Advances in Intelligent Systems and Computing 791

Pedro Miguel Ferreira Martins Arezes
*Editor*

# Advances in Safety Management and Human Factors

## Proceedings of the AHFE 2018 International Conference on Safety Management and Human Factors, July 21–25, 2018, Loews Sapphire Falls Resort at Universal Studios, Orlando, Florida, USA

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# Preface

Safety management and risk prevention is a common thread throughout every workplace, yet keeping employee safety and health knowledge current is a continual challenge for all employers. The discipline of safety management and human factors is a cross-disciplinary area concerned with protecting the safety, health, and welfare of people engaged in work or employment. The book offers a platform to showcase research and for the exchange of information in safety management and human factors. Mastering safety management and human factors concepts is fundamental both to the creation of products and systems that people are able to use and for work systems design, avoiding stresses and minimizing the risk for accidents.

This book focuses on the advances in the safety management and its relationship with human factors, which are a critical aspect in the design of any human-centered technological system. The ideas and practical solutions described in the book are the outcome of dedicated research by academics and practitioners aiming to advance theory and practice in this dynamic and all-encompassing discipline.

A total of six sections are presented in this book:

I. Organizational Safety Management and Risk Assessment
II. Accident Prevention
III. Applications in Safety Management and Loss Prevention
IV. Safety Behavior
V. Occupational Exposure and Safety in High-Risk and Complex Environments
VI. Safety and Prevention in Construction/Mining Sector

Each section contains research papers that have been reviewed by the members of the International Editorial Board. Our sincere thanks and appreciation to the board members as listed below:

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We hope that this book, which is the international state of the art in safety management domain of human factors, will be a valuable source of theoretical and applied knowledge for global markets.

July 2018 Pedro Arezes

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**Applications in Safety Management and Loss Prevention**

# Organizational Safety Management and Risk Assessment

# High Reliability Organisation (HRO) Principles of Collective Mindfulness: An Opportunity to Improve Construction Safety Management

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**Abstract.** The construction industry remains a high-risk industry, because of high fatality rates worldwide. Most construction accidents result from interaction between the work team, workplace, equipment and materials which lead to about 70% of injuries and fatalities. A wide range of safety management approaches have been implemented to manage construction risks, and they have been successful in reducing lost time injuries and incidents. However, a number of safety management approaches currently used in the industry have not kept pace with emerging theory on accident causation, prevention and safety management. To minimise accidents more advanced approaches and methods are required, and one of such methods is High Reliability Organisation (HRO) principles of collective mindfulness. This paper presents a systematic review of HRO research published in construction from 1990–2017. This review aims to identify the possibilities and barriers associated with transferring HRO principles to construction activities. Key findings from seven articles are discussed, research gaps identified and primary outcomes from the data will be presented descriptively.

**Keywords:** High reliability organization · Construction safety
Reliability

## 1 Introduction

High reliability organisations (HROs) have a distinctive attribute of being able to operate in hazardous, complex and uncertain environments nearly error-free [1], and at the same time achieve high safety and production performance. The construction industry on the other hand struggles to achieve nearly error-free operation and is not able to find the balance between safety and production yet. Construction industry is a high risk industry known for high fatality rates around the world [2]. The industry has experienced a significant decrease in the number of fatalities in recent years despite the


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belief that risk are inherent in construction activities and accidents cannot be avoided, and sometimes safety affects productivity when it competes with production [3]. Accident prevention in the industry focuses mostly on hazards and safety programs [3], and not on production practices, and previous attempts to improve safety have used models and approaches that are now outdated in managing accident causation and prevention. Therefore, there is the need to develop work strategies that are highly proactive and highly safe [3]. Also safety approaches have moved from the cultural age to the adaptive age which offers HROs and Resilience Engineering (RE) as safety management strategies [4, 5]. This paper will systematically review previous HRO literature to identify how the principles of collective mindfulness can improve construction safety management.

### 1.1 Construction Industry

The construction industry has one of the highest employment rate in any country, and is a major contributor to the economy [6]. In Australia, construction is the third largest employing industry, and accounts for about 8% of Gross Domestic Product (GDP) [7, 8]. The industry consist of 330,000 businesses nationwide, directly employing 1.1 million workers (9.1% of total employment) [8]. In the United States, construction is the ninth highest paying industry sector out of fourteen industry sectors, and accounts for 4.2% of Gross Domestic Product (GDP), with an employment increase rate of 4.5%. The sector employed 8.28 million people in 2015 and 7.92 million in 2014 [9]. However construction work remains one of the most dangerous occupation, because activities are classified as low risk and high risk activities with most accidents and fatalities resulting from high risk activities [10]. These fatalities are not always predictable because of the hazards associated with construction activities, and the uncertain nature of construction projects due to project deadlines. These changes makes it difficult to implement safer working environments, making the industry more complex [11].

### 1.2 High Reliability Organisations (HROs)

High reliability organisations (HRO) are organisations which operate in an environment of uncertainty but perform their activities almost accident-free [12]. HRO was conceptualised as a notion in a few group of organisations that conducted their day-to-day operations in relatively high risk, volatile and uncertain work environments, yet were able to sustain high levels of safety performance, while at the same time meeting highly unpredictable and demanding production tasks. In other words, they were able to achieve the right balance between safety and production something that many managers and organisations struggle with. At the time HROs was conceptualised, Charles Perrow [13], had sought to provide an alternative explanation (to safety culture) for explaining why organisational disasters such as the Three Mile Island (TMI) nuclear plant explosion were inevitable. Perrow argued that accidents in technological systems such as TMI were normal and inevitable because they had become so complex and tightly coupled such that a small event could trigger a series of cascading failures in many parts of the system, leading to an eventual disaster [13]. Moreover, he argued these events could not be controlled adequately or in a timely manner because those operating them were not fully aware of the consequences of such failures, or their ability to prevent them. This is a common problem with many plants, where operators are not involved in the design process [13].

However, a small group of researchers at Berkeley university campus refuted this explanation, because they believed there were some organisations that met Perrow's criteria (of complexity and tight coupling) but had achieved excellent safety and production goals [14].

HRO original studies were based on three industries; nuclear power generation stations, air traffic controls and aircraft carriers. It was centred on these organisation because of their similarities. They operate in unforgiving social and political environments, their technologies are risky and present potential for error, and to avoid failures, these organisations used complex processes to manage complex technologies [15]. They were also able to sustain high levels of safety performance, and demanding production tasks [15]. Some other researchers (Wieck et al.) [16], that were not part of the original HRO studies, from their investigations proposed that this was due to a "collective, cognitive mindset in these organisations regarding the management and control of organisational risks" [16]. They coined the term "collective mindfulness" to capture these capabilities, and identified five aspects of collective mindfulness present in all HROs: (a) preoccupation with failure; (b) reluctance to simplify interpretation; (c) sensitivity to operations; (d) commitment to resilience, and (e) deference to expertise [16, 17].

## 1.3 Principles of Collective Mindfulness

***Preoccupation with failure***

Preoccupation with failure is the process of operating with much concern about the possibility of unexpected events that may hinder safety by engaging in proactive analysis and discussions and after action reviews [15]. HRO constantly search for lapses and errors, identifying the fact that they can lead to larger failures, they believe that if warnings are identified and acted on, disaster can be averted [14], so they encourage reporting of errors and near misses, in order to learn from them and improve general safety performance.

***Reluctance to simplify***

HRO have a mental mindset where they try to maintain thinking at a conceptual and abstract level in order to manage the unexpected by deliberately questioning assumption and received wisdom, to create a clear and understandable picture of current situations, by simplifying less and seeing more [15, 18].

Focus is placed on avoiding categorisation and shallow comparison with past events which may lead to simplification, but important details about events such as minor signs of failure are preserved [19].

***Sensitivity to operations***

Sensitivity to operations is the ability to maintain the 'bigger picture' of operations in order to anticipate potential future failures. HRO actively seek views of front line staff to get a realistic picture of the status of operations. Consistent information is shared about potential and current human, and organisational failures, and adjustments are made to prevent the accumulation of errors and escalation of events [15]. Data on incidents and near misses are collected systematically, analysed and catalogued to capture the increasing sources of root causes [15].

***Commitment to resilience***
This is the capability to cope with, contain and bounce back from mishaps before they escalate and cause more damage [15]. HRO successfully recover from failures because of their ability and commitment to learn from past incidents; both from within and outside the organisation. They work on the assumption that errors are inevitable, so they make provision for alternative means of controls in the form of back-ups (redundancies) to deal with the consequences when required. Errors and adverse events still occur, but does not disable HRO [6].

***Deference to Expertise***
This involves applying the highest level of expertise irrespective of rank in solving a problem when the need arises. During emergencies or unexpected events for example, decision-making cascades down to those who have the most expertise to tackle the problem at hand, irrespective of where they are in the hierarchy [17]. Organisation reverts back to the usual hierarchy once the emergency is over.

## 2 Methods

The guidelines for Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [20], was used for this review because of its detailed structure for reporting reviews.

The article aims to investigate how HROs principles can improve construction safety management, by answering the following questions;

1. What types of contexts, work-settings have been used/suggested for investigating HRO studies in construction?
2. Which of the five principles have been investigated?
3. What research designs have been used?
4. What theoretical frameworks have been suggested
5. What are the barriers hindering the application of HRO in construction?
6. What are the possibilities of applying HRO principles in construction?

### 2.1 Search and Identification Strategy

An online database search was carried out to identify peer-reviewed journal articles. Six electronic databases (Cochrane library, Google scholar, Science direct, Scopus, EMBASE, and PSYCINFO) were searched for peer-reviewed journal articles, published in English from 1990 to 2017. The search started from 1990 because HRO was conceptualised in the 1980s and most articles were published from 1990. Checking of reference list was also used as a search strategy in order to identify other relevant articles. The keywords used were: (high reliability organisational theory OR high reliability organisations) AND (high reliability theory OR reliability theory) AND (high risk industries OR high-risk construction work OR high reliability safety management).

## 2.2 Selection Criteria

Papers were selected by two reviewers and included if they focused on;

- HROs theory and application in construction
- Conference papers that made reference to HRO in construction
- High risk industries with reference to construction
- Were peer-reviewed journals

Papers were excluded if they did not focus on;

- HRO theory and application in construction
- High risk industries with reference to construction
- Conference paper that made no reference to HRO in construction
- Non-peer reviewed

A total of seven relevant articles were included in the final review after screening 48 identified articles based on the selection criteria. The selection process is shown in Fig. 1.

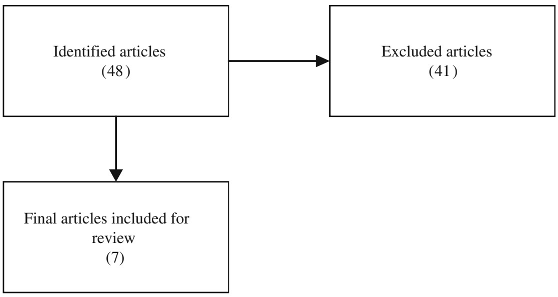


**Fig. 1.** Article selection process

## 2.3 Data Extraction

Data was extracted from the seven articles by the first author and included characteristics of studies presented in Table 1, barriers and possibilities of applying HRO principles in construction, principles and work setting used in various research.

**Table 1.** Research designs

| Study design | Setting | Data collection methods |
|---|---|---|
| Qualitative (exploratory case study) [19] | • Medium size Construction Company<br>• 10–100 employees<br>• 11 participant | • Semi-structured interviews<br>• Face-to-face interview |
| Qualitative (exploratory case study) [3] | • Medium size Construction Company<br>• 70–90 employee<br>• 14 participant | • Semi-structured interviews<br>• Face-to-face interview<br>• Observations |

### 2.4 Quality Appraisal

Quality appraisal for the studies was carried out by the first and third authors. This was done using the Critical Appraisal Skills Programme (CASP). The tool appraises studies to consider if the results are valid [21].

### 2.5 Data Synthesis

All the included studies for the review were qualitative studies, so a narrative synthesis was undertaken using tables and thick description of words for analysis.

## 3 Results

The characteristics of the included articles are presented in Table 2, all articles included in the review were qualitative studies. The barriers and possibilities of applying HRO principles in construction safety management and other findings are presented in the next section.

### 3.1 Principles of Collective Mindfulness Investigated

Four studies [5, 19, 22, 23], investigated the principles of HRO in improving construction safety management. The principles were grouped into two categories of anticipation and containment [22]. Anticipation (preoccupation with failure, reluctance to simplify and sensitivity to operation) which deals with identification of hazards and accident prevention. Containment (commitment to resilience and deference to expertise) deals with reacting and recovering from unforeseen situation, such as project deadlines, environmental conditions and general site uncertainty [22].

**Table 2.** Characteristics and summary of studies

| Study | Country | Methods | Outcomes |
|---|---|---|---|
| Harvey et al. [5] | UK | Review | Identified the barriers and possibilities of applying HRO and RE principles in construction |
| Hoyland et al. [19] | Norway | Case study | Surveys and quantitative assessments need to be conducted to further investigate HRO safety principles, for an understanding of safety mindset in HRO and practices |
| Koh et al. [25] | Hong Kong | Conceptual framework | Further research using mixed methods to explore high reliability practices and organisational processes should be conducted |
| Mitroupoulos et al. [3] | Netherlands | Case study | Prevention of error was identified as the key factor used by high reliability framing crews for increasing productivity and reducing the risk of accidents |
| Olde et al. [22] | USA | Review | HROs principles should be pragmatically interpreted to fit into construction safety management |
| Olde et al. [24] | USA | Review | Principles of HRO can be adopted by the construction industry to improve construction safety management |
| Pillay [23] | Australia | Review | The loosely coupled system in the construction industry makes it difficult to implement HROs principles, but attributes of mindfulness can be used as an approach for advancing HROS in construction |

## 3.2 Barriers Preventing the Application of HRO Principles in Construction

- Frontline operations in construction are taken for granted, because construction workers are victimised for being vocal about safety issues on site.
- Construction is a profit organisation, prone to economic pressure and inconsistent employment from financial constraints.
- The belief that risks are inherent in construction activities, so accidents cannot be avoided.
- The mindset that HRO is only applicable to safety critical industries, and high reliability is only attainable by organisations where safety is the primary focus [5, 24].

## 3.3 Possibilities of Applying HRO in Construction

- Investing more in creating safety awareness for frontline staff, through trainings and encouraging reporting of incidents and near misses rather than apportioning blame.
- Guidelines and strategies that do not jeopardise safety when it competes with production should be designed in reference with HROs procedures.

- Assigning job task to construction workers with the desired skills and training for the job.

### 3.4 Research Designs Used to Investigate HRO

Two empirical studies [3, 19], used qualitative methods in investigating HRO principles in construction. The details are provided in Table 1.

## 4 Discussion

This paper reviewed previous literature on how HRO principles can improve construction safety management. We aimed to identify the barriers and the possibilities of applying HROs principles in construction, HRO principles that have been investigated, research design used, theoretical framework suggested, and work-settings used for investigating HRO studies in construction.

Activities in the construction industry and that of HRO are carried out in complex and hazardous environment. But HRO are able to operate nearly accident-free, achieving the balance between safety and production. While the construction industry struggles to achieve a nearly accident-free performance, as safety is mostly neglected when it competes with production.

In an exploratory case study by Panagiotis et al. [3], they investigated the operations of high reliability framing crews. They discovered that the crew used; extensive material checking, identification of risk areas, error prevention in high risk activities, minimising production pressure, and monitoring alertness as their strategy of preventing errors and rework. The strategy increased productivity, minimised the risk of accidents. Their findings suggest that some principles of HRO overlap with certain construction safety practices but have not been empirically validated [3].

Høyland et al. [19], explored HRO safety principles present in the construction and health care sector in Norway. They found the following HRO safety principles; preoccupation with failure, sensitivity to operations, and commitment to resilience evident in the construction sector. The identified principles were linked to unwritten and informal safety practices in the industry [19].

It was discovered from the study that the identified principles of HRO in construction, were disrupted when focus was placed on production in order to meet project deadlines [19]. The focus on production then affects safety increasing the risk of accidents in the workplace.

Koh et al. [25] proposed a mediational framework of social capital, HRO and safety performance for achieving construction project safety in micro work process. Høyland et al. [19] developed a principles safety model developed from HRO literature. The model was used in their study to identify the presence of HRO safety principles in health care and construction. These were the only model and framework identified from the review.

HRO have systematic procedures which they apply in managing safety, because they operate in a tightly coupled system [5]. A system where activities are coordinated simultaneously, and any error will cause a chain reaction in the entire system of operations. While activities in the construction industry are loosely coupled, activities are not conducted simultaneously and errors from one event does not affect the entire system of operation [5].

The loosely coupled nature in construction industry is one of the major barriers that has hindered the application of HRO principles [5]. But studies have identified opportunities for applying some of HRO principles [3, 5, 19]. Another barrier is the general belief that risks are inherent in construction activities, this belief is something HROs don't agree with because of their cognitive mindset [5]. HRO are of the mindset that, there are certain procedures that can be followed to avoid accidents [16]. These procedures which involves their collective mindfulness and principles are attributes that can be transferred to construction safety management [16].

In the past years construction activities have become more complex, increasing the hazards and risk associated with such construction projects [5]. As complexity and uncertainty increases in the industry more advanced and systematic safety approaches are required to safely manage complex projects.

There are opportunities for applying the principles of HROs in the construction industry, as some of these principles have been identified in safety practices in the industry. Training can be provided to encourage mindful thinking, strategies to achieve the balance between safety and production can be adopted from HROs principles.

Empirical studies included in this review all used qualitative methods to investigate HRO principles in construction, the settings were mostly medium size construction companies, employing 10–100 workers. These principles are yet to be quantitatively explored, which is a major gap in the field. The absence of a theoretical framework or guidelines on how the principles can be transferred is another gap.

This review is part of the first author's PhD which will empirical investigate how HRO principles can be transferred and applied in managing construction safety.

## 5 Conclusion

This review presents the barriers hindering the application of HRO principles in managing construction safety, and also presents the possibilities of applying the principles. The low numbers of articles and absence of quantitative studies were the major limitations of this review.

Further research is needed to empirically validate those principles of HROs that are present in the construction industry [3, 19]. This can be done using mixed method and conducting case studies on some medium scale construction industry. The qualitative aspect will focus on top and middle management ant the quantitative will focus on middle managers and front-line staff using interviews and surveys. The outcome will identify the principles that can be applied to manage construction safety.

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# Organizational Factors, Residual Risk Management and Accident Causation in the Mining Industry: A Systematic Literature Review

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**Abstract.** Organizational factors are considered part of the broader human factors domain that links three aspects of industrial set-ups, namely, the job, the individual and the organization and how these impact on employee health and safety. The broader human factors domain in the context of sociotechnical systems has attracted a lot of research in the past three decades. In particular, organizational factors have long been suspected to have the greatest influence on individual and group behavior at the workplace, although there is little research on their influence in industrial accident causation. In addition, there is little research on the influence of organizational factors on residual risk management in high-risk industries such as mining. Residual or net risk is defined as the level of risk present with all identified risk control measures in place. Most accidents in the mining industry are as a result of residual risk, as compared to inherent risk. Therefore, it becomes imperative to examine accident causation in the context of residual risk management. This paper explains a systematic literature review that is intended to identify research studies published on organizational factors in the mining industry between 1980 and 2017. The aim of the review is to examine the relationship between organizational factors and accident causation in the context of residual risk management. Gaps identified in the literature review would assist in directing future research towards this critical relationship, which is responsible for the injury and loss of many lives in the mining industry. The search strategy involved identifying published and peer-reviewed articles in electronic databases such as Scopus, Web of Science, Proquest, EMBASE, ASCE and CINAHL. Selection of eligible articles was achieved through refined inclusion and exclusion criteria that resulted in a total of 27 articles eligible for review. Primary outcomes and research gaps from the data extraction are presented following the PRISMA reporting checklist.


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**Keywords:** Human factors · Organizational factors · Residual risk
Mining · Accident causation

## 1 Introduction

Despite huge investments in safety, mining companies experience unsatisfactory safety performance such as serious and fatal accidents [1–4]. In order to address the issue of industrial accidents and their causes, different approaches and safety models have been applied since the industrial revolution in the mid-1800 s [3]. Accident prevention in the mining industry in particular focuses on following the hierarchy of controls, wherein engineering controls that seek to eliminate or 'engineer out' hazards are most preferred [5]. More recently, human factors' proponents have advocated for an approach that recognize the centrality of humans in the design, implementation and operation of socio-technical systems [6, 7]. This implies recognizing human factors as possible contributors to mine accidents, especially during accident investigation and risk management processes. Already, the work of Reason [8–11] on active and latent failures illustrates the contribution of human attributes and fallibility on accident causation and therefore provides the basis for investigating human factors in complex high-risk industries.

Human Factors refer to environmental, organizational and job factors including human and individual characteristics, which influence behavior at work in a way that can affect employee health and safety [12]. The National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA) in Australia also retains the issue of interrelatedness between organizational, job and individual factors in its definition of human factors but adds the issue of *human reliability* as a factor in this interaction [13]. Again, according to NOPSEMA [13], these human factors should also be investigated as possible root causes of workplace accidents. Most of these factors are complex and therefore require in-depth analysis to arrive at the appropriate root-causes. The practice of wrongly assigning root-causes to accidents in safety critical domains could actually lead to more disastrous events occurring in future. A case in point is the Bhopal disaster, in which minor accidents that preceded the December 1984 gas leak were not properly investigated and risk-mitigating measures not adequately implemented [14–16].

There is a complex array of issues to be considered when looking at human factors in organizational set-ups. These issues can be divided into three major categories; job factors, individual factors and organizational factors [17]. The UK Health and Safety Executive [18] suggested that organizational factors have the greatest influence on individual and group behavior, yet these factors are often overlooked during the design of work and during investigation of accidents and incidents. Other industry safety specialists also concur and advocate for a clearer understanding of these organizational issues in order to create a principled basis for more effective culture-enhancing practices [10, 19].

Industry experience and research has shown that organizational factors in complex socio-technical systems can be divided into several attributes such as organizational safety culture, procedures, training and competence, safety-critical communication, resources, safety leadership and organizational learning [12]. Following this line of thought, this review aims to explore these factors in detail, validate them and extrapolate the most influential organizational factors in the mining industry, including the relationship between organizational factors and residual risk management. A deliberate focus on repeat accidents is informed by the fact that as lag indicators, repeat accidents are themselves a measure of how well mining companies manage their residual risk. The rationale is based on the assumption that if a company experiences repeat accidents, it implies that the risk controls implemented by the organization to mitigate against residual risk are not effective or ill targeted. Moreover, it also implies that the organization is not learning from its past accidents. Therefore, the scope of this systematic literature review (SLR) included the relationships between human factors (in general), organizational factors (in particular) and accident causation in so far as managing residual safety risk in the mining industry is concerned.

Cornelissen et al. [2] conducted a systematic literature review of determinants of safety outcomes and performance in four high-risk industries. Their aim was to provide a comprehensive overview of behavioral and circumstantial factors that positively or negatively impact on employee safety in construction, offshore petrochemical, warehouse and manufacturing industries [2]. Although similarities can be traced between the review by Cornelissen et al. [2] and this SLR, especially concerning behavioral and circumstantial factors, the fundamental differences lie in the population or domain under study, scope and the independent variables related to residual risk management. Cornelissen's review covers four industries, while this SLR will focus specifically on the mining industry. Furthermore, the review by Cornelissen et al. [2] is intentionally broad, focusing on broad keywords such as safety performance, safety compliance and safety participation. This approach has a possible effect of sidelining critical research conducted using nomenclature specific to the human factors domain. In contrast, this SLR sought to identify specific studies conducted within the mining industry so as to enhance understanding of organizational factors and attributes as possible causal agents to accidents in the mining industry. In the same studies, focus should be on the broader risk management protocols in the mining industry as suggested by Horberry et al. [5].

## 2 Objectives

This systematic literature review aims to identify research studies published on organizational factors and residual risk management in the mining industry between 1980 and 2017. The studies would also need to examine the relationship between organizational factors and accident causation. Specifically, we are interested in answering the following questions:

a. What is the relationship between organizational factors and accident causation in the mining industry?
b. What is the relationship between organizational factors and residual risk management in the mining industry?
c. What are the critical controls used to address organizational factors in the mining industry? Critical controls may also be error risk controls used to address human factors issues in the mining industry.

Although objective (c) forms part of the broader objectives of this SLR, the results presented in this paper will only be limited to objectives (a) and (b).

## 3 Methods

**Protocol and Registration**
A protocol was developed to guide the researchers in conducting the SLR. The protocol is currently not registered, although there is intention to register it with an open source journal such as Prospero. Currently, the protocol can be accessed by contacting the author(s).

**Eligibility Criteria**
Peer-reviewed articles published between 1980 and 2017 (inclusive) were considered for this SLR. The 1980–2017 range was selected because significant research on human factors was conducted towards the end of the 20$^{th}$ century as a result of major industrial accidents and disasters such as Bhopal, Challenger, Three-Mile Island and Chernobyl. For the purposes of this review, only articles from peer-reviewed journals and conference proceedings in the English language were included. Conference proceedings were included because most research and information sharing within the mining industry usually takes place in industry-specific conferences. In summary, the inclusion and exclusion criteria were set out as follows:

**Inclusion Criteria**
Published empirical studies, were included if they;

a. Focus on human factors and in particular organizational factors in the mining industry. Mining industry in this context refers to the total process cycle involved in the extraction and processing of mineral ore and coal.
b. Focus on the causes of incidents in the mining industry, in particular repeat incidents
c. Focus on the relationships between organizational factors and accidents in the mining industry
d. Focus on the critical controls used to address organizational factors-related risks in the mining industry
e. Focus on the gaps in knowledge or understanding of organizational factors in the mining industry
f. Focus on human factors in other high-risk industries that include mining
g. Are published in peer-reviewed journals and conference proceedings

**Exclusion Criteria**
Studies were excluded if:

a. They focus on organizational factors in irrelevant industries outside the minerals industry, for instance, non-high-risk industries such as information technology (IT), health, education etc.
b. They focus exclusively on a particular high-risk industry that excludes mining, for instance, aviation, construction, chemical etc.
c. They focus on other human factors such as job and individual factors while excluding organizational factors. However, studies that include all the three categories of human factors will be considered

d. They focus on illegal mining and artisanal mining
e. The literature was published prior to 1980
f. They are from non-refereed sources
g. They are published in non-English languages

**Information Sources**
Through guidance from local librarians, six databases were selected to provide the primary data of interest. These are Scopus, Web of Science, Proquest, EMBASE, ASCE and CINAHL. Full-text articles were obtained from sources provided by the University of Newcastle, Australia library. Authors of journal articles were also contacted to provide full text articles where these could not be obtained in the public domain.

**Searches**
The search strategy involved identifying key articles between 1980 and 2017 in the following electronic databases; Scopus, Web of Science, Proquest, EMBASE, ASCE and CINAHL. The aim was to capture as much literature as possible that examines the relationship between organizational factors and residual risk management in the mining industry. Therefore, the search strategy included both broad terms and specific terms such as the following keywords:

*Human factor**, *behavi** *factor**, *organi?ational factor**, *risk**, *safety, accident**, *incident**, *mining, miner**

The results of the search strategy produced 206 articles from Scopus, 32 articles from Web of Science and 5 articles from Proquest. The rest of the databases did not yield any results. All identified search results were exported to EndNote using built-in tools in each database. This approach minimized human error associated with manual transfer of search results.

**Study Selection**
The study selection process involved a simplified procedure adapted from Cornelissen et al. [2] to select the eligible full-text articles published between 1980 and 2017 (both years inclusive). A flowchart for this procedure is shown in Fig. 1, incorporating the results of the study selection process. Abstract screening and full-text screening was done by two independent reviewers. Disagreements on article selection were handled through engagement and discussion between the two reviewers. A third reviewer was available for any disputes that could not be resolved through this process.

**Data Collection**
Using guidance on systematic reviews from the Centre for Reviews and Dissemination at the University of York [20], a data extraction form was developed in Excel 2016 as a spreadsheet and used to capture information from the eligible articles. Some of the information captured included:

a. General information (for instance, researcher performing data extraction, date of data extraction)
b. Identification features of the study (unique identifying number, author(s), title etc.)

c. Study characteristics (e.g. aim of the study, study design)
d. Participant/population characteristics
e. Themes, sub-themes, type of analysis
f. Variables such as relationship between organizational factors and accident causation, human factors methods used, error risk controls and gaps for further research
g. Outcome data/Results

## 4 Results

A total of 243 articles were obtained from the literature search using the search strategy described in Sect. 3. As shown in Fig. 1, abstract and full-text screening were conducted following the eligibility criteria and resulted in 27 articles eligible for review.

