI, Confidence Interval, * $p < 0.2$, ** $p < 0.05$.

The current study also assessed factors that affect the knowledge and practices of nurses regarding infection prevention. The findings indicate that the knowledge of nurses about infection prevention was associated with education level, years of work experience, and status of training on infection prevention. Furthermore, nurses with an education level of diploma were less knowledgeable than nurses with an educational level of master's or above. This study was supported by the study conducted in Debre Markos referral hospital, Northwest Ethiopia, which showed that healthcare workers with an educational level of BSc or above were two times more likely to be knowledgeable than those with Diplomas (8). This could be attributed to the possibility that more educated nurses have better access to knowledge about infection prevention.

In this study, it is shown that years of work experience and knowledge of nurses had an indirect association. Nurses with fewer years of work experience were more likely to be knowledgeable compared to nurses who had more years of work experience. This might be due to the recalling effect, meaning that nurses with fewer years of work experience might recall courses taken during their

education more easily than nurses with more years of work experience.

Moreover, nurses who had ever been trained on infection prevention were more knowledgeable than nurses who had never. This finding is consistent with the study conducted in Debre Markos referral hospital, Northwest Ethiopia, where healthcare professionals who hadn't received infection prevention training were 75% less likely to be knowledgeable about infection prevention than those who had received training on infection prevention (8). This consistency might be due to the similarity of the health facility setup. This implies that training increases the chances of nurses accessing up-to-date information about infection prevention.

This study also showed that years of work experience and status of training on infection prevention were significantly associated with the infection prevention practice of nurses.

Nurses with fewer years of work experience were more likely to have good practice compared to nurses who had more years of work experience. This might be because nurses with more years of work experience may be bored, leading to negligence in the practice of nurses regarding the recommended protocols. This finding contrasts with the study done in Bahir Dar City, Ethiopia,

TABLE 5 Factors associated with the practice of the nurses regarding infection prevention at Debre Tabor Comprehensive Specialized Hospital, Northwest Ethiopia, 2021 ($n = 219$).

Variables	Practice regarding infection prevention		COR (95% CI)	AOR (95% CI)	P-Value
	Yes	No			
Sex					
Male	69	58	1.22 (1.56–3.99)*	1.0 (0.2–1.57)	1.3.
Female	54	151	1	1	
Educational level					
Diploma	20	9	1.6 (1.3–1.92)*	0.9 (0.73–6.34)	1.9.
BSc	96	82	0.72 (0.77–14.0)	0.6 (0.5–11.0)	2.2.
MSc and above	10	2	1	1	
Work experience (in years)					
<10	100	54	1.57 (1.4–15.00)*	1.5 (1.2–10.1)**	0.003
>10	69	60	1	1	
Work shift					
Day shift	100	167	0.5 (0.3–0.69)*	0.7 (0.2–2.3)	3.4.
Night shift	16	49	1	1	
Trained in infection prevention					
Yes	100	66	1.6 (1.5–12.1)*	2.2 (1.94–13.5)**	0.04
No	16	37	1	1	

AOR, Adjusted Odds Ratio; COR, Crude Odds Ratio; CI, Confidence Interval, * $p < 0.2$, ** $p < 0.05$.

where HCWs with work experience of 10 years and above were four times more likely to practice infection prevention than those with less than 10 years of experience (14). This difference might be due to the differences in the characteristics of the health institutions where the studies were conducted.

Similarly, nurses who had been trained on infection prevention had good practice compared to those who had not. This might be training enhanced the standards of practice of nurses. This implies that providing continuous training for nurses regarding infection prevention has an impact on putting their knowledge into practice.

Limitations of the study

Despite extensive efforts to minimize limitations, the study has some limitations that should be acknowledged. The study was conducted at Debre Tabor Comprehensive Specialized Hospital and, therefore, might not be representative of all health professionals across Ethiopia. There might be a recall bias during data collection time that could affect the true level of practice and knowledge of nurses regarding infection prevention. The other possible limitation of the study is that it only quantitatively assessed infection prevention, not qualitatively.

The strength of the study is that it incorporated two outcome variables (knowledge and practice) to attain more accurate evidence of IPC.

Conclusion and recommendations

The majority of nurses were knowledgeable and had good practice. However, a substantial proportion of respondents in the hospital had inadequate knowledge and practice regarding infection prevention. Moreover, the nurses' knowledge and practice were associated with years of work experience and status of training on infection prevention. Furthermore, the education level of nurses was another predictor variable of the knowledge of nurses.

Based on the findings of this study, it is recommended that healthcare workers in the hospital adhere to the national infection prevention protocol guidelines. policy makers should educate and train nurses on infection prevention and provide continuous professional development to maintain or improve knowledge and practice regarding infection prevention among nurses. Moreover, to attain more detailed information, future research should include a qualitative study.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical clearance was obtained from the Research Ethics Committee of Debre Tabor University Department of Nursing (Ref. no. DT/12596/214). Written informed consent was obtained from each participant following a brief explanation of the research objectives and data collection process of the study. Participants were also informed about their right to withdraw at any time or to skip a single question or several questions. All methods were carried out in accordance with the Declaration of Helsinki.

Author contributions

TT conceptualized the study. TT, DF, and TB contributed to the data extraction and analysis. TT, TB, and GA wrote the result interpretation. TT and TB prepared the first draft. TT and DF contributed to the conceptualization, interpretation of results, and substantial revision. TT, TB, DF, and GA revised and finalized the final draft manuscript. All the authors read and approved the final version of the manuscript.

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Improvement of the occupational risk management process in the work safety system of the enterprise

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Purpose: The research purpose is to improve the management of occupational risks associated with hazards as well as the organization's capabilities to identify hazardous factors (HFs) using the "BOW-TIE" method in accordance with the provisions of the ISO 45001:2019 standard.

Methods: To improve occupational risk management, the "BOW-TIE" method has been introduced into occupational health and safety management systems. This approach facilitates a comprehensive description and analysis of potential risk development from identifying hazardous factors to studying the consequences. It visually integrates fault and event trees to provide a holistic view of risk dynamics.

Results: The improvement of the occupational hazard risk management process considers both internal and external factors affecting the organization, thereby increasing the probability and severity of potential hazardous events. The revised approach categorizes risk levels as acceptable, unacceptable, or verifiable. In addition, occupational risk management requires an in-depth analysis of the organization's external and internal environment to identify hazards that affect the probability and severity of potential hazardous events.

Conclusion: This research proposes an innovative approach to occupational risk management by determining the magnitude of occupational risk as the cumulative result of assessing risks associated with all external and internal factors influencing the probability of hazardous event occurring. The introduction of the "BOW-TIE" method, combined with a comprehensive analysis of the organizational environments, facilitates a more effective and nuanced approach to occupational risk management.

KEYWORDS

occupational safety, occupational risk, assessment of occupational risk, hazardous factor, "BOW-TIE" method

1 Introduction

For the development of a country and society as a whole on the way to joining the European Union, it is necessary to ensure the implementation of production processes with the least expenditure of effort and resources, together with high occupational safety and health of employees (1–4).

The model of any business for managing losses, including losses of life and health of workers, can be presented in the form of a list of external and internal hazardous factors (hereinafter – HF): social, environmental, economic, industrial, innovative, scientific, and technical and other, which are interconnected and contribute to the improvement or deterioration of business process management systems at enterprises under certain conditions (5).

Under certain conditions, the cumulative impact of all hazardous factors will contribute to the deterioration of the effectiveness of business process management systems at enterprises (6, 7).

Therefore, their analysis, identification of the most influential ORs, or their combinations is the basis for making any decisions based on occupational risk (OR) assessment in occupational safety and health management systems to substantiate protective and precautionary measures to reduce injuries when performing production tasks (8–11). It is this approach that makes it possible to ensure the organization's resilience to the impact of destructive factors and reduce the impact of negative consequences and financial losses (12).

In accordance with the requirements of the ISO 45001:2018 standard (13), each enterprise must determine all external and internal HFs of organization environment that can increase the probability of the occurrence of hazards occurring in occupational safety and health management systems that will not achieve the intended result, reducing injuries and occupational diseases in the organization. In order to identify all the hazardous external and internal factors, the SWOT analysis is the basic one (14). If additional consideration of external groups of HFs (political, economic, social, etc.) is necessary, PEST analysis is added. To identify neutral HFs, which can be either negative or positive, requiring additional analysis, the SNW analysis method is used (Table 1).

At the same time, there is a challenge in identifying the HF impact on the level of occupational risks, the value of which forms awareness of the impact of uncertainty on the objectives set in the relevant management systems (19).

It is a common understanding that the risk assessment process focuses only on the analysis of the potential threat and its consequences. In this case, to determine the cause-and-effect relationship between the hazard and hazardous event, focus is made exclusively on one factor (20, 21).

With this approach to risk assessment, a complete understanding of the structure of the environment in which the enterprise operates is often lost. This does not allow to reflect all possible influences on the OR of hazards (probability and degree of severity of a hazardous event: accident, failure, etc.) at employees' workplaces (22, 23). Hence, the need arises to conduct appropriate scientific research to develop new or improve known OR management approaches that would allow taking into account the cumulative impact of any internal and external HFs of any enterprise organization.

There are 32 different methods for analyzing the OR management process in an enterprise environment, each having its own strengths and

TABLE 1 Methods of HF analysis of the enterprise environment.

Method	Description of the method
SWOT analysis (15)	SWOT analysis is a method of strategic planning, which consists in identifying the HF of the internal and external environment of the enterprise. The task of the SWOT analysis is to give a structured description of the situation in relation to which a decision must be made. The conclusions drawn on its basis are descriptive in nature without recommendations and prioritization.
PEST- analysis (16, 17)	The method is designed to identify political (<i>political</i>), economic (<i>economic</i>), social (<i>social</i>), and technological (<i>technological</i>) aspects of the external environment that affect the company's business. Varieties: PESTLE analysis, SLEPT-analysis, STEEPLE- analysis, STEEP, PESTEL, PESTELI, LONGPEST.
SNW analysis (18)	SNW analysis (strength, neutral, and weakness) is a method of analysing the company's strengths, neutrals, and weaknesses. The purpose of this process can be considered to be the identification of advantages, and then - the elimination of shortcomings among them and their strengthening.

weaknesses (24). However, there is always a question about the effectiveness of known methods for solving the tasks in a particular enterprise. The authors of the publication (25) concluded that in order to choose the best method, first of all, it is necessary to understand what results the company wants to achieve. Because none of the known methods for analyzing the influential HF of the general environment of the enterprise, used in isolation, gives a complete picture of the structure that functions in enterprises, errors occur in management decisions aimed at improving security. However, the study considers the solution of a specific case of environmental impact assessment, which does not allow the developed approach to be applied to other conditions. At the same time, the authors of the scientific study (26) recommend using the results combining several methods to obtain the most complete information about hazards during production operations. However, unfortunately, no recommendations were made how to combine or select them. As the authors of the study (27) noted, in order to promote the progressive, inclusive, and sustainable economic growth of the enterprise, it is necessary that the enterprise management system, which covers the entire set of interrelated elements, is aimed precisely at eliminating all major threats and challenges it faces. At the same time, the biggest problem arises when making an effective decision due to the fact that it is difficult to determine the probability of occurrence of hazardous events from various threats when employees perform production activities (28).

Sometimes this requires quite serious scientific research. However, quite a few enterprises can afford to finance such

projects. Moreover, the answer will be received after a certain period of time that is usually lacking. The specified task requires a clear understanding of the action of all possible hazards and HF, which can increase the probability of the occurrence of a hazardous event (29). We should note that the most popular for modeling hazardous processes, including accidents, were diagrams of cause-and-effect relationships, which received the names “failure tree” and “event tree” (30, 31). By getting all the information about the negative external or internal HF of enterprise, it is possible to understand the hazards in this or that scenario; it is possible to estimate the OR. If the OR is not acceptable, it should be reduced; that is, measures should be implemented to reduce the probability of occurrence of a hazardous event and/or the degree of severity of the consequences of a hazardous event. However, in most of the analyzed publications (32–35) regarding the assessment of OR, there is a misunderstanding between hazard and external and internal HF, which have a significant impact on the probability of the occurrence of a hazardous event and the severity of the consequences for the life and health of employees being a condition for OR changing (increasing or decreasing) (36). Therefore, there is a misunderstanding regarding measures to reduce the probability of the occurrence of a hazardous event and its severity since it is sometimes not possible to eliminate the hazard itself.

The purpose of the study is the improvement of the enterprise's OR risk management process taking into account the requirements of the standard ISO 45001:2019.

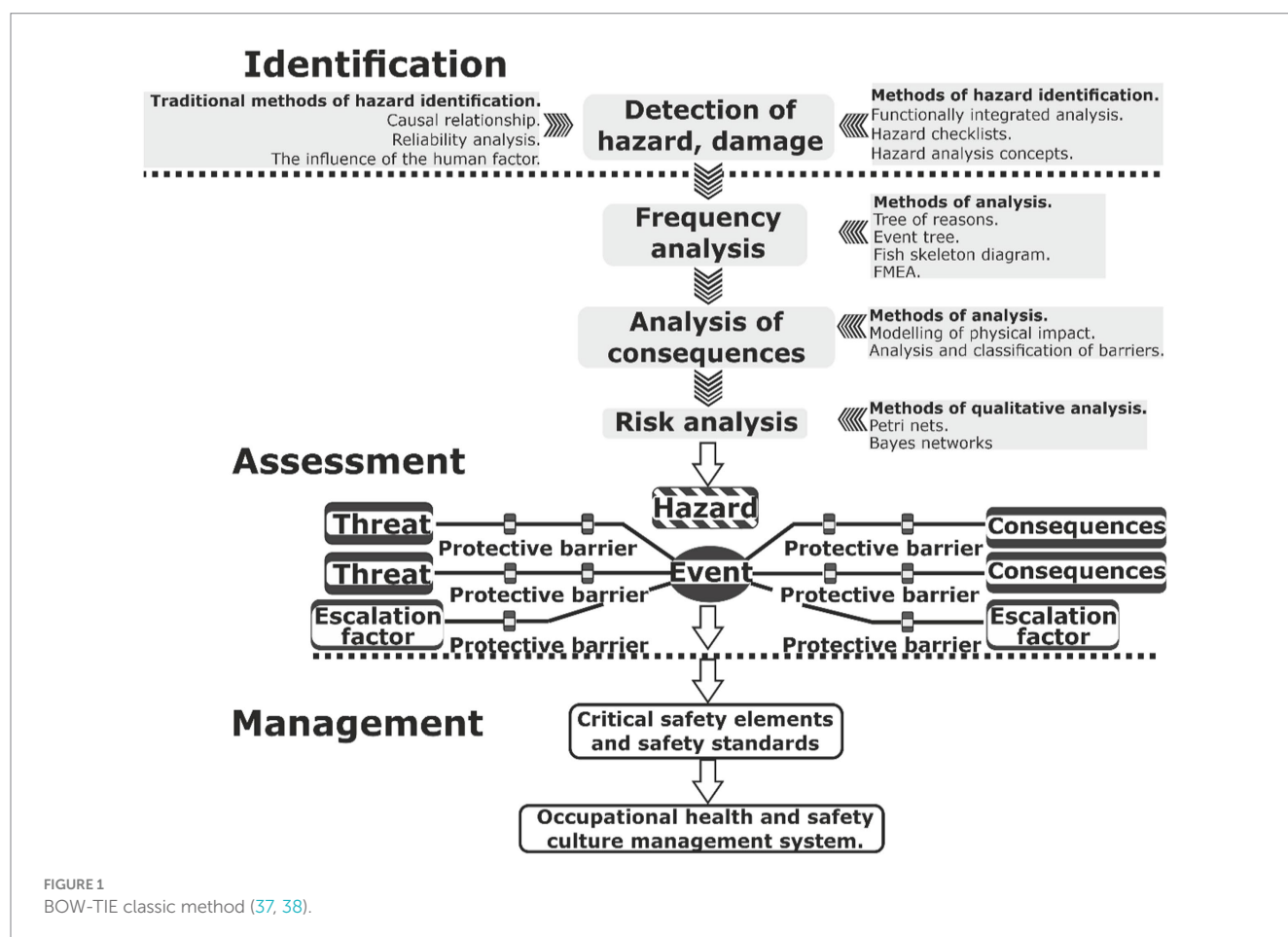
2 Materials and methods

The most common approach to OR management, which is the basis for developing an action plan to achieve the desired result in the operation of the OHSMS system of any organization, is the “BOW-TIE” method. This method provides, on the basis of a cause-and-effect relationship between hazard and a hazardous event, and it allows to describe and analyze occupational risks during any production operations (37, 38).

It can also be used to determine the effectiveness of proposed “barriers” (precautionary or protective measures) to reduce the probability of a hazardous situation on the one hand, and on the other hand, the severity of the consequences of an incident (Figure 1).

In general, the presented method provides for the calculation of the amount of occupational risk:

- Identification of hazards for the development of their register in the organization based on the study of sources of risk.
- Studying the mechanisms of the development of a hazardous event based on a cause-and-effect relationship.
- Determination of the probability of the occurrence of a hazardous event - due to the processing of statistical data on all incidents that occurred anywhere.
- Determining the severity of losses, calculating the number of days of incapacity for work or coefficients of the severity of injuries, economic losses.



- Calculation of occupational risk—by any suitable method, which is defined in IEC 31010:2019 risk management—risk assessment techniques.

Unfortunately, the well-known interpretation of the described method does not take into account the influence of internal and external hazardous factors on the probability of a hazardous event, information about which is collected in the organization by one of the above approaches (Table 1). As a result, there is a lack of clear understanding of what affects the probability of a hazardous event and its degree of severity. At the same time, the ISO 45001:2018 standard mentions the need to determine external and internal factors that affect the final result of the occupational safety and health management system, i.e., reducing the loss of health and life of workers. The standard requires the organization to use these factors to assess occupational risks but does not mention the mechanism for performing this procedure.

According to the IEC 31010:2019 standard, the “BOW-TIE” method is necessary to establish a cause-and-effect relationship to determine the amount of risk: “hazard–hazardous event consequences” while assessing the probability of the occurrence of a hazardous event and its degree of severity, which is not possible without identifying characteristic hazardous factors of the external and internal environment of the organization, which are related to a specific workplace. Therefore, it is proposed to improve the “BOW-TIE” model, in which, instead of the location of “barriers” [preventive or protective measures and means (Figure 1) that reduce the occurrence of a hazardous event and the severity of the consequences, we provide information about the entire set of negative and safe external and internal factors that increase the probability or severity of the consequences of a hazardous event (Figure 2)].

The basis of the improved “BOW-TIE” method is the calculation of the amount of occupational risk from the combined action of all hazardous factors: physical, chemical, climatic, biological, psychophysiological, ergonomic, technical, organizational, and others, as well as hazardous actions and inactions of employees (errors, malicious intent, professional incompatibility, etc.) in the organization (Figure 2). It should be recalled that according to the ISO 31010 standard, the limitations of this method include the inability to study

the occurrence of a hazardous situation in the absence of a clear relationship with the hazard, especially when there is more than one.

As a result, the effectiveness of the occupational risk management process is improved due to a comprehensive consideration of all hazardous external and internal factors or hazardous actions and inactions.

At the first stage of OR evaluation, there is a need for a clear understanding of OHSMS terms in accordance with the requirements of the ISO 45001:2018 standard. It is necessary to clearly distinguish what is a “hazard” and what are “influence factors”—a hazardous factor that increases the probability of a hazardous event.

According to ISO 45001:2018, a hazard is defined as any source with the possibility of causing injury and deterioration of health. A hazardous factor increases the probability of occurrence of a hazardous event (incident) or/and also influences and increases the severity of injury and deterioration of health that may be caused by a hazardous event (incident). That is, in order to calculate the probability of occurrence of a hazardous event and its severity, it is necessary to identify all hazardous factors (Figures 3, 4):

- Increase the probability of the occurrence of a hazardous event.
- Increase the degree of severity of a hazardous event.
- Increase both the probability of the occurrence of a hazardous event and the severity of its consequences.

In addition, it is proposed to increase the effectiveness of OR management by taking into account hazardous actions and without the action of the employee (39), which are as follows:

- Increase the probability of the occurrence of a hazardous event.
- Increase the degree of severity of a hazardous event.
- Increase the probability of occurrence of a hazardous event, as well as the degree of severity.

Hence, there is a need to improve the OR management process itself. In addition, it is proposed to identify low environmental factors of the enterprise, and hazardous actions and without the actions of employees. That is, in order to calculate the OR of hazard—j, we first

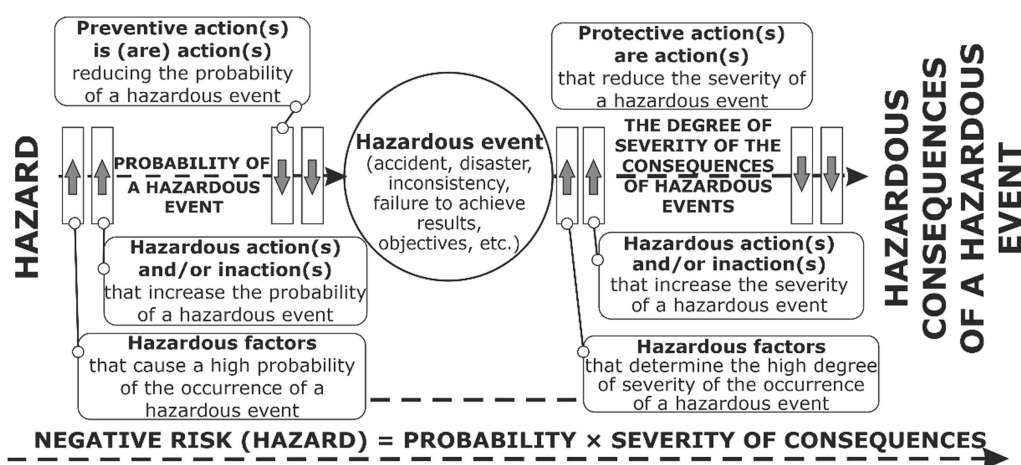


FIGURE 2

Method of OR hazards management of external and internal environment of the enterprise.

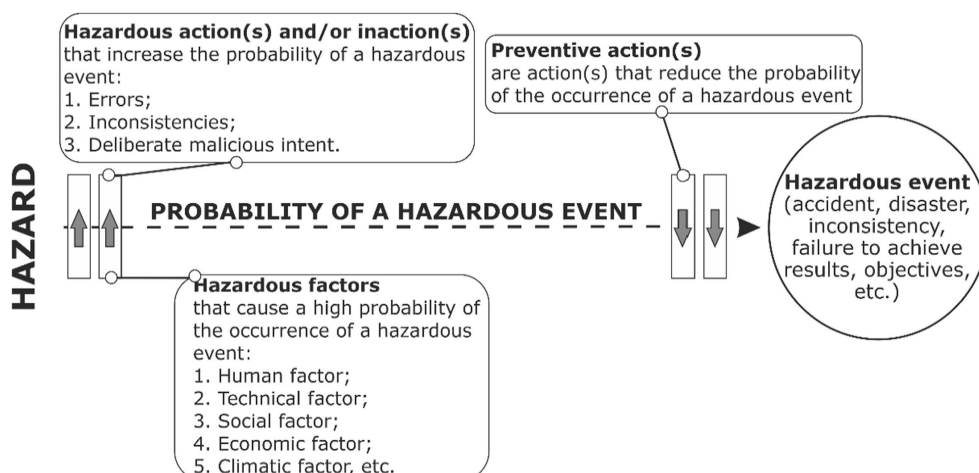


FIGURE 3

Method of OR hazards management of external and internal environment of the enterprise from the point of the probability of the occurrence of a hazardous event.