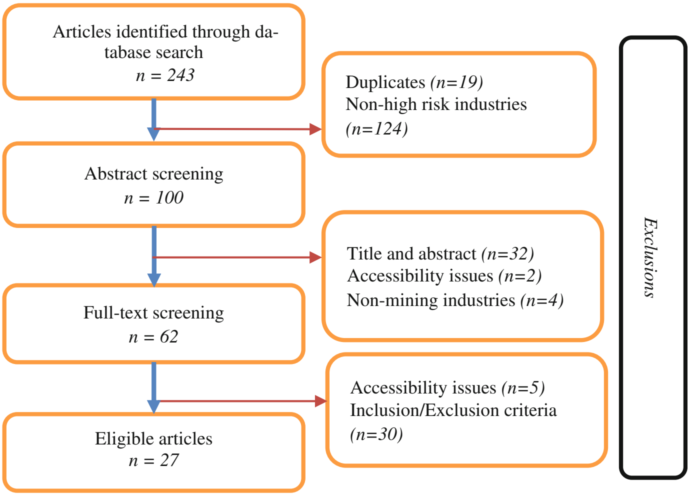


**Fig. 1.** Results of study selection

### 4.1 Study Characteristics

Table 1 gives a summary of study characteristics with respect to study designs. Although most studies overlapped in design characteristics, 70% of the studies were reviews, which either involved literature reviews or archival research. 54% were descriptive designs that included case studies and surveys. The rest were either cohort or experimental studies.

**Table 1.** Summary of study characteristics

| Study characteristic – study designs | Number of studies |
|---|---|
| Descriptive | 14 |
| Correlational | 2 |
| Experimental | 1 |
| Reviews | 19 |

Table 2 shows study characteristics based on the type of industry or sub-sector. From this categorization, it was observed that 48% of the studies reviewed, dealt with coal mining while 15% included mining and other high-risk industries such as nuclear and manufacturing. There were no studies that focused solely on metalliferous mining while 26% of the studies covered general mining and had no specific scope.

**Table 2.** Type of industries

| Type of industry | No. of studies |
|---|---|
| Coal mining | 13 |
| Metalliferous mining | 0 |
| Combined (Coal mining and metal mining) | 2 |
| Support Services (Engineering, Maintenance) | 1 |
| Mixed industries (Mining and other high-risk) | 4 |
| Not defined (Mining in general) | 7 |

## 4.2 Organizational Factors

Of the 27 studies reviewed, all but 1 study focused on organizational factors in one way or another. No study examined the extent of the influence of organizational factors on accident causation using mathematical models or the effect size of any of the organizational factors identified. However, 18 studies explored a somewhat relationship between organizational factors and accident causation as shown in Table 4. Table 3 shows the number of studies that examined organizational factors in the mining industry. From this analysis, it is clear that safety culture, communication and leadership have received the most attention from researchers, while learning from incidents, training and shift-work patterns have the least number of studies.

Table 4 shows the list of articles that examined relationships between organizational factors and variables of interests in this study, namely accident causation and residual risk management.

Table 4 shows that 18 articles examined the relationship between organizational factors and accident causation while only 2 articles included residual risk management as a variable in the relationship. The relationship examined was only limited to qualitative analyses where the thrust was to confirm that organizational factors have an influence in mining accidents including how mining companies manage their residual risk.

**Table 3.** Influential organizational factors reviewed

| Organizational factors | No. of studies |
|---|---|
| Safety culture (includes safety climate) | 14 |
| Communication | 12 |
| Leadership (includes OHS and operational leadership) | 10 |
| Procedures and Standards (includes violations) | 8 |
| Risk perception (includes risk-taking behaviors) | 6 |
| Management decisions (including commitment and errors) | 5 |
| Supervision (Middle level and front-line) | 5 |
| Resource management and allocation | 3 |
| Organizational learning (Learning from past incidents) | 2 |
| Training and competence (includes skill-based errors) | 2 |
| Shift work patterns | 1 |

**Table 4.** Relationships between organizational factors and variables of interest

| | Variable of interest | |
|---|---|---|
| Author(s) | Accident causation | Residual risk |
| Caples (1998) | Yes | No |
| Chen et al. (2012) | | Yes |
| Dodshon and Hassall (2017) | | No |
| Donovan et al. (2017) | | Yes |
| Dragan et al. (2017) | | No |
| Ghosh et al. (2004) | | No |
| Hermanus (2007) | | No |
| Lenné (2012) | | No |
| Nasarwanji (2016) | | No |
| Patterson and Shappell (2010) | | No |
| Peters and Wiehagen (1988) | | No |
| Stephan (2001) | | No |
| Terezopoulos (1996) | | No |
| Uchino and Inoue (2002) | | No |
| Verma and Chaudhari (2017) | | No |
| Xia (2010) | | No |
| Yulianto, Haramaini and Siregar (2015) | | No |
| Yunxiao and Yangke (2014) | | No |

**Key**:

**Yes**: *Refers to studies that examined or explored the relationship between at least one organizational factor with a variable of interest*

**No**: *Refers to studies that did not explore any relationship between an organizational factor with a variable of interest*

## 5 Conclusion

The systematic literature review confirmed several organizational factors, as shown in Table 3 as being influential in the mining industry. Although no studies examined this influence using quantitative analyses or mathematical models as a way of determining the extent of the influence, their popularity in research studies justify the need to dedicate more resources in examining the complex relationships around accident causation in the mining industry. It is also clear from the SLR that residual risk management as a concept that is directly related to accidents, especially recurrent ones has not been adequately explored. This relationship is crucial as more businesses shift towards risk-based safety management systems. Considerations on residual risk management would assist mining companies to focus on the effectiveness of risk controls, most of which are affected by human factors-related issues. This shift in approach is likely to result in less accidents occurring and an improved safety performance.

Through the outcomes of this SLR, it is now also possible to focus further research on, the most popular organizational factors as a way of developing effective industry interventions or focus on the less researched organizational factors in order to build up more knowledge. Furthermore, it is crucial to steer research on accident causation within the mining industry towards residual risk management, as this has potential to improve the overall safety risk culture of mining companies, thus translating to less accidents in the mining industry.

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# Measure Evaluation Tool MET: Promoting Safety by Optimizing the Human Scope of Action

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**Abstract.** Safety Management Systems (SMS) normally base on the assumption that safety can be guaranteed through a prescription of a one-best-way of activity performance. Any deviation from this one-best-way is considered a violation. Main objective of safety measures is therefore to eliminate variability in human performance. A more comprehensive safety perspective recognizes that the operating conditions under which activities must be performed are never ideal. The human ability to adapt performance depending on the current situation is consequently considered a strength that should be supported in order to enhance safety. The possibility to deploy this strength should therefore be guaranteed. For this purpose, a safety tool – the Measure Evaluation Tool (MET) – that supports the definition of an appropriate human scope of action was developed. This is following presented.

**Keywords:** Safety management · Safety-I · Safety-II · Human scope of action Prioritizing · Operating conditions

## 1 Introduction

Safety Management Systems (SMS) are a systematic approach to manage safety, including the necessary organizational structures, accountabilities, policies, and procedures [1]. Actual SMS normally incorporate a Safety-I perspective defining safety as the absence of things that go wrong (e.g. occurrences, incidents and accidents). From this perspective, such adverse events are caused by technical, human and/or organizational failure or malfunctioning [2, 3]. To avoid adverse events in future, their causes have to be identified and appropriate preventive measures have to be taken. Biased by hindsight the respective analyzes often reveal human behavior that deviates from the prescribed one-best-way to carry out an activity. Such deviations are seen as major contributions to the adverse events and hence as a risk. Thus, Safety-I views the human as a risk factor, potentially harming the system due to the variability in his behavior. To mitigate this risk, variability in human performance is restricted by means of standardization, regulation, automation and the like. From this perspective, reduction of human scope of action is required to guarantee stable results, i.e. to successfully achieve


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the aimed outcome of the activity. However, the operating conditions under which an activity normally has to be performed are dynamic and constantly changing [2, 3]. As a consequence, reducing scope of action restricts the humans' potentiality to adapt to the dynamics of operating conditions and therefore their chance to deliver stable results as outcome of their activities. Indeed, it is the need to adapt to dynamic operating conditions in order to achieve an aimed objective that creates variability in the way humans are carrying out activities [4]. Against this background, unsuitable restrictions of human scope of action does not only not provide to more stable results, it even hampers it. Therefore, standardization and the like may reduce system safety.

For this reason, the Safety-I based SMS-approach needs to be critically reflected regarding the appropriateness of standardizations and restrictions of human scope of action it delivers. To avoid unsuitable restrictions the Safety-I approach needs to be complemented by the Safety-II perspective. In contrast to Safety-I, Safety-II defines safety not as the absence of things that go wrong but rather as the presence of things that go right [2, 3]. It recognizes performance adjustments and hence performance variability as the basis for successful adaptation to dynamic operating conditions and therefore for successful performance. Since the human has the ability to adjust behavior to situational dynamics, Safety-II considers the human not a risk factor only but also a safety factor and a main source for system resilience and safety. Precondition to deploy this ability is scope of action.

## 2 Objectives and Proceeding of the Project

The Safety-II approach is very well founded in theory. However, it is much less clear how to implement the Safety-II perspective into existing SMS. It was therefore the objective of this project to develop a safety tool based on Safety-II assumptions, which can be integrated into existing Safety-I based SMS. Safety-II aims not at substituting Safety-I but at supporting and completing it. Correspondently, a Safety-II based tool is not aiming at contradicting Safety-I based means to assure safety but at improving them.

In order to concretize the focus of the Safety-II based tool as well as the framework conditions of its application, nine semi-standardized qualitative interviews with safety experts from aviation have been conducted. By means of a qualitative content analysis, specific objectives regarding *what* the tool should be able to achieve were identified. These objectives are described in the next section. Furthermore, the analysis also revealed *how* the tool should achieve its objectives – i.e. which framework conditions it should respect. As a result, a tool that is easy for appliers to understand, that produces clear results and high acceptance among appliers, that does not require excessive resources and that can be easily integrated into everyday work was envisioned.

Based on the identified objectives, indicators have been developed in order to evaluate the tool. Through pilot applications of the tool in different organizations, it could be assessed that these indicators were achieved. Hence, the Safety-II based tool as developed in this project is suitable to achieve the objectives as they were set by the safety experts. It is described in the following sections.

# 3 The Measure Evaluation Tool (MET)

The tool's purpose is to complement actual SMS by incorporating a Safety-II based approach into SMS. However, foci need to be set as the resources for applying the tool are limited. One possibility to set a focus is to use the tool for evaluating measures generated by the traditional, Safety-I based approach. Such measures – as outlined above – typically base on the analyzes of adverse events, identify deviations from the one-best-way as root causes and aim at protecting the one-best-way by means of standard operating procedures (SOP's) and the like. At this point, the tool can be used to analyze whether or not the Safety-I based measures create new risks as a side effect by depriving the human performer from scope of action required for the necessary performance adjustments in everyday operations. Setting this focus, the tool can be integrated into traditional, Safety-I based SMS thereby supporting the improvement of safety measures from both the Safety-I and the Safety-II perspective combined. Against this background, the tool has been named MET, i.e. Measure Evaluation Tool.

## 3.1 Objectives of the MET

The MET supports the identification of risks and side effects of safety measures that reduce the human scope of action. To reach this aim, the following objectives are set for the MET:

(1) Describing the work as it really is: The MET does not base on the assumption of idealistic operating conditions as it usually is the case for Safety-I based safety measures. It identifies and describes concrete operating conditions under which the human normally has to perform work. It therefore describes work as it really is, i.e. work as done.

(2) Identification of prioritizations: The MET recognizes that operating conditions are dynamic. It recognizes therefore that the human, based on the actual operating conditions, has to constantly adjust his performance. To do so, he puts more or less effort in an activity based on situational circumstances and thereby he prioritizes certain activities over others.

(3) Identification of the necessity of prioritizations: By identifying actual operating conditions, the MET is able to discern «why» and «how» prioritizations are made. Whereas the former describes the reason for performance adjustments, the latter identifies concrete decision-making criteria for prioritizing under everyday operating conditions.

(4) Identification of strengths and weaknesses of prioritizations: Based on the identified operating conditions, the MET allows on the one hand understanding what the strengths of prioritizations are. Every appropriate way in which prioritizations are made in order to adapt to the operating conditions present in a specific situation to achieve a specific objective is considered a strength of prioritizations. On the other hand, the MET also allows understanding what the weaknesses of prioritizations are. Every inappropriate way in which prioritizations are made is considered a weakness of prioritizations.

(5) Identification of risks and side effects of Safety-I based safety measures: Based on strengths and weaknesses of prioritizations, risks and side effects of Safety-I based safety measures are identified. These emerge from a reduced scope of action that hampers appropriate prioritizations.
(6) Support for the development/improvement of safety measures: The identification of risks and side effects allows improving safety measures.
(7) Integrating the tool in actual, Safety-I based SMS: Finally, it is an important objective of the project to develop a practicable tool that can be integrated into existing Safety-I based SMS complementing them with the Safety-II perspective.

### 3.2 Conceptual Background of the MET

The conceptual background of the MET is depicted in Fig. 1. It mainly refers to the above-mentioned necessity of performance adjustments, i.e. on the need to adapt the way of carrying out a certain activity to concrete and dynamic operating conditions. Whenever the human performs an activity, he has to balance efficiency and thoroughness (cf. Efficiency-Thoroughness Trade-Off (ETTO); [5]). Performing an activity thorough means to do it perfectly accurate without negligence or omissions. However, perfection of thoroughness is not achievable as there is always the possibility to perform an activity even more thoroughly. Perfect thoroughness therefore would require – at least theoretically – infinite time. As time is always limited, the activity has to be completed in due time and hence the human performer needs to decide on an appropriate level of thoroughness. By this decision, be it taken consciously or unconsciously, the performance's efficiency and thoroughness when carrying out the activity is balanced. Figure 1 depicts this continuum of efficiency and thoroughness on the axis of ordinates.

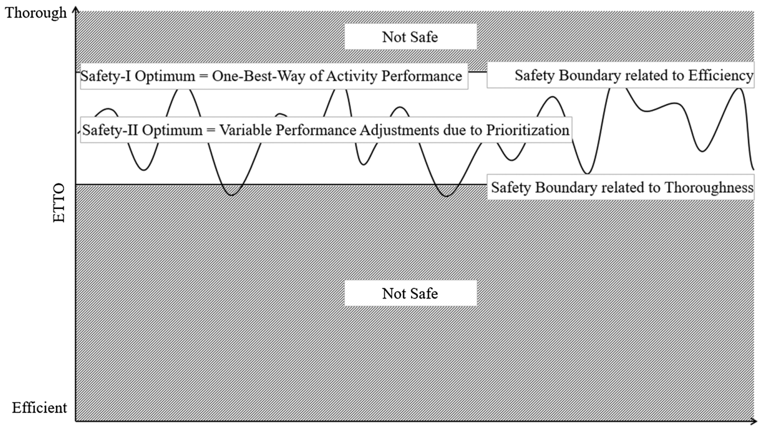


**Fig. 1.** Conceptual background of the MET

Safety-I based regulations often define a one-best-way for performing an activity (e.g. by SOP's). Thereby, ideal operating conditions are assumed for activity performance. Deviating from the prescribed one-best-way is hence considered a violation of the regulations. The evaluation scheme is bimodal, i.e. the one-best-way is considered right, any deviation from it is considered wrong. Figure 1 depicts the one-best-way as Safety-I Optimum. However, operating conditions are normally dynamic and not ideal (e.g. lack of time as many different activities need to be performed within a limited time slot). As a consequence, the human is forced to adjust his performance to the current situation by balancing efficiency and thoroughness in a way meeting a concrete situation's actual requirements. This creates variability in human performance, depicted in Fig. 1 as a winding line on the continuum of efficiency and thoroughness. In contrast to the viewpoint of Safety-I, Safety-II considers this performance variability not a deviation, but a necessary adjustment to normal operating conditions. From this point of view, performance variability is not only no violation. It even is the main human contribution to successful performance as it allows for resilient coping with non-idealistic, i.e. limited and dynamic operating conditions.

Even more, carrying out an activity perfectly thorough must not necessarily be safe. In emergency cases for example, safety may require quick rather than thorough action. Otherwise, the patient dies before the emergency physician comes up with a thorough diagnosis. Also, in normal operations activities need to be completed in due time in order to be safe. Endless analysis for example regarding the appropriateness of a measure may prevent from taking any measure at all, which in turn does not make the system safer. Consequently, the Safety-I Optimum as depicted in Fig. 1 also represents a Safety Boundary related to Efficiency. Going above this limit endangers safety due to too little efficiency, although this might be rare in workaday life.

On the other hand, a total prioritization of efficiency over thoroughness would – at least theoretically – mean to deliver zero thoroughness. Consequently, there is a lower limit for ETTO depicted as Safety Boundary related to Thoroughness in Fig. 1. This limit represents a safety boundary to performance variability. Going below it would endanger safety from both perspectives, Safety-I and Safety-II.

However, different to Safety-I, Safety-II takes the position that not only the one-best-way of performing an activity is safe but all the range between the Safety Boundary related to Efficiency as upper limit and the Safety Boundary related to Thoroughness as lower limit. The respective range is labeled Safety-II Optimum in Fig. 1 as it balances efficiency and thoroughness optimally for a specific activity in a specific situation. This also takes into consideration other activities that have to be performed in a specific situation, as time for performing a specific activity may be limited by the necessity to perform other activities as well. Consequently, the need for ETTO within an activity is not necessarily dependent on the activity itself only, but on the total workload.

Of course, the minimum thoroughness respectively the Safety Boundary related to Thoroughness is not known. However, crucial for the MET-concept is that variability in human performance within the optimal range is not considered a performance deviation but a normal performance that is both, necessary (as the adjustment is required by the situation) and adequate (as the adjustment is enhancing safety). Therefore, it is also considered safe, although it deviates from the one-best-way defined by Safety-I based regulations. Even more and in accordance with the Safety-II assumptions, variability is considered just normal in everyday work.

Against this background, it is crucial for safety that prioritizations are made appropriately, i.e. in a way adequately taking into account a situation's specific operating conditions. To support this adequacy, relevant decision-making criteria for balancing efficiency and thoroughness need to be understood. Systematically identifying such criteria is the main gain of the MET. It guides through several steps of analysis that are suitable to identify an activity's everyday operating conditions. Thereby it distinguishes between primary operating conditions that cause the need for performance adjustments (e.g. limited resources), and secondary operating conditions that are decisive when the performance concretely is adjusted, i.e. when a concrete balance of efficiency and thoroughness is established (e.g. activity's risk). Both types of operating conditions need to be considered adequately when deciding on performance adjustments. Hence, they are the respective decision-making criteria. The MET refers to the FRAM method [6] for conceptualizing different kinds of operating conditions (cf. Sect. 3.3).

The steps of the MET are described in the following section.

### 3.3 Steps of the MET

Following, the eight steps of the MET are described:

(1) In a first step, the core activity regulated by the safety measure to be evaluated is identified. The core activity is the very activity in the focus of the analysis when applying the MET. To identify the core activity, the activity where the prioritization (from a Safety-I perspective considered a deviation and hence a violation) took place has to be recognized. By analyzing prioritizations performed in order to adapt to varying operating conditions, it can be understood (in the further steps of the MET) how operating conditions are in reality – and not as imagined as often it is the case when regulations are developed. On the basis of this first step, it is subsequently possible to identify the work as done (objective 1) and to identify the prioritizations that the human performer normally has to do (objective 2).

(2) In the second step, the concept of operating conditions is introduced. Based on the FRAM method [6], the MET considers inputs, preconditions, time, controls and resources as the central operating conditions of activities that force the human to adjust his performance in order to achieve specific set objectives, i.e. the outputs of an activity. These outputs are defined as that which is the result of an activity. In the MET, the outputs are not considered operating conditions as they do not influence how activities are performed. Instead, they result from it. The inputs are that which starts the activity and/or is used or transformed to produce the outputs. Preconditions are conditions that must be fulfilled before an activity can be carried out. Time corresponds to temporal aspects that affect how an activity is performed. Controls correspond to that which supervises or regulates an activity (e.g. plans, procedures, guidelines or other activities). Resources are that which is needed or consumed for the performance of an activity (e.g. matter, energy,

competence, software, manpower). All these definitions correspond with the respective definitions used by Hollnagel in the FRAM method [6].

(3) In a third step, the outputs are identified in order to differentiate between wanted and unwanted outcomes of the core activity.

(4) In the fourth step, the inputs are identified (first part of objective 1). In addition, variabilities that can arise in the inputs are identified in this step. As mentioned, operating conditions are over the time respectively in different situations never exactly the same. In this step it should therefore be described how the inputs of the core activity usually are and how they typically variate in different situations at different times.

(5) In a fifth step, the remaining operating conditions and the variabilities that typically arise in these operating conditions are identified (second part of objective 1). In this step, for all the operating conditions is further specified if they are primary or secondary operating conditions, whereby some of them can be both. Primary operating conditions cause the necessity for performance adjustments. They determine the reason «why» there must be a performance adjustment. Through their identification, the necessity of prioritizations can therefore be acknowledged (objective 2 & 3). Scarcity of time is an example for a primary operating condition because, in order to achieve an output of the core activity in a given timeframe, this activity must be prioritized over other activities leading to a performance adjustment. Often, primary operating conditions are not activity specific but instead they result from the set of the activities to be performed in a specific situation (e.g. too many activities must be performed in too little time). Secondary operating conditions provide decision-making criteria for a performance adjustment. Hence, they determine the «how» of the prioritization. Riskiness of an activity (e.g. resulting from lacking resources) is an example for a secondary operating condition. An activity with a high riskiness needs to be performed more thoroughly than one with a low riskiness. When there is a need to prioritize between two activities because there is a primary operating condition in place, the secondary operating condition determines which of the two activities is prioritized over the other. Secondary operating conditions are activity specific because they base on the characteristics of a specific activity.

(6) In the sixth step, the importance of the operating conditions (i.e. how much they influence the decision of prioritization) is determined. More important operating conditions are used as a basis for suggestions aiming at improving the safety measure in the eighth and final step.

(7) The consequences of the prioritization are identified in the seventh step. Through this step, strengths and weaknesses of the prioritization (objective 4) and possible side effects of safety measures (objective 5) are assessed. As mentioned, every appropriate way in which prioritizations are made should be considered a strength, every inappropriate way a weakness. Only ways that enhance the probability of achieving wanted outcomes respectively of avoiding unwanted ones are appropriate and should therefore be supported by safety measures. Hindering the possibility to make appropriate prioritizations is considered a side effect of safety measures.

(8) In the eighth step, suggestions for developing/improving the safety measure are formulated (objective 6). From a Safety-I perspective, it is first focused on the most important primary operating conditions (identified in the fifth and sixth step) that should be controlled. This means that the necessity of prioritizations caused by these operating conditions should be reduced. As a consequence, the safety measure would result to be more appropriate for the operating conditions that really are present in typical situations where the human performs the activity. From a Safety-II perspective, it is then discussed which decisions of prioritizations should be supported and which should instead be hindered. This discussion is based on the secondary operating conditions identified in the fifth step. Hereby, only prioritizations that are identified to be appropriate should be supported.

### 3.4 Example of a Concrete Case

In the following section, a fictional case is described in order to illustrate the theoretical background of the project and how the MET can be applied:

*In an acute care hospital, the administration of medicine to the patients is regulated by a safety measure that imposes that, before nurses administer medicines to the patients, another nurse must have checked the medicines. However, the measure does not consider that the acute care hospital lacks nurses and because of the very big amount of patients, nurses typically do not have enough time to check the medicines of every patient before they are administrated. This means that in practice it is actually impossible to follow the safety measure as prescribed. Theoretically, it might be possible, but this would be at the cost of doing other safety-critical activities less thorough. In order to overcome this problem, nurses have always more thoroughly checked the medicines that must be administered to the patients that they consider «risk cases»–i.e. patients for which a mistake in the medicine administration would have severe consequences for their health. The medicines that had to be administered to the patients not considered «risk cases» were only checked thoroughly – or checked at all – if there was enough time. In this way, dangerous administrations of medicines could be avoided, respectively reduced as much as possible. However, after a patient died because of the administration of the wrong medicines, the safety measure has been strengthened. The check of the medicines by the nurses must now be documented with the signing of a document of approval. Since the measure cannot be followed because it does not take into account the typical operating conditions under which the hospital's personnel actually has to work, nurses are forced to continue deviating from the safety measure. As a consequence, nurses often sign the documents at the end of their work shift, not necessarily really having checked the medicines administered to the patients not considered «risk cases».*

In this example, the typical approach of Safety-I is described: If an occurrence takes place, its cause is typically found in human behavior that deviates from the right way to perform an activity (or the one way that is considered right, i.e. the one-best-way specified in the safety measure). Thus, to mitigate this risk, variability in human performance (i.e. the possibility to deviate from the safety measure) is further restricted. Following the steps of the MET's application are described with reference to the example.

(1) In the first step, the core activity is identified. In the present case, the core activity is «checking the medicines» because in this activity, a prioritization (from the Safety-I perspective considered a violation) took place.
(2) In the second step, the concept of operating conditions is introduced. This step can be carried out independently from the specific case analyzed.
(3) In the third step, the outputs of the core activity are identified. In this case, the main output corresponds to «checked correctness of medicine» . Based on the identification of the outputs, it can be differentiated between the wanted outcomes (e.g. incorrect medicine has been identified) and the unwanted outcomes (e.g. incorrect medicine has not been identified).
(4) Further, in the fourth step the inputs and the variabilities that typically arise in it are identified. In this case, the main input corresponds to receiving the medicines that must be checked. Typical variabilities in the input are for example that medicines sometimes arrive too late or that they are incorrect or incomplete.
(5) In the fifth step, it is possible to identify the other operating conditions under which the hospital's personnel actually has to work (i.e. preconditions, time, controls and resources) and how they typically variate. Such, the MET allows to identify among other factors that there is normally not enough time to perform the core activity because there are not enough resources. Thanks to the identification of the operating conditions and how they typically variate, it is furthermore acknowledged *why* and *how* the hospital's personnel has to prioritize. By doing so, it is distinguished between primary and secondary operating conditions. In this case, the lack of time and resources are identified as primary operating conditions. In fact, these force the hospital's personnel to prioritize certain checks of medicines over others. In the presented case, depending on the perceived severity of the patients' condition, nurses decide which medicines to check more thoroughly, i.e. the check of which medicines is prioritized. This operating condition describes *how*, i.e. based on which criteria, the hospital's personnel decides to prioritize medicines to be checked. It is therefore a decision-making criterion for a performance adjustment, and hence a secondary operating condition.
(6) In the sixth step, the importance of the identified operating conditions is assessed. In the case, lack of time and resources and the perceived severity of the patients' condition are assessed as important operating conditions because they strongly influence the performance of the core activity.
(7) The consequences of the prioritization are identified in the seventh step. In this case, consequences are that the medicines are checked more thoroughly for the most critical patients. Therefore, the probability that these patients get the correct medicines is enhanced and the probability that they get incorrect medicines is reduced – i.e. the achievement of wanted outcomes identified in the third step respectively the prevention against unwanted outcomes are improved. This means that constraining the possibility to check the medicines less thoroughly destined for non-critical patients in order to have enough resources to check the medicines more thoroughly destined for critical patients hinders a crucial strength of the prioritization and is therefore considered an unwanted side effect of the safety measure.

(8) Thanks to the MET, based on the most important primary operating conditions identified in the fifth and sixth steps, in the eighth step the safety measure could be improved from a Safety-I perspective by reducing the necessity to prioritize as much as possible. This could be achieved, for example, by hiring more health personnel or providing more time to check the medicines. However, as workload in hospitals normally is not equally distributed, there will always be workload peaks causing time pressure. Therefore, the safety measure should also be improved from a Safety-II perspective, formulating criteria based on which it should be decided how to prioritize accurately when checking medicine. To do so, reliable criteria are required. The identification of the most important secondary operating conditions in the fifth and sixth steps allows in the eighth step to identify such criteria. In this specific case, in fact, it could be discussed if the perceived severity of the patients' condition can be considered an appropriate criterion based on which it should be decided how to prioritize. If so, safety measures have to make sure that the perception of severity of the patients' condition is reliable. It must be avoided that health personnel considers «risk cases» non-risky. Accurate perception of the patients' condition makes sure that performance adjustments are made in a way not endangering safety.

## 4 Discussion

In the complexity of today's world, the safety approach of traditional SMS comes to its limits. Traditional SMS often introduce regulations that describe the one-best-way of performance for every activity and then require from the human to follow it perfectly thoroughly. Through this process, SMS aim at standardizing performance assuming that carrying out activities always in the exactly same and one-best-way is suitable to avoid adverse events and hence ensures safety. Every deviation from this one-best-way is therefore considered a violation. Consequently, because of the variability of his performance when performing activities, the human is seen as a risk factor. This perspective is known as Safety-I. A more comprehensive perspective, known as Safety-II, points out that the operating conditions under which activities must be performed are never ideal nor perfectly stable. It is therefore not possible to set a one-best-way for every activity in every situation. In order to adapt to the unideal, varying operating conditions, a certain amount of variability is needed. Variability in human performance – i.e. performance adjustments – is in fact the result of adaptation to the operating conditions present in a specific situation and should therefore not only be considered a risk factor but also a crucial safety factor. Reducing human scope of action when adjustment performances are actually needed can hinder safety and should therefore be considered an unwanted side effect of safety measures [3, 4].

The Measure Evaluation Tool (MET), devolved in this project and in close collaboration with safety experts from aviation, bases on the Safety-II assumptions. Thanks to the MET, actual operating conditions and their typical variations can be identified. This allows understanding why and how performance adjustments are needed. The results of the MET allow therefore to improve Safety-I based measures by reducing their side effects.

Strengths of the MET: A major strength of the MET is that it allows improving SMS with a new perspective that is appropriate for the complexity of today's reality. Furthermore, the MET is thought to be integrated in traditional SMS and can therefore be considered a practicable tool actually able to effectively apply the theoretical assumptions on which it is based.

Weakness of the MET: To fully implement the Safety-II assumptions, an organization's safety culture needs to develop. Among others, deviations from regulations should not be considered a priori violations and the need for variability and performance adjustments should be recognized. The MET alone can of course not change the safety culture of an organization. This can be considered a weakness of the tool. However, thanks to the MET, a first important step in the right direction can be made.

Practical implications: It is strongly recommended to integrate the Safety-II perspective in actual SMS. The MET represents a concrete way to realize this purpose allowing the recognition and avoidance of inappropriate, excessive standardization of work. Considering the complexity of today's organizations, optimizing human scope of action is the only way to make systems safer, hindering human weaknesses while supporting human strengths. Implementing the MET in aviation organizations would therefore improve their safety.

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# The Influence of Organisational Safety Climate on Group Safety Outcomes: The Mediation Role of Supervisor Safety Communication and Monitoring

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**Abstract.** Safety climate is an important leading indicator of safety performance and reflects the priority of safety within industrial operations. Previous research has identified safety climate as a multilevel and multidimensional construct, which involves the interaction of multiple social agents at various levels of organisations, including managers, supervisors, and work-groups. The present paper tests the mediation role of two types of safety supervision styles, safety monitoring supervision (SMS) and safety communication supervision (SCS), on the relationship between organisational safety climate (OSC) and relevant group outcomes for safety management. Results found that on one hand, OSC affects performative safety management dimensions of work-groups, through the influence of SMS. On the other hand, SCS seems to exercise a mediation role of the effects of OSC on work dimensions supporting psychological health and the quality of the psychosocial environment.

**Keywords:** Organizational safety climate · Safety supervision
Production pressure · Psychological job resources · Safety management

## 1 Introduction

The UK rail industry, including its supply chain, employs approximately 212,000 workers ranging from train drivers, station staff and those responsible for managing and maintaining 20,000 miles of track [1], including safety critical operations (e.g. electrification and track renewal). The rail industry has engaged in initiatives to improve safety over recent years including efforts to enhance safeguarding, compliance, processes and policies, perhaps contributing to the overall decline in injury rates (8,497 in 2008/9 and 7,350 in 2012/13). Despite this, more recent statistics have revealed an increase in injury figures. 6,713 injuries were reported in 2016/17, an increase of 0.5% compared to 2015/16 [2] where 164 of those injuries were classified as major injuries. This is also an increase from 154 major injuries reported in 2015/16 [3]. The rail


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industry is keen to reduce accidents and their associated costs (e.g. loss of production, healthcare costs) and as such have attempted to improve safety climate. This focus is particularly pertinent because rail organisations in the UK are required to report safety climate results to external regulators, such as the Office of Rail and Road (ORR), Rail Accident Investigation Branch (RAIB) and Rail Safety Standards Board (RSSB).

Safety climate has been previously defined as "surface features of safety culture discerned from workplace attitudes and perceptions at a given point in time […] providing an indicator of the underlying safety culture of a group or organisation" [4, p. 178]. Safety climate research has found associations with the frequency and severity of negative incidents, indicating that perceptions of a positive safety climate result in fewer accidents, that are less severe [5–8].

The present paper tests the mediation effects of two types of supervision styles, safety monitoring supervision and safety communication supervision on the relationship between organisational safety climate and relevant group outcomes. Group outcomes were clustered as safety management factors (safety priority, safety learning, production pressure, managing accident risk) and psychological health at work (job control, work relationships, peer support, organisational change support).

### 1.1 Safety Climate

Research on safety climate has found that it is an important indicator of workplace safety performance [6, 9, 10]. It is suggested that positive safety-related behaviours, such as safety compliance and safety participation [11, 12], are a result of a positive safety climate, which leads to a reduction in accidents [7]. Safety climate is complex in nature as it is both a multilevel (i.e. individual, organisational and group level) and multidimensional construct (i.e. consisting of various factors such as management commitment, safety priorities and safety communication). Despite this, it remains common practice for organisations to attempt to assess their current safety climate and make improvements based on the results. Efforts have been made to validate safety climate measures in other industries (e.g. nuclear, electrical and trucking), and more recently in the rail industry [13, 14] yet more research is required to determine the relationship between multilevel safety climate factors and safety outcomes in this industry.

### 1.2 Safety Climate as a Multilevel Construct

Safety climate can be measured at various levels of an organisation. Zohar and Luria, [15] developed a two-factor multilevel safety climate tool comprised of two separate measurement scales. The organisational level refers to organisational leaders whose responsibilities are at a strategic level. The organisational subscale measures perception of top management's commitment to safety. The second measurement scale, the group level, refers to supervisors who structure and facilitate work activities. The group level subscale measures perceptions of supervisors and group members' commitment to safety priorities.

Large rail organisations are typified by complicated hierarchical organisational structures including top management and group levels, which contributes further to the complex nature of safety climate in this industry. This further highlights the importance of understanding the effects of group level management (i.e. supervisors) on the relationship between organisational safety climate and group outcomes in the rail industry. Research at the organisational level indicates that safety climate mediates the relationship between leadership and safety outcomes [16, 17]. Despite numerous studies exploring the relationship between safety climate and safety performance, the mediating effects of group safety climate on outcomes are under-researched in this domain.

Equally, group level safety climate has been previously found to predict safety performance [18, 19]. Safety performance has been found to increase when supervisor safety involvement is higher [20] and supervisors discuss and reward safe performance [21]. When worksite observations are communicative, encouraging in nature and reinforced, safety behaviours improve [22, 23]. Similarly, harmonious supervisor-employee relationships were the strongest predictor of safety compliance [24] indicating the importance of exploring the mediating role of supervisor types on safety outcomes.

### 1.3 Multilevel Safety Climate Validation in the Railway Industry

Preliminary validation research of the multilevel safety climate scale (MSC) by Zohar and Luria, [15] was conducted in a sample of rail infrastructure workers [14] and design engineers [13] initially using an exploratory factor analysis (EFA) and further verified using confirmatory factor analysis (CFA). Results confirmed a three-factor model in comparison to the original two-factor proposed by Zohar & Luria [15]. A single factor was found at the organisational level, named organisational safety climate (OSC), which measures perceptions of management commitment to safety during competing demands. The group level safety climate revealed two factors labelled safety communication supervision (SCS) and safety monitoring supervision (SMS). SCS measures communication strategies to promote and encourage safety and SMS refers to the monitoring and checking of compliant safety activities. SCS and SMS factors were found to be positively correlated with relevant constructs such as consideration of future safety consequences and mood, and negatively associated with production pressure, with comparable effects for both SMS and SCS [13]. In addition, SCS was more strongly associated with social support related constructs (e.g. peer support) and SMS was more strongly associated with safety priority related constructs (e.g. safety compliance) [14].

### 1.4 Research Aims

Group safety climate has previously been found to mediate the relationship between organisational safety climate and safety behaviours [15]. This study intends to contribute to the advancement of safety climate literature by using a multidimensional approach at the group safety climate level, and by expanding on our knowledge of the 3-factor model of safety climate comprised of OSC, SMS, and SCS. Thereby, we aim to further contribute to the understanding of the mediation role of group level safety climate factors (SMS & SCS) in a rail infrastructure sample by incorporating factors that are seldom analysed within the safety climate literature [11]. First, we explore the distinct mediation effects of SMS and SCS on the relationship between OSC and specific safety management dimensions assessed at work-group level, such as safety priority, safety learning, production pressure, and perceived accident risk. Second, we explore the relationship between OSC and health and well-being dimensions such as job control, work relationships, peer support and organisational change support. Figure 1 presents our research model.

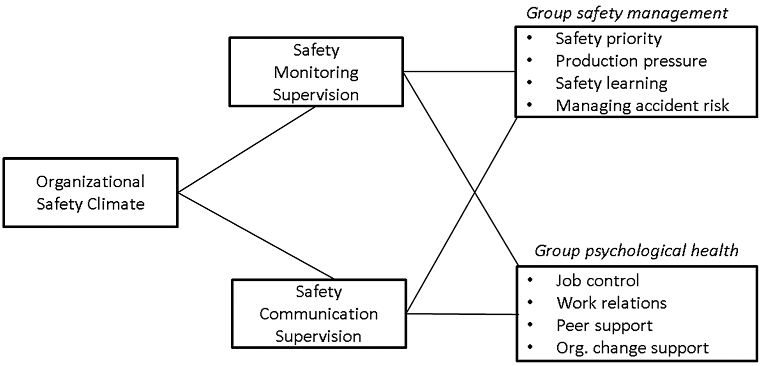


**Fig. 1.** Research model: the mediation role of safety monitoring supervision (SMS) and safety communication supervision (SCS) on group safety management and psychological health.

# 2 Method

## 2.1 Participants

Participants from an infrastructure maintenance organisation based in the UK were invited to take part in a questionnaire study. A total of 536 participants took part, however, 8 were removed due to incomplete responses. 528 responses were therefore collected in total from both direct and non-direct employees. The sample comprised of employees who work in safety critical rail operations and maintenance, such as track electrification, track renewals, switches, signalling and the inspection of assets (e.g. bridges). 40.5% of the sample reported being responsible for staff.

## 2.2 Measures

The questionnaire consisted of a number of measures made up of the multilevel safety climate, health and wellbeing and safety management measures described below. The properties of each scale are reported in Table 1.

*Multilevel safety climate (MSC)* developed by Zohar and Luria [15] was used in the present study. The original tool contains 16-items for the organisational safety climate factor (OSC) which measured employee perceptions of management commitment to safety when dealing with competing priorities ($\alpha$ = .95). An example item is: "*Top management invests a lot of time and money in safety training for workers*". The group

**Table 1.** Intercorrelations and descriptive statistics (N = 528)

| | M | Sd | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. OSC | 3.76 | .74 | – | | | | | | | | | |
| 2. SCS | 3.59 | .94 | .62 | – | | | | | | | | |
| 3. SMS | 3.91 | .79 | .58 | .72 | – | | | | | | | |
| 4. Job Control | 3.62 | .70 | .23 | .28 | .26 | – | | | | | | |
| 5. Work relationships | 4.13 | .62 | .27 | .31 | .30 | .30 | – | | | | | |
| 6. Peer support | 3.82 | .74 | .42 | .47 | .41 | .40 | .42 | – | | | | |
| 7. Org change support | 3.30 | .91 | .54 | .53 | .42 | .42 | .31 | .56 | – | | | |
| 8. Safety priority | 3.14 | .52 | .46 | .36 | .38 | .25 | .35 | .29 | .37 | – | | |
| 9. Safety learning | 3.28 | .48 | .46 | .42 | .46 | .29 | .35 | .41 | .41 | .54 | – | |
| 10. Production pressure | 2.78 | 1.34 | −.52 | −.38 | −.38 | −.33 | −.37 | −.33 | −.45 | −.55 | −.40 | – |
| 11. Managing accident risk | 1.86 | 1.31 | −.04 ns | .03 ns | −.00 ns | .10 | −.10 ns | −.00 ns | .06 ns | −.06 ns | .02 ns | .04 ns |

**Note**: Correlations are significant at $p < .05$; ns = no significant effect

level safety climate subscale was measured using our adapted and validated version of the MSC. Safety communication supervision (SCS) comprised of 6 items measuring promotion and encouragement of safety ($\alpha = .93$). An example item is: "*My direct supervisor discusses how to improve safety with us*". The second factor at the group level labelled safety monitoring supervision (SMS) comprised of 5 items measuring the control and checking of safety regulations and procedures ($\alpha = .81$). An example item is: "*My direct supervisor refuses to ignore safety rules when work falls behind schedule*". Each item on the subscales was measured using a 5-point Likert scale ranging from strongly agree (1) to strongly disagree (5).

*Workers safety priority* and *safety learning* were measured using the factors in the NOSACQ-50 tool developed by Kines et al. [25]. *Workers safety priority* measured the priority of safety and non-acceptance of risk-taking comprised of 7 items ($\alpha = .71$). An example item is: "*We who work here accept risk-taking at work*". *Safety learning* measured learning from experience, helping each other to work safely and trust in co-worker safety competence comprised of 8 items ($\alpha = .86$). An example item is: "*We who work here learn from our experiences to prevent accidents*". Each item was measured using a 5-point Likert scale ranging from strongly agree (1) to strongly disagree (4).

*Production pressure* was measured using the Organizational Production Pressure tool [26], comprised of a 4-item scale asking participants about the priority of safety and production ($\alpha = .78$). An example item is: "*I sometimes comprise safety in order to meet production demands*". Each item was measured on a 7-point Likert scale ranging from strongly disagree (1) to strongly agree (7).

*Managing accident risk* ($\alpha = .85$) was measured using a modified version of the Standard Shiftwork Index [27]. This assessed an additional subscale of perceived accident risk across different times of the day; morning, afternoon and night shifts. Participants were asked to rate each subscale at each time period on a scale ranging from extremely light (1) to extremely heavy (5) in comparison to other people performing a similar job in other parts of the organisation.

Job control, work relationships, peer support and organisational change support were assessed using the subscales in the UK Health and Safety Executive's Management Standards Stress Indicator Tool [28]. Each item was measured on a rating scale that ranged from never (1) to always (5):

> *Job control* ($\alpha$ = .78) was measured by asking participants to rate how much say they have in the way they complete their work across 6 items *(e.g. "I can decide when to take a break")*
> *Work relationships* ($\alpha$ = .71) assessed how participants perceive positive working and conflict management using 4 items (e.g. *"There is friction or anger between colleagues")*
> *Peer support* ($\alpha$ = .81) measured the extent of encouragement and resources from their colleagues over 4 items *(e.g. "If work gets difficult my colleagues will help me")*
> *Organisational change support* ($\alpha$ = .77) asked participants attitudes of managements communication of organisational change using 3 items *(e.g. "When changes are made at work, I am clear how they will work out in practice").*

## 2.3 Statistical Analysis Treatment

To assess the reliability of the measures related to our research variables, we calculated the Cronbach's alpha. The correlations between the variables were performed by the calculation of Spearman's rank order correlation coefficient (Spearman's rho). The goodness of the safety climate measurement model was assessed with confirmatory factor analysis, through structural equation models (SEM), and using the following cut-off indices, which were considered as useful criteria to assess the fit of the statistical model with the empirical data: $\chi 2$ ratio (<3.0), CFI ( $\geq 0.95$) and RMSEA (<0.08) [30]. The factor analyses were run through the software AMOS. Finally, the study of the mediation effects by SMS and SCS was achieved by using the PROCESS approach [29]. Each mediation effect was tested individually in a specific mediation model, using SMS and SCS as concurrent mediational variables in each model. All the mediation models were run through SPSS, using the macro PROCESS developed by Hayes [29].

## 2.4 Procedure

Employees were invited to attend voluntary one-hour workshops held during their shifts. A number of workshops were set up over a period of 6 weeks covering both day and night shifts. Each workshop was lead by the corresponding author who presented details of the study and research aims prior to completion. All participants who provided informed consent were given the questionnaire, taking approximately 30 min to complete in full. Upon completion participants sealed their responses in an envelope, posted in a ballot box. In addition, an online version of the questionnaire was created for those participants who could not attend workshops. Information on accessing the online questionnaire was distributed using posters, newsletters, and briefings. Each workshop and online questionnaire concluded with study debrief information.

# 3 Results

## 3.1 Preliminary Analysis

The psychometric goodness of our measurement model was preliminarily tested and verified through structural equation models using confirmative factor analyses [30]. We used maximum likelihood estimation to derive measurement model factor loadings. Factor analyses conducted on our questionnaire items confirmed the goodness of a measurement factor model with three latent factors of safety climate ($\chi 2/df = 2.96$, CFI = .94, RMSEA = 0.06).

## 3.2 Descriptive and Correlations Statistics

Descriptive and correlation statistics are reported in Table 1. Although the correlation between the three safety climate factors is high, this is not so high as to support a concurrent research hypothesis of substantial identity between the three factors.

Tables 2 and 3 below reports all the statistical indices for each mediation model run through the PROCESS macro for SPSS [29]. These results are discussed in detail in the proceeding paragraphs. Figure 2 presents a summary of all the verified direct regression effects.

## 3.3 Mediation Analysis: Group Safety Management Criteria

As can be seen in Table 2 our analyses showed a positive direct effect by OSC on safety priority (.26), and safety learning (.21). Moreover, our mediation analyses

**Table 2.** Summary of direct and indirect effects (N = 528): Group Safety Management criteria

| | *Group Safety Management criteria* | | | |
|---|---|---|---|---|
| | Safety priority | Production pressure | Safety learning | Managing accident risk |
| Direct effect by SCS | .03 ns | .04 ns | .03 ns | .15** |
| Direct effect by SMS | .15** | −.27** | .12** | .05 ns |
| Direct effect by OSC | .26** | −.83** | .21** | −.12 ns |
| Mediated effect by SCS | .02 ns | .06 ns | .03 ns | .11 |
| Mediated effect by SMS | .09 | −.16 | .08 | −.03 ns |
| Total variance explained | .24 | .28 | .24 | .22 |

**Note**: * p < .05; ** p < .01; ns = no significant effect. The significance of the mediational effects was tested with bootstrapping method (5,000 samples. Interval of confidence: .95)

**Table 3.** Summary of direct and indirect effects (N = 528): Group Psychological Health criteria

| | *Group Psychological Health criteria* | | | |
|---|---|---|---|---|
| | Job control | Work relationships | Peer support | Organisational change support |
| Direct effect by SCS | .15** | .11* | .21** | .35** |
| Direct effect by SMS | .02 | .06 ns | .05 ns | .04 ns |
| Direct effect by OSC | .11 ns | .12** | .25** | .46** |
| Mediated effect by SCS | .12 | .09 | .16 | .27 |
| Mediated effect by SMS | −.02 ns | .03 ns | .03 ns | .03 ns |
| Total variance explained | .10 | .12 | .25 | .39 |

**Note**: * p < .05; ** p < .01; ns = no significant effect. The significance of the mediational effects was tested with bootstrapping method (5,000 samples. Interval of confidence: .95)

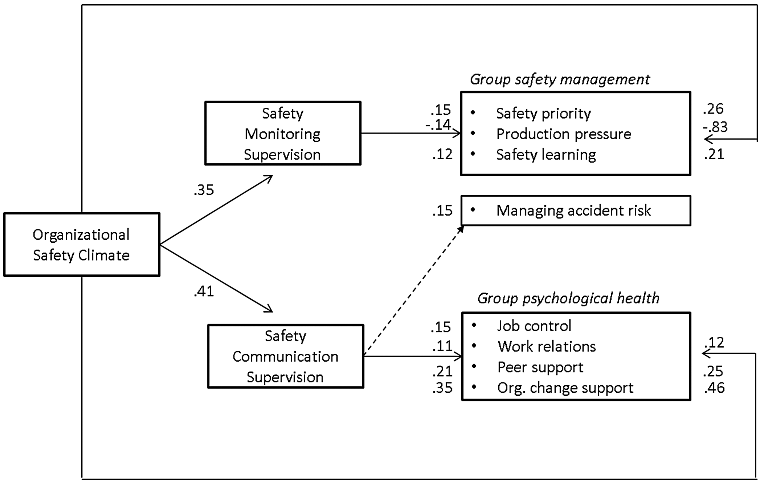


**Fig. 2.** A summary of all the direct effects of regression are displayed in the figure above. For each mediation criteria was tested a specific mediation model with safety monitoring supervision (SMS) and safety communication supervision (SCS) included in each model as potential concurrent mediators. Indirect effect indices are presented in Tables 2 and 3.

showed a further indirect effect by OSC on safety priority (.09) and safety learning (.08) through SMS. Interestingly, our findings showed a significant direct effect by SMS on both safety priority and safety learning, but no direct effect by SCS on the same variables. Production pressure was negatively affected by OSC (−.83) and by SMS (−.27), but not by SCS. Furthermore, our analyses showed an indirect and negative effect by OSC on production pressure (−.16), mediated by SMS. Finally we found SCS to directly affect the variable managing risk accident (.15), with an indirect effect by OSC through SCS (.09).

### 3.4 Mediation Analysis: Group Psychological Health Criteria

Table 3 summarises the mediation results on psychological health criteria, with direct and indirect effects by OSC, SCS and SMS, and the total variance explained for each psychological health criteria taken in consideration in our research.

Our statistical analyses showed the variable, job control, directly affected only by SCS (.15). In addition, OSC indirectly affected job control through SCS (.12). The variable, work relationships, was directly affected by both OSC (.12) and SCS (.11), with an indirect effect by OSC (.09) through the mediation of SCS. The variable peer support was also directly affected by both OSC (.25) and SCS (.21), with an indirect effect by OSC mediated by SCS (.16). Similarly, organisational change support was affected by both OSC (.46) and SCS (35), with another indirect effect by OSC through SCS (.27).

## 4 Discussion

### 4.1 Overview

The aim of our research was to test the mediation effects of two types of supervision styles identified in earlier research as safety monitoring supervision (SMS) and safety communication supervision (SCS) [14] on the relationship between organisational safety climate (OSC) and group outcomes. For the purpose of this research, the group outcomes were clustered into (a) safety management factors which included; safety priority, production pressure, safety learning and managing accident risk (b) wellbeing factors which included; job control, work relationships, peer support and organisational change support. Results showed that on one hand, SMS mediated the effects of OSC on safety management group outcomes, such as safety priority, safety learning, and, negatively, production pressure. On the other hand, SCS exercised a mediation role of the effects of OSC on health and wellbeing factors, and additionally on the variable managing accident risk.

### 4.2 Contribution to Literature

Overall, our study evidences the importance of investigating safety supervision and leadership as articulated phenomena inclusive of multiple dimensions, which present differentiated and complementary positive outcomes for groups and organisations. More specifically, our present study contributes to previous literature on safety supervision and leadership in two ways. First, we extended the understanding of how specific leader behaviours might affect safety management at the group level. Although the importance of leadership on safety has been well established at the individual level [11, 17, 18], specific supervisory actions most likely to support different aspects of group safety management remain unclear. Our study, however, evidenced the importance of monitoring supervision actions to support the prioritization of safety in standard group activities, the balancing of safety instances, production pressures, and the development of safety learning. On the other hand, safety communication actions by supervisors were found to mediate the relationship of organisational safety climate and the management of the emergent risks of accidents in the group work activities, which might be more difficult to predict. Second, although previous studies exploring group level supervision, suggest that monitoring, communication and encouragement improve safety behaviours and reduce accidents rates [22, 23, 31, 32], our results extend beyond safety behaviours as outcomes, and incorporated additional group outcomes associated with health and well being that are under-researched in safety climate studies [11]. Contributing to literature, our study evidenced a set of psychological benefits associated with safety communication supervision, beyond the management of accident related risks, including more positive work relationships, peer support, support to organisational changes.

### 4.3 Practical Implications

In terms of practical implications, the fact that SCS mediated the effects of OSC on health and wellbeing factors suggest that supervisors who adopt more communicative, open and encouraging behaviours, are associated with improved psychological health of team members. Although previous research has linked group safety climate to fewer accidents [31, 32], it should be considered that training to improve safety communication techniques will also impact psychological wellbeing positively, and in turn lead to a possible reduction in accident rates. Therefore when contemplating safety initiatives, rail organisations should consider supervisory communicative training (e.g. open innovative suggestions, listening and responding well to change) as opposed to typical safety awareness briefs aimed at frontline workers.

The fact that SMS mediated the effects of OSC on safety management factors suggests that supervisors who adopt more controlling, checking and consistent monitoring are associated with improved safety management. It should be considered that training methods that focus on supervisory monitoring are likely to lead improved safety through better understanding of safety priorities, learning and production pressure. For example, rail organisations might consider interventions at the group level that monitor specific safety systems (e.g. accident reporting monitoring) and improved methods to control and check such risks (e.g. risks associated with late changes to plans in rail operations) as a means to improve organisational safety.

### 4.4 Study Limitations and Future Research

In terms of research design, this study has a few limitations. One potential limitation is that supervisor behaviours and group safety and health criteria were both reported by participants themselves, thus creating common method bias. It is important for future studies to investigate additional measures, such as supervisor ratings of the safety priority manifested by group members, or the quality of work relationships. Furthermore, this study uses a cross-sectional design, thus the relationships are correlational in nature. Future research should adopt a longitudinal and/or experimental design to demonstrate the causality of the relationships found in this study. Finally, only safety supervision behaviours were examined in this study and other dimensions of organisational management and programs might provide a more differentiated picture of leadership effects on both health and safety group outcomes. This is particularly evident when we look to the statistical results of our mediation analyses, which mainly evidenced partial mediation of SMS and SCS. This may suggest that organisational safety climate may impact on group safety management and psychological health criteria through other potential meditational variables not included in the present study, such as training, communication and participation systems.

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# Safety Assessment for Decommissioning Worker

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**Abstract.** Nuclear power plants have a licensed lifetime. Nowadays, as the number of globally aged nuclear power plants increases, the need for research on the decommissioning of nuclear power plants is increasing. Unlike the decommissioning of other infrastructures, the decommissioning of nuclear power plants has a risk of radiation. Therefore, safety evaluation of dismantling worker about radiation is required. This study proposes a framework for evaluating the safety of workers during the decommissioning process of nuclear power plants and conducted a case study on Kori nuclear power plant unit 1 based on the proposed framework. It is expected that the risk information obtained from the evaluation can be used for developing a guideline for the dismantling worker to minimize potential risk.

**Keywords:** Nuclear power plant · Decommissioning worker
Safety assessment · Human error

## 1 Introduction

Recently, researches on the decommissioning of nuclear facilities have become active due to the end of nuclear power plant operating license. It is expected that there will be a large number of globally aged nuclear facilities (nuclear power plants, research reactors, nuclear fuel circulation facilities, etc.). Unlike the dismantling of other buildings, the dismantling of a nuclear power plant has a radiation risk. There also has little experience in decommissioning nuclear facilities. Since there is a risk of radiation, safety evaluation of workers dismantling nuclear power plants is necessary. Therefore, proper planning, assessment and case study should be conducted in order to safely carry out decommissioning activities [1].

Radiological hazards exist in the dismantling process of nuclear power plants.

Therefore, in dismantling nuclear plants, workers should be protected, and accidents should be prevented. In addition, a new systematic safety assessment to reduce the radiological risk of decommissioning is needed.

Through this study, a framework for safety assessment of workers was presented. This framework is used to derive radiological risks for workers in the radioactive area. It also provides guidelines for reducing risk.


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By performing safety evaluation according to the proposed framework, it will be possible to secure the safety of workers in decommissioning situations and prepare for accident scenarios.

## 2 Safety Assessment Framework

A safety assessment framework should be developed with a systematic approach to deriving potential hazards of decommissioning of nuclear facilities and possible accidents of decommissioning activities. In this work, to propose a safety evaluation procedure framework as shown in Fig. 1, the report of IAEA's "Safety Assessment for Decommissioning" was referred.

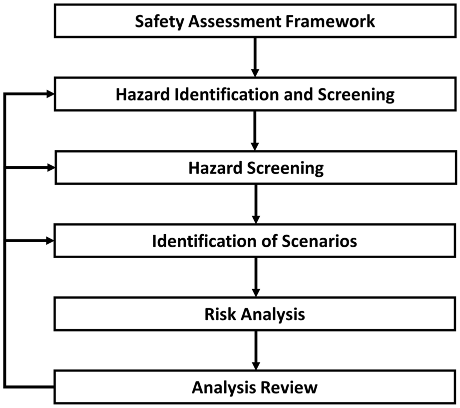


**Fig. 1.** Safety assessment framework

These safety assessment procedures should be used to assess potential hazards and doses during the decommissioning process and to compare the effective dose and risk with safety standards. The results (effective doses or risk factors) should also meet regulatory safety requirements, taking into account the safety assumptions, such as time, goal of the disassembly procedure step by step.

In order to evaluate the safety, a safety assessment approach (deterministic/probabilistic, conservative, etc.) should be used to derive the risk of decommissioning process [1, 2].

### 2.1 Hazard Identification

The hazard identification process should identify all areas where radioactive materials may be present, such as radioactive material, waste accumulations, surface and floor contamination, ventilation system and filters, etc., Consideration should be given to the possibility that radioactive material and dust may accumulate in the work area due to continuous decommissioning procedure.

The hazard identification process begins with an analysis of all possible potential initiating events.

### 2.2 Hazard Screening

During the decommissioning procedure, the risk factors are selected using the initial events in 2.1 information above. The screening process should take into account any potential exposure pathways that could harm workers working in the work area. Therefore, it is necessary to continuously analyze new pathways of exposure through continuous research. For example,

- direct emission of gamma emission nuclides of radioactive concrete
- contamination, external exposure from radioactive structures
- Internal exposure by dust of radioactive structure
- Combination of radiological contamination and personal injury (fall, collision etc.)