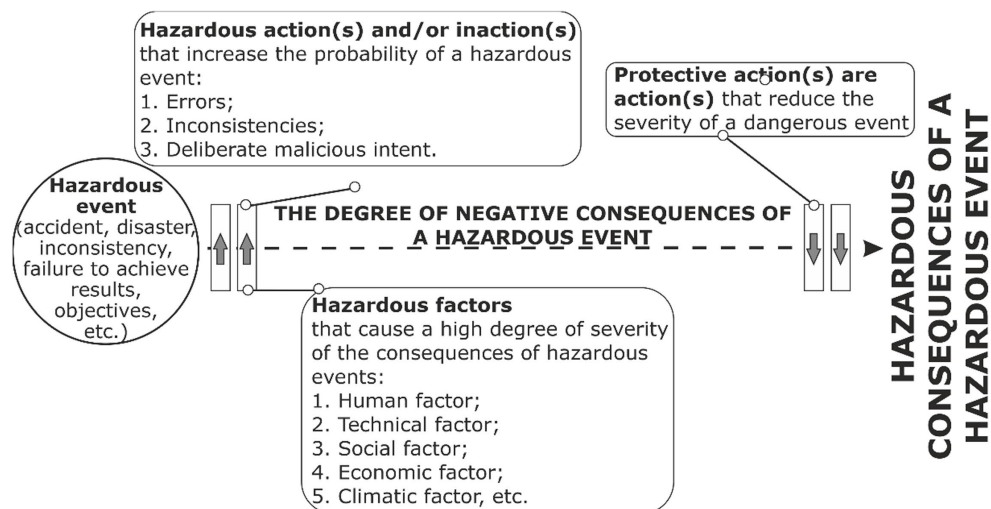


FIGURE 4

Method of OR hazards management of external and internal environment of the enterprise from the point of reduction of the degree of severity from the occurrence of a hazardous event.

identify all external and internal HF, hazardous actions. Next, we conduct a risk assessment for each hazardous factor (40, 41):

$$R_{nj} = B_{nj} \times T_{nj}.$$

Where R_{nj} is occupational risk of a hazardous event from hazard j taking into account hazard factors n ; B_{nj} is the probability of the occurrence of a hazardous event from hazard j under the influence of a hazardous factor n ; T_{nj} is degree of severity of consequences from a hazardous event from hazard j under the influence of a hazardous factor n .

To determine the probability of the occurrence of a hazardous event from hazard j , it is important to use statistical data that will become the basis for substantiating the point scale. Determination of the degree of severity of the consequences is based on the classification of types of injuries (Figure 5).

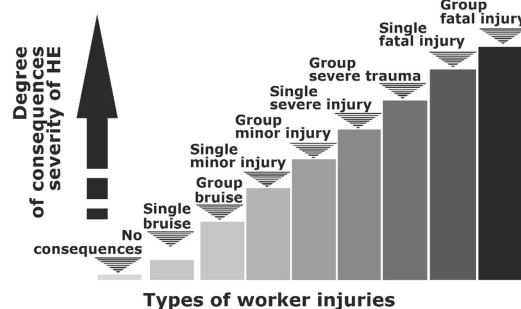


FIGURE 5

Degrees of severity of consequences of HE according to types of injuries of workers.

Matrix of OR for the types of injuries of workers			Probability (frequency) of HE occurrence at least once per:											
			Day	Week	Month	Quarter	Half a year	1 year	5 years	10 years	25 years	50 years	100 years	Never
			12	11	10	9	8	7	6	5	4	3	2	1
Severity of HE	Group fatal injury	9												
	Single fatal injury	8												
	Group severe trauma	7												
	Single severe injury	6												
	Group minor injury	5												
	Single minor injury	4												
	Group bruise	3												
	Single bruise	2												
	No consequences	1												

■ unacceptable OR
 ■ acceptable OR with verification
 ■ acceptable OR

FIGURE 6

Form of the matrix for determining the value of OR by hazardous factors considering of the type of injuries of workers.

To estimate the value of the OR, a special matrix with a scale of 9×12 (Figure 6) is proposed as an example, which is determined on the one hand by the number of negative consequences and, on the other hand, by the probability of the occurrence of the HE.

In order to determine the points for the calculation of the occupational risk for each hazardous factor, several experts are invited, the results of whose work are averaged and entered in Table 2, which represents the form of the OR hazard map j according to the proposed OR management process (Figure 7).

The next step is to determine the value of the occupational risk of hazard from the combined effect of all risks from hazardous factors associated with this hazard according to the formula:

$$Rn_j = Rn_{j1} + \dots + Rn_{jn}.$$

Where Rn_j is the total occupational risk from hazard j ; Rn_{j1} is occupational risk from the first hazardous factor; and Rn_{jn} is occupational risk from the n -th hazardous factor.

Next, we assess the total risk and assess its level of acceptability or unacceptability according to the criteria listed in Table 3.

3 Results

Based on the requirements of the ISO 45001:2018 standard, external and internal HFs (hazards, threats or opportunities) of

the working environment at the enterprise can be determined using one of the acceptable methods given in Table 1. In addition to examining hazards in the employees' workplaces themselves, attention should be paid to the organization's policy, planning processes in management systems, production technology, and other processes that form the organization's "environment."

Sources of information about external HF of enterprises can be information posted on the Internet: research, publications in periodicals, news sites, and official sites of state bodies. Information about the state of the internal environment of the enterprise can be obtained from reports on the effectiveness of the OHSMS at the enterprise, internal audits, results of self-assessment, minutes of meetings of managers of various levels, etc. It is important to understand that these HFs have an interrelated effect on the achievement of planned results, which leads to the need to identify OR factors that strengthen/weaken their effect (Figure 8).

Based on the analysis performed, we form a register of hazardous factors by relevant groups (42): organizational, technical, operational, ergonomic, environmental, hygienic, psychosocial, military, and others. The formed register makes it possible to determine the most significant hazardous factors for each emergency situation. This can be done by different methods such as Monte Carlo simulation (43) and expert methods such as fuzzy set theory and fuzzy AHP (44, 45).

TABLE 2 Identification of hazards, HF, analysis and assessment of hazard ORs j provided that hazard factor of ORs are acceptable and total OR is not acceptable.

Identification			Identification of HF, hazardous actions and inactions	The primary analysis is determination of the OR level for each HF and the overall OR hazard				Preventive and protective actions to reduce the primary OR j – hazard from i – HF	Final analysis taking into account actions to reduce OR j hazard			The final assessment of OR j hazard from i – HF	
Hazard	Hazardous event	Negative consequence	Impact on the probability of occurrence of a hazardous event and/or on the severity of the consequences of a hazardous event from HF	Probability of occurrence of a hazardous event from a hazardous factor - i	Severity of occurrence of hazardous event from HF - i	Level of OR from HF - i	The primary assessment of the negative OR of hazard - j for each HF - i and the total OR of hazard - j		Probability of occurrence of a hazardous event	The degree of severity of the consequences of a hazardous event	Negative OR		
Hazard at the workplace	An accident during the performance of production activities	Injuries, occupational diseases that are the result of an accident	HF ₁	Pe ₁	Se ₁	OR _{HF1}	Acceptable or Unacceptable	Preventive and/or protective action j ₁	P _{HEj1}	Sc ₁	ORκ ₁	Acceptable	
			HF ₂	Pe ₂	Se ₂	OR _{HF2}		--/-- j ₂	P _{HEj2}	Sc ₂	ORκ ₂		
			HF ₃	Pe ₃	Se ₃	OR _{HF3}		--/-- j ₃	P _{HEj3}	Sc ₃	ORκ ₃		
			HF ₄	Pe ₄	Se ₄	OR _{HF4}		--/-- j ₄	P _{HEj4}	Sc ₄	ORκ ₄		
			HF ₅	Pe ₅	Se ₅	OR _{HF5}		--/-- j ₅	P _{HEj5}	Sc ₅	ORκ ₅		
			HF ₆	Pe ₆	Se ₆	OR _{HF6}		--/-- j ₆	P _{HEj6}	Sc ₆	ORκ ₆		
			HF ₇	Pe ₇	Se ₇	OR _{HF7}		--/-- j ₇	P _{HEj7}	Sc ₇	ORκ ₇		
			HF ₈	Pe ₈	Se ₈	OR _{HF8}		--/-- j ₈	P _{HEj8}	Sc ₈	ORκ ₈		
			HF ₉	Pe ₉	Se ₉	OR _{HF9}		--/-- j ₉	P _{HEj9}	Sc ₉	ORκ ₉		
			HF ₁₀	Pe ₁₀	Se ₁₀	OR _{HF10}		--/-- j ₁₀	P _{HEj10}	Sc ₁₀	ORκ _{j10}		
			HF ₁₁	Pe ₁₁	Se ₁₁	OR _{HF11}		--/-- j ₁₁	P _{HEj11}	Sc ₁₁	ORκ _{j11}		
				
			HF _{<i>i</i>}	Pe _{<i>i</i>}	Se _{<i>i</i>}	OR _{HF<i>i</i>}		--/-- j _{<i>i</i>}	P _{HE<i>i</i>}	Sc _{<i>i</i>}	ORκ _{<i>i</i>}		
				
			HF _{<i>n</i>}	Pe _{<i>n</i>}	Se _{<i>n</i>}	OR _{HF<i>n</i>}		--/-- j _{<i>n</i>}	P _{HE<i>n</i>}	Sc _{<i>n</i>}	ORκ _{<i>n</i>}		
			Overall primary negative OR of hazard j from all n HF	OR _{HF<i>j</i>} = \sum Pe _{<i>jn</i>} × Se _{<i>jn</i>}				Overall final negative OR of hazard j from all n HF	ORκ _{<i>j</i>} = \sum P _{HE<i>jn</i>} × Sc _{<i>jn</i>}				

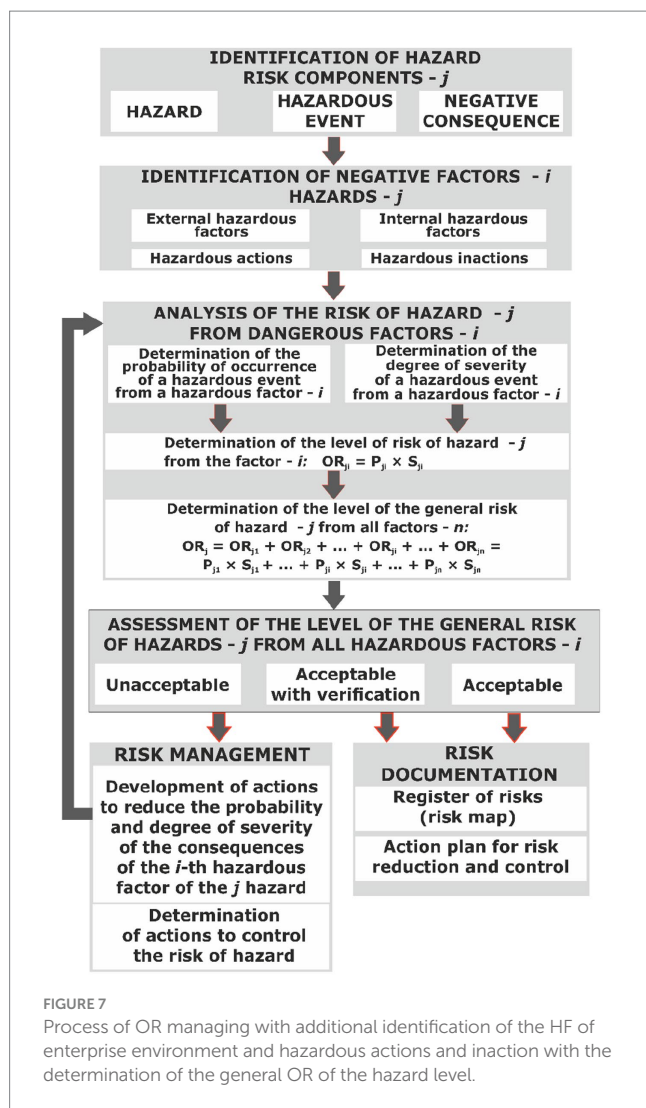


FIGURE 7

Process of OR managing with additional identification of the HF of enterprise environment and hazardous actions and inaction with the determination of the general OR of the hazard level.

TABLE 3 Acceptance criteria of (negative) OR of hazard.

Assessment of OR	Score
Acceptable slight negative OR	From 0 to 25
Acceptable (with verification) negative OR	From 25 to 50
Unacceptable negative OR	From 50 to 100

Considering different variants of the value of OR, which arise from external and internal HF, hazardous actions and inactions, together allow us to determine the value of the total OR of hazard j .

Therefore, when calculating the value of the total OR, situations may arise when all the ORs from HF are acceptable, and the total OR from the hazard is not acceptable (Table 4; Figure 9). In this case, there is a need to stop the production operation to eliminate or reduce the impact from several detected HFs. Such a situation requires a careful analysis of the impact of the most critical HF.

The next option may be a situation where the OR from HF action is acceptable, and the total OR is acceptable with verification, i.e., there is a need to control the hazard, HF, and the value of OR, as well as monitor HF or actions of workers that would allow to avoid an unacceptable level OR (Table 4; Figure 10).

The most acceptable situation is when all ORs from HF and actions are acceptable, which in sum allows us to obtain an acceptable overall OR (Table 4; Figure 11).

The most difficult situation is when there is a condition that one of the ORs from HF action is unacceptable, and the overall OR will also be unacceptable (Table 4; Figure 12). In this case, there is a need to eliminate the detected HF or introduce actions to reduce its influence and conduct a check on the overall value of the OR level.

There is a simple example of an occupational risk assessment of a logger who uses a chainsaw to fell trees in hard-to-reach places (Table 5). Work that is physically demanding (46) is characterized by an uncomfortable body position (47). The main hazard that causes injury is a tree (48). A hazardous event is a falling tree, and the consequences can be injuries of varying severity to the logger's musculoskeletal system (49). Loggers working outdoors are exposed to a number of different HFs, such as strong wind, inappropriate technical equipment (e.g., personal protective equipment), hygienic hazards [vibration (49), noise (50)], ergonomic hazards—unnatural or uncomfortable working position (48, 51), human factors—psychological inconsistency or health problems.

In the above example, each component of the total (cumulative) risk does not exceed acceptable limits, but if certain HFs occur together at any point in time, this will result in unacceptable risk, requiring a review of the impact of each HF. If a traditional method, such as a BOW-TIE, is used to analyze the occupational risk of a logger, each individual hazard will not exceed the critical risk level.

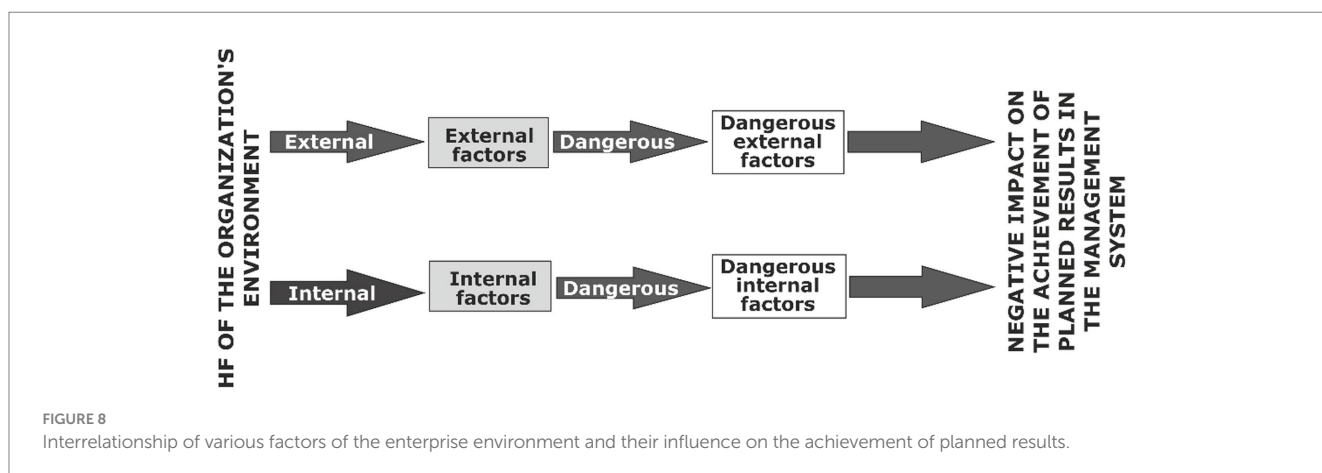


FIGURE 8

Interrelationship of various factors of the enterprise environment and their influence on the achievement of planned results.

TABLE 4 Hazard identification, HF, OR of hazard j analysis and assessment.

Identification			Identification of HF, hazardous actions and inactions	Primary analysis is determination of the OR level for each HF			
Hazard	Hazardous event	Negative consequences	Impact on the probability of the occurrence of a hazardous event and/or on the severity of the consequences of a hazardous event from HF	Probability of the occurrence of a hazardous event from HF - i	The degree of severity from the occurrence of a hazardous event from HF - i	OR level from HF - i	Primary assessment of hazard OR - j by HF - i and overall hazard OR - j
Analysis condition: ORs from HF are acceptable, and overall OR is unacceptable							
Hazard	Accident	Injury	HF ₁	P _{Ej1} = 3	S _{Ej1} = 5	OR _{ηj1} = 15	Acceptable
			HF ₂	P _{Ej2} = 6	S _{Ej2} = 1	OR _{ηj2} = 6	Acceptable
			HF ₃	P _{Ej3} = 1	S _{Ej3} = 6	OR _{ηj3} = 6	Acceptable
			HF ₄	P _{Ej4} = 6	S _{Ej4} = 4	OR _{ηj4} = 24	Acceptable
		
			General primary OR	OR _{ηj} = 15 + 6 + 6+ 24 = 51			
Analysis condition: ORs from HF are acceptable, and overall OR is acceptable with verification							
Hazard	Accident	Injury	HF ₁	P _{Ej1} = 3	S _{Ej1} = 5	OR _{ηj1} = 15	Acceptable
			HF ₂	P _{Ej2} = 1	S _{Ej2} = 2	OR _{ηj2} = 2	Acceptable
			HF ₃	P _{Ej3} = 2	S _{Ej3} = 3	OR _{ηj3} = 6	Acceptable
			HF ₄	P _{Ej4} = 6	S _{Ej4} = 4	OR _{ηj4} = 24	Acceptable
		
			General primary OR	OR _{ηj} = 15 + 2 + 6+ 24 = 47			
Analysis condition: ORs from HF are acceptable, and overall OR is acceptable too							
Hazard	Accident	Injury	HF ₁	P _{Ej1} = 3	S _{Ej1} = 2	OR _{ηj1} = 6	Acceptable
			HF ₂	P _{Ej2} = 1	S _{Ej2} = 1	OR _{ηj2} = 1	Acceptable
			HF ₃	P _{Ej3} = 2	S _{Ej3} = 3	OR _{ηj3} = 6	Acceptable
			HF ₄	P _{Ej4} = 5	S _{Ej4} = 2	OR _{ηj4} = 10	Acceptable
		
			General primary OR	OR _{ηj} = 6 + 1 + 6+ 10 = 23			
Analysis condition: the OR from the action of one of the HF is unacceptable, and the overall OR is also unacceptable							
Hazard	Accident	Injury	HF ₁	P _{Ej1} = 3	S _{Ej1} = 2	OR _{ηj1} = 6	Acceptable
			HF ₂	P _{Ej2} = 1	S _{Ej2} = 1	OR _{ηj2} = 1	Acceptable
			HF ₃	P _{Ej3} = 2	S _{Ej3} = 3	OR _{ηj3} = 6	Acceptable
			HF ₄	P _{Ej4} = 10	S _{Ej4} = 6	OR _{ηj4} = 60	Unacceptable
			General primary OR	OR _{ηj} = 6 + 1 + 6+ 60 = 73			

This risk assessment often leads to the error that additional precautions are not necessary. It is the total HF value of an unacceptable level that requires again reconsidering the influence of each HF and reducing their influence. In the above example, there is a need to find precautionary measures to reduce the entry of loggers with an inappropriate psychological state into the workplace. At least, we have an understanding of the need for additional introduction of precautionary and protective measures.

4 Discussion

A more advanced approach to the OR management process is proposed, which takes into account the influence of external and internal HFs on the probability of a hazardous event occurring and the severity of consequences by summing up the risks from all hazardous external and internal factors in the workplace, given the hazardous actions and inactions of employees.

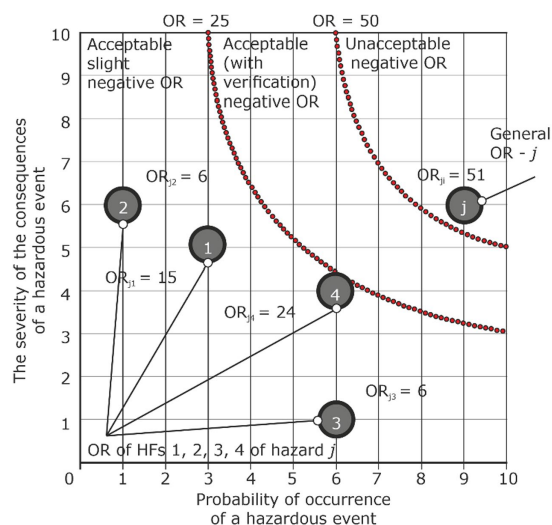


FIGURE 9

Graphical presentation of assessment of OR hazard j under the condition that the OR of hazardous factors are acceptable, and the general OR is not acceptable.

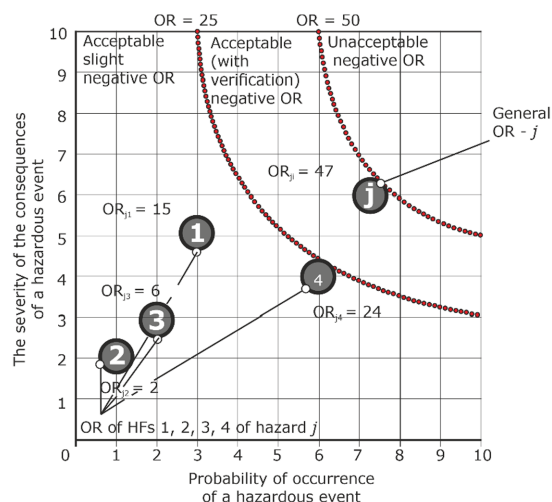


FIGURE 10

Graphical presentation of assessment of OR hazard j under the condition that the OR of HF is acceptable, and the general OR is acceptable with verification.

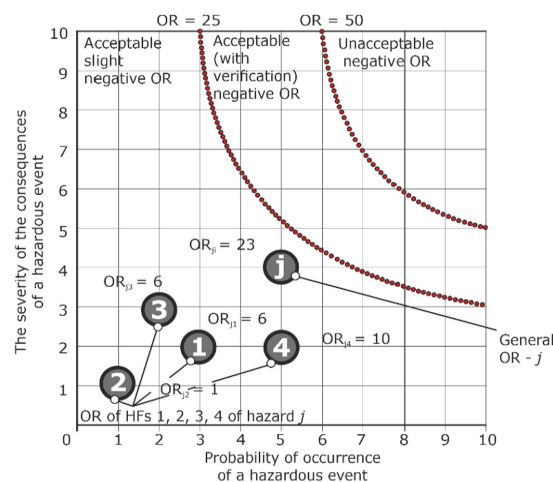


FIGURE 11

Graphical presentation of assessment of OR hazard j under the condition that the OR of HF is acceptable, and the general OR is acceptable too.

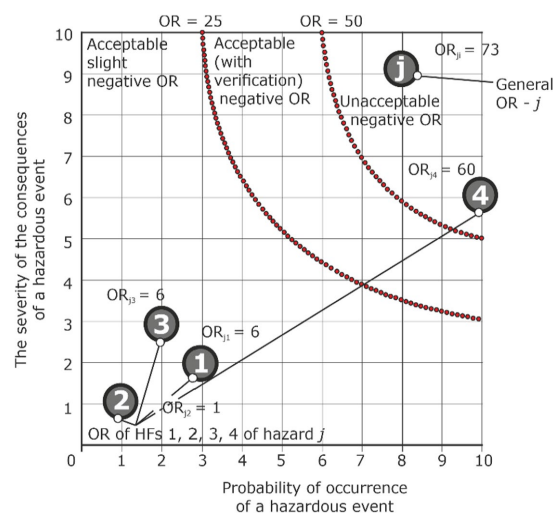


FIGURE 12

Graphical presentation of assessment of OR hazard j under the condition that the OR of one of HFs is unacceptable, and the general OR is unacceptable too.

Its difference from the BOW-TIE method is the ability to take into account the influence of a combination of HFs when analyzing cause-and-effect relationships, which can increase the probability of a hazardous event occurring. At the same time, obstacles that are determined through the hierarchy of precautionary measures (52–54) are reflected in the proposed model as “precautionary actions” that include the strengths of the production environment.

The proposed improved approach to the OR management process allows for a more thorough analysis of external and internal HF, which affect the probability of the occurrence of a hazardous event or the severity of its consequences and therefore ensures the improvement of business process management systems at the enterprise. We should note that any enterprise to ensure effective operation needs to take

into account the wishes of interested parties, identify weak points in technology, management systems (55). For this, it is important to ensure a response to all hazardous external and internal factors that threaten the production process in order to reduce losses.

This is implemented in the algorithm that considers four different situations for assessing the OR level from exposure to HFs, which provide conditions for the acceptability/unacceptability of the OR level from exposure to both individual HF and their combined effect. This will make it possible to identify significant HFs or their combination, which increases the probability of a hazardous event occurring. In addition, such an approach will reduce data uncertainty due to poor understanding of the phenomena characteristic of the production process, which is achieved by increasing information about the nature of the processes occurring in the systems (56, 57).

TABLE 5 Assessing the OR using the example of a logger taking into account the HF impact.

Identification			Identification of HF, hazardous actions and inactions	Primary analysis is determination of the OR level for each HF			
Hazard	Hazardous event	Negative consequences	Impact on the probability of the occurrence of a hazardous event and/or on the severity of the consequences of a hazardous event from HF	Probability of the occurrence of a hazardous event from HF - i	The degree of severity from the occurrence of a hazardous event from HF - i	OR level from HF - i	Primary assessment of hazard OR - j by HF - i and overall hazard OR - j
Tree	Tree falling	Injury of the musculoskeletal system	Inappropriate physical health of the logger	2	5	10	Acceptable
			Inadequate mental health status of the logger	4	5	20	Acceptable
			Inappropriate environmental conditions – strong wind	2	4	8	Acceptable
			Inadequate technical equipment - inappropriate personal protective equipment	1	4	4	Acceptable
			Inappropriate hygienic conditions: increased noise, vibration	4	3	12	Acceptable
			General primary OR	$OR_{\Pi} = 10 + 20 + 8 + 4 + 12 = 54$			Unacceptable

The Bayesian network has a similar probabilistic approach to assessing occupational risk (58). The method consists of two parts: a qualitative diagram and a probability distribution including a quantitative part of the analysis (21). In addition, it makes it possible to construct the same cause-and-effect relationships between various HFs that influence the occurrence of a hazardous situation, for example, according to Dempster's rule of combination (59). However, the use of this method for assessing occupational risks is difficult, since the algorithm requires a large amount of data, which is mostly determined heuristically or restrictions are introduced to ensure the construction of appropriate relationships between graphs (60). Based on the recommendations of the ISO 31010 standard, this method should only be used for risk assessment. While for other steps that are characteristic of risk management, identification of hazards, determination of the probability of a hazardous event occurring, there is a need to use other approaches, for example, the FMEA or HAZOP methods.

The BOW-TIE method was developed specifically for security management (61). The ISO 31010 standard recommends its use at all stages of risk management: identifying threats, analyzing consequences, risk probabilities, and assessing operational risks. In this sense, BOW-TIE analysis is a combination of FTA and ETA (62), and is very popular since it includes both the causes and consequences of an incident scenario (54).

Note that one of the important requirements of the ISO 45001 standard is the involvement of all employees in the risk management

process (63), requiring an appropriate universal approach characterized by easy comprehension and a minimum number of additional steps to assess risks. The BOW-TIE method satisfies these requirements well, so it was decided to improve it in order to increase the efficiency of decision-making. In addition, the ISO 31000 standard indicates the need to move from simple to complex (64). Hence, each of the above risk assessment methods exists and can be applied based on the tasks set before the organization, taking into account available resources to ensure the implementation of the precautionary or protective measures taken to preserve the life and health of the employee and to avoid emergency situations and accidents.

To manage the OR, it is additionally recommended to conduct an analysis of the external and internal environments of the enterprise in order to determine the HFs that affect the probability of the occurrence of a hazardous event and or the degree of severity of the consequences of a hazardous event. To determine the value of the OR of the hazard, it is taken as the sum of the OR from all external and internal HFs, affecting the probability of occurrence of a hazardous event. This approach is based on the assumption that OR is primarily financial losses; in this case, there is an opportunity to determine the total value as the sum of losses from the occurrence of a hazardous event (65, 66).

OR management methods consider the cause-and-effect chain "hazard-hazardous event-loss." However, the proposed OR management method shows that the occurrence of a hazardous event is possible not

only in the presence of hazard but also in conditions for the occurrence of a hazardous event. They are the HFs set, which are associated with negative human, technical, organizational, and other HFs belonging to HFs of the internal environment of the enterprise, as well as factors of the external environment of the enterprise such as season, presence of precipitation, and time of day. At the same time, it is proposed to consider the cause-and-effect chain “hazard-hazardous event-loss” with the influence of HF on the probability of the occurrence of a hazardous event and/or the degree of severity. It is proposed to define OR of hazard as the sum of OR of all HF of a hazardous event.

The shortcomings of this method, which require further research, include the inability to take into account the variability of HFs over time (67, 68). The analysis of various emergency situations and accidents shows (69–71) that the main reason for the occurrence of a hazardous situation is the sequence or simultaneous occurrence of a certain number of hazardous factors in a certain period of time. At the same time, HFs can have different impact on the probability of a hazardous event occurring when an employee performs production tasks, which is conditioned by the presence of strong points in the production environment (72). In particular, this is the competence of the employee, the periodic occurrence of noise or vibration in the workplace, the appearance of a minor technical malfunction in hard-to-diagnose equipment, etc. All this requires the use of combinatorics to identify the most probable combinations of hazardous factors that have a significant impact on the hazardous situation manifestation.

5 Conclusion

An improved management process of OR hazard has been developed, taking into account the HF of the internal and external environment of the enterprise, which increases the probability of the occurrence of a hazardous event and the severity of the consequences, provided that the level of OR is determined as acceptable, unacceptable, or acceptable with verification. It is suggested that during OR management, an additional analysis of the external and internal environments of the organization is carried out to determine HF, which affects the probability of the occurrence of a hazardous event and the degree of severity of the consequences of a hazardous event. The process of OR management determines the value of OR of hazard as the sum of OR from all external and internal HF, which affects the increase in the probability of the occurrence of a hazardous event and its severity of consequences. Four different situations were considered, regarding the calculation of the total value of OR, and an algorithm and the form of a map for hazard identification and HF estimation of the OR of the hazard were proposed.

The proposed approach to OR management when analyzing the cause-and-effect relationship between a hazard and a hazardous event makes it possible to identify significant HFs, the reduction of which

will allow a better substantiation of the appropriateness of precautions in the employee's workplace.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

OB: Funding acquisition, Project administration, Writing – original draft. VT: Conceptualization, Investigation, Supervision, Writing – original draft. MO: Conceptualization, Investigation, Validation, Writing – original draft. AP: Conceptualization, Methodology, Writing – original draft. SC: Formal analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. OY: Formal analysis, Methodology, Validation, Writing – original draft. OD: Formal analysis, Investigation, Methodology, Visualization, Writing – original draft. VL: Funding acquisition, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Factors affecting work-related non-fatal injuries among aged workers in South Korea

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Introduction: The objective of this paper is to investigate whether an aging workforce is associated with an increase in work-related non-fatal injuries and to explore the underlying reasons for this potential increase.

Methods: Aged workers were defined as those who were at least 55-years-old. Work-related non-fatal injuries were assessed in aged and young workers who were registered with the workers' compensation system from 2017 to 2021 of South Korea.

Results: The mean estimated rate of work-related non-fatal injuries of aged workers (0.88/100) was about 2.5-times higher than that of younger workers (0.35/100). Most work-related non-fatal injuries in the older adults were in individuals working in the "construction sector" (36.0%), those with "elementary occupations (unskilled workers)" (45.0%), and those with employment status of "daily worker" (44.0%). "Trip & slip" (28.7%) and "falling" (19.6%) were more frequent types of work-related non-fatal injuries in aged workers relative to young workers. The category of "buildings, structures, and surfaces" was a more frequent cause of work-related non-fatal injuries in aged workers than young workers.

Discussion: The incidence of non-fatal work-related injuries is higher among aged workers compared to their younger counterparts. The increased occurrence of aged workers participating in precarious employment and jobs, along with the greater physical vulnerability, is likely the cause of their higher rate of work-related non-fatal injuries.

KEYWORDS

worker, older, work-related injury, Korea, non-fatal accidents, precarious employment

Introduction

The aging of South Korea's population is occurring at a faster pace than any other country (1, 2). According to a demographic analysis, South Korea transitioned to an "aging society" in 2000, an "aged society" in 2018, and is projected to become a "super-aged" society by 2025 (1). This demographic shift is primarily attributed to the country's low birth rate and the accelerated aging process. As a result, South Korea is anticipated to have the highest proportion of economically active individuals in 2025, followed by a subsequent decline. As a result, there is

a growing expectation that the employment of older adults workers will rise to address the increasing labor shortages across various industries. Consequently, there is an ongoing upward trend in the percentage of workers aged 55 to 79 years (3). However, this aging workforce poses challenges in terms of workplace safety, as older adults employees are more susceptible to physiological declines in their sensory systems, equilibrium, and motor control (4–6). Therefore, there is a heightened need for policies that can effectively prevent occupational injuries among older workers in South Korea, given the impending labor shortages resulting from the rapid aging of the workforce.

Salminen (7) reviewed studies of non-fatal injuries and found that in 27% their results, there was no difference between older and younger workers; in 56%, younger workers are at most risk of a non-fatal injury; and the remaining 17%, older workers have more non-fatal injuries than younger workers. A comprehensive analysis of non-fatal injury data through a recent systematic review yielded the following results; out of the 57 studies reviewed, 49% (28 studies) indicated no significant correlation between workers' age and non-fatal injuries. In 31% (18 studies), advancing age was even identified as a protective factor, suggesting that older workers experienced fewer non-fatal injuries compared to their younger counterparts. Conversely, 19% (11 studies) reported a higher risk of non-fatal injuries among older workers when compared to younger workers (8). Peng and Chan showed that the incidence of non-fatal accident among older workers is slightly (5.8%) lower than that of younger workers (9).

Earlier research conducted on the construction industry workforce indicated that advanced age at the time of injury was associated with increased injury-related costs, while the number of injuries was found to be unrelated to age. The elevated costs incurred by older workers can likely be attributed to the greater severity of their injuries (10–12). Therefore, younger workers may experience injuries more frequently, whereas older workers tend to sustain more severe injuries resulting in higher-cost claims (11).

These inconsistent findings may be attributed to the lack of a clear-cut definition for older workers and differences in the inclusion of industrial sectors as well as the analysis of injury severity among different studies (8).

The impact of workforce aging on work-related non-fatal injuries and the underlying reasons for the impact remain a subject of ongoing debate. The objective of this paper is to provide clarity on this matter.

Methods

Materials and subjects

An extensive PubMed search that covered publications on “older workers” and “work-related injury” since 2000 was conducted and the relevant papers and their references were evaluated initially. Among them, key references were finally cited.

“Aged worker” was at least 55-years-old, as defined by the Enforcement Decree of the Act on Prohibition of Age Discrimination in Employment and Aged Employment Promotion (13). Work-related non-fatal injuries were assessed in aged and young workers who were registered with the workers' compensation system from 2017 to 2021 of South Korea.

Total waged workers, who were used as the denominator to estimate the work-related injury rates, were identified based on raw data of the Local Area Labor Force Survey from 2017 to 2021. The Local Area Labor Force Survey provides representative data on the age distribution, industry sector, occupational class, etc. of all waged workers. The number of participants in the survey ranged from 20,074,043 to 21,111,723.

Variables

A total of 21 industrial sections in Korean Standard Industrial Classification (KSIC) (14), which is based on the International Standard Industrial Classification (ISIC) (15), were collapsed into 7 industrial sectors. The industrial sectors were “agriculture, forestry and fishing,” “mining and quarrying,” “manufacturing,” “construction,” “service,” “transportation and storage, information and communication,” and “others.” “Service” sector consists of “wholesale and retail trade,” “accommodation and food service activities,” “financial and insurance activities,” “real estate activities,” “professional, scientific, and technical activities,” “education,” “human health and social work activities,” and “arts, entertainment, and recreation.” Occupations were classified into 9 major groups in the Korean Standard Classification of Occupations (KSCO) (16) based on the International Standard Classification of Occupations ISCO (17). The occupational classes were “managers,” “professionals and related workers,” “clerks,” “service workers,” “sales workers,” “skilled workers related to agriculture, forestry and fisheries workers,” “craft and related trade workers,” “workers related to equipment, machine operating and assembling,” and “elementary occupations” (unskilled manual workers). Employment status was categorized as a contract for regular employment (≥ 1 year), temporary employment (1 month– <1 year), or daily employment (<1 month). Type of injuries in aged workers, listed in descending order of frequency, included “trip and slip,” “falling,” “getting caught,” “cutting, laceration, and puncture,” “collision,” “being struck by an object,” and “others.”

Statistical analysis

The proportions of workplace non-fatal injuries in aged workers and younger workers were compared according to sex, industrial sector, occupational class, and employment status using a chi-squared test.

The number of aged workers who were registered for the workers' compensation system is not directly available. Thus, the mean proportions of waged workers under 55-years-old (15,634,225) and 55-years-old or more (4,895,007) in Local Area Labor Force Survey from 2017 to 2021 (18) were applied to calculate the number of workers registered for workers' compensation. The mean number of workers registered for workers' compensation therefore consisted of 14,426,623 individuals who were under 55-years-old and 4,515,741 individuals who were 55-years-old or more. These numbers were used as the denominator to estimate the mean work-related injury rates of young and aged workers from 2017 to 2021. In the same manner, the number of young and aged workers registered for workers' compensation in each industrial sector, occupational class, and employment status were also estimated. These numbers were used as

the denominator to estimate the rates of non-fatal injuries according to industrial sector, occupation, and employment status. Relative risk with 95% confidence intervals (CIs) were obtained by dividing the rates of non-fatal injuries of aged workers by those of young workers to compare the rates of non-fatal injuries between young and aged workers.

SPSS version 20 (IBM Corp, Armonk, NY) was used for all statistical analyses, and a *p* value below 0.05 was considered significant.

Results

We first compared the mean non-fatal work-related injuries among different age groups of men and women (Table 1). Aged workers accounted for 41.0% of work-related non-fatal injuries in men and 52.7% of work-related non-fatal injuries in women. Men comprised 80.4% of non-fatal injuries in non-aged workers, 71.8% of non-fatal injuries in aged workers, 76.6% of non-fatal injuries in overall workers. The average number of non-fatal injuries per year was 90,877.

The number of aged workers registered in the workers' compensation system is not directly available. We therefore used the proportions of waged workers under 55-years-old and those 55-years-old or more of Local Area Labor Force Survey from 2017 to 2021 to estimate the number of workers who were registered for workers' compensation. Based on these data, the mean estimated rate of work-related non-fatal injuries of aged workers (0.88/100) was about 2.5-times higher than that of younger workers (0.35/100) (Table 1). In addition, the estimated rate of work-related non-fatal injuries of all aged and young male workers was about two or three-times higher than those of all aged and young female workers.

We compared work-related non-fatal injuries in different industrial sectors (Table 2). Among aged workers, a largest proportion of work-related non-fatal injuries were in the "Construction" sector (36.0%), and this was followed by the "Service" sector (31.2%). However, the percentages of young workers with non-fatal injuries were greatest in the "Service" sector (34.7%) and then "Manufacturing" sector (29.6%). In addition, the proportion of aged workers in "Construction" sector was 57.1%. For the "Construction" sector, the estimated rate of work-related non-fatal injuries of both aged and younger workers was higher than average rate of those in overall industrial sectors (1.76/100 and 0.59/100 vs. 0.88/100 and 0.35/100).

Moreover, the estimated rate of work-related non-fatal injuries of aged workers was approximately 3-times higher than that of younger workers (relative risk, 2.97) in the "Construction" sector. For the subsector of "Human health and social work activities", which comprises 8.3 and 16.1% of the aged and younger workers in the "Service" sector, respectively, the estimated rate of work-related non-fatal injuries of both age groups was lower than the overall average rate in the "Service" sector (0.29/100 and 0.11/100 vs. 0.59/100 and 0.27/100). Although the estimated rate of work-related non-fatal injuries of aged and younger workers in "Mining and quarrying" sector was the highest, the proportion of aged workers in "Mining and quarrying" sector was the lowest among industrial sectors.

We also analyzed work-related non-fatal injuries according to occupational class (Table 3). Among aged workers, most work-related non-fatal injuries were for those with "elementary occupations" (45.0%), followed by "craft and related trade workers" (23.1%). Among young workers, these two classes were also responsible for most work-related non-fatal injuries. In addition, aged workers accounted for large percentages of workers employed in "elementary occupations" (46.5%), "skilled workers related to agriculture, forestry, and fisheries" (63.5%), and "craft and related trade workers" (49.7%). The highest estimated rate of work-related non-fatal injuries of aged workers was for those who were "skilled workers related to agriculture, forestry, and fisheries" (4.67/100), followed by "managers" (2.15/100) and "craft and related trade workers" (2.04/100). The estimated rates of work-related non-fatal injuries of young workers were also greatest for those employed as "skilled workers related to agriculture, forestry, and fisheries" (2.19/100), "managers" (1.84/100), and workers with "elementary occupations" (1.46/100). However, only a small proportion (less than 3%) of work-related non-fatal injuries were for "skilled workers related to agriculture, forestry, and fisheries" although the non-fatal injury rate in young and aged workers was highest among those workers. The estimated rates of work-related non-fatal injuries of aged workers employed in "elementary occupations" is similar to the average rate in overall occupational class.

We then compared work-related non-fatal injuries in different employment status (Table 4). The highest percentage of aged workers with work-related non-fatal injuries was for those employed as "regular workers" (51.5%) followed by "daily workers" (44.0%); the highest percentages for young workers were for those employed as "regular workers" (67.9%) followed by "daily workers" (27.4%). A comparison of all three categories of employment status showed that

TABLE 1 Mean non-fatal injuries according to age and gender.

Gender	Age < 55 yr	Age ≥ 55 yr	Proportion of aged workers	Relative risk (95% CI)
Men	41,127 (80.4%)	28,523 (71.8%)	41.0%	
	0.51	1.17		2.31 (2.27–2.34)
Women	10,051 (19.6%)	11,177 (28.2%)	52.7%	
	0.16	0.54		3.38 (3.29–3.47)
Total	51,177 (100.0%)	39,700 (100.0%)	43.7%	
	0.35	0.88		2.48 (2.45–2.51)

Non-bold numbers indicate *n* (%) of workers with non-fatal injuries, and bold numbers indicate *n*/100 workers. Workplace non-fatal injuries (%) in aged workers and younger workers were compared using the chi squared test for gender (*p* value < 0.001). The proportion of aged workers was calculated as the percentage (%) of aged workers among all workers with non-fatal injuries in each gender. Relative risk with 95% confidence intervals (CIs) were obtained by dividing the rate of non-fatal injuries of aged workers by those of young workers to compare the rates of non-fatal injuries between young and aged workers. CI, confidence interval.

TABLE 2 Mean non-fatal injuries according to age and industrial sector.

Industrial sector	Age < 55 yr	Age ≥ 55 yr	Proportion of aged workers	Relative risk (95% CI)
Service	17,744 (34.7%)	12,380 (31.2%)	41.1%	
	0.27	0.59		2.19 (2.14–2.25)
Construction	10,745 (21.0%)	14,307 (36.0%)	57.1%	
	0.59	1.76		2.97 (2.90–3.05)
Mining and quarrying	50 (0.1%)	95 (0.2%)	65.4%	
	0.79	2.08		2.65 (1.90–3.75)
Manufacturing	15,130 (29.6%)	7,754 (19.5%)	33.9%	
	0.45	1.12		2.48 (2.42–2.55)
Agriculture, forestry, and fishing	537 (1.0%)	1,085 (2.7%)	66.9%	
	0.69	1.06		1.54 (1.39–1.70)
Transportation, storage, information, and communication	4,387 (8.6%)	1,488 (3.7%)	25.3%	
	0.58	0.93		1.59 (1.50–1.69)
Others	2,584 (5.0%)	2,591 (6.5%)	50.1%	
	0.15	0.32		2.09 (1.98–2.21)
Total	51,177 (100.0%)	39,700 (100.0%)	43.7%	
	0.35	0.88		2.48 (2.45–2.51)

Non-bold numbers indicate *n* (%) of workers with non-fatal injuries, and bold numbers indicate *n*/100 workers. Workplace non-fatal injuries (%) in aged workers and younger workers were compared using the chi squared test for industrial sector (*p* value < 0.001). The proportion of aged workers was calculated as the percentage (%) of aged workers among all workers with non-fatal injuries in each industrial sector. Relative risk with 95% confidence intervals (CIs) were obtained by dividing the rate of non-fatal injuries of aged workers by those of young workers to compare the rates of non-fatal injuries between young and aged workers. CI, confidence interval.

aged workers accounted for the largest percentage of “daily workers” (55.5%). Analysis of “daily workers” showed that the estimated rate of work-related non-fatal injuries in the aged (3.11/100) and younger workers (1.89/100) was much higher than the average rate in any other employment status or overall employment status.