In this study, human error analysis through Hazard and Operability (HAZOP) and Mechanical error analysis through Failure Mode & Effect Analysis (FMEA) are qualitatively performed to find the path of exposure and risk factors.

### 2.3 Identification of Scenarios

As shown above, a list of several accident scenarios should be made taking into account the initial events, hazards and exposure pathways. It should also be analyzed in the normal case of the existing decommissioning work procedures as well as the accident scenarios. In order to derive accident scenarios, human error analysis and mechanical error analysis are used in the process steps derived from HAZOP and FMEA during the Hazard Screening phase. The accident scenarios are derived from the industrial accident cases investigation.

Accident scenarios require repeated analysis and validation of initial event identification, exposure pathways, and accident scenarios since more pathways and risk factors may be present than were initially identified (Fig. 2).

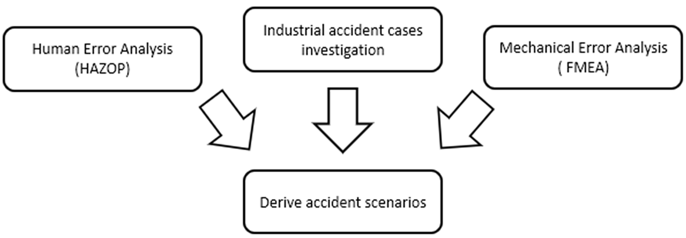


**Fig. 2.** Identification of scenario process

### 2.4 Risk Analysis

Risk analysis is to quantify the radiologic results of the workers for normal and accident scenarios. In other words, effective dose and risk should be calculated and evaluated by introducing normal, accident scenarios, decommissioning procedures, and radioactivity concentration to the probabilistic model. In addition, worker exposures in accident scenarios should be calculated and compared to the baseline, if the exposure exceeds the baseline, prophylactic and additional measures should be developed to reduce the consequences.

In this study, nuclide analysis is performed using MCNP [6], and VISIPLAN [7] is used to evaluate worker exposure. This study develops a quantitative model of accident scenarios through frequency analysis of derived accident scenarios. Also, a worker's guidebook is proposed to reduce the risk of workers during dismantling process through risk analysis.

## 3 Method

### 3.1 Hazard and Operability (HAZOP)

A systematic approach is needed to systematically derive human error. By introducing basic guidelines on this, it is possible to consider all possible human errors in a systematic way. HAZOP derives human errors in the process using guide words and human action factors. The guide words are introduced to take all possible deviations into consideration and is a total of 7 guide words.

The guide words are shown in Table 1 below. The guide words in Table 1 indicate that there is 'No', 'Not' to derive a situation where no action occurred, and the 'More' that leads to a situation in which a lot of actions occurred, 'Less' that results in less activity or rare occurrence. The 'Part of' that leads to a partial action. 'As well as', a situation that adds behavior. The 'reverse' to derive a situation that reverses the behavior. And finally, the 'other' situation, which does something different about the act. This guide words are used to modify the characteristics human factors and the purpose of analysis.

**Table 1.** Guidewords of HAZOP

| Guide words |
|---|
| No, Not, Node |
| More, High, Large, Fast |
| Less, Low, Small, Slow |
| Part of |
| As well as |
| Reverse |
| Other than |

The factors of human error are derived by combining the guide words of Table 1 and the human action factors of Table 2. For example, a combination of ‘catch’ and ‘not’ leads to ‘unable to catch’, and a possible accident of this action can lead to an accident that ‘cannot catch a safety railing’ [4].

**Table 2.** HAZOP human action factors

| | Human action factors | | Human action factors |
|---|---|---|---|
| Hand motion | Catch/grasp/support | Foot Motion | Slip/Fall |
| | Pull | | Bright |
| | Push/erect | | Kick |
| | Press down | Body Motion | Stand |
| | Stretch | | Sit |
| | Touch/Contact | | Bend |
| | Stroke | | Spread out |
| | To Wipe | | Back |
| | Lift | | Lay down |
| | Set/Lower | | Kneel down |
| | Turn | | Cover |
| | Shake | | Wear |
| | Throw | | Take off |
| | Stab | | Walk |
| | Wield | | Run |
| | Hit | | Lean |
| | Insert | | Jump |
| | remove | | Tremble/Shake/Keep |
| | Combine/Assemble | | |
| | Separation/Disassembly/Release | | |
| | Tilt | | |
| | Reverse | | |
| | Tumble | | |
| | Scratch | | |
| | Bet | | |
| | Turn on | | |
| | Turn off | | |

## 3.2 Failure Mode and Effect Analysis (FMEA)

Fault Mode and Impact Analysis (FMEA) is a method of deriving fault sources for a system or device. When a failure occurs in a device or a part, the effect of the failure on the system is analyzed to derive a device or part that has a great influence. Measures can be taken against equipment or components for which the risk has been derived, improving the availability, reliability or quality of the system. The purpose of the FMEA is to derive the mode, cause and effect of the potential failure of the equipment and to provide a solution to reduce or eliminate the occurrence of accidents, hazards and potential failures during the decommissioning process.

It is analyzed by the process shown in Fig. 3 below. First, the required equipment is selected, and the failure mode of the equipment is predicted, and the effect of the failure of the equipment is analyzed. It is possible to draw out the accidents [5].

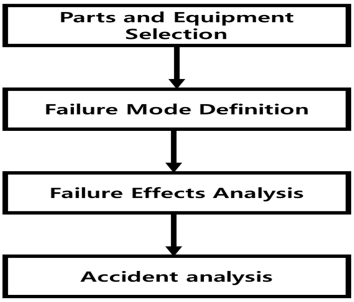


**Fig. 3.** Failure mode & effect analysis process

### 3.3 Event Tree Analysis (ETA)

The event tree method is a technique for qualitative and quantitative risk assessment of the final results arising from the initial events of the worker and elements of equipment.

Event tree is a method widely used in probabilistic safety assessment (PSA), which is often used for plant safety evaluation. This study is used for risk analysis using frequency analysis and worker exposure assessment [1].

## 4 Case Study

In this study, safety assessment of bioshield decommissioning process was performed. The bioshield is one of the characteristics of power plants. It is a concrete that prevents radiation from the core, so it is the concrete that exist radioactive material the most. This study assessed risks to derive radiologic risks to workers during the bioshield decommissioning process (Fig. 4).

The above safety framework is applied with the decommissioning scenario. The decommissioning scenario has been simplified and also derived from the research decommissioning scenario which is decommissioning KRR 1 & 2 [3]. Evaluate using Kori unit-1 bioshield decommissioing. Concrete decommissioning procedures were divided into preparation phase, cutting phase, drilling phase, and transportation phase. Also, the exposure was evaluated at 300, 800, and 1300 cm height.

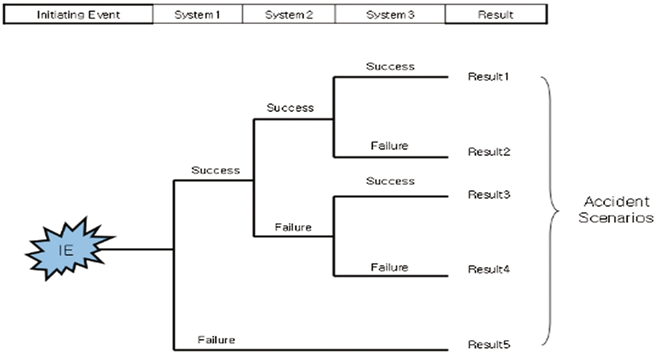


**Fig. 4.** Event tree analysis example

## 4.1 Human Error Analysis Result Using HAZOP

In the work step of the decommissioning procedure, Error factors is created by combining the guidewords of HAZOP and human factor action. Predictable accidents and risk factors is also derived. The following Table 3 is a part of the result of the analysis.

**Table 3.** Human error analysis example.

| Work step | Details activities | Error factor | Predictable accident | Risk factors |
|---|---|---|---|---|
| 3.5 Perform drilling using a piercer | 3.5.1 Carrying the perforator | Push back | When carrying perforator, it cannot be pushed well, the worker is laid | |
| | 3.5.2 Perforations are used to puncture the concretes | Not catch | When puncturing, hold the perforator weakly to fit the radioactive debris. | Flying, External exposure |
| 3.6 Insert the wire into the perforated hole and fix the wire by operating the crane hook. | 3.6.1 Insert wire into perforated hole | Only partly | Damage to fittings and protective equipment due to radioactive debris by hanging part of wire | Falling, Flying, External exposure, Internal exposure |
| | 3.6.2 Moving the crane near the perforated hole | Press another | Crane operator improperly manipulated and impacted by radioactive concrete and damaged protective equipment. | Collision, External exposure, Internal exposure |

(*continued*)

**Table 3.** (*continued*)

| Work step | Details activities | Error factor | Predictable accident | Risk factors |
|---|---|---|---|---|
| | 3.6.3 Fixing the wire by operating the crane hook | Only partly | Damage to fittings and protective equipment caused by radioactive debris by hanging part of the wire. | Falling, Flying, External exposure, Internal exposure |
| 3.7 Install diamond wire saw in working area | 3.7.1 Carrying diamond wire saw | Push back | Cannot push it well when carrying wire saw, the worker laying down. | Inversion, External exposure |
| | 3.7.2 Installation of diamond wire saws | | | |

## 4.2 Mechanical Failure Analysis Result Using FMEA

In the work step of the decommissioning procedure, failure modes and effects analysis were used to derive potential failure effects and possible accidents in the event of failure of equipment, parts and equipment. And analyzed as shown in Table 4 below.

**Table 4.** Mechanical error analysis example

| Details activities | Potential failure mode | Predictable accident | Potential failure effects |
|---|---|---|---|
| 1.3.1 Protective clothing and mask preparation | Defective protective equipment | Defective clothing and mask defective rate and bad condition not checked. | External exposure, Internal exposure |
| 3.5.2 Perforations are used to puncture the concretes | Equipment defect | Damage to objects and protective equipment due to radioactive debris from equipment failure | Flying, External exposure, Internal exposure |
| 3.6.2 Moving the crane near the perforated hole | Crane operating equipment damage | Crash of malfunctioning crane and operator and damage to protective equipment | Collision, External exposure, Internal exposure |
| 3.6.3 Fixing the wire by operating the crane hook | Only partly | Damage to fittings and protective equipment caused by radioactive debris by hanging part of the wire | Falling, Flying, External exposure, Internal exposure |
| 3.7.1 Carrying diamond wire saw | Push back | Cannot push it well when carrying wire saw, the worker laying down. | Inversion, External exposure |
| 3.7.2 Installation of diamond wire saws | | | |

### 4.3 Accident Scenario Example

The possible accidents during the dismantling process were derived through the previous safety assessment framework. Possible accidents during the dismantling process include accidents caused by mechanical errors, accidents caused by human errors, and accidents caused by natural disasters.

In the event of an accident caused by a mechanical error affecting internal exposures, such as a failure of the mask, a failure of the dust absorber, or a failure of the ventilation system, the failure of the crane, Falling, collapsing, falling, laying on, getting stuck on an object, pinching, cutting, piercing, fire, or electric shock. Among them, it is difficult to evaluate workers' exposure to accidents caused by natural disasters.

### 4.4 Risk Assessment Quantification Model Example

As an internal exposure accident scenario, the accident scenario was analyzed considering the failure or operation of the mask, the failure or operation of the ventilation system, and the failure or operation of the dust absorber. Exposure assessment was performed in consideration of dust absorption rate, ventilation system, and failure or operation of the mask in internal exposure evaluation equation and VISIPLAN. Also, in case of dust that should be considered in the internal exposure, it will occur only in cutting operation. Therefore, the internal exposure evaluation was carried out based on 1 h of cutting time.

Table 5 shows the results of evaluating the internal exposure in the mask accident scenario. S indicates that the component is operating normally, and F indicates a malfunction. The sequence first means that this mask is malfunctioning or working, the second is when the ventilation system is failed or worked, and the last time this dust absorber is failed or worked.

**Table 5.** Internal exposure in mask accident scenarios

| Height/Scenario(mSv) | 300 cm | 800 cm | 1300 cm |
|---|---|---|---|
| SSS | 9.24E−12 | 1.92E−22 | 1.37E−33 |
| SSF | 9.24E−10 | 1.92E−20 | 1.37E−31 |
| SFS | 2.31E−08 | 4.80E−19 | 3.42E−30 |
| SFF | 2.31E−06 | 4.80E−17 | 3.42E−28 |
| FSS | 9.24E−08 | 1.92E−18 | 1.37E−29 |
| FSF | 9.24E−06 | 1.92E−16 | 1.37E−27 |
| FFS | 2.31E−04 | 4.80E−15 | 3.42E−26 |
| FFF | 2.31E−02 | 4.80E−13 | 3.42E−24 |

In the following figure, Risk is obtained by using Event Tree using AIMS which is a PSA evaluation tool. Since there is no failure frequency data on the equipment used for dismantling, the failure frequency data is assumed based on the failure data of the equipment used in the nuclear power plant (Fig. 5).

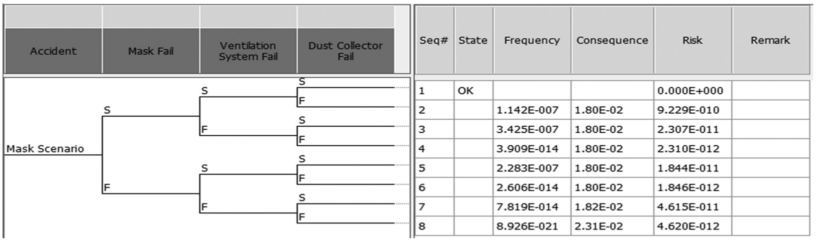


**Fig. 5.** Risks using AIMS and Event Tree in case of internal exposure accident scenario

As seeing the Table 6, when the height is 800 cm or 1,300 cm, the amount of internal exposure is negligible, irrespective of whether the component is malfunctioning or not. In the evaluation of the 300 cm point with the highest radiation level, the internal dose of the worker is 9.24E−12 mSv in case of no failure of the tool and the equipment (SSS). However, when all of the masks, ventilation systems, and dust absorbers fail (FFF), it is 2.31E−2 mSv, which is non-negligible.

**Table 6.** Internal and External exposure during mask accident scenarios

| Height/Scenario(mSv) | 300 cm | 800 cm | 1300 cm |
|---|---|---|---|
| SSS | 1.80E−02 | 4.30E−03 | 7.70E−04 |
| SSF | 1.80E−02 | 4.30E−03 | 7.70E−04 |
| SFS | 1.80E−02 | 4.30E−03 | 7.70E−04 |
| SFF | 1.80E−02 | 4.30E−03 | 7.70E−04 |
| FSS | 1.80E−02 | 4.30E−03 | 7.70E−04 |
| FSF | 1.80E−02 | 4.30E−03 | 7.70E−04 |
| FFS | 1.82E−02 | 4.30E−03 | 7.70E−04 |
| FFF | 4.11E−02 | 4.30E−03 | 7.70E−04 |

The above results are the result of evaluating the amount of exposure to failure. In order to evaluate the risk of the operator, the frequency of each case should be considered and evaluated. The risk of the mask accident scenario was rated at 1.02E−09 mSv/h. In case of no accidents, it is extremely low to 5.66E−06% compared with 1.80E−02 mSv/h, which is the worker exposure.

## 4.5 Worker Guideline

The risk information derived using the framework can be used on the operator guideline development. As an example, dose evaluation based on distance is performed in the table above. Derive the distance that the operator should work and, if an accident occurs, derive the guideline for the rescue route of the rescue team. As a guideline, the worker works under 1 m. The rescue worker goes to the rescue work using the weighting machine at less than 1 m (Table 8).

**Table 7.** Dose assessment by distance from bioshield

| | 1 m | 1.5 m | 2 m | 2.5 m | From bioshield |
|---|---|---|---|---|---|
| 3 m | 1.82E−02 | 1.90E−02 | 2.10E−02 | 2.10E−02 | |
| 8 m | 3,10E−03 | 3.70E−03 | 4.10E−03 | 4.30E−03 | |
| 13 m | 6.20E−04 | 6.80E−04 | 7.30E−04 | 7.70E−04 | |
| Height | | | | | mSv/h |

**Table 8.** Yearly and daily possible working time

| | Maximum exposure | Minimum exposure |
|---|---|---|
| Dose Rate(mSv/h) | 0.021 | 0.018 |
| Yearly Possible Working Time(h/y) | 952 | 1111 |
| Daily Possible Working Time(h/d) | 3.2 | 3.7 |

The annual radiation dose of radiation workers shall not exceed 20 mSv. If a worker work at a distance of 1 m, which is the minimum exposure, he will receive 0.018 mSv/h as shown in the Table 7, and the workable time will be 1111 h. Assuming that the worker can work around 300 days a year, the daily work time will be about 3 h and 40 min. As seeing the Table 6, If all three devices related to the internal exposure are out of order, over 2 h will exceed the daily dose. As another guideline, the internal exposure accident scenario results suggest that a check is made every 2 h in case three failures occur.

## 5 Conclusion

Assessment of exposure to nuclear power plant decommissioning process is very important for the safety of workers. In addition to the amount of worker's exposure in normal decommissioning work, it is also necessary to evaluate the risk of the worker when an accident occurs during decommissioning process. Therefore, this study aims to develop a system for evaluating the risk of decommissioning work of nuclear power plants and proposed a framework for deriving accident scenarios.

In this study, only one accident scenario was analyzed, but if the comprehensive risk is evaluated in consideration of various accident scenarios, the risk at the time of accident is expected to rise more than this value.

In addition, subjective evaluation by experts using semantic differential or fuzzy theory is often used as a risk evaluation during the actual dismantling process. Risk assessment with a quantitative model through this framework will be a risk assessment that can be further evaluated objectively. By developing worker's guideline based on the results, a guide to minimize the risk of radiation is presented.

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# Study on the Related Problems of Organizational Factors of Behavioral Safety

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**Abstract.** The safe production of enterprises not only relates to the safety of life and property of the people, but also to the overall situation of national reform and development and social stability. Every year there are many safety accidents in our country, especially in recent years, many important enterprise safety accidents, to China's economic and social development has brought very bad influence, serious interference to social order running smoothly. In this paper, the questionnaire was designed and the questions in the questionnaire are taken as the organizational factors that affect the safety production of the enterprise. SPSS19.0 software was used to process the questionnaire data distributed in the enterprise, and the credibility of the questionnaire data is obtained. The SEM model of structural equation was established by using LISREL software. Principal component factor analysis was used to further analyze the impact of four latent variables such as employee safety literacy, employee internal factor, business management factor and external environmental factor on safety production. The questionnaire data was divided into managers and employees. The influence of observational variables on enterprise safety is analyzed from different levels. Through the analysis of the path graph, we can get a deeper and thorough understanding of the differences in safety awareness between employees and managers. Managers should increase the investment in safety production and strengthen the training of enterprises in safety production. For ordinary employees, it is crucial to familiar with the rules of production safety.

**Keywords:** Organizational factors · Questionnaire survey
Statistical analysis of data · Structural equation · Factor analysis

## 1 Introduction

At present, there are many problems in the construction of corporate safety culture, such as the lack of guidance of theoretical methods and the effective operating tools, which make the construction of safety culture only manifest in a series of propaganda levels of safety concepts and safety slogans and are not implemented in the production [1]. In order to solve the problem of corporate safety culture construction, on the basis


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of trajectory intersection theory many safety experts make their research focus on behavioral safety research. This paper uses a combination of theory and practice in the study of behavioral safety [2]. The questionnaire is designed by dividing the organizational factors that affect the safety of employees into four main influential organizational factors, such as employee safety literacy, employee internal factors, enterprise management factors and external environmental factors. We analyze and study the impact of some safety issues in enterprises by using the actual data in the questionnaire. And we find the emphasis of improving the safety of enterprises, avoid some over-investment of funds and manpower. This paper analyzes the factors affecting the organization safety from the perspectives of managers and employees. So that the suggestions given can be aimed at employees at different levels, so as to rationalize the advantages and ultimately achieve the goal of enterprise safety production.

## 2 Questionnaire Design

This section collects and organizes a large amount of literature data, analyzes the organizational factors influencing employees' behavioral safety by using structural equation model [3] (SEM). Firstly, the organizational factors that affect the safety of employees' behavior are divided into four latent variables such as employee safety literacy, employee internal factors, business management factors and external environmental factors [4]. Among them, employee safety literacy ($\eta_1$), employee internal factors ($\eta_2$), And enterprise management factors ($\eta_3$) as the endogenous latent variables of the model and external environmental factors ($\xi$) as the exogenous latent variables of the model. Secondly, according to the above four latent variables, we design the questionnaire [5] including the endogenous and exogenous indicators corresponding to each factor. This questionnaire includes 20 observational variables that may affect employee safety behaviors, as shown in Table 1.

**Table 1.** Observation index variable table

| Variable name | Observed variable | Variable name | Observed variable |
|---|---|---|---|
| $A_1$ | Cognition of safe | $A_{11}$ | Influences between employees |
| $A_2$ | Work experience | $A_{12}$ | Environmental satisfaction level |
| $A_3$ | Safety skill proficiency | $A_{13}$ | Safe and cultural atmosphere |
| $A_4$ | Cognizance of the work risk | $A_{14}$ | Wear of production equipment |
| $A_5$ | Identification of safety rules and regulations | $A_{15}$ | Rationality of the plan |
| $A_6$ | Personal health | $A_{16}$ | Perfection of safety rules and regulations |
| $A_7$ | Degree of fatigue | $A_{17}$ | Reward and punish corporate safety production |
| $A_8$ | Attention to work | $A_{18}$ | Work safety capital investment |
| $A_9$ | Psychological quality | $A_{19}$ | Corporate safety supervision |
| $A_{10}$ | Supervision and coordination | $A_{20}$ | Corporate safety training |

Among them, $A_1$, $A_2$, $A_3$, $A_4$, $A_5$ are the endogenous observed variables of employee safety literacy; $A_6$, $A_7$, $A_8$, $A_9$ are the endogenous observed variables of employee internal factors; $A_{10}$, $A_{11}$, $A_{12}$ $A_{13}$, $A_{14}$ are external environmental factors Of exogenous variables; $A_{15}$, $A_{16}$, $A_{17}$, $A_{18}$, $A_{19}$, $A_{20}$ are the endogenous observed variables of business management. Questionnaire uses LIKERT five-point scale method [6], as shown in Table 2.

**Table 2.** Likert five component table

| Degree | No | Very low | Low | High | Very high |
|---|---|---|---|---|---|
| Score | 0 | 1 | 2 | 3 | 4 |

## 2.1 Determine the Total Sample Size

The number of observational variables is 20 in this survey. Considering the constraints of various factors in the survey conducted by the enterprises, it is finally decided to extract 657 valid sample sizes. The survey targets local employees of a company, including workers, team leaders and top leaders. A total of 962 questionnaires were distributed, and 300 invalid questionnaires were deleted because of missing and the same answers. The 657 valid questionnaires were obtained, with an effective rate of 68.7% and an ineffective rate of 31.3%. The inefficient rate also shows that nearly 30% of people did not pay attention to safety when filling in the questionnaire. This attitude is negative. Companies should strengthen safety education and training, to make employees take safety problems more seriously. Among the 657 valid questionnaires, the number of workers, group leaders and top leaders in the respondents are 555, 93 and 9, which a distribution ratio of 84%, 14% and 2% respectively.

## 2.2 Reliability Analysis of Questionnaire Data

In this paper, we conduct reliability test [7] on all the data in the questionnaire by using statistical analysis software SPSS19.0, the results of Cronbach's reliability coefficient test shown in Table 3.

**Table 3.** The overall Cronbach's reliability coefficient analysis results

| Reliability statistics | |
|---|---|
| Cronbach's reliability coefficient | number of items |
| 0.872 | 20 |

In Table 3, the overall Cronbach's reliability coefficient is 0.872, which is greater than 0.7, indicating that the overall credibility of the questionnaire is high. The reliability of each latent variable in the questionnaire was tested and analyzed. The results are shown in Table 4.

**Table 4.** Cronbach's reliability coefficient analysis

| Latent variables | Observed variables | Cronbach's reliability coefficient |
|---|---|---|
| Employee safety literacy | 5 | 0.734 |
| Employees internal factors | 4 | 0.831 |
| Companies management factors | 6 | 0.819 |
| External environmental factors | 5 | 0.698 |

According to Table 4, the environmental factors Cronbach's reliability coefficient [8] is lower than 0.7, the reliability is not high. The reasons are as follows: (1) The external environment is complex and difficult to design the questionnaire (2) In the course of the investigation, there are ambiguities in the employees' understanding of some design issues. The above reasons lead to lack of credibility, but the reliability coefficient of both is greater than 0.5, indicating that the design of measurement project is appropriate.

### 2.3 Validity Analysis of Questionnaire Data

Validity of the data was tested using structural validity [9]. The structural validity of the scale data was tested by fitting the model of the confirmatory factor analysis. The SPSS19.0 factor analysis module for applicability test, the results shown in Table 5.

**Table 5.** Results of KMO and Bartlett's Test

| KMO and Bartlett's test | | |
|---|---|---|
| Kaiser-Meyer-Olkin measure | | 0.866 |
| Bartlett's sphere test | Approximate chi square | 4641.127 |
| | df | 190 |
| | sig | 0.000 |

Among them, df is degree of freedom, sig is the level of significance. It can be seen from Table 5 that the value of KMO is 0.866 greater than 0.5 and the significance level is 0.000, which indicates that there is a correlation and it is suitable for factor analysis.

## 3 SEM Modeling and Correction

### 3.1 Establish SEM Model

According to the latent variables and observed variables, we construct the measurement equations and structural equations of the initial model [10] respectively, the structural equation is

$$\begin{bmatrix} \eta_1 \\ \eta_2 \\ \eta_3 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ \beta_{21} & 0 & \beta_{23} \\ \beta_{31} & 0 & 0 \end{bmatrix} \begin{bmatrix} \eta_1 \\ \eta_2 \\ \eta_3 \end{bmatrix} + \begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \gamma_3 \end{bmatrix} \xi + \begin{bmatrix} \zeta_1 \\ \zeta_2 \\ \zeta_3 \end{bmatrix} \quad (1)$$

Among them, $\xi$ and $\eta\,(i = 1, 2, 3)$ are the exogenous latent variables and endogenous latent variables of observed variables $x$ and $y$, $\beta_{23}$, $\beta_{21}$ and $\beta_{31}$ are the effects of endogenous latent variables, $\gamma_i\,(i = 1,2,3)$ indicates the effect of exogenous latent variables on endogenous latent variables, $\zeta_i\,(i = 1, 2, 3)$ indicates the error term of endogenous latent variables.

Endogenous latent variable y measurement equation is

$$y = \begin{bmatrix} 1 & 0 & 0 \\ \lambda_1 & 0 & 0 \\ \lambda_2 & 0 & 0 \\ \lambda_3 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & \lambda_4 & 0 \\ 0 & \lambda_5 & 0 \\ 0 & \lambda_6 & 0 \\ 0 & \lambda_7 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & \lambda_8 \\ 0 & 0 & \lambda_9 \\ 0 & 0 & \lambda_{10} \end{bmatrix} \eta + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \varepsilon_4 \\ \varepsilon_5 \\ \varepsilon_6 \\ \varepsilon_7 \\ \varepsilon_8 \\ \varepsilon_9 \\ \varepsilon_{10} \\ \varepsilon_{11} \\ \varepsilon_{12} \\ \varepsilon_{13} \end{bmatrix} \quad (2)$$

$\lambda_i\,(i = 1, 2, \ldots 10)$ represents the path coefficient between the endogenous latent variable and the endogenous observed variable, and $\varepsilon_i\,(i = 1, 2, \ldots 13)$ represents the error term of the endogenous observed variable.

The exogenous latent variable $x$ measurement equation is

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 1 \\ \lambda_{11} \\ \lambda_{12} \end{bmatrix} \xi + \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \end{bmatrix} \quad (3)$$

Among them, $\lambda_{11}$ and $\lambda_{12}$ represent the path coefficients between exogenous variables and exogenous variables, respectively, $\delta_1$, $\delta_2$ represent the error terms of the exogenous variables. Using LISREL software to build the model [11]. The path coefficient is standardized by using the method of maximum likelihood estimation fitting [12]. The result is shown in Fig. 1.

### 3.2 Modified SEM Model

This paper mainly uses the modified index method to correct the initial model [13]. By adding a path to the model that allows free estimation, it is advisable to add free parameters as long as the reduction in chi-square is significant [14]. The revised model path is shown in Fig. 2.

The parameters of the modified SEM model are estimated and fitting indexes are obtained. The results are shown in Table 6.

It can be seen from Table 6 that all the fitting indexes of the revised model satisfy the requirements, indicating that the fitting result of the model is better.