Analysis of the types of accidents responsible for work-related non-fatal injuries (Table 5) showed that “trip & slip” (28.7%) was the most common cause, followed by “falling” (19.6%) in aged workers, however, “trip & slip” (16.8%) and “getting caught” (16.6%) were the major causes in young workers. According to further analysis by industrial sectors, “trip & slip” (48.0%) and “falling” (33.7%) were the most common cause in aged workers of “service” and “construction” sector, respectively, whereas “getting caught” (16.6%) was the major causes in young workers of “manufacturing” sector (data not shown). Aged workers accounted for large percentages of “trip & slip” (57.0%) and “falling” (53.8%) as the types of accidents.

We also analyzed the specific agents responsible for non-fatal injuries (Table 6). The main agent in aged and young workers was “buildings, structures, and surfaces (e.g., floor, steps, various building, and structural components, etc.)” (45.2 and 30.4%, respectively). However, “equipment and machinery” accounted for larger percentage in young workers (21.5%) than in aged workers (15.8%). Aged workers accounted for large percentages of “buildings, structures, and surfaces” (53.6%) as specific agents for injuries, whereas younger workers accounted for larger percentages of “equipment and machinery” (63.6%).

Discussion

Previous studies have shown inconsistent findings regarding the association between workforce aging and work-related injuries (8). In

our present study, we observed a significantly higher mean estimated rate of work-related non-fatal injuries per 100 workers among aged workers (0.88) compared to young workers (0.35). Our study utilized a representative national workers’ compensation database for South Korea, encompassing all industrial sectors and occupations over the past 5 years. These findings indicate that aged workers have a higher incidence of work-related non-fatal injuries compared to their younger counterparts. Two factors likely contribute to this increased incidence of injuries among aged workers in comparison to their younger counterparts.

First, the increased occurrence of aged workers participating in precarious employment and jobs likely contribute to their higher rate of non-fatal injuries. Our study of aged workers in South Korea from 2017 to 2021 revealed that the highest percentages of work-related non-fatal injuries were observed among workers in the “construction sector” (36.0%) and those in “elementary occupations” (unskilled workers) (45.0%). Additionally, a significant proportion of aged workers were employed in the “construction sector” (57.1%) and held an employment status of “daily worker” (55.5%). These findings indicate that work-related non-fatal injuries among aged workers are more likely to occur in industrial sectors, occupations, and employment statuses with a higher concentration of aged workers. In the present study, “construction sector” and employment status of “daily worker” were identified as precarious, as they exhibited higher rates of non-fatal injuries among young workers as well as aged workers. Consequently, aged workers who have precarious employment and jobs that expose them to greater occupational safety and health risks are more susceptible to work-related non-fatal injuries. Our previous publication also found that “elementary occupations” had the largest proportion of aged workers (19). Bravo et al. similarly found that the higher injury rate among

TABLE 3 Mean non-fatal injuries according to age and occupation.

Occupation	Age < 55 yr	Age ≥ 55 yr	Proportion of aged workers	Relative risk (95% CI)
Managers	3,587 (7.3%)	2,842 (7.2%)	44.2%	
	1.84	2.15		1.17 (1.11–1.23)
Professionals and related workers	2,264 (4.6%)	1,025 (2.6%)	31.2%	
	0.06	0.25		4.15 (3.86–4.47)
Clerks	1,252 (2.5%)	203 (0.5%)	14.0%	
	0.03	0.05		1.41 (1.21–1.63)
Service workers	5,955 (12.1%)	3,877 (9.9%)	39.4%	
	0.45	0.70		1.56 (1.50–1.62)
Sales workers	963 (1.9%)	243 (0.6%)	20.1%	
	0.07	0.10		1.35 (1.17–1.55)
Skilled workers related to agriculture, forestry, and fisheries	648 (1.3%)	1,128 (2.9%)	63.5%	
	2.19	4.67		2.13 (1.94–2.35)
Craft and related trade workers	9,188 (18.6%)	9,067 (23.1%)	49.7%	
	0.77	2.04		2.66 (2.58–2.74)
Workers related to equipment, machine operating, and assembling	5,241 (10.6%)	3,252 (8.3%)	38.3%	
	0.34	0.66		1.95 (1.87–2.04)
Elementary occupations	20,322 (41.1%)	17,695 (45.0%)	46.5%	
	1.46	0.99		0.67 (0.66–0.69)
Total	49,420 (100.0%)	39,331 (100.0%)	44.3%	
	0.34	0.87		2.54 (2.51–2.58)

Non-bold numbers indicate *n* (%) of workers with non-fatal injuries, and bold numbers indicate *n*/100 workers. Workplace non-fatal injuries (%) in aged workers and younger workers were compared using the chi squared test for occupation (*p* value < 0.001). The proportion of aged workers was calculated as the percentage (%) of aged workers among all workers with non-fatal injuries in each occupation. Relative risk with 95% confidence intervals (CIs) were obtained by dividing the rate of non-fatal injuries of aged workers by those of young workers to compare the rates of non-fatal injuries between young and aged workers. CI, confidence interval.

TABLE 4 Mean non-fatal injuries according to age and employment status.

Employment status	Age < 55 yr	Age ≥ 55 yr	Proportion of aged workers	Relative risk (95% CI)
Regular	34,472 (67.9%)	20,352 (51.5%)	37.1%	
	0.32	0.89		2.82 (2.77–2.87)
Temporary	2,386 (4.7%)	1,761 (4.5%)	42.5%	
	0.08	0.10		1.24 (1.16–1.31)
Daily	13,928 (27.4%)	17,401 (44.0%)	55.5%	
	1.89	3.11		1.65 (1.61–1.66)
Total	50,786 (100.0%)	39,514 (100.0%)	43.8%	
	0.35	0.88		2.49 (2.45–2.52)

Non-bold numbers indicate *n* (%) of workers with non-fatal injuries, and bold numbers indicate *n*/100 workers. Workplace non-fatal injuries (%) in aged workers and younger workers were compared using the chi squared test for employment status (*p* value < 0.001). The proportion of aged workers was calculated as the percentage (%) of aged workers among all workers with non-fatal injuries in each employment status. Relative risk with 95% confidence intervals (CIs) were obtained by dividing the rate of non-fatal injuries of aged workers by those of young workers to compare the rates of non-fatal injuries between young and aged workers. CI, confidence interval.

aged workers may be attributed to the type of industry and employment contract, and nature of the occupation (8). For instance, industries such as construction and agriculture, which employ a substantial number of aged workers, typically experience higher fatality rates (8, 20). This suggests that employment in precarious employment and jobs makes aged workers more vulnerable to workplace injuries.

Second, the greater physical vulnerability of aged workers is likely the cause of their higher injury rate. Trip/slip and fall are the most common cause of non-fatal injuries (21, 22). Kemmlert and Lundholm conducted an analysis of the Swedish Occupational Injury Information System, which encompassed various industrial sectors. Their findings revealed that male workers aged 45 years and above had a higher occurrence of slip, trip, and fall incidents compared to workers under

TABLE 5 Accident types responsible for mean non-fatal injuries.

	Age < 55 yr	Age ≥ 55 yr	Proportion of aged workers
Trip, slip	8,594 (16.8%)	11,413 (28.7%)	57.0%
Falling	6,653 (13.0%)	7,762 (19.6%)	53.8%
Getting caught	8,473 (16.6%)	4,496 (11.3%)	34.7%
Cutting, laceration, puncture	6,417 (12.5%)	3,749 (9.4%)	36.9%
Collision	4,282 (8.4%)	3,144 (7.9%)	42.3%
Being struck by an object	3,984 (7.8%)	3,325 (8.4%)	45.5%
Others	12,774 (25.0%)	5,811 (14.6%)	31.3%
Total	51,177 (100.0%)	39,700 (100.0%)	43.7%

Workplace non-fatal injuries (%) in aged workers and younger workers were compared using the chi squared test for accident type (p value < 0.001). The proportion of aged workers was calculated as the percentage (%) of aged workers among all workers with non-fatal injuries in each accident type.

TABLE 6 Agents responsible for mean non-fatal injuries.

Fatal injury-causing agent	Age < 55 yr	Age ≥ 55 yr	Proportion of aged workers
Buildings, structures, and surfaces (e.g., floor, steps, various building and structural components, etc.)	15,544 (30.4%)	17,944 (45.2%)	53.6%
Equipment and machinery	11,010 (21.5%)	6,291 (15.8%)	36.4%
Parts, accessories, and materials	6,646 (13.0%)	4,980 (12.5%)	42.8%
Means of transportation	5,647 (11.0%)	2,637 (6.6%)	31.8%
Others	12,330 (24.1%)	7,848 (19.8%)	38.9%
Total	51,177 (100.0%)	39,700 (100.0%)	43.7%

Workplace non-fatal injuries (%) in aged workers and younger workers were compared using the chi squared test for causing agent (p value < 0.001). The proportion of aged workers was calculated as the percentage (%) of aged workers among all workers with non-fatal injuries in each causing agent.

the age of 45 (23). In another investigation by Coantonio et al., workers' compensation data from Ontario, Canada, was examined. The study revealed that falls accounted for 76% of traumatic brain injury (TBI) claims among construction workers aged 55 to 64, whereas only 45% of claims from workers aged 17 to 24 were related to TBI (23, 24). Furthermore, Schoenfisch et al. (25) found that injuries among more senior workers were more likely to cause serious problems that required longer hospitalization stays, indicating a slower recovery from injury. The present national representative study found that "trip/slip" and "falling" were the most common type of work-related non-fatal injury in aged workers than young workers. "Trip/slip" and "falling" may be related to the more limited physical abilities (muscle strength and agility) of aged workers. The physical, mental and motor skills (movement of arms, hands and legs) changes related to aging may affect older workers' performance and their health and safety. Age-related decline in lower extremity muscle strength increases likelihood of slips and falls. Age-related decline in balance control, for which sensory inputs such as vision, proprioception, and vestibular sensations are important, are also associated with a greater risk of slips or falls (4, 6, 26). Furthermore, age-related osteoporotic bones are more likely to break as a result of workplace slips or falls. Our analysis of injury-causing agents also showed that "buildings, structures, and surfaces" was a more common cause of work-related non-fatal injuries in aged workers than young workers. In a study using self-reported data from injured carpentry workers ($n=4,429$), the contributing factors to falls from the same level ("Trip/slip") were found to be tripping over debris, difficult work

terrain (rocky, muddy, uneven), the slope of the lot, lack of backfill around the foundation, and difficult access and/or egress from the building (27). Taken together, these results strongly suggest that the physical limitations of older adults workers were responsible for their higher frequency of occupational injuries. Other studies also reported that aged workers who had poor muscle strength and elasticity and limited range of joint motion were more likely to suffer from work-related fatal injuries (4, 28, 29).

Taken together, the increased occurrence of aged workers participating in precarious employment and jobs, along with the greater physical vulnerability, is likely the cause of their higher rate of work-related non-fatal injuries. This finding aligns with prior research, which similarly identified that precarious employment and jobs render aged workers more vulnerable to work-related injuries due to age-related declines in physical capabilities (8, 20).

Thus, implementing exercise programs aimed at improving the physical functional capacities, particularly balance and muscle strength, among aged workers, could prove beneficial in reducing the frequency of workplace injuries. For example, older workers should start low extremity muscle strengthening such as seated calf raises, seated knee lifts and leg lifts, seated leg extensions, standing leg lifts and sit-to-stand exercise, and then progress to squatting and core strengthening tailored to muscle strength status. They should also perform series of balance exercises such as standing with feet apart/together with eyes open, and then standing on one foot, with eyes open/closed based on balance control status.

The age structure of the workforce is currently changing significantly, defining the needs for creating age-friendly working conditions is becoming a priority in many countries. We can identify good practices in several countries. In USA, the National Institute of Occupational Safety and Health (NIOSH) National Center for Productive Aging and Work seeks to advance lifelong well-being for workers of all ages and supports productive aging across the working life (30). The Center continues to work on such important issues as how organizations are addressing the needs of an aging workforce and identifying interventions and strategies to support both workers of all age groups and organizations that employ them. The European Agency for Safety and Health at Work coordinated the European campaign “Healthy workplaces for all ages” to promote sustainable work and healthy aging from the start of a person’s working life, and to prevent health problems and enable people to work for longer in 2016–2017 (31). Japanese government has developed and disseminated aging-friendly occupational health and safety guidelines with action checklist and good practices to prevent work-related injury in older workers according to industrial sectors (32).

The present study has several strengths. Firstly, it was based on a representative national workers’ compensation database for South Korea that encompasses all industrial sectors and occupations. Secondly, it estimated the incidences of work-related non-fatal injuries among aged workers in comparison to their younger counterparts.

Our research also had several limitations. Firstly, due to the cross-sectional design of the study, we are unable to establish causal relationships. Secondly, the precise incidence rates of work-related non-fatal injuries among aged workers could not be calculated due to the unavailability of the exact age distribution for all workers registered under the workers’ compensation scheme. Consequently, our data provides estimates of the incidence of work-related non-fatal injuries based on information derived from a representative Local Area Labor Force Survey. Finally, aging is not easily distinguishable between age groups. There is no universally agreed-upon age at which someone becomes an “aged worker.” Instead, it is often defined based on the specific needs, policies, or research objectives of a particular group or institution. Consequently, our results address the characteristics of non-fatal injuries among workers aged 55 years or older compared to those under 55 years, rather than among “aged workers” in a general sense.

The present study holds significant practical implications for mitigating the occurrence of work-related injuries. Firstly, it emphasizes the importance of directing greater attention towards aged workers, given their higher susceptibility to such injuries compared to their younger counterparts. Secondly, it underscores the necessity for improving occupational safety and health measures specifically tailored to individuals engaged in precarious employment and jobs, as a considerable number of aged workers fall into this category. Thirdly, it highlights the need for industries and occupations with a substantial aging workforce to establish a work environment that addresses the increased physical vulnerabilities of aged workers.

In conclusion, the number of aged workers in South Korea engaging in various economic activities and working as waged employees is consistently rising. The incidence of non-fatal work-related injuries is higher among aged workers compared to their younger counterparts. Combined with engagement in precarious employment and jobs, frailty likely contribute to having higher rate of

work-related non-fatal injuries in aged workers. To mitigate workplace injuries, it is crucial for employers to enhance safety and health standards specifically tailored to the employment types and jobs most common among aged workers. Additionally, implementing preventive measures that enhance the physical and functional capabilities of aged workers, particularly focusing on balance and muscle strength, can play a vital role in averting work-related injuries in this demographic.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: Korea Occupational Safety and Health Agency. Requests to access these datasets should be directed to MN, mino05@kosha.or.kr.

Ethics statement

The studies involving humans were approved by Institutional Review Board of Ulsan University Hospital. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

JP: Writing – original draft. J-sP: Methodology, Writing – review & editing. YJ: Investigation, Writing – review & editing. MN: Investigation, Writing – review & editing. YK: Conceptualization, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Research status and trends of enterprise safety culture: a knowledge graph analysis based on CiteSpace

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The cultivation of safety culture within enterprises has evolved into a pivotal facet of overall safety progress, drawing increased attention from a myriad of businesses. With a comprehensive examination of relevant literature, 635 documents from both domestic and international sources were selected as the subjects of analysis. The developmental trends, both domestically and internationally, follow a generally consistent pattern, resembling an inverted “V” shape. The initial phase witnessed gradual development, followed by a substantial and rapid growth phase in the mid-term. In the later phase, a decline is observed. This study utilizes the CiteSpace software for keyword clustering analysis, employing the Log Likelihood Ratio (LLR) algorithm with default parameters to delve into the themes within the specific research field of enterprise safety culture. It was observed that domestic research predominantly centers on the practical perspective of mitigating accidents through the establishment of enterprise safety culture, while international research places greater emphasis on theoretical considerations, specifically focusing on the impact of safety culture atmospheres within enterprises on employees.

KEYWORDS

safety culture, knowledge graph analysis, enterprise safety culture, citation burst, CiteSpace

1 Introduction

Following the Chernobyl nuclear accident in 1986, the introduction of the “safety culture” triggered extensive discussions within the global safety science community. Aligned with the contemporary safety management philosophy, tenets such as “safety first,” “people-oriented,” and “care for life, focus on safety” have been seamlessly integrated into safety culture construction, emerging as indispensable guiding principles for enterprise safety management. The cultivation of safety culture within enterprises has evolved into a pivotal facet of overall safety progress, drawing increased attention from a myriad of businesses. Yet, in the course of safety culture construction, enterprises have grappled with a lack of comprehension and recognition regarding the interplay between safety culture and safety management. Challenges have arisen, exemplified by perspectives like “culture is useless,” treating safety culture construction as mere rhetoric or the posting of slogans. Furthermore, some have disconnected safety culture construction from practical safety management, impeding enterprises from achieving safety management enhancement through safety culture initiatives.

In recent years, both domestic and international scholars have conducted extensive research on the connotations, characteristics, dimensions, measurement methods, and influencing factors of enterprise safety culture (1–4). Through a comprehensive review and analysis of abundant literature, it is evident that domestic research on enterprise safety culture predominantly centers on conceptual definition, dimension delineation, measurement methods, and influencing factors (5, 6). In contrast, international research places a greater emphasis on theoretical exploration (7, 8). Due to disparities in cultural backgrounds, economic levels, and developmental stages between domestic and international countries, domestic scholars focus on comparative studies among different nations (9). However, the existing theoretical research on enterprise safety culture in domestic remains in an exploratory stage, necessitating further enrichment and refinement. This review and analysis of relevant literature, both domestic and international, aim to furnish a reference for the theoretical and practical research on enterprise safety culture in domestic.

2 Literature retrieval of enterprise safety culture

2.1 Definition of enterprise safety culture

The notion of enterprise safety culture was initially introduced by safety management personnel. Despite sustained research interest in recent years, a unified consensus on its conceptual definition remains elusive. Presently, three primary perspectives contribute to the understanding of the content of enterprise safety culture. Firstly, safety culture is perceived as a people-oriented management philosophy, accentuating the pivotal role of individuals in the production process, thereby establishing an innovative management model. This culture-oriented perspective is chiefly evident in employees' attitudes and behaviors toward safety production (10). Secondly, safety culture encompasses the values, behavioral norms, regulatory systems, and management methods shaped by enterprises in the course of production and operation. Its core content embodies a management philosophy and ideology developed by enterprises concerning people, objects, environment, and management throughout the production and operation process (11). Thirdly, safety culture is regarded as a novel type resulting from the integration of safety management into enterprise culture construction, guided by safety management theory. This emerging culture emphasizes commencing with people, conducting comprehensive management and control of individuals throughout the entire process, encompassing the cultivation of safety awareness, and guiding behavior norms (12).

Consequently, in this study, during the literature selection process, a comprehensive consideration of the three aforementioned aspects is undertaken to define the concept of enterprise safety culture. Further distinctions are made in researching specific themes during the literature screening process.

2.2 Data sources

- (1) Retrieval sources: The Web of Science and CNKI databases served as the chosen retrieval sources. Employing a standardized sampling method, the literature's validity was

affirmed through three rules: First, screening for literature relevance based on research topics and abstracts; Second, deduplication of all retrieval results; Third, reading the content of the remaining literature, leading to the exclusion of irrelevant materials. This meticulous process yielded a total of 635 valid retrieval results (refer to Table 1 for details).

- (2) Keywords retrieval: The selection of keywords represents a critical and challenging aspect of literature research. The significance lies in the fact that keyword selection shapes the research content and direction, while the challenge arises from the varying perspectives of different academic factions. Initially searching using “enterprise safety culture” and “企业安全文化(enterprise safety culture)” as subject terms in selected domestic and international journals, the preliminary search results underwent careful review to eliminate articles with lower relevance to the degree of enterprise safety culture, such as those related to safety education, food safety, medical safety, etc. The research sample for this study was then meticulously determined.
- (3) Timespan: To secure a comprehensive research sample, the time range for literature retrieval was extended to the years 1900–2023. The final retrieval results indicated that formal literature on foreign enterprise safety culture research can be traced back to 2007 with the publication of “Risk, safety and culture in Brazil and Argentina: the case of TransInc Corporation” by Perez-Floriano and Gonzalez. The earliest domestic article on enterprise safety culture research was Professor Cao Qi's discussion on the category of safety culture published in 1995 in “Labor Protection.”

To avoid overlooking relevant literature, this study retained literature that clearly included the aforementioned keywords in the title or abstract fields. Additionally, through literature tracing, the indexing and citation status of the selected literature were investigated. With this retrieval strategy, this study ensured the inclusion of important literature, ultimately selecting 635 research samples, including 68 foreign-language articles and 567 domestic articles, forming the initial sample for this paper.

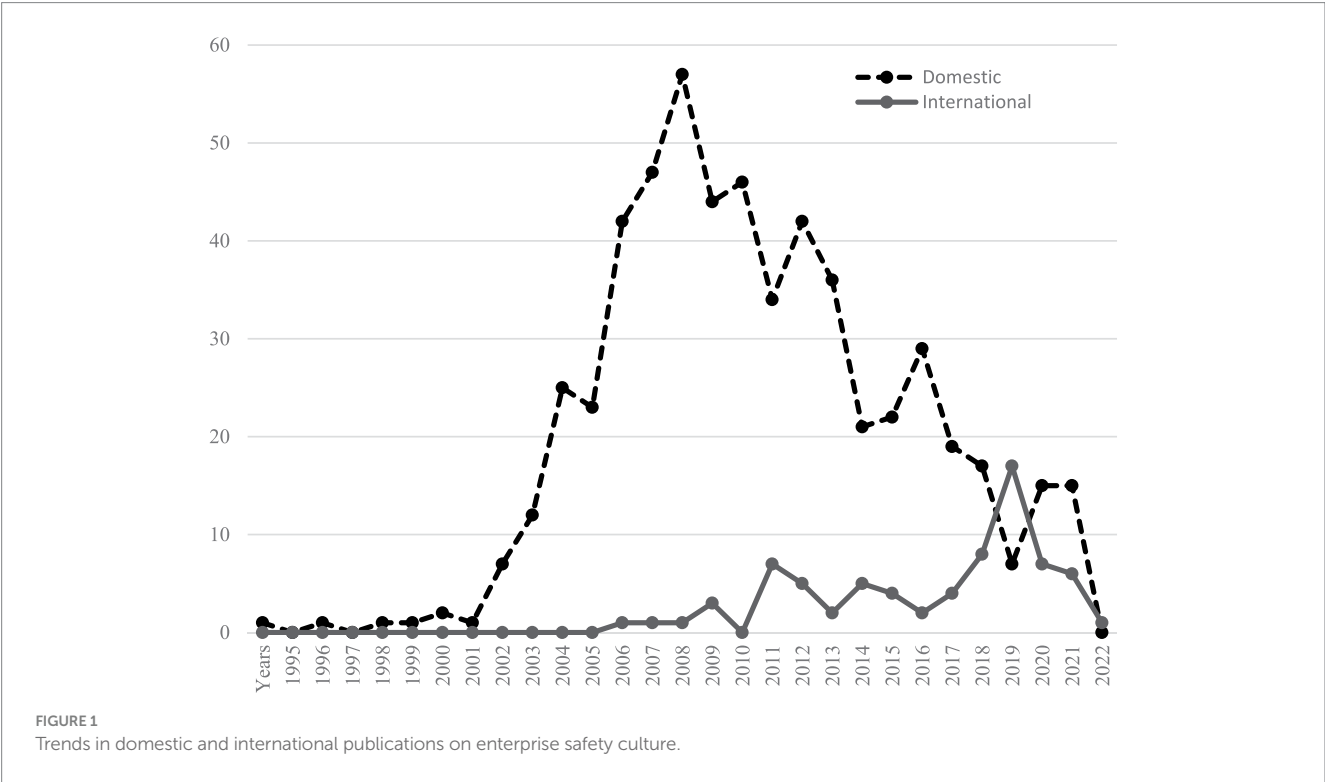
2.3 Research trends

Through literature retrieval and screening, this study conducted a comprehensive analysis of the literature sources. The developmental trends, both domestically and internationally, follow a generally consistent pattern, resembling an inverted “V” shape. The initial phase witnessed gradual development, followed by a substantial and rapid growth phase in the mid-term. In the later phase, a decline is observed, but there is a notable difference in the overall research quantity (Figure 1).

International research commenced relatively late, with the first article appearing in 2007. It can be broadly divided into three stages. The first stage, spanning from 2007 to 2017, represents the initial development phase characterized by slow growth, with only 1–5 articles per year. During this period, there was limited relevant research, and the outcomes were not yet mature. The second stage, from 2018 to 2020, witnessed accelerated growth, with the number of articles surging from 8 in 2019 to 17 in 2020,

TABLE 1 Literature retrieval.

Database	Keyword	Document type	Conditions	Timespan	Records	Qualified
CNKI	企业&安全文化 (enterprise & safety culture)	主题(topic)	1. “类别”选择“学术期刊”(Document type—academic journal)	1900–2023	697	567
			2. “来源类别”选择“核心期刊”(citing source—core collection)			
Web of Science	Enterprise safety culture	topic	1. “Database”—“Web of Science Core Collection”	1900–2023	179	68
			2. “Document type”—“article、review article、published online”			
Article included finally						635



indicating an intensified growth rate. The third stage, from 2021 to 2023, reveals a growth decline, returning to an annual publication quantity of around 5 articles, with a more measured growth rate.

Contrastingly, domestic research initiated earlier and compared to international research, demonstrates an overall trend of “rapid growth and stable development.” It can be roughly divided into three stages. The first stage, from 1995 to 2002, represents a period of stable development, with an annual publication quantity of around 1 article, indicating limited relevant research. The second stage, from 2003 to 2009, is characterized by rapid growth, exhibiting the fastest growth rate, increasing consistently each year. The annual number of published articles remained between 30 and 50, peaking at 57 in 2009. The third stage, from 2009 to 2023, signifies a growth decline, with a decreasing growth rate and an annual average publication quantity maintained at 15 to 25 articles.

3 Methods

This paper chooses CiteSpace as a knowledge graph analysis tool to examine research related to corporate safety culture, and its rationality lies in the following three aspects.

Firstly, corporate safety culture is a complex and multidimensional research field that involves multiple aspects such as safety values, safety thinking and awareness, safety style and attitude, safety management mechanisms and norms. These aspects are interrelated and mutually influential, forming a complex knowledge network. CiteSpace, as a professional knowledge graph analysis tool, can deeply explore and analyze these complex knowledge networks, helping researchers better understand and grasp the connotation and extension of corporate safety culture.

Secondly, research on corporate safety culture requires a large amount of literature support and empirical analysis. CiteSpace has

powerful literature data processing capabilities, which can quickly and accurately extract key information from literature, such as authors, institutions, keywords, citation relationships, etc., thereby helping researchers build a complete and accurate knowledge graph. At the same time, CiteSpace also supports various visual display methods, such as clustering graphs, timeline graphs, network graphs, etc., allowing researchers to have a more intuitive understanding of the research status and development trends of corporate safety culture.

Finally, research on corporate safety culture needs to be constantly updated and improved. With the continuous development of society and the continuous innovation of enterprise safety management, the connotation and extension of enterprise safety culture are also constantly changing. CiteSpace has powerful dynamic updating capabilities, which can track the latest research results and dynamic changes in real time, helping researchers to timely understand and grasp the latest progress and trends in corporate safety culture research.

However, CiteSpace may be affected by factors such as incomplete data sources, language and cultural biases, and differences in user interpretation and understanding during its application, making it difficult for research results to truly reflect the current status and trends in the field of safety culture. Based on the limitations of CiteSpace itself mentioned above, this study comprehensively considered Chinese and English literature databases to ensure sufficient literature coverage. At the same time, the research team has participated in safety culture related research and practice activities in various countries around the world multiple times, reducing differences in understanding of safety culture in enterprises from different countries. In addition, due to the long-term work of the research team in the field of safety culture, Have a certain level of professional knowledge and the ability to explain research trends. Therefore, it can effectively enhance the adaptability of research methods and improve the scientificity of research conclusions.

The CiteSpace V software utilized in this study is a widely used tool for scientific literature metrics. Developed by Professor Chaomei Chen, a Chinese American scholar at Drexel University in the United States, this analysis tool is based on the Java environment. Introduced to China in 2006, the software is extensively employed in both natural and social sciences, renowned for its notable feature of visualizing literature metrics. Its application extends to the analysis of literature, identification of research development trajectories, exploration of cutting-edge directions, and highlighting of hot topics. The software enables the quantitative and dynamic presentation of evolutionary trends and the current status within a research field.

3.1 Keywords clustering analysis

This study utilizes the CiteSpace software for keyword clustering analysis, employing the Log Likelihood Ratio (LLR) algorithm with default parameters to delve into the themes within the specific research field of enterprise safety culture. The Modularity Q values, assessing network structure and clustering clarity, stand at 0.6706 for domestic research and 0.5832 for international research. These values surpass the standard threshold ($Q \geq 0.3$), indicating a robust clustering structure and high network stability. Additionally, the Mean Silhouette (S value) scores of 0.9341 and 0.8308 for domestic and international research, respectively, exceed the general standard ($S \geq 0.7$), signifying

excellent clustering effects with notable homogeneity, effective clustering, and clear thematic delineation (Figure 2).

Examining the clustering results, domestic enterprise safety culture research unfolds into nine distinct themes, with primary focuses on “safety culture” and “safety management.” Concurrently, attention is directed toward safety performance and case studies in coal mine safety. In the international domain, enterprise safety culture research crystallizes into eight themes, spotlighting “prospective safety performance evaluation,” “application study,” and “safety management system.” Noteworthy is the frequent utilization of coal mine safety as a case study in international research, unraveling the intricacies of safety culture through the analysis of incidents and addressing deficiencies in enterprise safety culture.

3.2 Keyword frequency and centrality analysis

To gain deeper insights into research hotspots within enterprise safety culture and explore evolving trends, this study employs co-occurrence and timeline analyses of keywords in the literature collection. Research hotspots signify topics commonly addressed by scholars, requiring a quantitative evaluation of centrality to gauge keyword significance within the co-word network, considering network science principles.

The visualization software CiteSpace V constructs a knowledge graph of keyword clusters, analyzing the knowledge structure and research directions in the field of enterprise safety culture. The CiteSpace analysis model spans “1995–2023” and “2007–2023,” extracting keywords yearly. CiteSpace generates a keyword co-occurrence graph (Figure 3), identifying high-frequency keywords with centrality (Tables 2, 3, displaying keywords with a frequency greater than 2 and centrality exceeding 0.01). Figure 4 illustrates that both domestic and international research exhibits a multi-axis radial structure converging toward the center. The co-occurrence graph for domestic research comprises 461 nodes and 866 connections with a density of 0.0082, while the international counterpart has 234 nodes and 953 connections with a density of 0.035. The overall low density in both contexts suggests a relatively divergent landscape in current research on enterprise safety culture.

In the co-occurrence graph, the positive correlation between keyword frequency and centrality reflects scholars’ collective attention, unveiling research hotspots. Centrality signifies a node’s significance, with higher frequency and centrality indicating greater importance in the research domain. A comparison of domestic and international research exposes variations in focus areas and keywords, suggesting distinct research intensities and frequencies.

For domestic research (Table 2), keywords occurring 10 times or more total 16, with the top ten including safety culture (202 times, 0.81), safety management (78 times, 0.25), coal mine (37 times, 0.03), safety production (35 times, 0.11), coal mine enterprise (26 times, 0.08), coal mine safety (24 times, 0.04), construction (20 times, 0.01), enterprise culture (16 times, 0.03), safety (15 times, 0.03), intrinsic safety (13 times, 0.04). Frequent mentions of safety highlight its centrality, serving as a crucial “intermediary” term in enterprise safety culture research. “High-frequency but low-centrality” keywords like “coal mine” and “coal mine safety” suggest their importance is

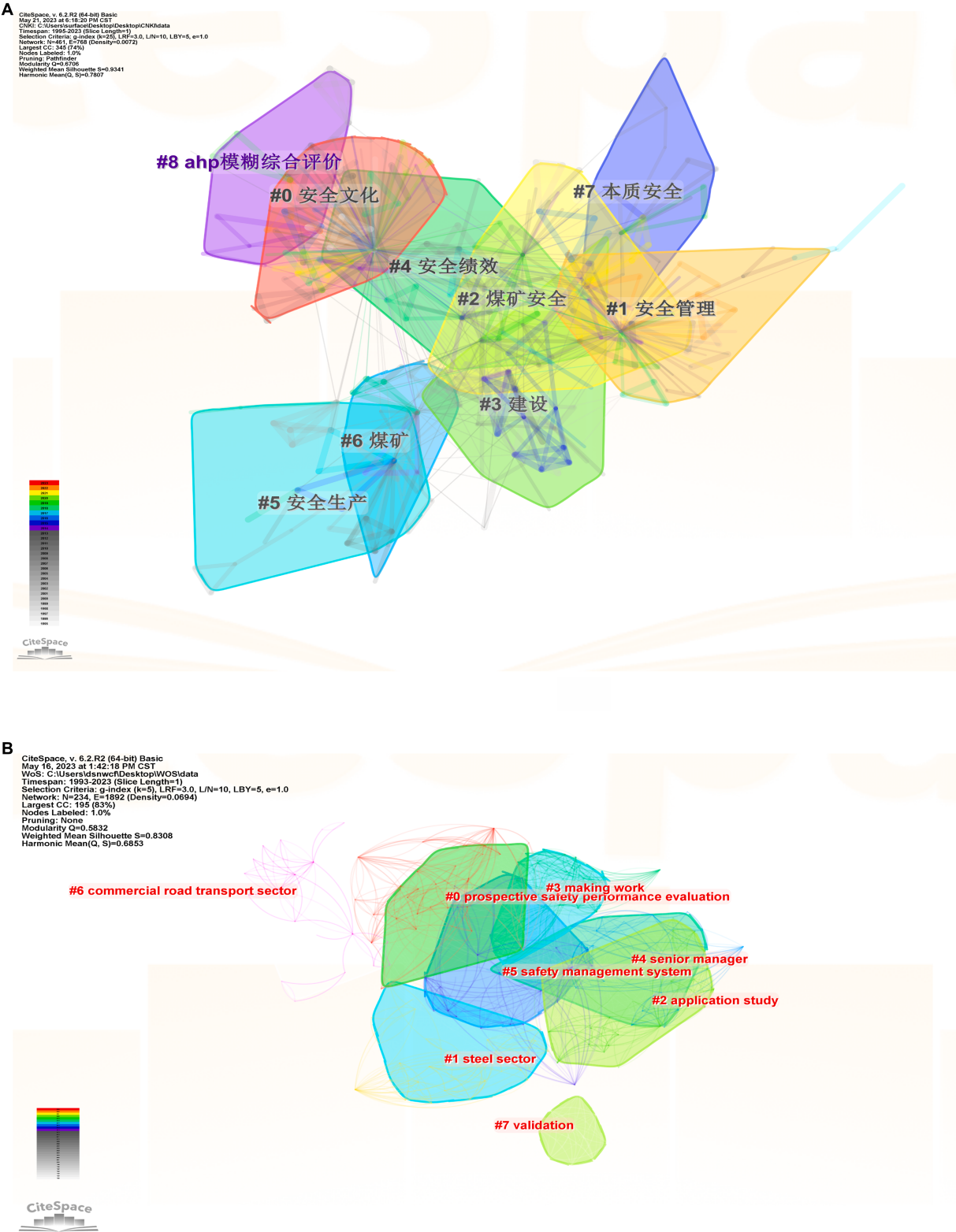


FIGURE 2
Clustering map of keywords on enterprise safety culture between domestic and international. **(A)** for domestic and **(B)** for international. In the **(A)**, #0 = safety culture, #1 = safety management, #2 = coal mine safety, #3 = construction, #4 = safety performance, #5 = safety production, #6 = coal mine, #7 = intrinsic safety, #8 = AHP fuzzy comprehensive evaluation.

relatively low despite frequent references, possibly due to a narrowed focus on specific aspects of enterprise safety culture, such as energy industry concerns.

In foreign research (Table 3), keywords occurring 5 times or more total 16, with the top ten including culture (24 times, 0.03), climate (23 times, 0.17), safety culture (16 times, 0.08), behavior (13 times, 0.17),



Utilizing CiteSpace software to construct a timeline graph of keywords in the field of enterprise safety culture unveils the duration and evolution trends of research hotspots, depicted in [Figure 4](#). The chronological arrangement of the keyword evolution graph, from left to right, showcases square nodes whose sizes are proportional to the frequency of corresponding keywords. Conducting a thematic evolution analysis of research hotspots in both domestic and foreign

TABLE 2 The keywords and centrality in the domestic research field of enterprise safety culture from 1995 to 2023.

Rank	Keywords	Frequency	Centralities
1	安全文化(safety culture)	202	0.81
2	安全管理(safety management)	78	0.25
3	煤矿(coal mine)	37	0.03
4	安全生产(safety production)	35	0.11
5	煤矿企业(coal mine enterprise)	26	0.08
6	煤矿安全(coal mine safety)	24	0.04
7	建设(construction)	20	0.01
8	企业文化(enterprise culture)	16	0.02
9	安全(safety)	15	0.03
10	本质安全(intrinsic safety)	13	0.04
11	煤炭企业(coal enterprise)	13	0.01
12	安全绩效(safety performance)	12	0.01
13	以人为本(people-oriented)	11	0.02
14	安全氛围(safety atmosphere)	11	0.03
15	企业(enterprise)	10	0.01
16	安全行为(safety behavior)	10	0.02

selected literature using CiteSpace software, with time parameters set as 1995–2023 and 2007–2023, Year per slice = 1, Node type = Keyword, the results of the thematic cluster evolution are illustrated in the graph. The graph generated from domestic literature produces 461 nodes and 768 links, with $Q=0.6706$, while the graph generated from foreign literature produces 234 nodes and 953 links, with $Q=0.5832$, indicating a clearly defined structure.

Examining the timeline evolution graph of keywords, the prominence of keywords in the domestic timeline has undergone two significant phases with substantial fluctuations: A large-span stage with considerable fluctuations and a larger-span stage with an increase followed by a decrease. This indicates that the development of research on enterprise safety culture in domestic has experienced three stages: steady development, rapid growth, and relatively stable development. Domestic researchers have encountered certain fluctuations in the process of studying enterprise safety culture.

In the graph, besides the node with the maximum frequency for the term “safety culture,” two other significant nodes, “safety management” and “safety production,” emerged around 2005. This signifies that these terms are research hotspots in this field, indicating the importance of safety management and safety production in the development of enterprise safety culture research. The prominence of the keyword “safety production” takes the forefront of the timeline, suggesting that research in this field began exploring based on this keyword, and subsequently, all related studies on enterprise safety culture are associated with this keyword.

This emergence can be attributed to the surge in safety accidents in domestic in 2005, with an increase of 34.9% YoY in severe accidents in coal mining enterprises. The State Council responded by issuing special regulations on preventing coal mine production safety accidents that year (13). This led to a systematic

analysis of the causes of frequent production accidents and targeted improvements in the state of production safety, making safety production and safety management hot topics in the research on enterprise safety culture. On the right side of the graph are keyword cluster labels, evolving into nine clusters: safety culture, safety management, coal mine safety, construction, safety performance, safety production, coal mine, intrinsic safety, and AHP fuzzy comprehensive evaluation.

In contrast to domestic research, the prominence of keywords on the international timeline starts later and changes more gradually, undergoing three stages of slow development, rapid growth, and decline. In the graph, nodes related to safety performance, safety management, and safety behavior are more prominent, indicating that these keywords are research hotspots in the field of international enterprise safety culture. Analyzing each stage, during the slow development stage, scholars mainly explored the construction of safety culture within enterprises and the impact of the formation of a safety atmosphere on employee behavior (14, 15). In the rapid growth stage, scholars further expanded the influence of leaders and senior management on enterprise safety culture and safety performance based on previous research (16, 17). Finally, during the stage of declining growth, the main research focus is on the construction of safety culture and the related research on safety management systems in different countries, industries, and enterprises (18). On the right side of the graph are keyword cluster labels for foreign enterprise safety culture research, evolving into seven clusters: prospective safety performance evaluation, steel industry, applied research, production work, senior management, safety management system, and commercial transportation.

3.4 Burst analysis of keywords

Burst analysis is one of the important tools in current literature content mining, reflecting active or frontier research nodes. Research frontier trends are understood by detecting the burst rate of relevant literature in a certain period and tracking the future direction of research based on the changing trend of literature. Keeping other parameters unchanged, setting the minimum duration for bursting (Minimum Duration) to 1 year, and running the “Citation/Frequency Burst Histor” function, lists of bursting keywords in the fields of domestic and international enterprise safety culture were generated, obtaining 20 and 10 burst keywords, respectively. Burst words in CiteSpace refer to keywords that suddenly appear in a research field, representing the forefront of research in that field. By using the burst analysis function in CiteSpace software, this study obtained burst keywords at different stages of the literature collection.

Utilizing CiteSpace V’s functionalities and analysis, where deeper colors indicate that researchers in the field have conducted relevant studies in that year and lighter colors indicate that almost no scholars have been involved in the field during that year. The first year of deep color appearance indicates the time when the keyword was first mentioned by scholars in the related field. In terms of domestic research results, the field of enterprise safety culture research has undergone nearly two decades of development and evolution. The results of the 20 strongest bursting keywords are shown in Figure 5. In 2006, there was a research boom in the keyword “safety production,”

TABLE 3 The keywords and centrality in the international research field of enterprise safety culture from 2007 to 2023.

Rank	Keywords	Frequency	Centralities
1	Culture	24	0.23
2	Climate	23	0.17
3	Safety culture	16	0.18
4	Behavior	13	0.17
5	Performance	13	0.21
6	Management	13	0.22
7	Model	11	0.12
8	Industry	8	0.04
9	Leadership	8	0.04
10	Accidents	7	0.04
11	Health	7	0.05
12	Occupational health	7	0.03
13	China	6	0.13
14	Risk management	5	0.09
15	Enterprises	5	0.1
16	Framework	5	0.02

focusing on safety production and construction areas, as well as research hotspots related to coal mines and coal mine enterprises. In 2011, on the basis of previous research, there was a burst of research hotspots on “safety behavior,” “cultural construction,” and “safety training.” In 2016, influencing factors and enterprise culture became research hotspots. In terms of burst intensity, safety culture began to appear in 2013, while enterprise culture began to burst in 2016. Although the attention of scholars to the field of enterprise safety culture has decreased in recent years, it indicates that safety culture and enterprise culture may still be key directions and trends for future research.

Examining the results of international research on enterprise safety culture, the field has undergone only over a decade of development and evolution. The outcomes of the ten strongest bursting keywords are presented in [Figure 6](#). In 2013, there was a research boom regarding leadership and safety management. In 2020, there was a burst of research hotspots on safety culture based on previous research. In 2021, industrial production safety, accident prevention and handling, as well as safety performance became research hotspots. From the perspective of burst intensity, safety culture emerged after 2020, and the burst intensity of analyzing individual and organizational unsafe behaviors has been very high to the present, indicating that safety culture and accident prevention are upcoming hotspots and trends.

4 Discussion

This study, grounded in a bibliometric analysis of the current state of domestic and international enterprise safety culture research, alongside advancements in related research and practice, posits several areas for future research from theoretical and practical perspective.

4.1 Definition and system model of safety culture

Currently, a lack of a unified definition of safety culture and theory, both domestically and internationally, has led to confusion in management practices. Thus, it is imperative to precisely define enterprise safety culture and construct a unified, scientific, and systematic model. Simultaneously, a thorough analysis of various factors influencing the formation of enterprise safety culture is necessary. With the rapid development of safety accidents and accident prevention technology in recent years, there is a deeper understanding of the essence of enterprise safety culture. It is gradually recognized as a cultural atmosphere formed through long-term practical activities within a certain area. Future research can clarify the concept of enterprise safety culture by reviewing relevant theories and research findings. For example, by analyzing various types of enterprises in China to define the characteristics of their safety culture and delineate its connotations and extensions. Furthermore, future research can establish an evaluation indicator system for enterprise safety culture from the dimensions of personnel, materials, and the environment, determine the weights of various indicators using the Analytic Hierarchy Process, evaluate enterprise safety culture using fuzzy comprehensive evaluation, and propose an enterprise safety culture system model based on the dimensions of personnel and the environment.