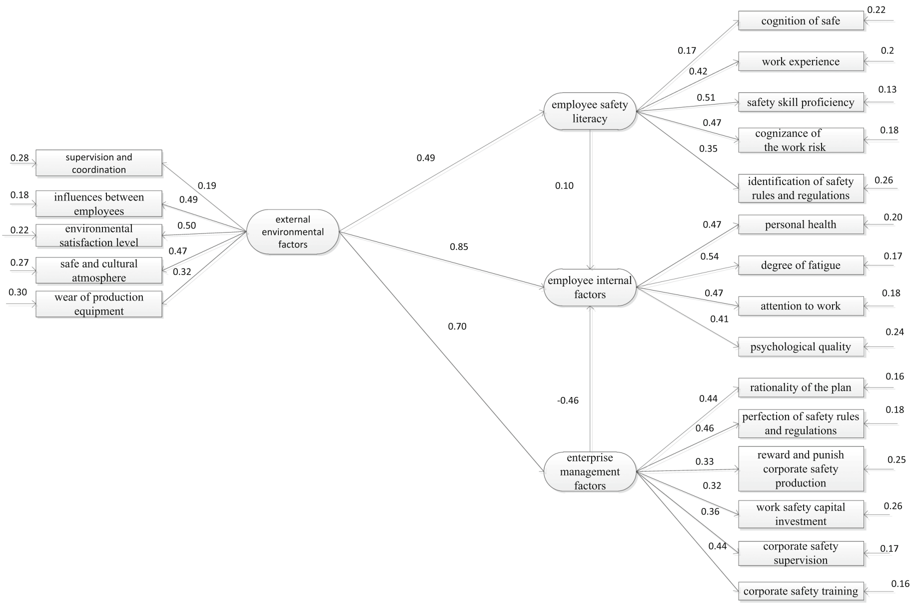


**Fig. 1.** Initial SEM path graph

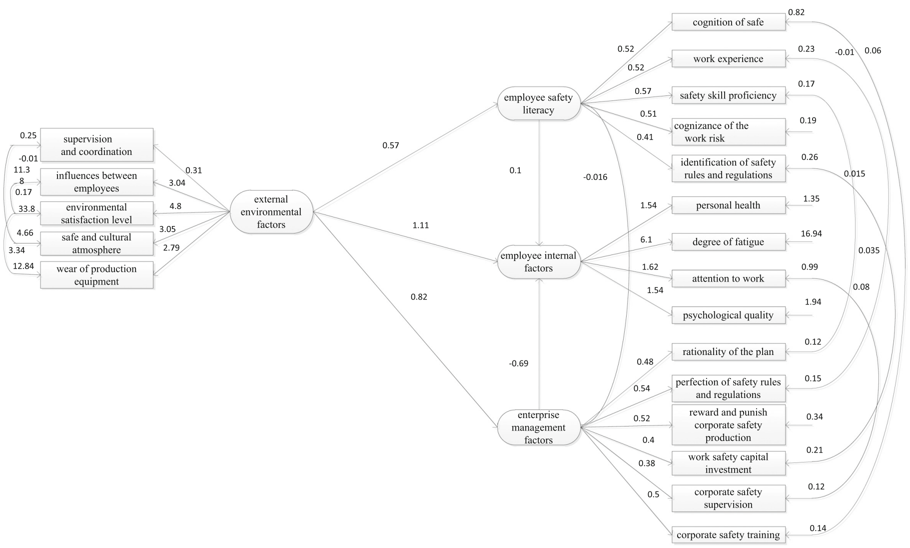


**Fig. 2.** Modified SEM path diagram

**Table 6.** Fitting index of modified SEM model

| Goodness of fit indicator | RMSEA | CFI | NFI | IFI |
|---|---|---|---|---|
| Estimated value | 0.052 | 0.90 | 0.91 | 0.92 |
| fitting standards | $\leq 0.08$ | $\geq 0.9$ | $\geq 0.9$ | $\geq 0.9$ |

## 4 The Influence of Organizational Factors on Employees' Safety Behavior Based on SEM

After confirming and validating the theoretical model of organizational factors that affect the safety of employees, the index of each factor is measured. The weighted average method is used to compare the load factor of each index with all the indicators of the corresponding latent variables as the weight coefficient of the index, and weighted average with the index of each index to obtain the influence index of each latent variable factor. As shown in Table 7.

From Table 7, it can be seen that the index of influence of organizational factors on safe behavior as follows: employee safety literacy (3.5), employee internal factor (3.25), external environmental factor (3.28), enterprise management factor (3.35). Among them, the influence index of internal factors and external environmental factors of employees is relatively low, which shows that the external environment of the

**Table 7.** Each factor influence index and weight coefficient

| Latent variable factor | Average value | Observed variables | Average value | Weights |
|---|---|---|---|---|
| Safety literacy | 3.5 | $A_1$ | 3.64 | 0.11 |
| | | $A_2$ | 3.41 | 0.2 |
| | | $A_3$ | 3.51 | 0.25 |
| | | $A_4$ | 3.51 | 0.25 |
| | | $A_5$ | 3.44 | 0.19 |
| Internal factors | 3.25 | $A_6$ | 3.23 | 0.26 |
| | | $A_7$ | 3.36 | 0.24 |
| | | $A_8$ | 3.31 | 0.25 |
| | | $A_9$ | 3.1 | 0.25 |
| Environmental factor | 3.28 | $A_{10}$ | 3.55 | 0.19 |
| | | $A_{11}$ | 3.26 | 0.17 |
| | | $A_{12}$ | 3.11 | 0.21 |
| | | $A_{13}$ | 3.09 | 0.17 |
| | | $A_{14}$ | 3.37 | 0.26 |
| Management factors | 3.35 | $A_{15}$ | 3.28 | 0.15 |
| | | $A_{16}$ | 3.4 | 0.16 |
| | | $A_{17}$ | 3.32 | 0.13 |
| | | $A_{18}$ | 3.44 | 0.21 |
| | | $A_{19}$ | 3.43 | 0.18 |
| | | $A_{20}$ | 3.23 | 0.17 |

enterprise and the overall health status of workers are good. When working, the state of mind is full, and attention is relatively concentrated, meanwhile the external environment is more capable of coping with changes. Employees' safety literacy and enterprise management factors have a higher index of influence, reflecting enterprises need to attach importance to education, training, organizational culture and establish a good corporate culture. The proficiency of safety operation skills and the cognitive impact index of position risk are relatively high, which indicates that the enterprise needs to specially enhance emergency training, employees' safety awareness, employees' ability to deal with emergencies and job proficiency. Through Pre-job training and other simulated operational procedures to further enhance staff awareness of safe operation, we should always urge employees to maintain a safe and cautious attitude and strengthen supervision to ensure the personal safety of employees. It can be seen from Table 4 that enterprises have a high index of influence on safety in production, and their investment in safety production can reflect the importance attached by the enterprise to staff safety. Increasing investment in safety production to build a scientific and modern production line can not only ensure the safe operation of employees technically, enhance the overall safety of the enterprise environment, but also make safety awareness of production safety operations deep into each employee.

### 4.1 Analysis of the Relationship Between Latent and Observed Variables

The Relationship between Safety Literacy Factors and Observational Variables. In the safety literacy factors, the effect of each observation variable was as follows: proficiency in safe operation skill (0.57), cognition of safety regulations (0.52) and current work experience (0.51), understanding of position risk (0.5), safety production operation (0.41). It shows that proficiency in safe operation skills is the cornerstone of personal safety literacy. However, the cognition of safety regulations and the experience of employees in the company provide important guarantee for the employees' behavior safety. The degree of familiarity with job operation risk is also an important factor that can not be ignored.

The Relationship between Employee Internal Factors and Observational Variables. Among the internal factors of employees, the influence of each of the observed variables is as follows: employee fatigue (6.1), employee attention (1.61), employee health (1.54) and security staff psychological quality (1.53). It shows that the degree of employee fatigue in work is the basic factor that affects the safety of behavior. Therefore, the work plan should be rationally designed to avoid the occurrence of some safety accidents caused by over-exhaustion of employees. From the data point of view the internal factors of staff fatigue is far greater than the impact of other factors, business managers consider safety in production, but also need to create a comfortable environment and appropriate relaxation to ease the fatigue of staff to ensure that Safe production. At the same time, enterprises also need to strengthen their employees' safety concepts, enhance their safety awareness and enhance their employees' attention during working hours so as to ensure safety in production.

The Relationship between Enterprise Management Factors and Observational Variables. The influence of the observation variables in the factors of enterprise management are as follows: the perfection degree of the safety rules and regulations

(0.54), the rewards and punishments (0.52) of the enterprise safety production, the training frequency and intensity of the enterprise staff (0.5), the perfection of the enterprise safety plan (0.48), investment in safe production funds (0.4) and corporate safety supervision (0.38). This shows that the perfection of enterprise production rules and regulations has a significant impact on staff behavior safety. Therefore, enterprises should formulate and improve the rules and regulations on safety production, make the operation process detailed and modularized so as to ensure the safety of production system. In formulating production plans and rules and regulations, enterprises should consider whether the production plan is reasonable, whether the rules and regulations are perfect, and whether employees should accept proper investigation of these production plans and rules and regulations. The enterprises in the production safety through the development of a reasonable system of rewards and punishments, but also can stimulate the enthusiasm of employees, improve the work of staff attention. If there is illegal operation, appropriate punishment, but also can play a warning role.

The impact of the observed variables in the external environment factors were as follows: the environment in which the employees work daily (4.8), the workplace safety atmosphere (3.05), the interaction between employees (3.04), the wear of production equipment (2.79) Coordination (0.3). It shows that staff daily work environment is an important guarantee for the safety of employees. At the same time, the interaction between the production safety environment of the enterprise and employees affects the overall production and working environment. Therefore, continuous improvement of safety culture and improvement of organizational culture are indispensable. Enterprises should also increase investment in production equipment to avoid production safety problems caused by equipment aging or failure. At the same time, enterprises also need to strengthen supervision and coordination to prevent unsafe behavior.

## 5 Multi-angle Analysis of Safety Organization Factors

In this section, we classify the sample data into two parts: manager and employee. The structural equation model (SEM) is used to analyze the organizational factors that affect the employee behavior safety. According to the SEM's effective path map, the factors affecting the safety organization are analyzed from different perspectives.

This paper mainly uses the modified index method [15] to correct the initial model. By adding a path to the model, it is advisable to add free parameters as long as the reduction in chi-square is significant. The corrected structural equation path coefficients are shown in Table 8 below.

In terms of the internal factors of employees, comparing the path coefficients in Table 8 shows that the managers think that the attentiveness of employees during work is the main factor in the work safety, because from the leadership point of view, the employees will pass the annual medical examination Work, so employee health for the safety of enterprises less affected. The degree of fatigue is only one factor that affects employees' attention. Managers analyze the employees' internal factors that affect the production safety in the overall situation. The employees are too unimpressive in analyzing the factors that affect the safety organization and remind managers that Many

**Table 8.** Structural equation path coefficient of employees and managers

| Latent variable factor | Observed variables | Manager | Employee |
|---|---|---|---|
| Safety literacy | $A_1$ | 0.06 | 0.17 |
| | $A_2$ | 0.12 | 0.33 |
| | $A_3$ | 0.25 | 0.31 |
| | $A_4$ | 0.26 | 0.34 |
| | $A_5$ | 0.29 | 0.35 |
| Internal factors | $A_6$ | 0.26 | 0.47 |
| | $A_7$ | 0.33 | 0.54 |
| | $A_8$ | 0.47 | 0.47 |
| | $A_9$ | 0.32 | 0.41 |
| Environmental factor | $A_{10}$ | 0.29 | 0.19 |
| | $A_{11}$ | 0.26 | 0.49 |
| | $A_{12}$ | 0.30 | 0.50 |
| | $A_{13}$ | 0.42 | 0.47 |
| | $A_{14}$ | 0.44 | 0.34 |
| Management factors | $A_{15}$ | 0.50 | 0.44 |
| | $A_{16}$ | 0.54 | 0.45 |
| | $A_{17}$ | 0.47 | 0.28 |
| | $A_{18}$ | 0.58 | 0.29 |
| | $A_{19}$ | 0.49 | 0.29 |
| | $A_{20}$ | 0.63 | 0.37 |

accidents in the employee's mind have a major connection with over-fatigue. Therefore, as a manager should be appropriate arrangements for rest, keep abreast of the physical condition of employees. As a manager should try to avoid employees due to fatigue caused by work time inattention, resulting in security incidents.

In the aspect of enterprise management. According to the path coefficient in Table 8, managers can think that the safety training and safety investment of the enterprise are crucial to the safety production of the enterprise, whereas the employees believe that the safety regulations and production planning rationality is safe production protection. The main reason for differences in business management is that managers have the power to manage the business and employees are the people to be managed. The reasonable work arrangements will allow employees at work not be too tired and always maintain a full state of mind. Improve the rules and regulations is the cornerstone of production safety in the hearts of employees. In the investment of corporate security funds, you can introduce some of the management of high-end talent in order to develop a perfect work for the enterprise's own plan. In the staff of enterprise safety education and training, the emphasis should be on corporate safety rules and regulations.

In terms of external environmental factors, we can see from the comparison of the path coefficients in Table 8, Managers generally believe that the wear and tear of production equipment and safety culture of enterprises play an important role in safety production. However, employees think the comfort of the work environment and the interaction between employees are important factors in safe production. In the aspect of enterprise safety production, managers should implement safety training to every employee and integrate the safety idea into the heart of every employee. Managers should increase investment in production safety equipment, replace some worn-out production equipment with more advanced technology to ensure that employees work in a safe and comfortable environment, which can greatly reduce the occurrence of safety accidents.

## 6 Conclusion

In this paper, the effective sample size of the questionnaire is more extensive, it is covering 657 valid sample data including the leading staff. Through the overall survey and classification of the survey we give the following suggestions for the production safety:

1. To increase education and training efforts in the area of enterprise safety production, we must not only conduct pre-job skills training and emergency skills training, but also conduct manual training and rigorous training assessments to enhance staff proficiency in production to ensure that each Staff proficiency in production operations;
2. To strengthen the supervision and coordination of management, enhance the safety culture of the enterprise and provide staff with a harmonious working team;
3. At the same time, to develop a reasonable work plan, arrange reasonable working hours, relax appropriately to avoid staff in production operations are too tired;
4. To develop a reasonable work plan and rules and regulations, make full use of modern technical means and methods, timely notice of changes to the work plan to employees, strengthen communication with employees, the staff do not understand the work planning process, timely and accurate Explain the coordination and encourage employees to put forward suggestions for rationalization;

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# Reducing Injuries by Applying Behavior Based Safety

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**Abstract.** Many companies have made many efforts to reach to a safe operation. These efforts have led to improve their safety level but all too often still unwanted events associated with injuries occur. To achieve a sustainable safety, many techniques have been adopted. Among them, behavior-based safety has been applied to improve safety through employees' safe behavior. In this paper, the BBS model is more closely studied. The aim of the study is to understand the features of the BBS model, its coming into existence, its pros and cons and how the model works in the industry.

**Keywords:** Behavior based safety · Reducing injuries · Workplace safety

## 1 Introduction

Safety is an important task in every workplace. In a safe workplace, it is not only important to protect the employee's health and wellbeing, but also to minimize the costs connected to occupational injuries. In 2009 there were 25 260 reported occupational injuries in Sweden, of them were 41 fatal [1]. These numbers indicate that the safety culture and the human behavior must be integrated to a higher extent, and the work with safety systems must continue and be even more effective than they are today. During the last decades, there has been an improvement in the working conditions, and this has led to a decrease in occupational injuries. Nowadays, in Sweden, most occupational injuries are not connected to working conditions, but instead to human behavior. Therefore, it is necessary to change people's attitudes towards safety. Several psychological models have been developed to work with safety within workplaces. Examples of these models are critical incident analysis, attitude creation group discussions, risk analysis and behavior-based safety [2].

## 2 Objectives of the Study

The objectives with this paper are:

- Implementation of BBS into industries,
- Investigation of everyday work including the BBS Performance at the complex under the study will be investigated,
- Advantages and disadvantages with the BBS model, and


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- An analysis of the safety culture will be done with the purpose to evaluate how the BBS model affects the safety culture and vice versa.

The goal of the study is to decrease the work-based injuries.

## 3 Methodology

The objectives will be fulfilled by conducting literature studies, case studies and interviews. The literature study is used to receive an overview of the BBS model in a broad perspective. For the more detailed view of how the BBS model works in reality, in a chemical plant in Sweden, an interview with a safety engineer working in the complex was performed. The interview was focused on the implementation of the BBS model, if the employees and managers have noticed any changes in safety behavior. This study is mainly prepared based on a project conducted at Chalmers University of Technology, Gothenburg, Sweden [3].

## 4 Description of the Concept

One reason why people not always act safe is because unsafe actions might be followed by short-term positive consequences that are appealing, like comfort, convenience and efficiency. Therefore, it is not unlikely that people act unsafe because that leads to the best positive consequences in a short-term perspective. An unsafe behavior may save time, uncomfortable protecting clothes are not needed, and reward is gained in a short-term perspective. However, in the long term the risk for accidents and injuries is increased. It is important to consider what the consequences for a desired behavior are and try to make these consequences positive. A usual way to describe behavior and their consequences is with a so-called ABC-analysis. A is standing for *antecedent*, B is standing for *behavior*, and C is standing for *consequence*. An antecedent is the incident that comes before the behavior. An example of an ABC-analysis is given as follows:

A: A machine item breaks down
B: Someone fixes the machine quickly without concerning current safety regulations (which would have taken longer time).
C: The advantages are that time is saved and that reward is gained due to a rapid action. But in the long run the risk for injuries is increased.

**Advantages**
There are several advantages with using the BBS model compared to use methods that are more traditional. There is sufficient with minimal professional training to be able to administrate the BBS model and it is a relatively easy to administer since the behavior-change interventions are straightforward. It is also a cost-effective method that can reach people where the problems occur since the BBS model, unlike traditional methods, teaches the employees to take control of their own safety. Another advantage is that managers can teach the behavior-change techniques which are most likely to work in their specific case [4].

**Disadvantages**
Even though the BBS model has a large potential it is not a universal tool that can be applied in every situation, and there are some problems with using the BBS model to increase safety. The individual worker does not create most problems with quality and safety; hence trying to change the behavior of the workers will not improve the safety. With the BBS model, the workers are treated, as they know nothing about what they want and need regarding safety. They should do as the management tells them even though the workers in most cases know more about the safety needed in the everyday work. The employees might feel anxiety during the BBS control since they are being watched, which may cause long term negative consequences [4].

Another problem with the BBS model is that by only concentrating on the employees' behavior it is possible that the real causes to accidents are ignored, i.e. organizational problems and technical problems. To improve safety, focus must first be on engineering improvements. When the number of accidents is no longer decreased by the engineering improvements a shift in focus towards the safety management systems should be done for further safety improvements. Finally, when both engineering improvements and safety management systems have exhausted their potential, the focus should be shifted to behavior-based safety. This indicates that the BBS model is the last step in a long chain of safety procedures, and that the BBS model should only be used when the work with the safety process has come far. The BBS model can also be misguiding if it is only used for the workers at the end of the production chain. In order to have the best result it is important to understand that the safety work must be carried out in all directions in an organization [5].

## 5 Implementation of BBS in Industries

The BBS model focuses on what people do (action), analyze their action and then implement a strategy to improve the behavior of the performance. The purpose of implementing with the BBS model is to create an environment where safe behavior is connected to positive consequences and at-risk behavior is connected to negative consequences. There are four steps to implement the BBS model:

1. Risk assessment: Identify at-risk behaviors causing injuries and losses,
2. Observation: Observation over sometime period of identified at-risk behavior,
3. Intervene: Trying to increase safe behaviors and reduce at-risk behaviors,
4. Improvement: Improvement based on findings and feedback on the performance [6].

## 6 Application of BBS at Chemical Company A in Sweden

Chemical company A started to implement the BBS model in 2003 but the model ended up in the shadow of other models and was first used in a wider extent in 2008. After the safety training was performed at the company, 81% of the employees thought they had changed their approach and had become more positive toward safety work and 62% were more focused on the safety in their work [3]. One of the daily projects of the company is behavior-based safety, where the project leader together with the other employees works to implement the safety behaviors as a fundamental behavior; emphasizes the importance of role of BBS models, shearing knowledge with each other, having dialogues, giving feedback and having focus on safe behavior [3]. One simple everyday example he gives is, "*Why we always walk against the red light? We rarely think about the consequence of the risk that is taken every day*". The project leader repeats the importance of having the courage to criticize and questioning the risks that are taken without pointing fingers [3]. To be anonymous makes it easier for the management to collect information about the risks in the daily work. The information collected can further be distributed to every employee. Several other employees will probably recognize the at-risk behaviors and the risk behind the behaviors and how it can be prevented can be explained. In order to change a behavior, it is important that the management motivate the employees to safe daily work and reward safe behavior immediately. It is also important to allow errors, so they can be detected and prevented in the future. Long-term and clear priorities and goals should be set so that every employee easily can understand the goals, but also be able to perform them. The project leader stresses that behavior changes takes time and is a process that cannot be generalized. To change a behavior might take 10–15 years and cannot be done without following up the behavior [3].

> "*Chase results are not the goal, instead we should slowly try to build fundamental safety behaviors", says project leader* [10 in 3]

## 7 Performance of BBS Observation in Chemical Company A

The BBS observations are performed spontaneously or at scheduled time at the company where one observant evaluates the performance of a worker. The BBS observation should be performed in every department but is mainly focused on the area where accidents most likely happen. The BBS observations are usually performed on the employees in the production. The behaviors studied are for example body position, ergonomics, tools/equipment, instruction/routines, protective equipment, work environment and transportation. The used checklist contains a questionnaire about the place, time, work task and the number of people observed. The area of work is for example an office, a workshop, a lab, a plant or a loading site. "No names – no one to blame" is written at the top of the checklist, which means that the person that is observed will be anonymous. While the work is done, the observant fills in the questionnaire regarding if the worker acts safe or has an at-risk behavior.

The behaviors that are considered safe respectively the behaviors that are considered to be at- risk are counted in order to receive an overview of the risks at each area. The comments that were made during the observation will finally be discussed. The discussion provides information and understanding for people's actions and makes it possible to analyze the areas at risk. An example of a part of a checklist is presented in Table 1.

**Table 1.** Checklist for a BBS procedure [3].

| Protective equipment | | Safe | At risk |
|---|---|---|---|
| 1 | Helmet | | |
| 2 | Goggles | | |
| 3 | Safety shoes/boots | | |
| 4 | Ear protection | | |
| 5 | Correct protective clothing/gloves | | |
| 6 | Respirator | | |
| 7 | Fall protection | | |

The company target is to decrease the total reportable accident rate per million working hours down to two [3]. The actions taken to reach this target are:

- show sustainable behavior-based safety (BBS) system for all employees and contractors
- meet challenging targets for number of BBS observations
- meet implementation rate for BBS-improvements >60%
- analyze the root cause to all incidents
- action plans with improvements at all sites

The critical success factors are a good safety culture and an efficient communication about safety between employees and between sites. It is shown that by applying safety culture and by changing behaviors, the absence from work decreases significantly [11 in 3].

## 8 Safety Culture and BBS

The safety culture within a company is very crucial for the outcome of a BBS operation. To be able to have a successful BBS work every employee must have the same believes about safety and how the company should work towards a safety environment. An important factor to reach a good safety climate is the employee's feeling of having empowerment, which means that they feel that they make a difference and have the power to affect the situation they are in. The feeling of empowerment is reliable on the feelings of self-efficacy, personal control and optimism. Empowerment together with self-esteem and belonging creates a working safety culture. This is shown in Fig. 1 in an orderly manner. In the middle of Fig. 1 where the circles empowerment, self-esteem and belonging meet the desired feeling of "we can make valuable differences" is created [6].

It should be noted that, the situation described above is not too often match reality. Many companies struggle with problems in the safety culture, which makes it difficult to work with the BBS model. Safety is a social and psychological phenomenon that is based on people's values, believes and attitudes. Sometimes it is said that a particular manner "is in the walls", but it is always the mentality between people that sets the culture. Therefore, it is much more difficult for an individual to break social rules than

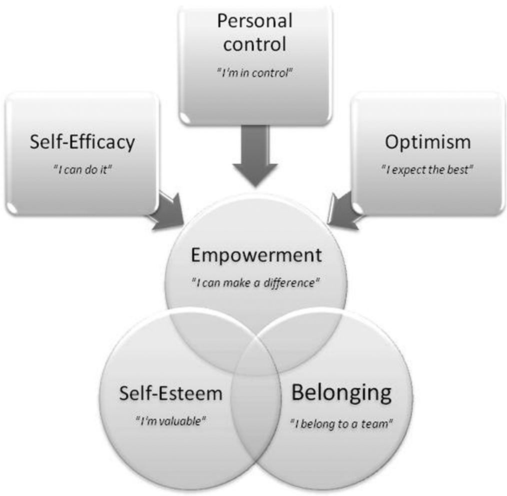


**Fig. 1.** Important factors to get employees to care for the safety and health of each other [6].

technical rules. People that work in a safe way might be told that they work too slowly, that they are not “macho” and that they are “chickens”. The outcome of this might be that people, who act safe, stop using protecting clothes, do not ask the manager about safety equipment and choose to work quickly rather than safely. It is also of highest importance to remember that the behavior of the management is almost always a factor contributing to how the safety climate is. For the management to convey a safe behavior there cannot be any double messages such as “Safety rules are OK – but it takes too long time if we always should follow them!”. If there are double messages like this a sustainable and lasting safety culture can never be achieved, and the BBS model cannot be used. There will be conflicts between what the manager says in a meeting and what s/he later on conveys in the real process.

Normalization of risk is a phenomenon when the risks in a process are not considered as risks since they are so common. The same is with the silent consensus phenomenon that means that the common ways of thinking and doing things are never questioned. These behaviors create a “safety culture” where some risks are not considered as important, and an implementation of a safety system is not possible because no one thinks there are any risks at the workplace. Many safety systems are good, but they will not support a good safety culture unless the employees consider the system meaningful [12 in 3].

To be able to have a well-functioning safety climate the atmosphere must be that the employees feel that they can inform the management about incidents without fearing blaming or dismissal. To reach a safety climate that works it is not possible to have the philosophy: “the one that finds a problem is the problem and should therefore solve the problem”. If it works that way no one will ever report any incidents that are not obvious to everyone, and therefore no improvements can be made. In order to have all accidents and near misses reported it is necessarily to have a blame-free organization. This is also important from the view that something should be learnt from previous accidents or near misses. If they never are reported, the same accidents might happen repeatedly. To be able to integrate a safety system like the BBS model in the safety culture it is important that the company has come so far in their safety work that when someone tells a colleague to put on a helmet, or similar, it is not seen as a threat by the person who is told, but instead as an act of kindness [13 in 3].

Behavior is perhaps the most important factor in order to reach a safety culture. Attitudes, norms and perceived control are all aspects that contribute to a specific behavior. To change a person's attitude, and thereby their behavior can be hard. If a desired behavior is voluntary, it is likely that a person, whose attitudes or beliefs do not agree with this behavior, do not care about the behavior. Stress can be created if a behavior is in conflict with a person's beliefs or attitudes. However, if the behavior is mandatory the person will in time change the attitude. One example of this is the behavior of wearing a helmet within a plant. If this behavior is mandatory, with no excuses the employees will adopt this behavior and in the end all individuals will wear a helmet regardless what their opinion was in the beginning. However, to make certain behaviors mandatory is first and foremost working on simple behaviors, when the desired behavior is complex it is more difficult to solve it with mandatory procedures. The risk is that the employees feel controlled by the management and do the opposite anyway [12 in 3].

Some BBS projects are well functional and some fail, and much of the outcome is dependent on the safety culture in the company. It has been shown that in order to have a BBS project that works the triangle in Fig. 2 should be applicable Trust is stated as the interpersonal attribute on the "person side" of the triangle. This means that in order to have a working BBS project the employees must trust the management and have faith in the management's decisions. Management support is stated on the "environment side" of the triangle. This means in order to have a working BBS project the environment must be that the management supports the safety work. There must be follow-ups and the manager must be involved in, and a part of the safety system. On the "behavior side" of the triangle, participation is stated as the important factor. Participation is necessarily in order to have a working BBS project. Everyone must work towards the same goal and everyone must believe that this is the right direction to go. The sides in the triangle are not static, but dynamic and interactive. If one side in the triangle is changed, the other sides are also affected. In the middle of the triangle, BBS training is stated. When the employees and the management have received the principles and the tools for a working BBS project it is important with training so this is something that can be implemented in all parts of the company [7].

## 9 Discussion

The BBS model is a psychological model with the purpose to reduce at-risk behavior, promote, and introduce safe behavior. There have been many discussions about the value of using BBS as a model to increase the safety within a company, and the model has both advocates and critics.