4.2 Construction of enterprise safety culture system

Firstly, future research necessitates an in-depth exploration of the connotation and dimensions of enterprise safety culture. Based on this understanding, personalized enterprise safety culture systems should be crafted, accounting for the unique circumstances and industry characteristics of each enterprise. Secondly, leveraging emerging technologies, information means, intelligent devices, and systems is crucial for developing a safety culture system aligned with the specific needs of an enterprise. Different production processes, such as mechanical manufacturing or coal mining, have distinct functional requirements for the human-machine-environment system, directly influencing the role it plays during production. Therefore, constructing the enterprise safety culture system requires an analysis and study of the human-machine-environment system, ensuring it serves a more reasonable purpose. Simultaneously, research should delve into the mechanisms of the role of safety culture in various production processes and its influencing factors. Finally, future research can explore the construction of an enterprise safety culture system with Chinese characteristics. On one hand, by learning from the successful experiences and theoretical achievements of developed Western countries and combining them with China's national conditions and enterprise realities, it's possible to explore safety culture systems suited to China's unique circumstances. On the other hand, by drawing on the successful experiences and theoretical achievements of advanced enterprises and combining them with the current situation of Chinese enterprises, constructing an enterprise safety culture system that aligns with China's national conditions is essential.

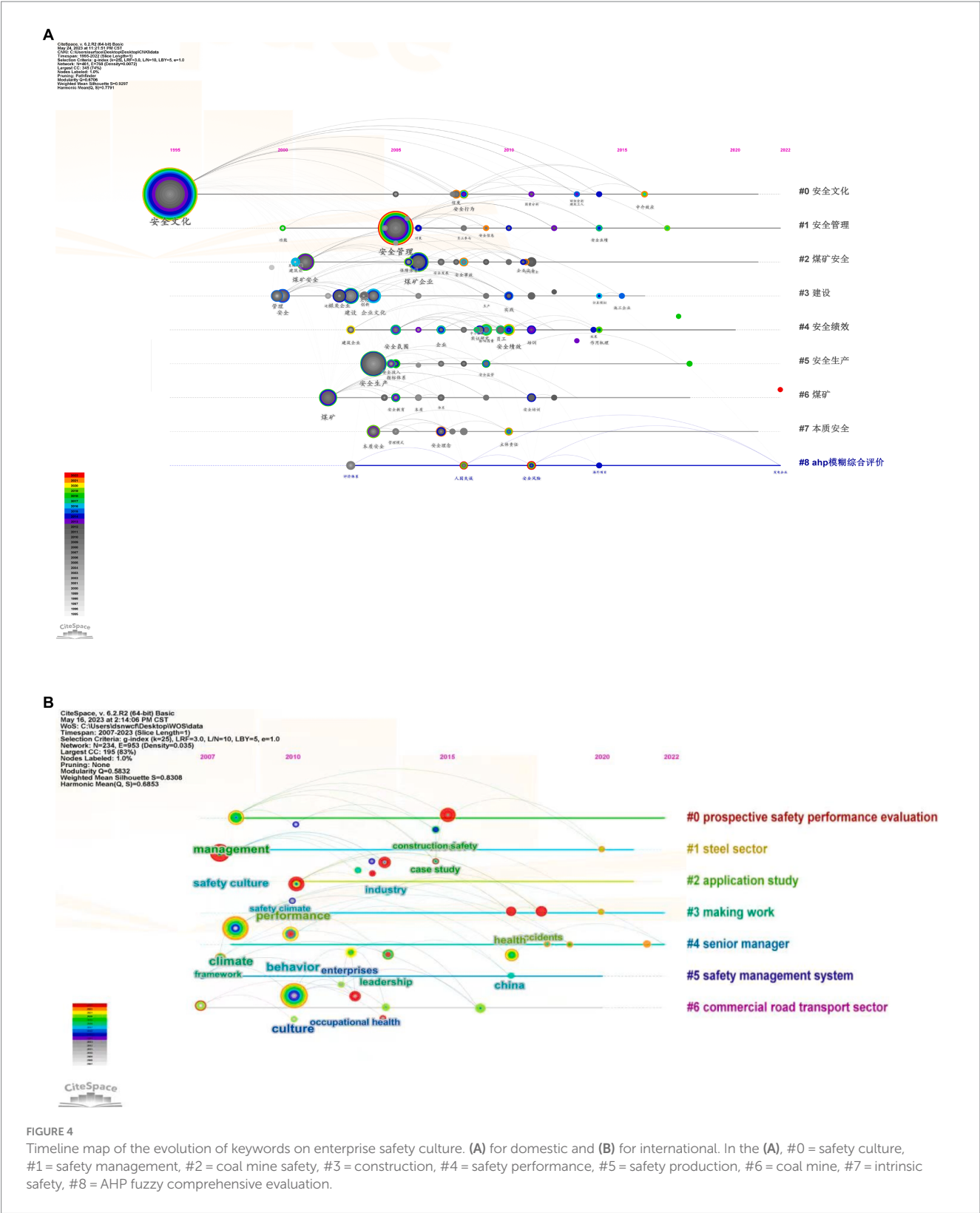


FIGURE 4
Timeline map of the evolution of keywords on enterprise safety culture. (A) for domestic and (B) for international. In the (A), #0 = safety culture, #1 = safety management, #2 = coal mine safety, #3 = construction, #4 = safety performance, #5 = safety production, #6 = coal mine, #7 = intrinsic safety, #8 = AHP fuzzy comprehensive evaluation.

4.3 Practical application of enterprise safety culture

Enterprise safety culture is the soul and core of safety management, constituting an essential component of safety production management.

This study conducted a comprehensive literature analysis on the field of safety culture through diversified, time-sharing, and dynamic information visualization technologies. Through analysis, the distribution of research hotspots, trends, and research forces in the field of safety culture can be clearly presented. The results show that despite

Top 20 References with the Strongest Citation Bursts

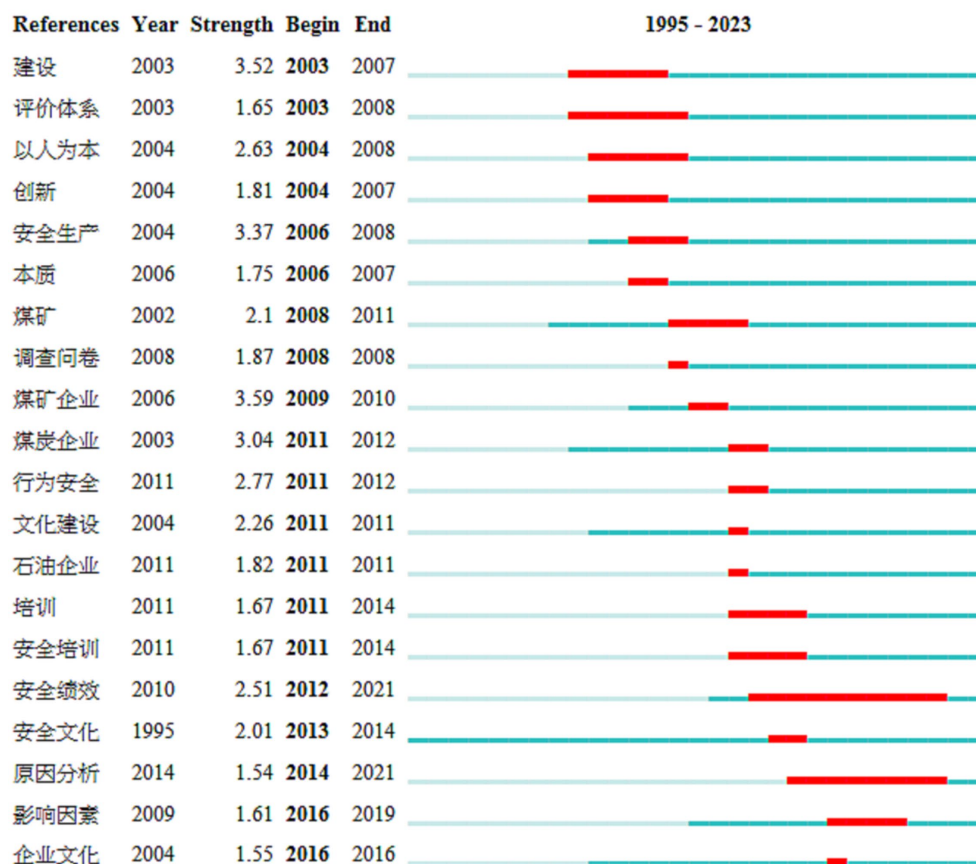


FIGURE 5

Top 20 references with the strongest citation bursts on domestic enterprise safety culture research from 1995 to 2023. They are "construction, evaluation system, people-oriented, innovation, safety production, intrinsic, coal mine, questionnaire, coal mine enterprise, behavior safety, culture construction, oil enterprise, training, safety training, safety performance, safety culture, cause analysis, influencing factors, enterprise culture".

Top 10 Keywords with the Strongest Citation Bursts

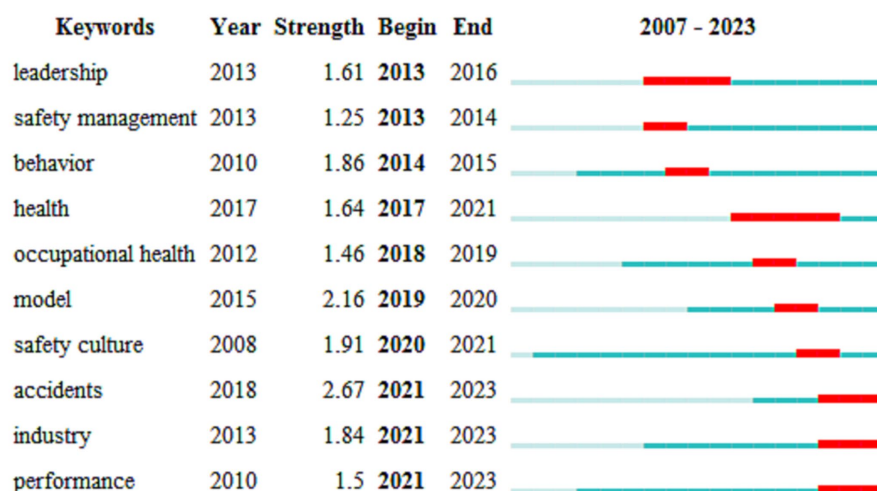


FIGURE 6

Top 10 keywords with the strongest citation bursts on international enterprise safety culture research from 2007 to 2023.

extensive safety culture-related research, several issues persist, including a lack of unified understanding of safety culture definitions, essence, and developmental paths, limited research methods, and a prevalence of qualitative research over quantitative research. Therefore, practitioners should aim for a comprehensive understanding of safety culture and guide theoretical development through practical applications. In addition, this study also reveals key research issues and gaps in the field of safety culture, which may become issues that practitioners need to pay attention to and solve in practical work, thereby promoting continuous improvement and refinement of safety culture practices. The research results of this article indicate that practitioners in enterprises should systematically and deeply study the main factors and related mechanisms that affect safety culture. They should pay attention to the development of evaluation and evaluation mechanisms, innovation and promotion models for enterprise safety culture. At the same time, it is crucial to establish a standardized evaluation index system to adapt the construction of enterprise safety culture to the characteristics of the enterprise and the actual production process. Furthermore, effective models for the practical application of safety culture should be explored based on the actual situation of different industries, enterprises, and regions.

5 Conclusion

Building upon a systematic examination of domestic and international literature on enterprise safety culture, this research, through a comprehensive literature analysis, precisely delineated the concept and theoretical underpinnings of enterprise safety culture. Conducting an in-depth content analysis of 635 domestic and international documents, this study discerned the distribution of research themes pertaining to enterprise safety culture. It was observed that domestic research predominantly centers on the practical perspective of mitigating accidents through the establishment of enterprise safety culture, while international research places greater emphasis on theoretical considerations, specifically focusing on the impact of safety culture atmospheres within enterprises on employees. These findings offer valuable insights for the trajectory of domestic enterprise safety culture research.

Subsequently, employing literature visualization analysis, this study outlined the domestic and international research hotspots and trends in enterprise safety culture. It surfaced that, in contrast to international scholars engaging in theoretical discussions, domestic research predominantly concentrates on defining the concept of enterprise safety culture, categorizing dimensions, scrutinizing influencing factors, and appraising effects. Given the escalating severity of safety production situations, there is a growing urgency for enterprise safety culture research in China. However, there exists a relative scarcity of research on the factors influencing enterprise safety culture and its effectiveness, necessitating further empirical analysis.

In conclusion, recognizing the limitations in existing domestic and international research, this study suggests further avenues for the advancement of enterprise safety culture research. These include refining the definition of the safety culture concept and system model, developing the enterprise safety culture system, exploring the practical application of enterprise safety culture, and examining the interplay between enterprise safety culture and pertinent national laws, regulations, and policies.

Compared with existing literature, this study uses CiteSpace to conduct a systematic analysis of safety culture related research. The uniqueness of this article lies in the following three aspects: firstly, it provides a comprehensive research perspective. By integrating and analyzing a large number of literature, this article provides researchers with a comprehensive perspective on enterprise safety culture, which helps them to have a deeper understanding of the complexity and diversity of this field; Secondly, revealing research gaps and trends, this article reveals the research gaps and trends in the field of corporate safety culture through visual knowledge graphs, providing valuable references for future research; Thirdly, promoting interdisciplinary cooperation. The analysis results of this article can help researchers from different disciplines find common research interests, thereby promoting interdisciplinary cooperation and communication. In summary, this article not only provides researchers with deeper insights, but also provides more specific guidance and suggestions for practitioners.

In the future research on safety culture, on the one hand, it is possible to deeply analyze the application of artificial intelligence and machine learning in safety culture. With the rapid development of artificial intelligence and machine learning, these technologies are becoming increasingly widely used in the field of safety. For example, these technologies can be used to predict and prevent accidents, improve safety performance, optimize safety processes, etc. Therefore, further research is needed on how to better integrate these technologies into safety culture to improve safety levels and efficiency. On the other hand, research on cross-cultural safety culture can be widely carried out. In the context of globalization, communication and interaction between different cultures are becoming increasingly frequent. Therefore, further research is needed on the differences and similarities of safety culture in different cultural backgrounds in order to better understand and respond to cross-cultural safety issues.

Author contributions

MW: Formal analysis, Investigation, Methodology, Resources, Visualization, Writing – original draft, Writing – review & editing. ZG: Formal analysis, Investigation, Resources, Writing – original draft, Writing – review & editing. CX: Formal analysis, Investigation, Methodology, Resources, Writing – original draft, Writing – review & editing. YW: Formal analysis, Investigation, Methodology, Resources, Writing – original draft, Writing – review & editing. DC: Formal analysis, Investigation, Resources, Writing – original draft, Writing – review & editing.

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Conflict of interest

MW, ZG, CX, YW, and DC are employees of PetroChina Southwest Oil and Gas Field Company.

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Exploring the challenges faced by Dutch truck drivers in the era of technological advancement

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Introduction: Despite their important role in the economy, truck drivers face several challenges, including adapting to advancing technology. The current study investigated the occupational experiences of Dutch truck drivers to detect common patterns.

Methods: A questionnaire was distributed to professional drivers in order to collect data on public image, traffic safety, work pressure, transport crime, driver shortage, and sector improvements.

Results: The findings based on 3,708 respondents revealed a general dissatisfaction with the image of the industry and reluctance to recommend the profession. A factor analysis of the questionnaire items identified two primary factors: 'Work Pressure', more common among national drivers, and 'Safety & Security Concerns', more common among international drivers. A ChatGPT-assisted analysis of textbox comments indicated that vehicle technology received mixed feedback, with praise for safety and fuel-efficiency improvements, but concerns about reliability and intrusiveness.

Discussion: In conclusion, Dutch professional truck drivers indicate a need for industry improvements. While the work pressure for truck drivers in general may not be high relative to certain other occupational groups, truck drivers appear to face a deficit of support and respect.

KEYWORDS

professional drivers, work pressure perception, safety, truck drivers, vehicle technologies

1 Introduction

Given the Netherlands' strategic position as a gateway to Europe and its port infrastructure, the truck driving profession plays a key role in the economic success of the country. As of 2021, approximately 91,000 professional truck drivers were registered in the Netherlands (1).

Truck drivers face various challenges that can affect their well-being, such as long working hours and extended periods away from home, which may adversely impact mental health and familial relationships (2–7). Additionally, the sedentary nature of the truck driving profession involves health risks such as obesity (8–10). Another challenge faced is the pressure to meet tight delivery schedules, which can result in fatigue and compromised road safety (2, 11–13). A study among truck drivers by Wijngaards et al. (14) showed that the driving itself, as well as the rest breaks and administrative tasks, are associated with greater momentary happiness compared to logistical work and the delivery/pickup of goods.

Truck drivers also grapple with adapting to the evolving technological landscape, including the adoption of advanced driver assistance systems (ADAS), such as adaptive cruise control (ACC) and lane keeping assistance (LKA) systems, as well as digital tools that aim to improve safety and efficiency (15). While new technologies offer potential benefits, they can also generate resistance (16), cause apprehension about job displacement (17), and require truck drivers to acquire new skills (18–20). Semeijn et al. (21), for example, reported that the digital tachograph is a source of stress.

Various studies have been undertaken on the topic of ADAS, typically using driving simulators and focusing on passenger vehicles (22–24). Current literature suggests a preference among truck drivers for a silent cabin environment (25, 26). Certain systems, such as autonomous emergency braking (AEB) and warning systems, are likely beneficial from a safety perspective (27, 28). However, these systems exhibit a propensity for false interventions/alarms, rendering them as annoying or intrusive (29–32). Camera systems and ADAS that reduce blind spots, on the other hand, have been met with approval by truck drivers (33). Still, which ADAS are perceived by truck drivers as useful and which as less useful has not yet been well documented in the literature.

1.1 Research aim

Although certain pain points in the trucking industry have been documented [e.g., tight schedules, stress, and fatigue (34–37)], there is still limited knowledge about how truck drivers experience their daily work. This is particularly relevant in recent years, as factors such as driver shortages (38) and the introduction of new technologies are playing increasingly large roles.

The aim of this study is to document the experiences of Dutch truck drivers. A large-scale questionnaire was conducted by Transporteffect BV (which is engaged in advisory services and mediation within the transportation sector) and foundation Chauffeursnieuws (a website focused on the transport industry). Although the results of the questionnaire have been published in raw form on the organization's website (39), they have not yet been subjected to scientific evaluation. This paper analyzes the results of this questionnaire, which includes responses from over 3,700 drivers, through a multivariate statistical approach and through a ChatGPT-aided text summarization approach. This analysis allowed for making informed statements about the experiences of drivers and to determine whether there are relevant patterns in their experiences, which may potentially correlate with individual differences such as gender, age, and type of work (national vs. international). By better understanding truck driver experiences, policymakers and industry stakeholders could make more informed decisions to improve the working conditions and job satisfaction of truck drivers.

2 Methods

2.1 Questionnaire design

The questionnaire header indicated that Chauffeursnieuws & Transporteffect aimed to address the long-neglected concerns of professional drivers and promote their welfare. It stated that by

providing a platform for drivers to voice their opinions, the organizations were committed to creating a positive impact on the transportation sector.

The questionnaire was administered in Dutch and consisted of 68 questions divided into 9 parts. It included 51 multiple-choice questions, 1 checkbox question, and 15 open comment boxes that provided the option to the respondent to elaborate on the preceding multiple-choice questions.

Part 1: Introduction (Q2–Q6) gathered general information about the respondents. Example questions included: “*Your gender?*” (Q2) with response options *Male* and *Female*, and “*Are you a professional driver?*” (Q3) with response options *Yes* and *No*.

Part 2: Organizations (Q7–Q12) focused on the respondents' involvement and opinions on trade unions and other organizations. For example, “*Are you a member of a trade union?*” (Q7) with response options *Yes* and *No*, and “*CNV – What grade would you give?*” (Q9), with response options 1 (*Very bad*) to 5 (*Very good*), and *No opinion*.

Part 3: Image (Q13–Q17) dealt with the public image of drivers and related topics. Example questions were: “*Do you think the image of the driver needs to be improved?*” (Q13) and “*Do you think a mobile toilet (DIXI) at companies is a good solution for drivers?*” (Q14), both with response options *No*, *Yes*, and *Neutral*.

Part 4: Traffic safety (Q18–Q30) explored the respondents' views on various traffic safety issues. Example questions included: “*Do you think a stand-alone air conditioner contributes to road safety in Europe?*” (Q18) with response options *Yes*, *No*, and *No opinion*, and “*Do you find text signs with information adequate for international traffic?*” (Q21) with response options *No – creates dangerous situations*, *No*, *Yes*, and *No opinion*.

Part 5: Work pressure (Q31–Q39) investigated the respondents' experiences and opinions about work pressure. Example questions were: “*Do you experience high work pressure?*” (Q31) with response options *No*, *Yes – every day*, *Yes – 1 or 2 times per week*, and *Yes – 1 time per month on average*, and “*Do you think work pressure should be addressed?*” (Q35) with response options *Yes*, *No*, and *No opinion*.

Part 6: Transport crime (Q40–Q44) focused on transport crime issues and their impact on the respondents. Example questions included: “*Have you dealt with transport crime?*” (Q40) with response options *Yes – regularly*, *Yes – sometimes*, and *No*, and “*Do you report all forms of crime to the authorities? Or via <https://meldpunt-transport.nl/>*” (Q42) with response options *No – small events not*, *No – never*, *Yes – only big events*, and *Yes – all events*.

Part 7: Driver shortage (Q45–Q56) explored the respondents' perceptions of the driver shortage and related topics. Example questions were: “*Do you feel the demand for professional drivers has increased?*” (Q45) with response options *Yes – much more demand*, *Yes – a little more*, *No – not more than in the last 10 years*, and *No opinion*, and “*Do you find the hourly wage sufficient compared to similar jobs?*” (Q47) with response options *Yes*, *No*, and *No opinion*.

Part 8: General questions (Q57–Q66) dealt with various topics, including paid parking and the European Mobility Package [EU regulations to improve road transport conditions (40)]. Example questions included: “*Do you think paid parking for trucks is a solution?*” (Q57) with response options *Yes – better facilities*, *Yes – only if well organized*, *No – only take money from the sector*, *No – no rest possible*, and *No opinion*, and “*What do you think of the current European Mobility Package?*” (Q62) with response options 1 (*Bad*) to 5 (*Very good*).

Part 9: The concluding section (Q67–Q68) provided space for respondents to share their opinions on the most important changes needed in the sector and any additional comments or suggestions. The two questions were: “Open question: What is, in your opinion, the first thing that needs to change in the sector? (Please provide 1 answer)” (Q67), and “Comments and suggestions that you could not include in the questions can be written below.” (Q68).

The open comment boxes were present in each part: Part 2 (Q12), Part 3 (Q17), Part 4 (Q25, Q28, Q30), Part 5 (Q34, Q39), Part 6 (Q44), Part 7 (Q51, Q53), Part 8 (Q58, Q60, Q63), and Part 9 (Q67, Q68). For an overview of all questions, please refer to the [Data availability section](#).

2.2 Questionnaire dissemination

The questionnaire was administered in September and October 2021, with invitations disseminated through the website www.transporeffect.com and the corresponding LinkedIn and Facebook pages, platforms for sharing truck-related news articles.

2.3 Data pre-processing

In total, 3,845 respondents completed the questionnaire. Of these, 137 indicated that they were not professional truck drivers and were therefore excluded from the analysis, leaving 3,708 respondents. The questionnaire contained 51 multiple-choice items, which were analyzed separately from the open comment boxes. One question (Q15, about mobile toilets) was excluded because we considered it unclear.