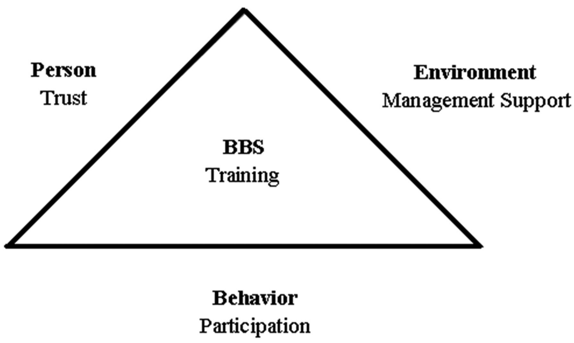


**Fig. 2.** BBS safety success triangle [7].

One important aspect to point out is that many companies introduce the BBS model too early in their safety process, and that is one reason why many BBS projects tend to fail. Another aspect is that companies may tend to expect consisting result after a very short time period. The BBS model is dealing with behaviors, and a behavior is very difficult to change for an individual. According to the BBS project leader of company A, it can take 10–15 years to change a specific behavior. With that in mind it is interesting that Kemi claims that only two years after the introduction of the BBS model at company A over 80% of the employees state that they have changed their attitudes towards safety at work, and that they now have a more positive attitude towards safety work.

The question is if this is only because the BBS model has recently been introduced and therefore there is a positive trend in the result. The change in behavior might be because the employees feel involved in the safety work and they understand the purposes of it. That shows that company A has managed to engage the employees to work towards the same direction. It would be interesting to have an evaluation of the BBS work at company A a couple of years from now to be able to compare the results. It would also be interesting to do a comparison between the management's opinion about the use of the BBS model and the employee's opinion. The result of such a comparison might be that the management believes that the safety work with the BBS model works fine while the employees do not agree. This can especially happen if the communication between the management and the employees is not working efficiently and the employees therefore cannot see the use of the safety work. Another interesting aspect to evaluate would be study how the employees who have undergone a BBS project affect new recruits that has not been part of a BBS project. An interesting question would then be if the "old" employees affect the new recruits in a way, so the new recruits change their behaviors and attitudes and adopt a safer behavior.

As was discussed above, behavior and attitudes are difficult to change because they are many times rooted in people's values and beliefs. To make a desired behavior mandatory is one way to force the employees in the direction towards a safe behavior. But if the situation is very complex this solution might not work. If the employees feel forced by the management and if they do not understand the importance of the safety work they might just do the opposite to what they are told just to show that they can take decisions about themselves. Another way to reach a desired behavior is to reward the employees, for example with money. But this will probably just give positive effects in short-term perspective. People tend to forget what they ought to do if they do not fully realize the consequences. In the end people need to understand that they act in a certain way to ensure the safety for them and their surroundings, and not for the money. Therefore, the only way to make employees behave safe in complex situations is to ensure that they are aware of the risks, why a safe behavior is necessarily and what the consequences can be if they have an at-risk behavior. The feedback and the management's commitment are therefore two factors that are crucial for the BBS model to work. Those factors are not just important in the beginning, but during the entire process. The culture within a company is many times set by the conduct of the management. It is of highest importance that the management understands the features of the safety work and can convey the importance of it to the employees.

Often people have an at-risk behavior because no injuries or accidents have happened. Statements like "I have always done the work in this way" are not rare. But even though no accidents have occurred until today the risk is high that there eventually will be an accident caused by the unsafe behavior. To realize and pay attention to at-risk behaviors and take action before something severe happens is of crucial importance.

It is important for both the management and the employees to realize that the BBS model is not about pointing fingers on individuals. It is not about finding errors in certain individuals, but to change the overall behavior and climate within a workplace. Even in this situation the management has an important role. It is the management's responsibility to ensure that the climate within the group of employees is open and friendly and make sure that the BBS work is not about finding an individual's mistakes.

Normalization of risks is a phenomenon that is hard to reduce. The BBS model will not help to solve this problem since the persons in the situation are not aware of the risks. One possible solution would be to use consultants that have not been part of the team before to make them document all risks they see. A disadvantage with this is that the employees might feel that somebody from the "outside" comes and tell them what to do and how to perform their work.

It is everybody's responsibility to be aware of the risks in a workplace in order to prevent normalization of risks.

In order to have a more efficient implementation of the BBS model in the industry there are some things in the implementation strategy that could be improved. First of all, it can sometimes be hard to identify the desired behaviors. This can be because the people involved have worked at the same workplace for a long time and have become used to their situation. Study visits to other plants and companies can be a solution to this. This makes it possible to see how other people work and think about safety and it also makes it possible to exchange experiences. To improve the implementation further it is important to have a parallel work with the safety culture within the company. To be able to create a sustainable safety climate it is important that the focus is not only on the behavior in the work, but also on the behavior toward each other. The BBS model does not consider how the climate between individuals is in a group. That aspect should be included since the ability to reach a desired safety culture many times is dependent on the behavior between individuals. To be able to work towards the same goal it is desired that the BBS model is implemented in the entire company and not only in one department. This will also facilitate collaborations across borders, which will increase the effectiveness of the implementation of the BBS model.

## 10 Conclusion

The BBS model can be useful in the safety work in industries. The purpose with the model is to identify at-risk behaviors and reduce them. It can be an effective model to ensure a safer climate if the problem is the behaviors and attitudes among the employees. However, it is important to be aware of the limitations and not believe that this is a miracle model that will solve all safety issues within a short time. Safety work is a continuous process that must take part in all levels of an organization and include all employees without any exceptions.

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# Barriers, Drivers and Impact of a Simplified Occupational Safety and Health Management System in Micro and Small Enterprises

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**Abstract.** Micro and Small enterprises (MiSEs) are the most widespread kinds of company present in the world. As far as these companies' management structures are concerned, huge variety and fragmentation seem to be critical factors in the effective and efficient implementation of a standard (e.g., BS OHSAS 18001, now ISO 45001) occupational safety and health management system (OHSMS), together with a systematic lack of resources (both economic and in terms of available man-hours). This research identifies and discusses the barriers to and drivers of the implementation of a OSHMS and its impact on MiSEs through a multistep research methodology consisting of: (1) a review of the existent literature; (2) a survey; (3) a dialogue workshop; and (4) follow-up interviews. The results are reported and discussed, so as to underline critical aspects linked to OSHMS implementation, together with practical suggestions aiming at supporting such companies in their implementation process.

**Keywords:** Occupational Safety and Health Management System · Simplified · Barriers · Drivers · Impact · Micro enterprises · Small enterprises

## 1 Introduction

Small businesses are fundamental actors in the worldwide economy. According to 2015 National Institute for Statistics data (ISTAT, Table 1), in Italy there are more than 4,200,000 active enterprises, 99.4% of which have fewer than 50 employees (i.e., small), and 95% of active enterprises have fewer than 10 employees (i.e., micro).

Several authors agree that MiSEs are usually affected by a lack of informative, economic and managerial resources [1], and this leads them to have a lower safety level


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**Table 1.** Classification of Italian industries by size from ISTAT, 2015.

| Size of firm | Frequency | Percentage |
|---|---|---|
| Sole proprietorship | 2,477,500 | 58.7 |
| 02–05 | 1,316,025 | 31.2 |
| 06–09 | 215,876 | 5.1 |
| 10–19 | 134,519 | 3.2 |
| 20–49 | 52,495 | 1.2 |
| 50–249 | 20,838 | 0.5 |
| 250+ | 3,468 | 0.1 |
| Total | 4,220,721 | 100 |

than large enterprises (LEs) [2]. In MiSEs there is also an inverse relationship between the size of the company and the magnitude and frequency index rate of accidents [3]. Recently several researchers have investigated the relationship between the difficulties that an MiSE faces in improving its safety standards and its structure. It has been proven that considering MiSEs as if they were LEs, and thus ignoring the huge variety and fragmentation involved in those companies, has led to further difficulties in terms of safety improvements [4], particularly regarding the effective and efficient implementation of a standard (e.g., BS OHSAS 18001, now ISO 45001) occupational safety and health management system (OSHMS).

There are several standard protocols for occupational and safety improvement, but in MiSEs they are only occasionally adopted, because, quoting a statement in a Health and Safety Executive report, they tend not to have ‘enough time to spend on addressing issues of health and safety when faced with other more immediate challenges’ [5, p. 17]. However, the reasons why MiSEs do not adopt OSHMSs effectively are not entirely clear.

In this paper the results of research aimed at identifying the barriers to and drivers of the implementation of a simplified occupational safety and health management system (OSHMS) in MiSEs are presented. The focus of the research is the metalworking sector, which has the highest incidence of occupational accidents for MiSEs [6].

The research consists of:

– a summary of bibliographic evidence concerning the barriers to and enablers of the implementation of a non-simplified OSHMS;
– a preliminary survey mainly addressing the drivers of and barriers to the implementation of a simplified occupational safety and health management system and possible solutions;
– a dialogue workshop to delve deeply into the results from the survey;
– follow-up interviews with a few selected workshop participants to investigate the impact of such systems.

Some incisive comments and a viable set of guidelines to cope with the main issues raised in this paper, is presented at the end of the article.

## 2 Barriers to and Enablers of the Implementation of a Non-simplified OSHMS

### 2.1 Barriers

The relevance of OHS matters to the micro and especially small enterprise context is covered quite well in the literature. Several studies [2, 7] have argued that OHS is approached by MiSEs as a matter of legislative compliance rather than an efficient way to improve the company itself, with particular regard to several activity sectors, like the one of interest in this research, the metalworking industry in northern Italy [4].

However, the literature becomes bare when the focus shifts to the awareness of this branch of industries about the impact that the implementation of a system able to control safety and health based on a standard procedure could have on their safety and economic performance. This issue can be analysed on different levels according to the themes, some of which are discussed in different studies in the literature and some of which are not, that are relevant to MiSEs.

Knowledge regarding the availability of such a system (OSHMS) is one of the main barriers to the implementation of the system itself. This refers to firms' lack of sufficient resources, both informative [8] and economic [1], to be able to understand and then implement a system of this type [9]. Such companies consider management systems to be expensive, time wasting and ineffective [10]. Standard OSHMSs, like OHSAS 18001/ISO 45001, are designed for large homogeneous enterprises and do not match MiSEs' inhomogeneity. As different studies have reported, standards and national laws treat this family of industries as a whole [4] and do not pay attention to the infinite details that characterize one micro enterprise with respect to another, maybe of the same class and size. This leads to a lack of interest in this topic from MiSEs that translates into a lack of information about OHS and its relative impact [1].

The inability of MiSEs to analyse accidents and injuries is another critical topic. The literature, as previously mentioned, has proved that small industries have a higher average accident risk than larger ones [3], but, on the other side, due to the small number of employees in these companies, the number of injuries is quite low. Because of this, owners often underestimate the risks inside their factories, and this leads to an overall decrease of health and safety in the company.

### 2.2 Enablers

The implementation of an occupational safety and health management system guarantees a certain impact on crucial themes within every company that applies the system. It has been researched on different levels, and its impacts have been reviewed [11] and classified according to the safety system's grade of complexity. The findings are all positive, but it has been stated that, to confirm them and make strong recommendations in support of an OSHMS, further methodological studies must be undertaken [12].

Based on the literature, the application of a standard procedure to evaluate the risks inside a factory will drastically improve the level of safety in the company, leading to [13, 14]:

- A better evaluation of the risks;
- The achievement of the best working conditions for each employee;
- A reduction in the accident rates with a consequent reduction in the costs and day losses from the employee;
- The guarantee of a certain level of standard for customers and suppliers.

Looking at the main barrier affecting MiSEs, resources, as previously quoted, there is substantial evidence that should lead those companies to implement an OSHMS. In fact, this choice would guarantee the corresponding installation of a solid managerial and analysis system of injuries and accidents that also considers 'near misses' and relative registration and analysis. This, as multiple reports have demonstrated [15], will have a significant impact on the company in terms of a better understanding of the risks, a reduction of day losses and consequent better economic results and the introduction of a culture of greater self-awareness among employees in terms of health and safety.

## 3 Research Methodology

### 3.1 Survey

To understand better the details that make a non-simplified OSHMS difficult for MiSEs to apply and to investigate the features that a simplified OSHMS should have to be used effectively by MiSEs, a survey was initially performed.

A closed-format questionnaire was submitted to over 1400 enterprises to investigate the overall issues regarding the knowledge and accessibility of OSHMSs and occupational health and safety software tools. The survey contained 36 questions divided into 4 main paragraphs: company records, risk assessment and OSHMSs, the application and use of an occupational health and safety software tool and the application and use of a registration and analysis system for injuries and near misses.

Enterprises were randomly chosen from among over 30,000 micro–small industries in the AIDA database available for the Politecnico di Milano (including enterprises located throughout Italy). The survey was submitted by e-mail to 512 (34.5% of the sample) micro enterprises (1–10 employees), 452 (30.4% of the sample) semi-micro enterprises (10–20 employees) and 521 (35.1% of the sample) small (20–50 employees) and smaller-medium (50–100 employees), achieving an overall response rate close to 8% (118 answers); 82 of them were complete and consistent, thus resulting in 5.5% response rate. The sample is representative of the project's interests: 63.3% in the metalworking sector, 12.5% involved in the industrial production of wood and paper and 24.2% from other sectors.

Open-ended questions were posed to verify the full understanding of some questions or to complete closed answers that were previously provided. Due to the lack of space, not all the descriptive results are reported in this paper.

Data analysis was carried out through a qualitative analysis: the survey's results were used to identify the most relevant aspects to be further investigated in the second phase of the methodology (i.e. the workshop). The results of the survey are summarized in the section relating to the overall results obtained.

### 3.2 Workshop

A focus group took place at API (Associazione Piccole e medie Imprese), an association of MiSEs (and medium ones) in the province of Lecco (Italy), involving some companies associated with this organization and others from nearby. During the workshop the possible modalities of application of a simplified OSHMS were discussed as well as the use of a software tool able to guide MiSEs in the management of the minimum information necessary for the proper functioning of the management system and the effective organization of the information outputs for small businesses. The focus group was formed both by companies that already had experience in implementing management systems and by companies that were approaching the issue for the first time. The sample of companies involved also included companies that had experience in OSH software tools for risk assessment: this allowed an understanding of the appreciated and less appreciated aspects of this type of facilitator.

### 3.3 Follow-up Interviews

As the last step of the methodological research, a few firms (4), which had previously been contacted through the survey and workshop, were chosen to participate in a follow-up interview to investigate in depth some aspects related to the type of information that can be provided effortlessly for a simplified OSHMS and the kind of minimum results that an MiSE can expect to obtain to consider the management system to be effective. The respondents were business owners and/or OSH managers. In addition, issues such as the use of a hypothetical software tool for the implementation of a simplified OSHMS were studied as well as the advantages associated with the return of highly detailed information that a simplified OSHMS could easily provide, such as that related to 'near misses'. The data were then filtered according to the variables applied in the study and they are reported below.

## 4 Results and Discussion

Overall 82 companies contributed to the research. They were divided into three different samples: the largest one consisting of all 82 companies that completely and consistently answered the online survey (5.5% of the total contacted), a smaller group consisting of 12 firms that took part in the workshop and a chosen group of 4 companies that participated in the follow-up interviews.

The respondents to the questionnaire were business owners with a safety manager role (29.3%), business owners without a safety manager role (24.4%), employees with a safety manager role (20.7%) and other employees or external consultants (29.6%).

The companies to which the questionnaire was applied were composed entirely of MiSEs: the responses were obtained prevalently from companies with a number of employees in the range 11–30 (43.9%), in the range 31–50 (19.5%) and in the range 5–10 (17.1%). This sample is therefore perfectly representative of the reality under consideration.

The following analysis was carried out, stating as the four main independent variables the most relevant themes linked to the efficient implementation of an OSHMS in an MiSE:

V1. Knowledge and implementation of an OSHMS;
V2. How risk assessment is performed;
V3. The availability and implementation of software for management safety purposes;
V4. How injuries and accidents are registered and analysed and their relative impact on the safety of the company.

Correlated with these, some dependent variables were identified, and they are described in the discussion of the results.

After a careful evaluation in order to avoid a biased analysis, the data collected and shown below have been filtered to avoid considering firms with 50 or more employees. Therefore, the maximum number of answers collected for each variable in the following of the paper is reduced from 82 to 70 companies.

The first topic researched regards the knowledge of micro and small enterprises about the existence of an occupational safety management system and consecutively the possibility of its implementation.

From the survey data (Table 2), it is possible to see that 34.3% of the sample knows about and has implemented such a system, while the largest group of firms, 37.1%, has no knowledge regarding the topic.

**Table 2.** Knowledge about OSHMSs.

| Variable | | |
|---|---|---|
| Existence of an OSHMS, even in an informal structure | Frequency | Percentage |
| No, I do not know what an OSHMS is | 26 | 37.1 |
| No, I have not implemented an OSHMS | 20 | 28.6 |
| Yes, I have implemented an informal OSHMS | 15 | 21.4 |
| Yes, I have implemented an OSHMS based on a company model | 3 | 4.3 |
| Yes, I have implemented an OSHMS based on a reference standard | 6 | 8.6 |
| Total | 70 | 100 |

It is interesting to look at the data achieved, filtered by a positive response to the previous question, following the successive question of the survey: more than 78% of the MiSEs that had adopted an OSHMS entrust the management of the system to an external safety consultancy agency. The workshop further confirmed these data: over 80% do not apply a safety management system and every company that had already implemented an OSHMS stated that it is helpful to ensure a better quality and safety standard inside the company.

Regarding the impact that OSHMS implementation could exert within an MiSE, further data were obtained through the follow-up interviews, which remarked that, from the owner's point of view, the main aspect that will be affected by such system is risk assessment and everything correlated with this in terms of time reduction and managerial simplification.

A parallel theme that would arise through the support of a management safety system is the risk assessment in this kind of firm. In Italy, the Legislative Decree n. 81/2008 and its subsequent amendments introduced standardized procedures for risk assessment mainly targeting enterprises up to 10 employees. Implemented with Interministerial Decree 11.30.2012, these procedures indicate a reference model with detailed guidelines, including forms to be filled in and containing the minimum requirements for risk assessment. These companies therefore have the right to use the traditional evaluation model or this simplified model. In the survey the MiSEs were asked whether they are aware of this simplified risk evaluation approach and whether they use it (Table 3). Only 35.7% know about and have actively adopted the simplified standard procedures that, according to Legislative Decree 11.30.2012, should help firms of this size to save resources and to be more efficient.

**Table 3.** Risk assessment in MiSEs.

| Variable | | |
|---|---|---|
| Use of standard procedures to perform risk assessment | Frequency | Percentage |
| Yes | 25 | 35.7 |
| No, I do not know about them/I do not know what the standard procedures stand for | 38 | 54.3 |
| No, I know what the standard procedures are but I choose not to use them | 5 | 7.1 |
| No, the standard procedures are not implementable in my company | 2 | 2.9 |
| Total | 70 | 100 |

Another question asked in the survey highlighted the influence of an external safety consultancy agency on the knowledge of these industries: 90.6% empower an external company to conduct risk assessment and to compile the risk assessment document.

Regarding the software topic, multiple data were collected through all three phases of the research. The percentage of respondents who answered positively the survey's question (Table 4) about the use of software for safety purposes is relevant: only 8.6%. This percentage was further confirmed through a direct question posed during the workshop, from which we found that only 15% of the MiSEs has never implemented SW in their company.

One of the most important aspects collected through the methodology, directly asking the MiSEs collaborating within the project, is the possible barriers to and drivers of the implementation of SW. A comparison among the different results obtained during the two steps is shown in Table 5, described through a scale that ranges from high (relevance) to low.

Regarding the conceivable drivers of SW implementation, during the follow-up interviews, four MiSEs were asked what the possible impact of such implementation on their own company could be. One of the most highlighted aspects was better accessibility to all safety-related data and, consequently, better and more complete management of safety issues thanks to the partial automation of several processes. On the

**Table 4.** Implementation of software in MiSEs.

| Variable | | |
|---|---|---|
| Use of SW for safety management | Frequency | Percentage |
| Yes | 6 | 8.6 |
| No | 64 | 91.4 |
| Total | 70 | 100 |

**Table 5.** Barriers to and drivers of SW implementation.

| Variable | | |
|---|---|---|
| Feature | Survey | Workshop |
| Time spent on use/implementation | Low | High |
| Cost | High | Normal |
| Inadequacy for the firm's dimension | High | High |
| Flexibility | Normal | Normal |
| User-friendly | Normal | High |

opposite side, according to the MiSEs, the greatest barrier is the amount of time that is usually required to make the software work properly.

Relevant data were also collected regarding the diffusion and implementation inside MiSEs of a system for the registration and analysis of accidents and injuries. Almost 50% (48.3%) of the firms in the survey's sample do not know about this or do not have such a system (Table 6).

**Table 6.** Management of injuries and accidents in MiSEs.

| Variable | | |
|---|---|---|
| Existence of an accident analysis process | Frequency | Percentage |
| Yes, it has been developed based on INAIL (Italian workers' compensation authority) standard indications | 7 | 12.1 |
| Yes, it has been developed based on an own model | 10 | 17.2 |
| Yes, it has been developed based on an external model | 8 | 13.8 |
| No, it does not exist | 15 | 25.9 |
| I do not know about the existence of such a process | 13 | 22.4 |
| Other | 5 | 8.6 |
| Total | 58 | 100 |
| Skipped | 12 | |

The workshop data reaffirmed those percentages and, through descriptive sentences, clarified the major issue: the lack of serious accidents in micro enterprises leads to general indifference to an accident and injury analysis process (over 70% of the companies interviewed). This is even more alarming when looking at the data concerning 'near misses': 51% of the survey's participants do not know what they are and, filtering the positive answers, only 55% that know about the topic have adopted a registration system.

However, the overall impact that such a process has on a firm seems to be quite positive: only one micro enterprise answered the survey stating that 'the implementation of an injury analysis process increased the conflict between workers and managers', while the remaining firms were divided among a 'really positive impact' (23%), a 'positive impact' (23%) and 'no impact' (16%). During the follow-up interviews, the majority of the owners declared, in response to open-ended questions, that they expected to see or already do see, if they had previously adopted one, a relevant impact of this system on risk assessment in terms of employees' awareness of hazardous situations. However, it was also remarked by over 50% of those interviewed that the small amount of resources, especially in relation to time, could lead to serious difficulties in the implementation of such an analysis system.

## 5 Conclusion

The main purpose of this research was to review the existing literature on OHS in micro and small firms and empirically investigate with a special focus on the impacts that the implementation of an occupational health and safety management system could exert within such companies. Overall, the research highlighted that companies are not only barely aware of the concerned issues, but also that they are apparently not interested in. This lack of interest seems to stem from a little understanding of the potential benefits associated with the implementation of an OSHMS, as well as the fear of not being able to successfully manage its implementation. Overall, this reinforces what the literature has highlighted as the main barrier to improvement in MiSEs: the lack of resources [1, 4, 8]. This should emphasize the importance of the role of institutions (national or local) in helping these industries to improve their OHS level.

At the same time, an important aspect that should be highlighted is the percentage of firms that refer to an external consultancy agency for risk assessment (over 90%). This should lead us to point out further the great impact that the implementation of an internal system, like an OSHMS, could have on MiSEs in terms of reliability and self-awareness of their own risks. To improve this aspect, a crucial theme is to broadcast better the importance of injury and accident analysis, especially for these kinds of firms, in terms of 'near misses'. As the survey showed, just half of the pool of firms knew what we were talking about, and very few owners understood how important this theme is and how critically it affects risk assessment and risk management.

What came up rather clearly from the workshop and the follow-up interviews, is that in order to support and help MiSEs implementing an OSHMS in terms of time spent, a possible answer is to provide them with an electronic tool (i.e. safety software) developed to be user friendly for those kinds of companies. Although this driver is not strictly supported by the literature, a well-rounded and easy to use software would be helpful in supporting the implementation of a relatively complicated system. This represents, in fact, the next step of this ongoing research, so to manage (more) easily all the tasks necessary to implement an OSHMS, and to spread a better safety culture in MiSEs through an easy and efficient instrument, like a web-based open-source software.

The ongoing project SOLVO aims to develop a web-based software for risk assessment and OSH management tool tailored for MiSEs. The software will also allow the transfer of data and information from the Italian national surveillance system of fatal and serious injuries (Infor.MO): this system, started experimentally in 2002 and now fully active throughout the country, aims to collect and analyze accidents information occurred in Italy. Infor.MO has got a database with more than 7,000 accident dynamics and can highlight modes of occurrence as well as causes of the events.

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# Quality Management in Healthcare: Assessment Tools in Clinical Diagnostic Laboratories

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**Abstract.** Various strategies have been adopted to reduce medical diagnostic laboratory errors. Proficiency testing (PT) is one of the most efficient external quality assessment (EQA) approaches which include an external assessment of a laboratory's analytical performance in comparison to its peers or to an accuracy-based reference system. To assess quality, the clinical biochemistry laboratory routinely participated in two external PT programs: Provincial Health Metrx and College of American Pathologists (CAP) survey. In Health Metrx, 598 tests for 43 analyte resulted in 3 discrepancies, yielding a total discrepancy rate of 0.50%. In CAP survey, of 431 tests for 58 analyte, 3 discrepancies resulted, yielding a total discrepancy rate of 0.70%. These results are in sync with the performance criteria and requirements set up by provincial regulatory agencies and both PT surveys. We suggest that proficiency testing programs should be an integral part of quality care to promote continuous quality improvement in healthcare.

**Keywords:** Quality · Assessment · Quality control · Quality assurance
Proficiency testing

## 1 Introduction

Medical diagnostic laboratory results play a major role in guiding decisions concerning patient management [1–4]. As such, it is imperative that lab results are accurate in order to dictate a proper course of medical action. Inaccurate results can cause over- or under-treatment, or even no treatment at all. Various strategies have been adopted to reduce laboratory errors, including internal quality control (QC) procedures, external quality assessment (EQA) programs, certification of education programs, licensing of laboratory professionals, accreditation of clinical laboratories, and the regulation of laboratory services [5–10]. Despite efforts to reduce errors in clinical laboratories via the establishment of international standards that harmonize laboratory practices, errors continue to occur [11–17]. External quality assessment programs are used to address this issue of


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quality in the laboratory. From a quality perspective, the principal goal of EQA is to evaluate clinical acceptability of laboratory results. Proficiency testing (PT) is one of the most efficient quality assessment (QA) approaches. Proficiency testing is an external assessment of a laboratory's analytical performance in comparison to its peers or to an accuracy-based reference system. Proficiency testing serves as a regulatory process, whereas EQA typically addresses self-assessment and improvement [18]. The majority of EQA programs, including PT, use conventional processed materials to evaluate participants by comparing laboratory results to those of peer laboratories. This allows individual laboratories to determine if they are applying a measurement technology correctly and are in agreement with other laboratories.

Proficiency testing is one of the most efficient EQA approaches. In EQA, numerous laboratories will report their result to a centralized agency for evaluation. Each participating laboratory then receives a report of their performance alongside a summary of other participating laboratories that achieved satisfactory results in a peer group format. Satisfactory performance "according to Clinical Laboratory Improvement Amendments (CLIA) of 1988 are United States federal regulatory standards that apply to all clinical laboratory testing performed on humans in the United States except clinical trials and basic research" is testing 80% or better on each challenge in either two consecutive tests, or two of three tests within the span of one year. The results must be reported within the time frame specified by the instructions that come with the samples. Failure to submit results within the required time frame will result in a score of zero. According to American federal regulations, it is stipulated "the samples must be examined or tested with the laboratory's regular patient workload by personnel who routinely perform the testing in the laboratory, using the laboratory's routine methods" [19].

PT agencies believe that by a comparison to the most relevant instrument/reagent combinations a laboratory's performance is accurately assessed. Passing the proficiency testing is a condition for accreditation and licensing of a clinical laboratory under various regulations (Clinical Laboratory Improvement Act). In Canada, it is required by provincial regulatory bodies – in the case of Saskatchewan, the College of Physicians and Surgeons of Saskatchewan (CPSS), that each regional or hospital laboratory enrolls in approved PT programs. A central regional laboratory operates this process. External quality assessment programs should have four goals [20]. First, they should have a participation-based performance method of evaluation. In an ideal scenario, the control samples should remain unknown to the laboratory team, recreating daily routine practices. It is suggested that proper performance evaluation must be subjected to professional judgment [20]. Moreover, in addition to analytical results being assessed, so should immunization status, clinical interpretation, and suggestions for diagnosis as well as additional laboratory investigations. Second, EQA programs should have a method-based performance evaluation. Comparing results of users of the same in-vitro diagnostics can reveal inherent method performance. Third, post-marker vigilance should exist in EQA programs to ensure that accredited laboratories continue to achieve desired results. Finally, EQA programs should provide training and offer help to prospective laboratories [20]. Fahey et al. maintain that many of the advantages that new, inexperienced, or otherwise disadvantaged laboratories derive from participating in EQA programs is due to the fact that they are able to consult with more experienced personnel [21]. Proficiency testing programs typically provide participants, manufacturers and standardization organizations with information for about such things as the traceability of methods to reference systems, the effectiveness of a manufacturer's transfer of calibration traceability to routine measurement procedures in the field, and the harmonization amongst routine measurement procedures from different manufacturers.

To assess quality and a possible need for improvement in this study, clinical biochemistry laboratory routinely participated in two external PT programs: Provincial Health Metrx – which is mandated by the College of Physicians and Surgeons of Saskatchewan (CPSS) and the College of American Pathologists (CAP) survey to evaluate the assessment of a laboratory's analytical performance in comparison to its peers or to an accuracy-based reference system.

## 2 Methods

Laboratory tests commonly used to manage patients were retrospectively reviewed and examined for the period of one year (January 1, 2009 to December 31, 2009) for any discrepancies. PT samples were tested and assayed on the same instruments used for routine clinical determinations in the same manner as routine clinical material, without consultation with other clinical testing personnel. PT material was received three times each year. Each sample set contained five specimens for each analysis – for example, five sera for total cholesterol. For each analyte, there occurred fifteen PT challenges over the entire year. In the Health Metrx PT, 5 groups of 43 analytes were analyzed. In the CAP survey PT, 12 groups of 58 analyte were analyzed.

## 3 Results and Discussion

In the CAP survey (Table 1), three discrepancies were identified out of 431 tests for 58 analyte that were divided into 12 groups, with a total discrepancy rate of 0.70%. There were no discrepancies in Groups 1–9. In Group 10, one of the markers (Digoxin) had two discrepancies. In Group 11, total protein was the only discrepant marker, with one discrepancy.

In the Health Metrx PT's, the analytes were divided into five groups (Table 2). Three discrepancies occurred out of 598 tests for 43 analytes, yielding a total discrepancy rate of 0.50%.

**Comparison of Group Results**

In Health Metrx PT, of 598 tests for 43 analytes, resulted in 3 discrepancies, yielding a total discrepancy rate of 0.50%. In the CAP survey PT, of 431 tests for 58 analytes, resulted in 3 discrepancies, yielding a total discrepancy rate of 0.70% (Fig. 1). In both surveys the remaining tests had no discrepancies. Appropriate and timely corrective action was taken to resolve concerns related to any discrepant results. The laboratory results satisfied the performance criteria and requirements established by provincial regulatory agencies as well as both the PT surveys.

**Table 1.** Groups of analysis samples and discrepancies in the college of American Pathologists survey

| Group | # categories in group | Total # tests | Total discrepancies | Total % discrepancies |
|---|---|---|---|---|
| 1. Diagnostic Allergy | 10 | 57 | 0 | 0.00 |
| 2. Sweat Analysis | 2 | 6 | 0 | 0.00 |
| 3. Tumour Markers | 1 | 6 | 0 | 0.00 |
| 4. Lung Maturity | 2 | 8 | 0 | 0.00 |
| 5. Cardiac Risk & Cardiac Survey Set | 5 | 48 | 0 | 0.00 |
| 6. Serum Alcohol/Volatiles | 4 | 46 | 0 | 0.00 |
| 7. B-type natriuretic peptide (BNP) | 1 | 4 | 0 | 0.00 |
| 8. Chemistry | 1 | 2 | 0 | 0.00 |
| 9. Immunosuppressive Drugs | 3 | 3 | 0 | 0.00 |
| 10. Therapeutic drug monitoring | 13 | 149 | 2 | 1.34 |
| 11. Cerebrospinal Fluid | 7 | 36 | 1 | 2.78 |
| 12. Diagnostic Immunology | 9 | 66 | 0 | 0.00 |
| Total | 58 | 431 | 3 | 0.70 |

**Table 2.** Groups of Analysis Samples and Discrepancies in the Health Metrx Survey

| Group | # categories in group | Total # tests | Total discrepancies | Total % discrepancies |
|---|---|---|---|---|
| 1. Routine Biochemistry | 26 | 468 | 2 | 0.43 |
| 2. Urine Biochemistry | 5 | 10 | 0 | 0.00 |
| 3. Special Chemistry | 6 | 12 | 0 | 0.00 |
| 4. Lipid Chemistry | 5 | 93 | 1 | 1.08 |
| 5. Neonatal Bilirubin | 1 | 15 | 0 | 0.00 |
| Total | 43 | 598 | 3 | 0.50 |

Peer grouping and analysing PT samples using a reference measurement are the two most common procedures to assign target values. These values are designed to reflect an accuracy base in clinical chemistry measurements, transferring the accuracy base to the routine laboratories by direct validation of routine methods against Reference Methods – preferably in the state of method development – and by the assessment of routine methods in EQA schemes operating with accuracy-based target values [22]. It is important to note that limitations exist in analysing PT results. The majority of sample materials used in PT assessments are modified during preparation in such a manner that

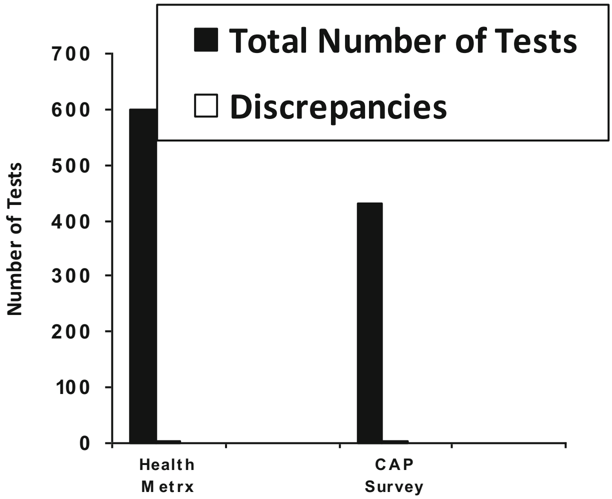


**Fig. 1.** Discrepancy rates for college of American Pathologists and Health Metrx proficiency testing surveys

they are no longer commutable with the native clinical samples. In these cases, peer grouping is important to ensure that different laboratories are employing similar measurement conditions so that the results are comparable. In special cases where the PT samples are commutable with the native clinical samples using a reference measurement procedure is applied instead. Unacceptable or incongruent results necessitate an investigation to identify the root cause of the error in order to take corrective action to rectify the situation. Such an investigation is documented, with a given cause. If nothing can be identified to explain an error, it is considered to be a random event. Corrective action is not appropriate in such an instance, because the process of unsure corrective action might result in additional errors. As a result, it is common practice to perform repeated measurements of PT samples that yield unacceptable results, or other samples from the same set, to confirm whether the original result was indeed a random event. When multiple test results yield relatively large differences that are scattered on either side of the target value it suggests inadequate method precision. Multiple results with relatively large differences in the same direction, however, suggest a bias problem. The overall participants' mean is the traditional method for setting target values in EQA. These peer group measurements are obtained by adding a specific amount of analyte into a matrix that is free from the specific analyte. As a result, the quality of the control materials used becomes extremely important. Various PT programs use commutable samples, which are freshly collected and minimally processed human samples.

## 4 Conclusion

The assay results in the clinical biochemistry laboratory were acceptable and meet the performance criteria and requirements established by both Health Metrx and the CAP survey. These results indicate that the quality in the clinical laboratory is maintained in a satisfactory manner and that it is prudent to monitor, promote and enhance quality services for patients. Our study suggests that participation by our laboratories in well-run external PT programs were performed in a satisfactory manner.

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# Approach of a Risk Weighting Method of Ergonomic Tools Based on the Combination of the Concepts of FMEA, Risk Matrix and Company Specifications

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**Abstract.** The use of methods and tools in ergonomic risk assessment presents variations of the interpretation of its results, being more or less restrictive on the measurement related to the severity of the risk. This happens because of many reasons: it begins with the choice of the method, going through the content and limitations of each tool, the underlying factors, such as the interpretation of the analyst and the peculiarities of the activity, of the system and of the organization of the company itself, which leads to doubts regarding the accuracy of the final conclusion. The objective of this paper is to propose the approach to a risk weighting method of the ergonomic tools based on the combination of FMEA concepts, risk matrix and company specifications, considering, besides the final result of the ergonomic tool, other factors involving the existing probabilities and controls, with greater emphasis on the method of ergonomic assessment, thus respecting the company particularities and those of the workers who constitute it, where both receive a greater protagonism role on the final result of the assessment and in the commitment with the improvements.

**Keywords:** Ergonomic risk assessment · Weighting of ergonomic tools FMEA and risk matrix

## 1 Introduction

Ergonomics is a science that relies on a wide range of different methods, tools and models to aid in the analysis of tasks, projects and on the interaction between man and work systems. This multiplicity implies in some challenges both for those who develop the methods and for those who use them [1].

According to Stanton et al. [1], the challenges regarding the development and application of ergonomic methods are:

- Develop methods that integrate with other methods;
- Methods that have a connection with the ergonomics theory;
- Facilitate the use of these tools and methods;
- Provide proof of reliability and validity;
- Show that the results of ergonomic tools and methods lead to economically viable interventions;


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- Encourage the ethical application of methods;

The author classifies ergonomic methods into two types: analytical methods and evaluative methods. The former helps the analyst to understand the mechanisms underlying the interaction man × machine. The evaluative methods estimate pre-selected interaction parameters between this man and machine relation. In this way, we can say that ergonomic tools can be qualitative, quantitative or a combination of these two forms, semi quantitative. These two types of methods can be divided into 5 basic categories in data design, as shown in Table 1. The darker highlight represents the primary research in the data design; the lighter represents the secondary research, or what contributes to the data design.

**Table 1.** Wilson's map of five basic types of design data, [1]

| | Data about People | Systems Development | Human Machine Performance | Demand and Effects on People | Ergonomics Management Programs |
|---|---|---|---|---|---|
| Physical | | | | | |
| Phychophysiological | | | | | |
| Behavioral - Cognitive | | | | | |
| Team | | | | | |
| Environmental | | | | | |
| Macroergonomics | | | | | |

The division presented in Table 1 contributes to the understanding of the lack of ideal or complete method that is able to satisfy every demand that an activity may require. In addition, when the analyst selects a single tool, method or even summarizes the result of an ergonomic risk assessment to a checklist, in detriment of the overall situation and the specificity of the company, the analysis result as well as the recommendations for improvements suggested based on this data will be distorted and questionable, [2]. Another problem involving the use of ergonomic tools are the questions asked by a part of the users. According to Stanton et al. [1], the most frequently asked questions of users of ergonomic tools are:

- How deep should the analysis be?
- Which methods of data collection should be used?
- How should the analysis be presented?
- Where is the use of the method appropriate?
- How much time and effort does each method require?
- How much and what type of expertise is needed to use the method?
- What tools are there to support the use of the method?
- How reliable and valid is the method?

Once both of the two problems previously exposed are solved:

1. Do not work the ergonomic tool in isolation, as the only solution to find all the answers that an analysis can offer and,
2. Reflect deeply on the doubts that involve the application of a method or tool.

Another challenge is to obtain a better understanding regarding the consistence reliability and validation of an ergonomic tool and its reflection on the accuracy regarding the conclusion of the ergonomic risk, which in many cases is the main argument for the implementation of improvement actions. It even serves as a kind of validation of the recognition of the workers' verbalizations, which further increases the responsibility of the ergonomist to base his conclusions and proposal for solutions only in the result of a tool.

For Guérin et al. [2], the conclusion about the effectiveness of an ergonomic action is not simple, since it involves the judgment and perception of several actors (direction, management, operators and others). Every action can put a lot at stake, which ends up involving the reliability of the technical capacity and the effectiveness of the specialist's practice. Concluding or not the risk is part of an ergonomic action, and as such will be subject to this judgment.

What makes a tool or method valid and reliable is the ability to satisfy three criteria: It needs to have framework: It needs to be relevant and able to encompass content; it needs to be applicable. Besides these characteristics, the method needs to be tested and replied over time by different people [1].

All differences in the results of the tools and methods should occur entirely due to the specifities of the system, company, project or activity being evaluated and not by different interpretations depending on the expertise or even the personal interests of the evaluators or the expectations of the agents around them [1, 2].

Contrary to what is practiced in Occupational Safety, there is no reference standard in Ergonomics for the classification of the ergonomic risk. An example is what happens in the United States, where there are objective criteria, such as the TLV from ACGIH, when it comes to Occupational Hygiene [3].

By the very objective and purpose of ergonomics, which seeks to preserve the health and well-being of the worker [4], verifying the comfort, without being limited by aspects of limits of tolerance, as in Occupational Hygiene, the conclusion about the ergonomic risk and/or the choice of method that assists in this action is optional to the ergonomist. When the analyst chooses to complete an ergonomic analysis, addressing the issue of risk, he can do so starting with his empirical knowledge, or based on the results of an ergonomic method or tool. In both cases, unlike in Occupational Safety, there are no universal limits established.

For Bird Jr. and Germain [5], risk can be understood as the product of the multiplication between the factors of likelihood of occurrence of a dangerous event and its severity in relation to injuries, wounds or health damage. The representation of this association through a ranking constitutes a relevant technique for analyzing the factors that surround the risks of an activity, and can be done as suggested by the author through a matrix.

In addition to the concepts of definition and schematization through a risk matrix, the approach proposed in this study makes use of the concepts of the Failure Mode and Effect Analysis (FMEA) method.

The FMEA method evaluates the relative risk of a failure and its effects through the analysis of three factors: severity, probability and detection. Using the data, the knowledge of the process, the mode of occurrence of a failure and its effects, it is established a rating for each of the three factors, on a scale ranging between 1 to 10, from low to high. By multiplying the ranking of the three factors (severity × probability × detection), it is found the risk priority number (RPN) for each potential of failure mode and effect. The higher the score, the higher it's priority.

This paper has the objective of purposing an ergonomic risk weighting approach, based on the concepts of FMEA, risk matrix and company specifications, considering, besides the final results of the ergonomic tool, other factors involving the probabilities and the controls existing in the systems, projects, workstations and their activities. Thus, this approach respects the particularities of the company and those of the workers who constitute it, where both receive a greater protagonism role on the result of the analysis and in the commitment with the improvements.

# 2 Methods

## 2.1 Previous Studies

In the previous studies, an ergonomic risk assessment of the work involving a nursing activity was carried out, where the nurse performs the change of decubitus of the bedridden patients. In addition to the ergonomic risk assessment of the work, the ergonomic tool Rapid Entire Body Assessment (REBA) was used, with the results presented in image 1 and Table 2, below (Fig. 1).

**Company activity**: Hospital
**Activity analyzed**: Change of decubitus in bedridden patients
**Ergonomic tool used**: Rapid Entire Body Assessment (REBA)
**Tool score**: Discomfort, difficulty or fatigue **(corresponding to a medium risk)**
**Interpretation of the score and action recommended by the tool**: Table 2.

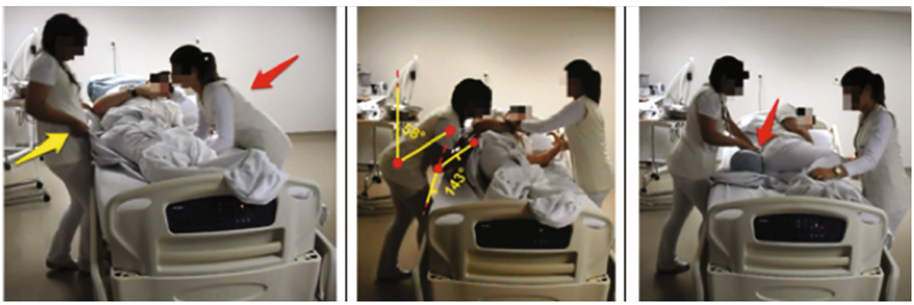

**Fig. 1.** Evidence by photographic records of the ergonomic risk assessment of the nursing activity

**Table 2.** REBA action levels, [1]

| REBA Score | Risk Level | Action Level | Action (including further assessment) |
|---|---|---|---|
| 1 | negligible0 | none necessary | |
| 2 - 3 | low | 1 | may be necessary |
| **4 - 7** | **medium** | **2** | **necessary** |
| 8 - 10 | high | 3 | necessary soon |
| 11 - 15 | very high | 4 | necessary now |

## 2.2 Definition of a Table with the Indicators and Factors of Probability and Control of the Ergonomic Risk Through Literature References

According to Chengalur et al. [8], there are indicators of possible ergonomic problems and risk factors that make jobs difficult. These indicators and factors are presented in the table below.

Based on the indicators and factors described in Table 3 and other findings in the literature, the FMEA rating concepts were combined for a definition of relevance criteria of each indicator or factor that contributes to the relevance of the probability of presence of ergonomic risk. A scale ranging from 5 to 1 was defined, from the highest to the lowest.

**Table 3.** Indicators of possible issues and risk factors that make jobs difficult (Chengalur et al.), [6].

| Ergonomics issues indicators | |
|---|---|
| Accident and incident history on the job | Frequent rework of product |
| Medical restrictions needed often | High turnover on job |
| Quality problems on the job | Above-average absenteeism |
| Second person needed to assist frequently | Few women or older workers |
| Long training times | Production bottlenecks |
| Lack of flexibility to meet production needs | Frequent overtime worked |
| **Risk factors that make jobs difficult** | |
| Sustained awkward working postures | Heavy manual handling |
| Low operator control over job pattern | High forces required |
| Very repetitive hand/foot work with force | High external pacing |
| Environmental stressors (heat, glare, noise) | Complex tasks; multiple tasks done simultaneously |

After that, criteria were defined for the evidences of existing controls or for those that could be implemented in order to eliminate or mitigate the ergonomic risks. For these criteria, the scale ranges from 5 to 1, but in this case, from the lowest to the highest control, in order to decrease the weighting.

The premise used to define the values used in the weighting, besides respecting the hierarchy of importance evidenced in the literature, considered the logic that the factors with greater weight were those of quantitative or semi-quantitative origin. Those of smaller weight are the ones of more qualitative and/or subjective aspect. Having a common point, that in both cases it is possible to prove the origin of the information.

### 2.3 Elaboration of a Table, with the Determination of the Indicators and Factors of Probability and of Control of the Ergonomic Risk, with Different Weights

### 2.4 Analysis and Selection of the Indicators and Factors of Probability and Control in the Company that Was Part of This Study

Through an interview with the actors of different sectors of the company (management, supervision, operation), indicators and factors that contribute to the probability and control of ergonomic risks were identified, as presented in Table 4, taking care that all information could be evidenced by the company. In addition to this database, the questions in the table were considered, which could be evidenced by means of the ergonomic risk assessment, in order to find answers to the other indicators and factors that were not known to the company. From the highlighted questions, both on the interviews and through the ergonomic risk assessment, those with greater weight were considered, other results being disregarded, for the purposes of application in the method. It was identified as a probability factor the duration of the activity longer than 8 daily hours, which represents a score = 5. The identified control factors concern the possibility of the worker being able to regulate his rhythm, which represents a score = 3.

**Table 4.** Indicators and Probability Factors and of Control of Ergonomic Risk [2, 3, 8, 10, ]

| Indicators and probability factors of ergonomic risk | |
|---|---|
| Weight 5 | Medical leave with proven link<br>Non-compliance of legal requirements<br>Very repetitive work (cycle < 6 s or = 10 times per minute)<br>Environmental stressors (heat, glare, noise) – as referenced in the literature or norms<br>Activity period longer than 8 h per day<br>Other non-specified (that are referenced in the literature) |
| Weight 4 | Few women or older workers<br>Frequent overtime worked<br>Production bottlenecks<br>Second person needed to assist frequently<br>High external pacing<br>Complex tasks, multiple tasks done simultaneously<br>Verbalization of discomfort, difficulty or fatigue related to the work<br>Absence of the possibility of short pauses (physiological needs) |

(*continued*)

**Table 4.** (*continued*)

| Indicators and probability factors of ergonomic risk | |
|---|---|
| Weight 3 | Medical restrictions needed often<br>Accident and incident history on the job<br>Absence of mandatory training for the development of the activity<br>Lighting below the required limits – as referenced in the literature or norms<br>Other non-specified (that are referenced in the literature) |
| Weight 2 | History of medical leaves related to musculoskeletal and/or ergonomic problems<br>Quality problems on the job<br>Frequent rework of product<br>High turnover on job<br>Above-average absenteeism<br>Low operator control over job pattern<br>Other non-specified (that are referenced in the literature) |
| Weight 1 | Absence of indicators or probability factors |
| **Indicators and control factors of ergonomic risk** | |
| Weight 5 | Absence of indicators or control factors |
| Weight 4 | Women or older workers can do the activity without difficult<br>Other non-specified (that are referenced in the literature and which are possible to prove their efficiency) |
| Weight 3 | The worker can regulate his pace (lung area, flexibility, autonomy).<br>Ergonomics training (acting committee, or efficient ergonomic training programs)<br>Other non-specified (that are referenced in the literature and which are possible to prove their efficiency) |
| Weight 2 | Absence of verbalizations of discomfort, difficulty or fatigue<br>Labor gymnastics programs<br>Other non-specified (that are referenced in the literature and which are possible to prove their efficiency) |
| Weight 1 | Possibility of manual handling of loads by 2 workers (NIOSH)<br>Duration of the activity in percentage = or < that 10% of the working day<br>Duration of work shift equal to or less than 6 h per day<br>Rotating and/or pausing system with proven effectiveness<br>Activity allows postural variation between seated × standing work in an efficient way<br>Good anthropometric conditions and possibilities of adjustments (furniture, equipment, machines)<br>Automation systems or ergonomic devices (pantograph table, manipulators, hoists)<br>Other non-specified (that are referenced in the literature and which are possible to prove their efficiency) |

### 2.5 Application of the Risk Matrix (Probability × Control) to Obtain the Weighted Rating

Once the most representative score between the indicators and factors of probability and control of the ergonomic risks was identified, this number was multiplied using the concept of the risk matrix, represented by the multiplication of the probability

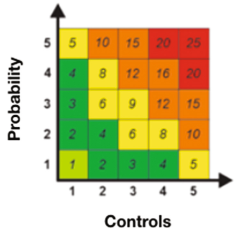


**Fig. 2.** Matrix for the determination of the score resulting from the multiplication between the most representative weight and of the indicators and factors of (probability × control)

factors × control factors. As a parameter to identify the value of this weighting, a 5 × 5 matrix was used (Fig. 2).

### 2.6 Determination of the Rating, from the Color Corresponding to the Result of the Risk Matrix (Probability × Control)

As shown in Fig. 3, the score resulting of the multiplication between the most representative weight of the indicators and factors of probability and control are correlated in the table Probability × Control with five different colors, which represent weights from 1 to 5, as in: light green = 1, dark green = 2, yellow = 3, orange = 4 and red = 5.

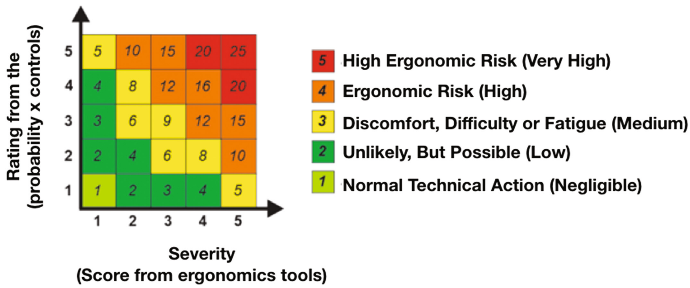


**Fig. 3.** Matrix for the determination of the classification of ergonomic risk weighting

### 2.7 Weighted Risk Rating Through the Risk Severity Factor (Score of the Ergonomic Tool Results) and of the Rating Corresponding to the Risk Matrix Weighting

Once the weight indicated by the risk matrix is defined, the results of the ergonomic tools (considered by the method as the risk severity factors) are used, which must be correlated with the definition of risk described on image 4, which goes from a high ergonomic risk (5 Red/High) to a normal technical action (1 Light Green/Negligible).

### 2.8 Risk Weighting from the Tool and Weight Obtained Through the Risk Matrix

**Weight** = 4 (Probability (5) × Control (3) = 15 = Weight 4/orange color)
**Result of the tool** = Equivalent to Weight 3 (Discomfort, difficulty or fatigue/yellow color/Medium (relation between Table 4 and the corresponding in Fig. 3)
**Weighted Risk** = (4 × 3) = 12.

The risk went from (Discomfort, Difficulty or Fatigue/Yellow Color/Medium) to (Ergonomic Risk/Orange Color/High).

### 2.9 Projection of a Future Scenario

The main advantage presented by the method proposed in this paper is the possibility of the company to know what are the main influences between the existing factors of probability and control, which contribute to the increase of the risk, and using this information, to be able to take more assertive actions, considering the overview of all the actors involved in the process of the analysis construction. In addition, ensuring that the actions proposed in the ergonomic analysis of the work will mitigate the ergonomic risk, through the control factors. It is possible through this to design a future scenario.

### 2.10 Extrapolation of the Weighting

If the result of the weighting, up or down, shows a difference of two scales or more, for example: risk weighted from green to orange or vice versa, the analyst should review the tool used (severity factor), or review the criteria used in the weighting, concerning the information of the existing factors of probability controls. This type of error can occur when the analyst chooses a physical/postural type tool (REBA, RULA or OWAS, for example), and the demand for ergonomic concern is predominantly behavioral/cognitive or psychophysiological, or when the chosen tool is not very sensitive (has simplified content which does not cover a number of relevant factors such as: duration, frequency and occupancy rate, for example). Another possibility is that the analyst has missed some relevant information regarding the probability and control factors or the company has not provided all the necessary data.

There can be no inconsistency in the choice of factors that will be weighted in the measure between probability and control. Table 5 should be used by the analyst for pre-analysis purposes before filling out the probability and control factor worksheets. The lightest highlights represents the secondary relation between the factors and the ergonomic tool chosen by the analyst, and the darker the primary/more intimate relation.

**Table 5.** Matrix of the connection between the probability and control factors and the type of ergonomic tools

| | Probability Factors | Types Ergonomics Tools: Biomechanics Posture | Biomechanics Hold/Gripp | Psychophysical | Behavioral Cognitive | Weight | Controls Factors | |
|---|---|---|---|---|---|---|---|---|
| Light | •Lightning below the 80% limit of the value defined by the norm. | | | | | | | |
| | | | | | | | •Automation systems or ergonomic devices, like pantograph table, manipulators, hoists. | Autom. |
| Law | •Prize / bonus payment for productivity or any other type of incentive. | | | | | | | |
| Freq. | •Very repetitive work (cycle <6s or = 10 repetitions per minute). | | | | | | | |
| Time | •Activity duration > 8h/day<br>•Frequent overtime<br>•Frequent rework that is related to ergonomic concerns in the activity.<br>•Absence of possibility to take small breaks for hydration and / or sanitary use | | | | | | •The worker can regulate his pace (lung area, flexibility, autonomy).<br>•Duration of activity in percentage = or <that 10% of daily work<br>•Shift duration = or <than 6 hours per day.<br>•Rotation and/or Pause with effectiveness in mitigating the constraints of the activity. | Time |
| Environ. | •Stressing environments (vibration, heat, cold, noise).<br>•High external stimulus (problems with: technology, machines, maintenance, raw material, material, labor). | | | | | | •Furniture, equipment or machines having effective adjustment means. | Environ. |
| People | •Restrictions on female workers or above 45 years of age.<br>•Verbalization of difficulties related to work.<br>•High turnover.<br>•High rates of absenteeism. | | | | | | •Elderly workers and women develop activity without difficulty.<br>•Absence of verbalizations of work-related difficulties | People |
| Health | •Medical leave with proved link.<br>•Ergonomic-related medical restrictions to work in this activity.<br>•Historic of medical leaves with CIDM which activity related to biomechanical risks. | | | | | | | |
| Manag. | •Production bottleneck, absence of lung area, rhythm imposed by the system.<br>•Complex activities, multiple tasks done simultaneously.<br>•Low operator control without working standard.<br>•History of accident related to the activity and with ergonomic factors.<br>•Absence of mandatory training for the development of activity.<br>•Quality problems that are related to ergonomic concerns of this activity. | | | | | | •Ergonomics training<br>•Efficient Labor Gymnastics Program<br>•Activity allows postural variation between sitting or semi-sitting work x standing work and / or use of anti-fatigue mat. | Manag. |
| Effort | •Frequent necessity of a second person to develop the activity. | | | | | | •Possibility of the MMC to be done by 2 workers. | Effort |

# 3 Results and Discussion

## 3.1 Results

The results found after the ergonomic risk weighting, both for the current situation (primary analysis – before) and for the improved situation (secondary analysis – after) can be observed in the images below (Table 6):

**Table 6.** Results of the weighted risk on the primary and secondary analysis

| | BEFORE | AFTER |
|---|---|---|
| (A) Severity (REBA) | **3 (medium)** | **3 (medium)** |
| (B) Probability | **5** | **1** |
| (C) Control | **3** | **1** |
| (D) (B x C) | **5 x 3 = 15 (15 = Weight 4)** | **1 x 1 = 1 (1 = Weight 1)** |
| (E) Weight (as in Fig. 3) | **4** | **1** |
| Multiplication (A x E) | **3 x 4 = 12 (12 = Weight 4)** | **3 x 1 = 3 (3 = Weight 2)** |
| Final Result | **Weight 4 (High)** | **Weight 2 (Low)** |

In the primary analysis (before), the high probability factor (score 5), due to the fact that the duration of the activity was greater than 8 daily hours, multiplied by the medium control, greater margin for maneuver by the nurses (score 3), resulted in a risk weighting up, from yellow (medium risk) to orange (high risk). In the secondary analysis (after), after the implementation of improvement actions by the company, in the implementation of efficient rotation programs, which reduced the duration of work in the analyzed activity and the absence of probability factors, resulted in scores of 1 for both factors, which resulted in a weight also equal to 1. In this new scenario the weighting went from yellow (average risk) to green (low risk).