The 50 remaining questions were divided into three categories:

- Driver-related questions (Q2: “Your gender?”; Q3: “Are you a professional driver?”; Q4: “Where do you primarily drive?” (1: National, 2: Benelux + Ruhr area, 3: International), Q5: “How old are you?”).
- General outcome questions (Q13: “Do you think the image of the driver needs to be improved?”; Q16: “What is your general impression of the image of the professional driver?”; Q46: “Would you recommend the profession to family or acquaintances?”; Q56: “What grade would you generally give to the professional driver’s profession?”; Q64: “How do you see the future as a Dutch professional driver?”).
- Forty-one, more specific, questions.

The driver-related questions and general outcome questions were used as criterion variables, while the remaining questions were subjected to a multivariate statistical analysis.

Response options for questions were not always on an ordinal scale and sometimes included *Not applicable*, *No opinion*, or *Do not know* choices. Therefore, the response options were sorted from low to high, response options that were equivalent on an ordinal scale (for example, *No – creates dangerous situations* and *No*) were combined, and the *Not applicable/No opinion/Do not know* options were marked as missing responses, since such responses cannot be used in standard linear statistical methods. For an overview of the response frequency

distributions pertaining to each question, please refer to the [Data availability section](#).

The number of times *No opinion*, *Not applicable*, or *Do not know* were answered was low for some questions (e.g., 0.2% for Q50, “Do you think the driver’s profession gets the respect it deserves?”). However, for some questions, these responses were more frequent. For example, for the question “Do you report all forms of crime to the authorities? or via <https://meldpunt-transport.nl/>” (Q42), 42.4% reported *Not applicable*, presumably because these drivers had not experienced any crime.

Regarding the grading of different unions and trade organizations (Q8–Q11), there was also a high prevalence of *No opinion* responses (26.0, 44.0, 32.8, and 24.9%), likely because drivers were not members or had not dealt with every organization. Since the aim of our research was to assess the general sentiment of drivers, not specific organizations, these four questions were combined into one by averaging, reducing the percentage of missing data for this question to 10.0%.

As the overall number of missing responses was low (6.9% of the $3,708 \times 38$ matrix of numbers), it was decided to impute these missing values, approximately preserving the means and intercorrelations between item responses. Specifically, missing data were imputed using the nearest-neighbor method, whereby the missing data in the $3,708$ respondents \times 38 questions matrix were imputed with the value of the nearest-neighbor row according to the Euclidean distance.

2.4 Statistical analysis

The mean scores on the 38 questions were interpreted to describe key patterns. Following this, the data ($3,708 \times 38$ matrix of numbers) were subjected to exploratory maximum likelihood factor analysis. This statistical method aims to explain the correlations among variables by identifying latent factors that influence these variables; it is frequently used in the analysis of questionnaire data to reveal underlying psychological constructs (41). The number of factors to extract was based on the screen plot, a graphical representation where eigenvalues (corresponding to the percentage of variable explained) of the correlation matrix are plotted in descending order. The plot generally begins with a steep slope before leveling off, creating an elbow-like shape. The point at which the slope starts to level off is deemed the optimal number of factors to retain (42).

Subsequently, the factor loadings were orthogonally rotated using the Varimax method. Although it could be expected that underlying factors would correlate positively, an orthogonal rotation was chosen. This was done because we were interested in the discriminative power of the factors and their relationship with driver characteristics (rather than a ‘general positivity’ that may be expressed in multiple factors). Factor scores were calculated using the weighted least-squares method. The factor scores were subsequently standardized to have a mean of 0 and a standard deviation of 1.

The scores on the extracted factors were then correlated with the aforementioned criterion variables. Note that Q3 (“Are you a professional driver?”) was not used in this analysis because we only included respondents who answered *Yes* to this question; hence, this item exhibits no variance.

2.5 Text analysis: summaries of open comment boxes

The questionnaire contained a number of open comment boxes. Traditional methods such as content analysis and thematic analysis involve human raters examining the text for specific themes [e.g., (43, 44)]. However, these methods come with the disadvantage of subjectivity and limited reproducibility (45, 46).

Recently, large language models have emerged as a promising alternative. ChatGPT has been shown to perform well in reading comprehension and other linguistic tasks (47–50). In this paper, we will use it for two purposes: summarizing open-ended responses and extracting sentiment from responses.

In summarization applications, ChatGPT's capabilities have been shown in various fields (51), including clinical texts (52) and news items (53). Regarding sentiment analysis, research has shown that ChatGPT can generate mean sentiment scores that correlate strongly with human sentiment ratings and with VADER sentiment analysis, an existing sentiment analysis model (54). ChatGPT has also been found to outperform humans in extracting the stance and topics of tweets (55, 56), and surpass state-of-the-art models in analyzing various types of texts such as customer reviews, social media posts, and news items (57).

We used a custom script to upload the responses for each open comment box to OpenAI's API (GPT-4, model: gpt-4-0125-preview; date: March 2, 2024). The responses were accompanied by the following prompt: "Please make a very very short summary of the respondents' comments shown above, IN ENGLISH; do not enumerate." The parameter temperature, which determines the degree of randomness of the output, was set to 0 to yield a nearly deterministic output.

Although ChatGPT can properly handle potential gibberish responses or 'empty' responses such as a single character (54), we have nonetheless applied a filter whereby only text responses of 4 or more characters were included in the input to ChatGPT. By excluding extremely short responses, we ensured our sample size was more accurately represented by respondents who offered feedback.

2.6 Text analysis: vehicle aids and on-board computer

A key research question of this study focuses on drivers' perceptions of technology. The responses to the open-ended question regarding vehicle aids (Q30; "Comment: vehicle aids") featured numerous comments on specific assistance systems, predominantly concerning the following four types:

- Adaptive cruise control (ACC)
- Lane departure warnings (LDW)/Lane keeping assistance (LKA)
- Emergency braking/AEB
- Camera systems and smart mirrors

For the comments in Q30, we manually identified the system(s) being referred to in the comment (Appendix A). Then, for each of the systems, the corresponding quotes were fed to GPT-4, with the following prompt:

What do the users think about the discussed system? Give a very short summary; do not enumerate.

The same prompt was used for the responses to the open-ended question regarding the onboard computer (Q34; "Comment: on-board computer").

Finally, numerical sentiment scores were generated for the comments for each of the four ADAS in Q30, through the following prompt:

These text messages are obtained from a textbox in a questionnaire about technology in trucks. I need you to provide a single sentiment rating about the technology being discussed in the comments, from 1 (extremely negative) to 100 (extremely positive). Only report a single number between 1 and 100, rounded to two decimals. no text!

A bootstrapping approach was adopted for this process (54, 58), where all comments per ADAS (Q30) were sorted in random order, and the mean score over 1,000 attempts was taken as an overall indicator of sentiment. The use of this method was deemed necessary because the way ChatGPT operates brings a certain randomness to the output. By averaging over a large number of repetitions under effectively identical conditions (only the order of the comments differs), a statistically reliable assessment is obtained of how ChatGPT judges the sentiment of the respondents' texts.

3 Results

3.1 Driver-related questions

A total of 3,708 respondents were included in the study, with 3,541 (95%) identifying as male (Q2). The age distribution of the respondents (Q5) was as follows: 270 individuals aged 18–25, 969 aged 25–40, 884 aged 40–50, 1,175 aged 50–60, and 410 aged 60–75 years old. In terms of driving regions (Q4), 1,483 respondents reported being national drivers, 1,552 identified as international drivers, 666 specified driving in the Benelux & Ruhr area (i.e., Belgium, Netherlands, Luxembourg, and the Ruhr industrial region in Western Germany), while 7 respondents indicated that the question was not applicable to them.

3.2 General outcome questions

Respondents expressed some concerns about the image of their industry, hesitancy to recommend the career to others, and a neutral to slightly negative outlook on the future. Specifically:

- 88.1% (3265) of respondents believe the image of the driver needs improvement, 7.3% (269) remain neutral, and 4.7% (174) disagree (Q13).
- The general impression of the image of the professional driver leans toward negative, with a mean score on the scale of 1 (Very negative) to 5 (Very positive) of 2.62 (Q16).
- 68.7% (2,549 respondents) would not recommend the profession of a professional driver to family or acquaintances, while 31.3% (1,159 respondents) would recommend it (Q46).

- Responding to the question, “*What grade would you generally give to the professional driver’s profession?*,” the mean grade provided by respondents was 6.27 out of 10 (Q56). The most common grade was 7 ($n = 1,006$).
- Finally, the majority of the respondents have a neutral to slightly negative outlook on the future, with a mean of 4.48 on a scale of 1 (*Very negative*) to 10 (*Very positive*) (Q64). The most frequently selected grade was 5 ($n = 770$).

3.3 Specific questions: mean ratings

The questionnaire used different response options for the questions, including yes/no and scales of 1–3 or 1–5. This differentiation aimed to better match the nature of each question, and may increase respondent engagement while reducing yea-saying bias (59). However, it inhibits direct comparison of items based on their mean score.

Table 1 shows mean scores for the 38 items, with a ‘normalized mean’ column ranging from 0 to 1, which allows a clearer view of the drivers’ agreement with statements across items. The results are interpreted below on this 0 to 1 scale.

Regarding workplace and road safety, the use of mobile toilets at companies received a low score of 0.05 (Q14). Overtaking bans on highways scored only 0.14 (Q24). Aids in vehicles were assigned a score of 0.72, indicating a general agreement about their contribution to road safety (Q29). Furthermore, respondents found that a stand-alone air conditioner contributes to road safety (Q18, score: 0.89). A score of 0.91 was reported for the feeling that space on the roads has decreased, indicating a universal observation (Q22).

Regarding work pressure, a score of 0.45 was observed for drivers experiencing high work pressure (Q31), with a score of 0.44 regarding the feeling that work pressure affects their driving behavior (Q19). A high score of 0.81 was obtained for the belief that work pressure should be addressed (Q35).

In terms of compensation and financial aspects, a low score of 0.04 was found for the sufficiency of the hourly wage compared to similar jobs (Q47), while a score of 0.49 indicated that nearly half of the drivers find it difficult to make ends meet with one salary (Q66).

As for work-related issues, while most drivers reported that they are satisfied with their employers (0.90; Q6) and have not experienced labor exploitation (Q61) or intimidation (Q37) from their employers, a portion of respondents reported such issues (0.24 and 0.12, respectively). Additionally, a score of 0.18 was observed for having dealt with transport crime (Q40).

When considering work-life balance, a score of 0.62 was obtained for drivers who prefer to be home every evening (Q65). On the other hand, a score of 0.66 was obtained for drivers who exceed driving times out of necessity (Q38). This points to the difficulty some drivers face in maintaining a balance between work and personal life.

In the context of infrastructure, the quality of roads in the Netherlands received a high score of 0.75 (Q26). However, drivers reported a score of 0.60 for experiencing problems finding a decent parking spot in time (Q55).

Finally, regarding the perception of the profession and industry-related organizations, a score of 0.17 was reported for the belief that the truck driver’s profession receives the respect it deserves (Q50). A

high score of 0.83 was obtained for the importance of driver education for raising awareness (Q43), while 0.86 was reported for the increased demand for professional drivers (Q45). However, a high score of 0.89 was observed for the belief that organizations supporting transport are doing too little (Q52).

3.4 Specific questions: factor analysis

The results from the 38 questions were subjected to a factor analysis in order to extract underlying factors. The scree plot (Figure 1) indicated that the extraction of two factors would be appropriate, though the percentage of explained variance was not high. However, this may not impact the reliability of the constructs as long as a large number of variables correlates with the factor (60).

The Varimax-rotated loadings (please refer to the [Data availability section](#)) allowed us to interpret the two factors as follows: (1) Work Pressure and (2) Safety & Security Concerns. More specifically:

Factor 1: Work Pressure. Items with high loadings on this factor relate to work pressure and its impact on drivers. The strongest loadings relate to experiencing high work pressure (0.75; Q31; and 0.74; Q19). Other high loadings involve ever experiencing intimidation from one’s employer (0.45; Q37), experiencing the profession as demanding (0.45; Q48), being satisfied with one’s employer (−0.44; Q6), continuing to drive when feeling tired (0.46; Q32), the on-board computer contributing to high work pressure (0.46; Q33), and having ever felt that one was dealing with labor exploitation (0.42; Q61).

Factor 2: Safety & Security Concerns. Items with high loadings on this factor are related to the security and working conditions of drivers. The strongest loadings are related to dealing with transport crime (0.49; Q40), having one’s tarp cut (0.45; Q41), experiencing problems finding decent parking spots (0.51; Q55), and exceeding driving times out of necessity (0.45; Q38). Variables related to international driving showed strong loadings as well: preferring being home every evening (−0.49; Q65) and opinion about the European Mobility Package (−0.39; Q62).

The reported crimes (Q44) primarily involve diesel theft, alongside other offenses such as vehicle or container break-ins, and theft of personal belongings or cargo. Incidents of stowaways and intimidating encounters with migrants have also been noted.

Next, factor scores were calculated and correlated with the driver-related questions and the general outcome questions. The results in Table 2 show that there are small gender differences, with women being slightly more burdened by work pressure and men slightly more by crime. This latter finding can be explained by the increased likelihood of men being international drivers.

The factor scores consistently correlate with the outcome measures, such as the respondents’ impression of the image of the truck driver (Q16), whether they would recommend the profession to family or acquaintances (Q46), the score they attribute to the profession as a whole (Q56), and how they view the future (Q64). Work Pressure is primarily associated with the impression of the profession now (Q56), while Safety & Security Concerns are more strongly associated with whether the future is judged optimistically (Q64).

Finally, a trend emerges wherein Work Pressure is relatively high among drivers operating nationally, while Safety & Security Concerns

TABLE 1 Overview of the 38 items subjected to statistical analysis.

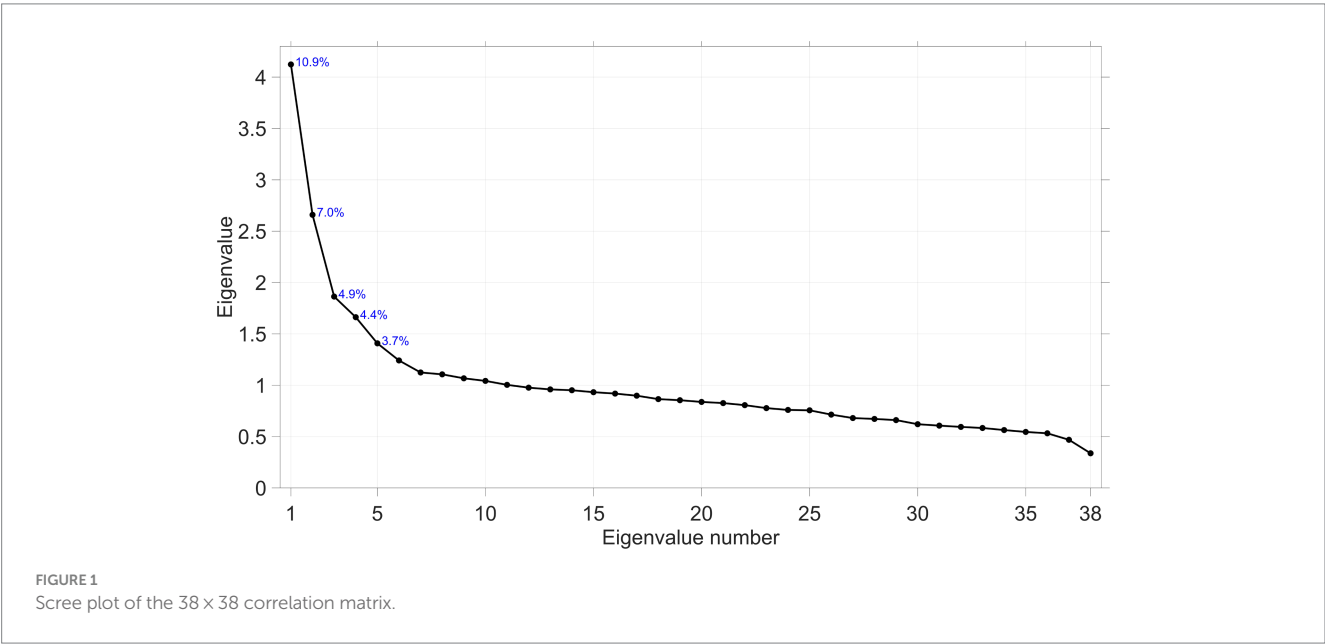
No	Question	Response options	Mean	SD	Mean (normalized)
Q47	Do you find the hourly wage sufficient compared to similar jobs?	1 = No, 2 = Yes	1.04	0.20	0.04
Q14	Do you think a mobile toilet (DIXI) at companies is a good solution for drivers?	1 = No, 3 = Yes	1.09	0.38	0.05
Q37	Do you ever experience intimidation from your employer?	1 = No, 2 = Yes	1.12	0.32	0.12
Q36	Have you ever been asked to commit tachograph fraud?	1 = No, never, 3 = Yes, regularly	1.24	0.51	0.12
Q24	Do you find overtaking bans on highways beneficial for road safety?	1 = No, 2 = Yes	1.14	0.35	0.14
Q50	Do you think the driver's profession gets the respect it deserves?	1 = No, 3 = Yes	1.34	0.53	0.17
Q40	Have you dealt with transport crime?	1 = No, 3 = Yes, regularly	1.35	0.52	0.18
Q49	Do you think you will be able to perform the job until 70 +?	1 = No, 2 = Yes	1.19	0.39	0.19
Q61	Have you ever felt that you were dealing with labor exploitation?	1 = No, 2 = Yes	1.24	0.43	0.24
Q21	Do you find text signs with information adequate for international traffic?	1 = No, 2 = Yes	1.24	0.43	0.24
Q42	Do you report all forms of crime to the authorities? Or via https://meldpunt-transport.nl/	1 = No, never, 4 = Yes, all events	1.77	0.97	0.26
Q41	Has your tarp ever been cut?	1 = No, 3 = Yes, regularly	1.53	0.61	0.27
Q7	Are you a member of a trade union?	1 = No, 2 = Yes	1.31	0.46	0.31
Q62	What do you think of the current European Mobility Package?	1 = Bad, 5 = Very good	2.45	0.88	0.36
Q33	Do you think the on-board computer contributes to high work pressure?	1 = No, 2 = Yes, definitely	1.43	0.49	0.43
Q59	What grade would you give to existing paid parking spaces?	1 = Very bad, 5 = Very good	2.72	0.95	0.43
Q19	Do you feel work pressure that affects your driving behavior?	1 = No, 3 = Yes, regularly	1.87	0.71	0.44
Q31	Do you experience high work pressure?	1 = No, 4 = Yes, every day	2.36	1.16	0.45
Q57	Do you think paid parking for trucks is a solution?	1 = No, 2 = Yes	1.46	0.50	0.46
Q66	Can you make ends meet with one salary?	1 = No, 2 = Yes	1.49	0.50	0.49
Q20	Have you ever held the phone while driving?	1 = No, never, 3 = Yes, regularly	2.05	0.67	0.52
Q8– Q11	Organizations – What grade would you give?	1 = Very bad, 5 = Very good	3.10	0.94	0.53
Q32	Do you ever continue driving when you feel tired?	1 = No, never, 3 = Yes, regularly	2.08	0.69	0.54
Q54	Do you spend every day calculating to comply with driving and rest time regulations?	1 = No, 3 = Yes, it's difficult	2.11	0.79	0.56
Q55	Do you experience problems finding a decent parking spot in time?	1 = No, 4 = Yes, every day	2.79	0.94	0.60
Q65	As a professional driver, do you prefer to be home every evening?	1 = No, I want to be on the move as much as possible, 4 = Yes	2.87	0.83	0.62
Q48	Do you find the profession you practice demanding?	1 = No, 3 = Yes it's heavy	2.31	0.65	0.66
Q38	Do you ever exceed driving times out of necessity?	1 = No, 3 = Yes	2.32	0.82	0.66
Q23	Do you think increasing truck speed contributes to better traffic flow and safety?	1 = No, 80 kilometers is fine, 3 = Yes, 90 kilometers is ideal	2.43	0.74	0.71
Q29	Do you think the aids in vehicles contribute to road safety?	1 = No, not at all, 4 = Yes	3.15	0.63	0.72
Q26	How do you find the quality of roads in the Netherlands?	1 = Very bad, 5 = Very good	3.99	0.67	0.75
Q35	Do you think work pressure should be addressed?	1 = No, 2 = Yes	1.81	0.39	0.81
Q43	Do you think driver education is important for raising awareness?	1 = No, 2 = Yes	1.83	0.37	0.83

(Continued)

TABLE 1 (Continued)

No	Question	Response options	Mean	SD	Mean (normalized)
Q45	Do you feel the demand for professional drivers has increased?	1 = Not more than in the last 10 years, 3 = Yes, much more demand	2.72	0.58	0.86
Q52	Do you think organizations that are there for transport are doing too little?	1 = No, 2 = Yes	1.89	0.31	0.89
Q18	Do you think a stand-alone air conditioner contributes to road safety in Europe?	1 = No, 2 = Yes	1.89	0.31	0.89
Q6	Are you generally satisfied with your employer?	1 = Very negative, 4 = Positive	3.71	0.55	0.90
Q22	Do you feel that space on the roads has decreased?	1 = No, 2 = Yes	1.91	0.29	0.91

This table presents the mean score and standard deviation (SD) for 3,708 respondents, along with the normalized mean, which is the mean linearly scaled between the minimum and maximum possible score on the question.



are relatively high among international drivers (Q4). The mean (SD) scores for Work Pressure are 0.22 (0.98) for national drivers, 0.05 (0.95) for drivers in the Benelux/Ruhr Area, and -0.23 (0.99) for international drivers.

On the other hand, the mean (SD) scores for Safety & Security Concerns are -0.57 (0.90) for national drivers, 0.00 (0.86) for Benelux/Ruhr Area drivers, and 0.55 (0.82 for international drivers. The difference in these experiences between national and international drivers is visually illustrated in [Figure 2](#).

3.5 Text analysis: summaries of open comment boxes

[Appendix B](#) provides summaries of respondents' comments regarding the 15 open-ended questions presented in the questionnaire. These summaries reveal themes that encompass a wide array of subjects, including the perceived commitment of

organizations, concerns surrounding driving times, availability of parking spaces, and the contentious issue of overtaking bans for trucks. Given that the summaries of the 15 open comment boxes still contain a lot of information, and sometimes in a redundant form, we asked ChatGPT to generate a single meta-summary using the following prompt.

Formulate a very concise summary from the following summaries without mentioning specific persons or organizations.

The meta-summary generated by ChatGPT is as follows:

Truck drivers express widespread dissatisfaction with their profession, citing undervaluation, mistreatment, and poor working conditions. They highlight issues such as unsanitary facilities, lack of respect from employers, clients, and the public, and the negative impact of foreign drivers. Concerns also include dangerous road conditions due to overtaking bans, inadequate education on blind

TABLE 2 Correlation coefficients between item responses and factor scores.

No	Question	Response options	Work Pressure	Safety & Security Concerns
Q2	Your gender?	1 = Male, 2 = Female	0.05	−0.09
Q4	Where do you primarily drive?	1 = National, 2 = Benelux + Ruhr area, 3 = International	−0.21	0.51
Q5	How old are you?	1 = 18–25, 5 = 60–75	−0.03	0.00
Q13	Do you think the image of the driver needs to be improved?	1 = No, 3 = Yes	0.09	0.01
Q16	What is your general impression of the image of the professional driver?	1 = Very negative, 5 = Very positive	−0.19	−0.24
Q46	Would you recommend the profession to family or acquaintances?	1 = No, 2 = Yes	−0.22	−0.17
Q56	What grade would you generally give to the professional driver's profession?	1 = Very bad, 10 = Very good	−0.37	−0.24
Q64	How do you see the future as a Dutch professional driver?	1 = Very negative, 10 = Very positive	−0.22	−0.34

Correlation coefficients with binary variables (Q2, Q46) are also known as point-biserial correlation coefficients. Given the substantial sample size ($n = 3,708$), minor correlations statistically deviate from zero, with $p < 0.01$ when $|r|$ is greater than or equal to 0.05.

spots, and mixed opinions on technological aids, which some say decrease attentiveness. Many criticize trade unions and employer organizations for not effectively representing their interests, particularly regarding wages and working conditions. The use of onboard computers is seen as increasing work pressure and invading privacy. Criminal activities like diesel theft and insufficient secure parking are major concerns, alongside the high costs and poor quality of paid parking facilities. Drivers call for improved treatment, compensation, and better enforcement of regulations to ensure fair competition and working conditions, emphasizing the need for higher wages, more flexible working hours, and better parking and rest facilities.

3.6 Text analysis: vehicle aids

In addition to the general summary of the open comment boxes provided above, we conducted an analysis specifically focusing on the evaluation of technologies in the vehicle. The results of this analysis are shown in Table 3.

ACC is valued for its safety, fuel efficiency, and calming effect on driving, though concerns about incorrect reactions and potential distractions exist. LDW and LKA systems can be irritating due to frequent alerts, leading some drivers to disable them. AEB systems can prevent accidents but raise safety concerns due to false activations, causing potential hazards for following traffic and heavy loads. Opinions on camera systems and smart mirrors are mixed; they increase visibility and reduce blind spots but can malfunction and disconnect drivers from the environment. Finally, on-board computers improve logistical efficiency and communication but may increase work pressure, create additional tasks, and infringe on driver autonomy due to real-time tracking.

The above findings are corroborated by numerical sentiment scores computed using ChatGPT. More specifically, the mean (SD) sentiment scores across the bootstrapped batches were 58.0 (5.07) for

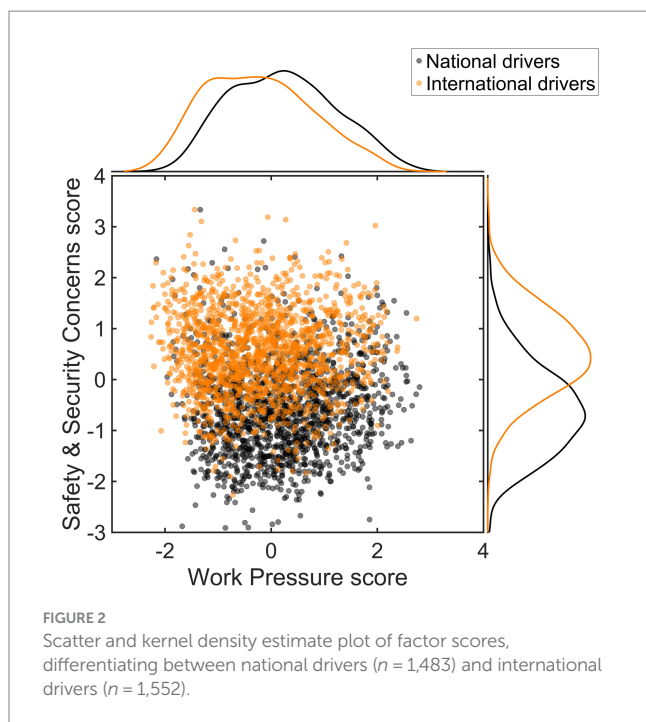
ACC, 26.7 (3.83) for LDW/LKA, 32.6 (4.92) for emergency braking, and 67.5 (5.14) for camera systems and smart mirrors, on a scale from 1 (*Extremely negative*) to 100 (*Extremely positive*). The reported means are shown in Figure 3.

4 Discussion

Truck drivers play a vital role in national distribution and international trade, yet face considerable challenges, with the rapid adoption of new technologies adding to these challenges (15, 61). However, comprehension of truck drivers' daily experiences has been limited. The current study aimed to fill this knowledge gap through a large-scale questionnaire from 3,708 Dutch professional truck drivers. The responses to multiple-choice questions were statistically analyzed, while a large language model was used to analyze the responses to the open comment boxes.

The results revealed that Dutch professional drivers view the image of their profession as needing improvement, are hesitant to recommend it, and possess a neutral to slightly negative outlook. There was evident concern about decreased space on roads. When considering work pressure, compensation, and work-life balance, scores indicated moderate work pressure, high dissatisfaction with wages, challenges in maintaining a balance between work and personal life, and lack of support from transport organizations.

Factor analysis revealed two primary types of concerns among drivers: Work Pressure and Safety & Security Concerns. Work Pressure, characterized by high loadings on items like the impact of pressure on driving behavior and intimidation from employers, was more commonly reported by national drivers. Safety & Security Concerns, marked by high loadings on items like dealing with transport crime and finding decent parking, were more prevalent among international drivers. These results can be explained as crime primarily pertains to fuel or cargo theft when the vehicle is parked, in addition to instances of unauthorized migrants clandestinely boarding the truck (62–64). Moreover, long-distance drivers more frequently



work during night hours, which may contribute to a feeling of unsafety. Work pressure was more of an issue for the national (short-distance) drivers, which may be explained by the larger number of trips they have to complete, the busier daytime traffic conditions, or the more urban traffic environments they are exposed to, in typically less comfortable vehicles (65).

In addition, our research addressed the perception of technological systems, namely ADAS and the on-board computer. ACC was appreciated for its safety features and fuel-saving properties, but concerns exist due to incorrect interventions. LKA systems were often perceived as irritating due to frequent false alerts, leading some drivers to turn them off. Some respondents saw emergency braking technology as useful in preventing accidents, but various safety concerns were raised regarding false activations [see also (29, 66)]. Camera systems and mirror technology received mixed reviews; while many respondents appreciated increased visibility and reduced blind spots [see also (33, 67)], others pointed out that the substitution of conventional mirrors with digital cameras disrupts the reciprocal visual communication between the driver and other road users, and may lead to a disconnection from the surrounding environment. Finally, on-board computers were found to improve logistical efficiency and communication but also increased perceived work pressure due to real-time tracking, potential for additional work, and a sense of surveillance. Similar concerns apply to data-driven driver coaching. Although data recorded by onboard computers has been shown to be predictive of traffic incidents [e.g., (68)], drivers may not readily accept driver monitoring systems. This reluctance could arise from drivers being unaware of the benefits or their discomfort with sharing their data with external parties (69).

These findings can be broadly interpreted in the context of automation disuse (70, 71): in general, drivers appeared to value systems that tangibly contribute to accident prevention and workload reduction, while demonstrating resistance toward less reliable systems, false alarms, and perceived intrusions of autonomy. The findings of our research can also be interpreted through the lens of Ivan Illich's

concept of 'Tools for Conviviality', which advocates for technology that promotes autonomy and fruitful interaction (72, 73). While features such as ACC, AEB, and camera systems can increase driver autonomy and safety when working optimally, concerns about false activations, reliability, and a sense of intrusive surveillance represent a departure from conviviality.

The sentiment ratings revealed that LDW and emergency braking yielded the lowest scores. However, these results should be interpreted with caution, as there is a possibility that drivers might have confused AEB with ACC. In recent years, ADAS have progressed substantially, typically integrating a variety of subsystems (74, 75), and their functionality may not always be clear to drivers (76, 77). Also for the authors of the current study, it was occasionally challenging to accurately classify specific comments. For example, drivers frequently referred to the term 'distance sensor'. Technically, this is not an ADAS, but measurement equipment that is used in both ACC and AEB. This confusion may partially account for the low sentiment score for AEB, where false-positive braking interventions are typically ascribed to AEB, rather than ACC. Furthermore, for AEB, it is predominantly these false positives that drivers perceive, while the number of instances in which AEB averts accidents is logically low (78), since (near-)accidents are infrequent events. However, from a cost-benefit perspective, the AEB system might still be beneficial despite the low sentiment score, considering the substantial costs of accidents.

The acceptance of technology by drivers is essential, particularly in the context of the increasing mandating of technological systems in trucks. As of November 2015, EU regulations have made it compulsory for all new trucks to be equipped with AEB and LDW systems (79). From July 2022, new trucks are required to have additional systems, such as a blind spot information system, pedestrian/cyclist collision prevention, reversing detection, a driver availability monitoring system, and tire pressure monitoring. The mandate extends further in January 2026, when systems such as direct vision for vulnerable user protection, event data recorders, and advanced driver distraction warning systems will become obligatory (80). As more technologies become mandatory, the need for such systems to be reliable and conducive to the driver is reinforced.

Several limitations must be considered with this study. One is that the questionnaire was conducted at the end of 2021. During the COVID-19 pandemic, truck drivers dealt with less social contact as amenities closed down, while social media sentiment analysis revealed that public appreciation for their work actually grew (81).

Furthermore, it should be considered that ADAS sensors and algorithms continue to improve. While these improvements likely result in fewer false positives, there also exists the issue of human variability: false positive warnings in AEB and LDW may be inevitable considering that a threshold needs to be set for a critical time-to-collision or lateral deviation. According to the principles of signal-detection theory, this will involve a trade-off between timely warnings and false positives, as interpreted by the driver [e.g., (82, 83)]. This inescapable threshold could potentially explain why, despite many years of development, AEB and LDW systems are still perceived as irritating by drivers [e.g., (84, 85)]. Arguably, a more fundamental consideration needs to be given to the usefulness of warning systems compared to systems that automatically maintain the lane or exert torque feedback on the steering wheel (86, 87).

In this study, a large number of drivers were surveyed, which implies that the results are statistically precise. However, the results are not necessarily free of bias: it is possible that the mean values as

TABLE 3 Number of comments, ChatGPT summaries, and manually selected comments for systems mentioned in Q30 and Q34.

Category	Count	GPT-4 response and manually selected quotes
Adaptive cruise control (ACC)	74	<p>The opinions on the Adaptive Cruise Control (ACC) system among users are mixed. Some praise it for its convenience, safety enhancements, and fuel-saving potential, appreciating its ability to maintain distance and assist in driving. Others criticize it for causing unnecessary braking, reacting to non-hazardous objects, and potentially leading to decreased driver attentiveness and reliance on technology. Concerns are also raised about its effectiveness in heavy traffic and interactions with other drivers' unpredictable behaviors. Overall, while many see the benefits of ACC, there are significant concerns about its current implementation and impact on driving habits.</p> <ul style="list-style-type: none"> • “Wouldn't want to miss the ACC ... anymore!” • “Some aids also react to other situations like adaptive cruise control that also reacts to viaducts traffic signs and then it makes an emergency stop out of nowhere also extremely dangerous” • “Certain aids are fantastic, but some also promote inattentiveness such as ACC.”
Lane departure warnings (LDW)/ Lane keeping assistance (LKA)	25	<p>The users generally find the lane assist or line detection system to be annoying, irritating, and often unnecessary. They express frustration with false alarms and the system's intrusiveness, with some preferring traditional driving methods without such interventions.</p> <ul style="list-style-type: none"> • “Lane assist is mega annoying and I turn it off when I'm fit. Later in the day, it comes on.” • “You get insanely annoyed by all those alarms. Especially from that line detection. 9 out of 10 times it goes off for no reason.” • “Line detection ... encourages you to pick up your mobile. And all that touchscreen stuff only takes the eyes off the road. Just give me press and twist buttons. The more stuff on a car the less alert people are. If something suddenly happens, people no longer know how to intervene.”
Emergency braking/AEB	58	<p>The users express significant concerns and dissatisfaction with the automatic emergency braking systems in vehicles, particularly trucks. They report that these systems often activate inappropriately, responding to non-hazards like traffic signs, reflections, or even shadows, leading to dangerous and unexpected braking situations. While a few see the potential safety benefits, the majority criticize the systems for creating more risks than they mitigate, especially in situations where following drivers are caught off guard by sudden stops. There's a general sentiment that these systems need improvement to truly enhance road safety.</p> <ul style="list-style-type: none"> • “Yes absolutely. My truck automatically brakes in an emergency situation. If it ever comes to the point where every truck has this technology (mandatory), then at least no truck will ever run into the back of a stationary traffic jam.” • “I turn them off. Almost had an accident because the truck went full on the brakes in a slight curve at 80 km/h. The automatic braking system was triggered because my own light (headlights) reflected on a traffic sign.” • “Some systems are downright life-threatening. For example, the emergency braking system, when you are cut off by a motorist, the system goes into action causing a great chance that your follower will shoot under your trailer.”
Camera systems and smart mirrors	58	<p>The users express mixed opinions about the use of camera systems in vehicles. Some appreciate the enhanced visibility and safety features cameras provide, such as reducing blind spots and aiding in maneuvers like reversing. They find cameras, including blind spot and reversing cameras, to be helpful tools that can prevent accidents. However, others raise concerns about reliability issues, such as cameras being affected by weather conditions or failing to accurately reflect depth. There's also a sentiment that reliance on cameras can lead to decreased attention to traditional driving practices, like using mirrors and making eye contact with other drivers, potentially reducing interaction with other traffic and increasing distraction. Overall, while many see the benefits of camera systems for safety and visibility, there are significant reservations about their effectiveness and impact on driving habits.</p> <ul style="list-style-type: none"> • “I have a camera system etc. for London on my car, this camera greatly reduces my blind spot and I now see much more on the highway but also on roundabouts and through cities.” • “... Some camera systems can help. Cameras instead of mirrors, not so much, because you lose visual contact with other road users.” • “Camera mirrors do not reflect depth and when it rains you see nothing and they break quickly.”
On-board computer	625	<p>The users have mixed feelings about the system, with some seeing it as a helpful tool that can make work more efficient and reduce the need for constant communication with the planning department. Others feel it increases work pressure by allowing for constant monitoring and adding more tasks, leading to a sense of being constantly watched and reducing personal freedom. Some users also mention the system can be distracting and contribute to stress, especially when it leads to additional administrative tasks or when planning uses it to push for more work to be done in less time.</p> <ul style="list-style-type: none"> • “It depends on how the on-board computer is used. You as a driver and on the other side the planning that provides you with work. If there is good consultation with the planning, then the on-board computer is also an addition that could bring peace.” • “You are continuously monitored, if you are ahead of schedule then extra loading addresses are added.” • “... The on-board computer does take away the so-called “sense of freedom” although I have complete understanding for the need to account for hours.”

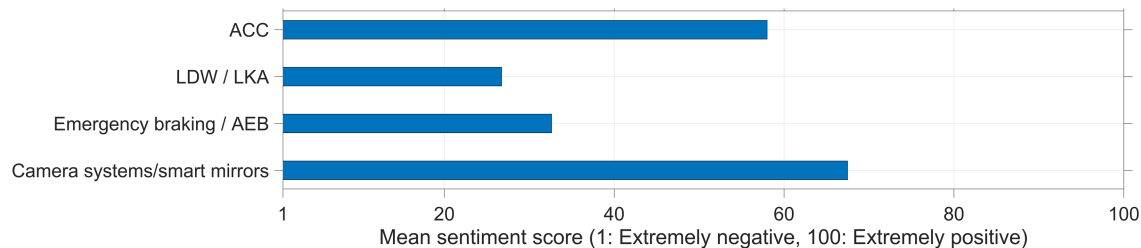


FIGURE 3

Sentiment scores for four categories of vehicle aids, as assessed by ChatGPT based on textbox comments. ACC, adaptive cruise control; LDW, lane departure warnings; LKA, lane keeping assistance; AEB, autonomous emergency braking.

shown in Table 1 are negatively skewed if primarily drivers who wished to complain completed the questionnaire, or if drivers exaggerated certain points in the hope that their responses would prompt a shift in national politics and business practices. In this context, it is useful to compare our results with questionnaires said to be nationally representative, specifically the National Employment Survey conducted by the Netherlands Organization for Applied Scientific Research (TNO), Statistics Netherlands, and the Ministry of Social Affairs and Employment (88). In our questionnaire, there were two questions that were highly similar to questions in this nationally representative survey. Specifically, to the question “Do you ever experience intimidation from your employer?” (Q37), 11.9% of our respondents answered *Yes*, compared to 10.9% in the national survey who answered *Yes* (occasionally, often, or very often) to the question “Can you indicate to what extent you have personally experienced intimidation by superiors or colleagues in the past 12 months?” Another comparable question was Q31: “Do you experience high work pressure?,” to which 19.2% of our respondents answered *Yes – every day* and 34.3% *Yes – 1 or 2 times per week* (a total of 53.5%). In the nationally representative survey, 37.1% answered *Often* or *Always* to the question “Do you have to do a lot of work?” In summary, our results are in line with results from a representative sample of truck drivers in the Netherlands, suggesting no substantial bias in our questionnaire. However, it is worth noting that our open comment boxes were often left empty, with response rates ranging widely between questions (see Appendix B). It may be that drivers who wanted to suggest improvements in particular took the opportunity to fill in the open comment boxes, still introducing a form of bias.

Besides representativeness for the Dutch population, it is necessary to consider how our results relate to those of other countries. There are large national differences in road network density, road quality, accident risk, and the quality of organizations and operations. Despite this, certain factors concerning the well-being of drivers, such as stress, fatigue, and physical and mental health, recur both within Europe (13, 36, 37) and on other continents (12, 89–93).

The impression that drivers left in our questionnaire was quite negative. They appeared pessimistic about the profession as a whole and found their salary to be mediocre. At the same time, respondents were satisfied with their own employer, and the majority did not experience high work pressure, with 36.7% of respondents reporting no high work pressure and 19.2% indicating high work pressure on a daily basis. This is also evident from the aforementioned national survey, where other professional groups such as elementary school teachers, managers, cooks, lawyers,

doctors, directors, social workers, and caregivers reported much higher work pressure than truck drivers (88). Possible explanations are that, even though truck drivers have many grievances about their field, ‘being on the road’ is a job that offers a certain level of satisfaction (94, 95). It is also possible that truck drivers experience pressure, but do not perceive or express it as such due to their hardship and stoicism (3). Additionally, while truck drivers may not have to work hard in physical terms, their work scheduling is highly dictated as compared to some other professions like directors, scientists, and advisors. The literature concurs that flexibility and autonomy over work hours can influence job satisfaction; a meta-analysis by Shifrin and Michel (96) highlights the positive impact of flexible work arrangements on overall job stress levels. Work-related pressures, often tied to truck driving accidents, can stem from various factors such as supervisor pressure, inadequate training, and unsupportive management (34, 36, 37). Further, loading/off-loading site culture (37, 97, 98), as well as other road users’ behavior (7, 21, 99–101), can be a source of stress.

Beyond the issue of representativeness, it is important to also monitor the quality of the responses, that is, whether the questionnaire appears to have been completed sincerely. Our impression is that the quality of the responses was high compared to other questionnaires that seem to be plagued by acquiescence bias [for discussions, see (102–104)]. An illustration of the high quality of responses is that only 3 of the 3,708 respondents (0.08%) rated the quality of roads in the Netherlands (Q26) as very bad. If there were mindless responses, the distribution of responses would be more uniform.

A noteworthy aspect of our study is that the text analysis was done automatically. Our observation is that the summaries and sentiment scores correspond to how we ourselves would summarize and rate the truck drivers’ comments. This statement is supported by a growing body of literature demonstrating that ChatGPT performs well in linguistic tasks, such as answering exam questions, labeling tweets and reviews, and analysis of sentiment (48, 50, 55, 56, 105, 106). The fact that texts were submitted to ChatGPT in Dutch rather than English is not necessarily a problem, as shown in several studies (107, 108). We agree with Mellon et al. (109) that the availability of large language models makes the use of open-ended questions in future questionnaires more attractive.

Nevertheless, there are some limitations to using ChatGPT. While ChatGPT is proficient in summarization and sentiment analysis [e.g., (47, 54, 110)], it may lack domain-specific expertise (111). Moreover, its output can be sensitive to the specific wording of the prompt (47). For these reasons, we undertook a manual classification of individual comments into the four ADAS categories (Q30). This approach

ensured the sentiment scores were directly relevant to the specific ADAS under evaluation.

5 Conclusion

This study provided new insights into the experiences and perceptions of Dutch professional truck drivers. The findings illustrate the need for improved working conditions and support from transport organizations, as well as greater attention to safety and security concerns, especially among international drivers.

What policy recommendations arise from this research? Truck drivers often indicate that they should receive better financial compensation. However, when we consider the entirety of this work, including [Appendix B](#), it becomes clear that the drivers are not just concerned with monetary incentives but also with recognition and respect for their profession. The current study offers various starting points that can help improve the welfare and status of drivers, including better sanitary and parking facilities. Additionally, it is recommended to act at an international level against fuel theft, break-ins, and other forms of transport crime. In the development of new technology, the minimization of perceived intrusiveness should be a key design criterion, both in a direct sense (unnecessary automated braking interventions and alarms) and in an indirect sense (perceived intrusions in work flexibility and autonomy). Although truck drivers appreciate technologies that improve safety and efficiency, the feeling of autonomy being compromised indicates a need for less meddlesome technology.

Data availability statement

Original datasets are available in a publicly accessible repository: The original contributions presented in the study are publicly available. This data can be found here: <https://doi.org/10.4121/577c120a-b5bb-4ba5-93b8-6143759d0249>. Further inquiries can be directed to the corresponding author.

Ethics statement

The study was conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants in accordance with the local legislation and institutional requirements. Approval for analysis of the questionnaire data was provided by the TU Delft Human Research Ethics Committee (approval number 3013).

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Author contributions

JW: Visualization, Validation, Supervision, Software, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization, Writing – review & editing, Writing – original draft. TD: Writing – review & editing, Writing – original draft, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. DD: Writing – review & editing, Resources. AC: Writing – review & editing, Resources, Project administration, Methodology, Investigation, Data curation, Conceptualization.

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Conflict of interest

AC is CEO of Transporteffect BV and Chauffeurnieuws. He was not involved in the current analysis and interpretation of the data.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

Appendices A and B can be found online at: <https://www.frontiersin.org/articles/10.3389/fpubh.2024.1352979/full#supplementary-material>

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