### 3.2 Discussion

In this paper, a method of approaching ergonomic tools risk weighting was proposed, through the combination of the concepts of FMEA, risk matrix and the specifities of the company. This combination allows a much more in-depth analysis, where all actors involved with the demands of the analysis participate in its construction, not limiting the conclusions to simple applications of ergonomic tools. However, the main disadvantage of this method is the delay in collection and compiling the data. The time required for collecting the data is inversely proportional to the level of control and history that the company possesses.

It is important to consider some cautions regarding the application, results interpretation and restrictions on the application of the method proposed in this article. There is a restriction regarding the weighting in the cases where situations of extrapolated ergonomic factors are shown, according to references found in the literature, in norms, internal procedures or when the ergonomic tool itself displays an over range result, for example: high intensities in manual movement of load, very high frequency, displacements in push/pull activities that exceed the maximum limits set in tables. Another restriction in the use of the weighting method may exist when the company does not provide the information related to the probability factors, or when it is not possible to prove the veracity of the records. This usually occurs because of lack of traceability of the information, lack of records or even because the company does not want to provide evidence against itself.

The results obtained in the case study of this paper show the care that the ergonomist should have, both in the choice of the ergonomic tool or method, and in the conclusion that is obtained through the interpretation of its results. The weighting through a data collection effort that contemplates the specifities of the company and its various actors is not limited to a restricted method, pre-defined from the results applied in similar situations, but often do not represent in the slightest the existing condition in the moment the ergonomist needs to fulfill a certain demand for ergonomic analysis, where each actor has their own expectation regarding the final conclusion about the presence or not of an ergonomic risk. Finally, the method suggested in this paper is not defined as a restricted method. On the contrary, it constantly seeks to consider the whole globality that ergonomic actions demand.

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# Organizational Management, Human Resources and Mobbing. Findings in Colombia

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**Abstract.** It is said that mobbing is born in interpersonal relationships and little in the management of the organization.

The objective is to carry out the study of psychosocial risk factors and stress as precursors of mobbing. It is an applied, mixed and correlational research, developed in 2 vehicle maintenance company, with a population of 116 workers and a sample of 102. The workers signed informed consent. Use of a battery of instruments for the evaluation of psychosocial risk factors, with levels of reliability in intra - occupation 0.957, extra - occupation 0.944 and stress 0.83. The correlation of mobbing was determined in the dimensions of leadership and social relations at work, control of work, demands for work, reward, time away from work and symptoms associated with stress; which are aggravated by weak organizational practices.

**Keywords:** Human factors · Psychosocial risk factors · Stress Mobbing

## 1 Introduction

Mobbing, considered as a behavior exercised by a person or group towards a person, with the objective of causing harm. Behaviors such as psychological pressure, harassment, intimidation, terror, trigger a variety of reactions in the person, in their economy and in their family environment. The worker assumes the abuse as if it were part of the salary, this causes it to be spread, maintained and never denounced.

Leymann, defined mobbing as a form of extreme psychological violence that can occur in an organization of various forms with varied behavior. It is systematic, at least once a week and for a prolonged time of more than 6 months, about another person at work. The parties show of equal power, however, the harasser has an attitude of conflict and psychological violence toward the victim [1]. This is why the harasser has more resources, alliances, seniority, support, hierarchical superior position that he uses to harm the other.

On the other hand, Hirigoyen, defines mobbing as any abusive behavior that attempts, by its repetition, against the dignity or the psychic or physical integrity of a person, endangering their employment or degrading the work environment [2].


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Piñuel and Zabala, affirm that mobbing is not a disease, but rather a psychosocial work risk. In addition, it determines that it is important to establish the levels of exposure to this risk, since it triggers alterations that make people lose their ability to work [3].

Vogel says that "the victim is trapped looking for solutions. Proceedings, mainly complaints, are organized, but it does not go further". It is then necessary to verify the actions in the organization of work [4].

## 2 Materials and Methods

Applied, mixed and correlational research. Analyzes the relationship between intra - occupational, extra - occupational conditions, individual involvement by stress and mobbing. Qualitative taking into account that individual interviews were conducted to verify harassment testimonies. Quantitative due to the use of rating scales with pre-established scores [5]. Correlational for establishing causal relationships between risk factors and triggers of stress symptoms with respect to mobbing.

Research carried out in 2 companies of maintenance services for vehicles in the western zone of Colombia in 2016.

Sample of 102 workers from a population of 116. Voluntary participation and signing of informed consent. 9 workers in charge of headship and 93 are operational.

Use of the Instrument Battery for the Evaluation of Risk Factors [6], based on model models Demand - Control - Social Support and Imbalance - Effort - Reward that describe and analyze work situations in which stressors are chronic with a detrimental effect on health [7]. Regarding stress, application of the JCQ model of evaluation that defines symptomatology caused by physiological, intellectual, labor, psycho-emotional stress and social behavior [8].

Levels of Reliability of the intra - occupational questionnaire with 0.944; of the extra - occupational with 0.88 and stress with 0.83.

Regarding the individual conditions, analysis constructs were established for occupational information and socio-demographic information [6].

The results obtained from these instruments will allow us to compare the risks to which the population is exposed.

The intra - occupational data obtained were correlated with the characteristics of leadership, social relations at work, relationship with employees, control and autonomy over work, and role consistency in forms A and B. In addition, the extra - occupational condition with data of time outside of work and stress for its psychic and psychophysical manifestations.

Form A, applied to workers with managerial work activities and personnel subordinate to it. Its activity manages results and responds for the work of other collaborators. In addition, they have a level of training as professionals or technicians, and a broad level of autonomy for decision making. The charges included to respond the form was; plant manager, production engineer, plant manager, plant supervisor, design engineer, quality manager, quality manager and quality control inspector II.

For Form B, it was answered by collaborators with knowledge of a technique, but with less autonomy. They receive orders issued by a head office, here the positions of administrative assistant, assistant, technical assistant and operatives were incorporated.

This methodology understands the condition of extra - occupational risk as that which analyzes the socioeconomic and family environment of the worker and includes the housing conditions.

The individual condition is established as the elements that are part of each individual such as sex, age, marital status, educational level, profession or occupation, city of residence, socioeconomic scale, type of housing and number of people who depend economically on the worker [9].

Stress is established with the presence of symptoms in 4 categories; physiological, intellectual, psycho - emotional and social behavior.

For the Mobbing approach, revisions of the different conditions and their risk levels were made. The results were related to situations of alterations reported as medium, high or very high for stress. The results of the intra - occupational conditions were verified, in the domains of work demands, control and leadership, and social and extra - occupational relationships with the dimension of time outside of work.

The questionnaires for intra - occupational, extra - occupational, individual characteristics and stress conditions, defined for this methodology, should be applied to the defined charges.

## 3 Results

A population composed of 9 workers in charge of headship and 93 with operational positions.

**The individual conditions.** Of 102 workers surveyed, they gave the following information:

10 women and 92 men.

In relation to age, 49 workers, between 24 and 35 years old; 31 of them, between 36 and 45 years of age; and 22 with ages exceeding 46 years.

Regarding the schooling of the population, 10 workers with incomplete baccalaureate, 15 with full baccalaureate, 6 are professionals, 54 are technicians or technologists and 17 have not completed their technical or technological studies.

According to the seniority in the company, 51 workers are reported between 1 and 2 years; 27 between 3 and 4 years; 9 between 5 and 6 years old; and 15 with more than 7 years.

According to the civil status, the surveyed workers express that 48 are single, 9 married, 1 divorced, 2 are widowed, 1 is separated and 31 are in free union.

Regarding the social stratum, 21 workers are in stratum 1; 25 in stratum 2; 43 in stratum 3; and in stratum 5 and 6, only 2 workers.

The hours that report work in the daily work are; for 59 workers, 8 h a day; 32 work 9 h; 6 say 10 h; 3 mention 11 h of work and 1 worker affirms 12 h daily.

According to the number of people who depend economically on the worker, 13 do not have dependents; 14 reports 1 person; 20 record 2; 29 affirm 3; 17 say 4; 5 record 5; and 2 say they are 6 and 7 people in charge.

The type of employment contract for workers is reported as follows: 82 have indefinite contracts, 16 have a temporary contract and 4 provide services.

According to the type of salary, 60 employees have a fixed salary, 12 workers have a variable salary and 30 have a salary composed of a fixed part and a variable salary.

Regarding the type of housing, 55 workers live in a rented house, 28 in a family house and 19 have their own house.

**Intra - occupational conditions.** The occurrence of mobbing is verified in 76% of the workers included in the investigation, as well:

74% in control over work; 93% in work demands; 86% in reward and 85% of workers affected by the risk factors associated with leadership and social relations at work, with leadership being the most influential in the work experience, since it is verified in 40% of managers and 68% of the operating personnel.

The factors for this risk that are most influencing are defined in the management carried out by the managers with respect to planning, assigning work, achieving results or solving problems, being more burdensome due to difficulties in communication processes and lack of respect. Regarding this, the dimension of social relations at work showed an influence on 37% of the bosses and 42% of the workers with evidence of disrespectful, aggressive or distrustful treatment, generating a deficient environment of social interaction and a limited or no possibility of receiving social support from colleagues that prevents teamwork.

Other risk factors that were also found to be deficient constituted the mechanisms of participation and social support generated from their leaders for their collaborators.

In the relationship dimension with the employees (subordinates) 22% of the bosses say they are affected by them, due to conflicting social relationship schemes, with reports of permanent and ill-intentioned rumors.

In the domain of control over work, 22% of managers and operational staff say they are affected by the dimension of control and autonomy over work. The surveyed employees express situations that generate stressful environments that alter the work climate.

Regarding the demands of the work, 53% of the heads expressed to be affected by the consistency of the role, because they are made requests for tasks that do not belong to their position.

**Extra - occupational conditions,** influence was verified and its direct correlation with the presence of mobbing of time outside of work for this condition.

It was found that 70% of bosses and operatives, express being affected by long periods of stay in their place of work at different times than their usual schedule, in such a way that it diminishes or annuls the times of at home or in places of rest.

**Stress conditions,** 43% of heads and operative personnel with alterations derived from stress are shown with risk levels: 11% very high, 20% high and 13% average.

The symptomatology found for these risk levels are presented in Table 1:

**Table 1.** Malestars that most affect the health of workers

| Symptom | Malestars | n (%) |
|---|---|---|
| Physiological | Pains in the neck and back or muscle tension | 23 (52%) |
| | Palpitations in the chest | |
| | Gastrointestinal disorders | |
| | Headache | |
| | Sleep disorders | |
| Social behavior | Difficulty in relationships with other people | 11 (25%) |
| | Sensation of isolation | |
| Intellectuals and labor | Increase in the number of work accidents | 6 (14%) |
| | Feeling of frustration | |
| | Fatigue | |
| Psychoemotional | Consumption of alcoholic beverages or coffee or cigarette | 4 (9%) |
| Grand total | | 44 (43%) |

## 4 Conclusions

The dimensions of leadership characteristics, social relationships at work, relationship with employees (subordinates), control and autonomy over work and role consistency were verified with a direct relationship in the influence of work environments and direct action in the work environment.

Organizations with deficiencies in the management of human resources that do not prioritize actions to promote healthy work environments, of a relational and communicative nature, are affected by scenarios of arbitrariness and workplace violence towards the active presence of mobbing [10].

The time out of work dimension is decisive in the verification of actions taken by a possible harassed, since for this investigation it was found that the harasser made repeated unjustified changes in the work schedule.

It is necessary in organizations to emphasize knowledge of the reasons why a worker makes the decision to give up their work, in such a way that it establishes the need for companies to emphasize the development of retirement interviews, such as an information and action mechanism for the improvement and strengthening of administrative, organizational and occupational health and safety management.

The stress found through the symptomatology expressed by the workers is evidence of a direct relationship with acts conducive to mobbing, confirming clear actions in their social behavior (difficulty in relationships with other people, feelings of isolation and disinterest), in addition to situations of feeling of frustration that lead him to demonstrate or express sadness, fatigue or reluctance, in front of his work and the team to which he belongs; nullifying the labor welfare, the physical and mental health, of those who were found to be affected [11].

It is confirmed for this investigation that mobbing situations have their origin in the departments of human resources and health and safety at work, due to the absence of unified standards for social coexistence and effective communication.

It establishes the need to develop in the companies, work coexistence manuals, that protocolize coexistence in workplaces.

It is necessary that companies conduct educational campaigns to disseminate the standards of work coexistence [12].

It is essential that responsible departments implement training, communication and information, adequate and sufficient, with workers in, leadership, communication and good treatment for the promotion of healthy and safe work scenarios [13].

Finally, there is evidence of the need to continue carrying out research processes on mobbing, from administrative management and health and safety at work in any type of company, due to the fact that little is known about the subject, taking into account that they are varied productive processes that exist and that there is not yet information about them.

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# Control of Collective Security Equipment by RFID in the Construction Site

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**Abstract.** The use of information and communication technology (ICT) makes it possible to propose solutions to optimize the management of people and processes. This work presents the development of a remote monitoring system of safety equipment using Radio Frequency Identification technology (RFID), managed by a software, also developed in this research. The routine combined laboratory testing for hosting and system validation and testing at a construction site for verification of the system in an environment of real construction. The model proved to be efficient in the identification and localization of the equipment through the indication of its position using images in plant. The model has also supplied graphical reports showing the characteristics of each equipment presenting the following data: name, construction, placement, brand, material, conservation, revision and person responsible. The development of managerial tools contributes to the advance of the security equipment optimized management in the construction site.

**Keywords:** Information and communication technology (ICT)
Radio Frequency Identification (RFID) · Safety equipment
Collective protection system

## 1 Introduction

The great amount and diversity of the physical resources involved in the production process, such as material, equipment, and laborers, generates the necessity to create more efficient and transparent management procedures for use of the managers and decision makers in civil construction. The use of information and communication technology (ICT) for tracking and gathering information enables the decisions and control of production to be based on actual monitoring data.

The specificities and diversity of activities carried out on construction sites extend the risks to which workers are exposed, requiring preventive measures of occupational health and safety to be taken. The regulatory norms and technical standards determine that various measures for the prevention or reduction of industrial accidents be taken. Among them stands out the deployment of systems or Collective Protection Equipment (CPE), which are defined according to the characteristics of the current activities being


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executed. However, the CPE are not always installed efficiently, or properly controlled during their use.

Thus, it is important to develop a management process for this equipment to facilitate the decision making and the security preservation in the construction site. It is observed that management support systems can be developed to control, for example, the maintenance frequency, or to check the local installation according to the projects.

According to [1], there are problems in the traditional methods for tracing and controlling materials and/or equipment that result in delayed deliveries, lack of components, or incorrect installation and assembly. For these authors, the use of data collection technologies, such as Radio Frequency Identification (RFID), can help in the management of components in construction supply chains.

This study, therefore, proposes a system for the safety equipment control and monitoring using RFID technology. This system is intended to contribute to the management of the safety equipment components distributed in the building plant. In addition, the labelling of each component will provide the identification of characteristics and technical information (name, work, location, brand, constituent material, conservation status, the next revision scheduled and person responsible). Throughout its operation, the system will store all the registered information, creating a data base and a description of the activities.

For this, a computational program was developed specifically for this work. The simulation of the program operation sought to test and validate the procedures and functioning of the management tool developed. The contributions achieved in this study include the results of the tests, an evaluation of the developed functioning system using RFID technology, the development of a new software and recommendations for future research.

## 2 RFID Technology

RFID technology considers the use of an electronic device via radio frequency or variation of the magnetic field for data transmission [2]. The detailed functioning of the system is described by [3, 4] and [5]. According to these authors, the typical identification structural system through radio frequency includes three basic components: a reader equipped with a transmitter with decoder, a transponder configured by a radio frequency tag (Tag) electronically programmed, and a control software. The reader emits radio signals continuously in a given frequency. When a Tag configured to detect the used work frequency contacts these signals, it is activated and communicates with the reader through frequency transmittance modulation. The reader gets and analyzes the data and sends it to the system that is connected to recognize communication protocols on a computer.

The RFID communication system can be classified as active when the equipment is powered by a battery or classified as passive when not using batteries [6]. Passive Tags are normally “inactive” until they are activated by the field emitted by the reader. In passive Tags the reader’s electromagnetic field acts to charge the capacitor that feeds the Tag. Due to the intensity of the signal required, passive Tags are used more often for applications at short distances (<1.5 m) and require a high-power reader with an antenna able to read the transmitted information. The passive tags are light, compact and have limitless life expectancy [4].

The Active Tags are typically powered by an internal battery. This battery may last for many years however, this period is strictly related to its application. Tags are used for long range applications, with readings of up to 100 m. They can emit signals continuously and allow reading and writing of data. Due to these increases in capacity, Active Tags are heavier, more expensive and have limited life expectancy [7, 8].

The main advantage of the use of RFID systems is to enable reading without contact or direct viewing of the reader with the tag, as in the barcode [9]. Unlike light beams used in the barcode system, RFID technology uses electromagnetic waves (radio signals) to transmit or capture data stored on a chip or tag.

An important characteristic of the reader is its ability to prevent collisions among the frequencies of RFID labels by using specific methods of separation. When using collision avoidance methods, a reader can perform multiple readings, which speeds up the process. The use of an efficient anti-collision system is essential to calculate the data transmission and the rate of the reading process in terms of the number of reads per second [4].

This is a technology applied in numerous market sectors. Amongst the applications are: the warehouse control, location of materials and people, control of entry and exit of goods, vehicles, and people, identification of tools or animals, among others.

## 3 Collective Protection System

Collective Protection Equipment (CPE), also called Collective Protection Systems (CPS), are part of an integrated system that considers the set of devices which provide security protection for the greatest number of individuals in the workplace, that is, devices that protect occupant individuals from risks in a working environment.

Among the CPS usually employed in Brazil against the risks of falls from height in construction sites are Platform System and Guardrail and Toeboard System (GTS), as shown in Fig. 1.

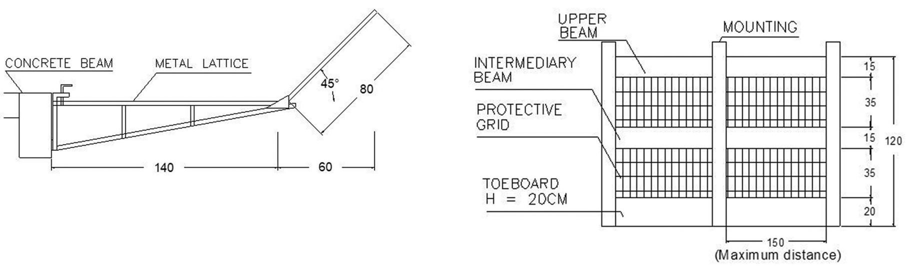



**Fig. 1.** Protection systems for falls from heights: Platform and Guardrail and Toeboard.

Concerning security, as established by Regulation Norm 18 (NR-18) item 18.3.1, “the installation of collective protection is mandatory where there is the risk of fall of workers or projection of materials" [10]. As such, these two systems - Platform and Guardrail and Toeboard - are regarded as protection elements of the type barrier against fall of workers or materials. However, they are not the preventive type, that is, they are not capable of alerting workers about imminent danger.

## 4 Development

The methodology adopted for this research was Design Science Research (DSR). According to [11], this methodology operationalizes and substantiates the conduction of research when the objective to be reached is an artifact, that is, the main means through which new findings can be generated based on practical experiences. As such, DSR is a rigorous process to project artifacts that will solve problems, evaluate what has been projected or is functioning, and communicate the results obtained.

The definition of the methodology for this research has considered a basic characteristic of DSR as method. According to [12], this methodology is focused on the solution of specific problems and not necessarily searching for definitive solutions, but, yes, satisfactory solutions for the situation concerned. However, the generated solutions must be capable of generalization for a class of problems. This generalization must allow other researchers and professionals, in diverse situations, to make use of the generated knowledge as well.

One of the main reasons for the implementation of DSR in this study was the possibility to overcome the existing gap on the RFID technology and its specific application in the management of the equipment in risk of fall in construction sites. For [12], this occurs because it is a method guided to the solution of problems that, at the same time, produces knowledge that can be a reference for the improvement of theories.

The proposed research covers, therefore, the development of a monitoring and control system that integrates RFID technology and the determination of its functionality depending on the need for management of CPE.

For the identification of the security equipment the passive Tag Model B-20070/C-20055, whose data transmission functioning is resistant to the interference of metallic structures and the weather (Table 1), was used. This passive model does not have its own power source; its functions are activated when the Tag enters the reader's work field and the communication through electromagnetic waves starts [4]. For the recognition of the Tags the mobile RFID reader model UHF 900 BT was used. This is a light equipment, of great mobility, that operates in frequency band 800 to 960 MHz. Access to its internal data base can be done via bluetooth or a data transmission cable.

The tests were divided in two stages. The first stage happened in laboratory environment aiming the development, evaluation, and validation of the procedures and functioning of the collection system and data processing. After the formatting of the procedures and validation of the system functioning, the second stage was initiated, which consisted of the execution of tests in an actual operational construction site, reproducing the assay routine thoroughly as established in the laboratory.

The laboratory tests have simulated the identification of a security equipment consisting of a metallic archetype of a secondary support lattice tray manufactured in a

**Table 1.** RFID equipments used in the tests.

| Equipment | Brand | Model | Description |
|---|---|---|---|
| Tag/RFID passive label | RFID IF | B - 20070/C-20055 | Frequency: 915 MHz<br>Memory: 128 bits CPE<br>Dimension: 140 × 31 mm |
| Mobile RFID reader | Acura Global | UHF 900 BT | Frequency: 800-960 MHz<br>Weight: 170 g<br>Dimension: 14,8 × 5, 1 × 3,0 cm<br>Interface: Bluetooth 2,0 EDR/USB 1,1/UART 3,3V/3-wires |

reduced scale (2/1), equipped with a Tag previously registered. The readings took place with the approach of the RFID reader to the Tag until an acoustic signal was emitted by the reader, indicating the success of the reading. This operation was repeated ten times to verify the functionality of the procedure.

The validation tests consisted of reiterating the approach tests in other ten recognition repetitions. The protocol for the tests execution is described in Table 2.

**Table 2.** Test protocol - management of collective security equipment

| Item | Action | Description |
|---|---|---|
| Step 1 | Delimitation of the testing area. | Define the standard floor of a building in construction as testing area |
| Step 2 | Position of RFID reader | Mobile RFID reader |
| Step 3 | Software/Reader | The RFID reading equipment will interface with the support equipment fed by the software developed for this experiment |
| Step 4 | Tag | Use Tag model IF RFID B - 20070/C/20055. Each piece of equipment is to receive only one Tag fixed in place that allows easy reading |
| Step 5 | Reading taking | The collaborator/researcher will approximate the reader to the Tag fixed in the equipment and perform an independent reading for each apparatus |
| Step 6 | Amount of readings | One only reading for each equipment shall be collected |
| Step 7 | Definition of placement | To define the placement of the equipment in the construction site, the plant shall be divided into 2 m × 2 m quadrants. The quadrants will be identified by numbers on the coordinate abscissas' axle (x) and letters on the ordinate coordinates axle (y) forming a matrix of coordinates as guidance model |
| Step 8 | Data collection | The data collected by the reader will be unloaded or transferred to a support equipment fed by the software developed for this study |
| 8.1 | | Registered data: Equipment/Function/Placement (Quadrant)/Brand/Conservation/Next revision/Responsible |
| Step 9 | Closing of the tests | The closing of the tests will happen after the readings. In case of interferences the reading will be deleted and a new reading will be carried through in sequence |
| Step 10 | Data compilation | The data will be compiled after the closing of the tests with the use of the software |

With this test, it was expected to identify reading variations that could invalidate the functioning of the set. In this stage, all the data obtained during the readings were written down in an assay control spreadsheet. The development of the software responsible for controlling, storing and organizing the tests' data was developed throughout this stage and used the information obtained during the tests for the construction of its architecture and logical structure.

The use of security equipment may occur throughout the construction site, therefore, during the field or construction site tests a floor of a building in construction was selected, and the readings were done in different places on that floor. The given floor and the project of distribution of the trays and GTS can be seen in Fig. 3. Six passive tags were previously registered and installed in the collective protection equipment in different points of the construction site. Amongst the monitored pieces of equipment were the wood and metal GTS system (identified by circles) and fall-proof protection Trays (identified by triangles) (Figs. 1 and 2).

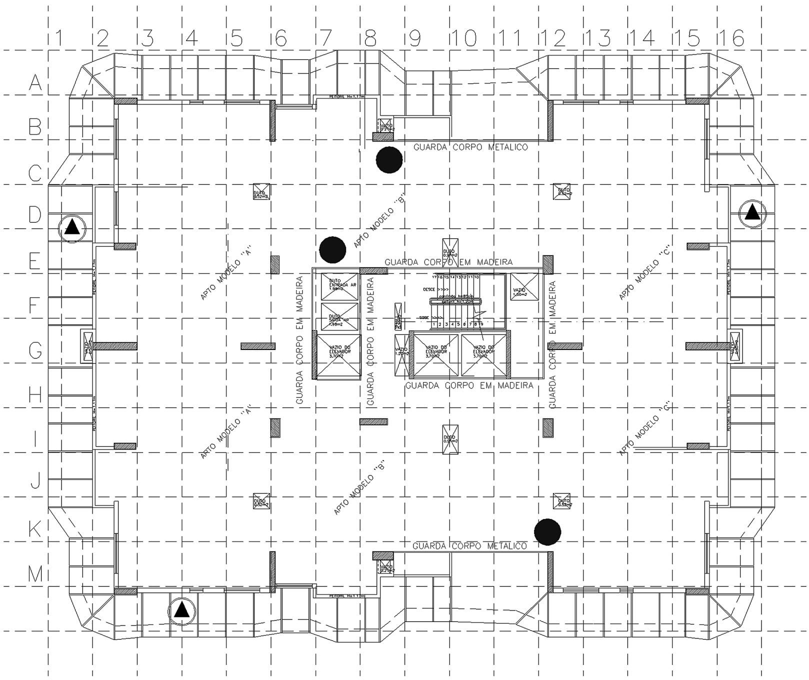


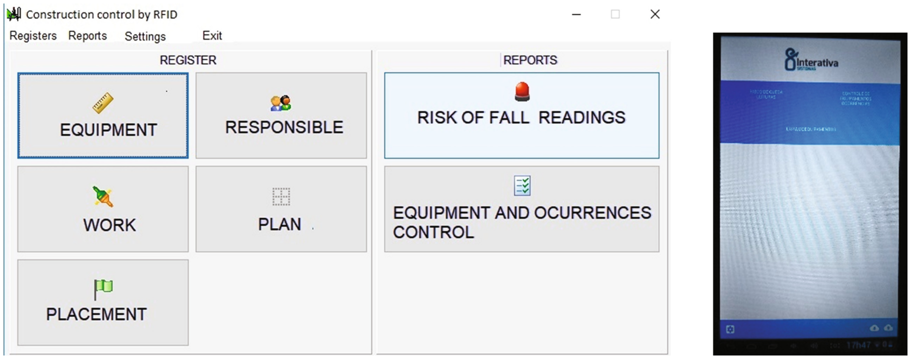

**Fig. 2.** Floor plan of the 13th floor of the construction site where the tests were carried through.

To evaluate the operation of the equipment's identification function, three possible situations were simulated: present, dislocated and absent. For the "present" situation the Tag was installed in an equipment located in the correct place of the register. When the reading presents the "dislocated" situation, it means that the Tag was installed in a different place from that registered. The "absent" situation means that no Tag was installed in the analyzed equipment and that in the initial or previous register it appeared as "present".

For the data collection procedure, a tablet and a mobile RFID reader were used. After the readings were done, the tablet's database was transferred to the computer having the program responsible for the compilation of the information obtained.

## 5 Interface and Software Implantation

The interface developed for the software had as objective to make the operator's communication accessible and easily understandable, aiming the adaptation of the tool to the necessities and characteristics of the workers in civil construction. Thus, special attention was given to the visual programming which provides the functions in the form of organized icons according to the logical sequence of use. The software was developed for Windows and Android platforms, allowing its lodging in computers using the Windows operational system (Fig. 3a) and tablets or smartphones using the Android operational system (Fig. 3b).




a) b)

**Fig. 3.** Software interface for Windows platform (**a**) and Android platform (**b**).

The software and the main database were housed in a mobile master computer responsible for compiling and storing all the information obtained with the system. The in loco readings were done with the use of a tablet, that, through an application, also developed during the research, communicated with the RFID mobile reader and filed the information then obtained. The interface between the tablet and the master computer occurred through the connection of the equipment in one same net and one same IP (Internet Protocol) address.

The first step in the implantation of the monitoring system using passive RFID was the registration of all the equipment used in the tests. Each equipment received a RFID Tag with an exclusive identification number. For the registration, the system provides a set of icons that display windows for the insertion of all the necessary data for the software functioning as in the examples in Fig. 4.

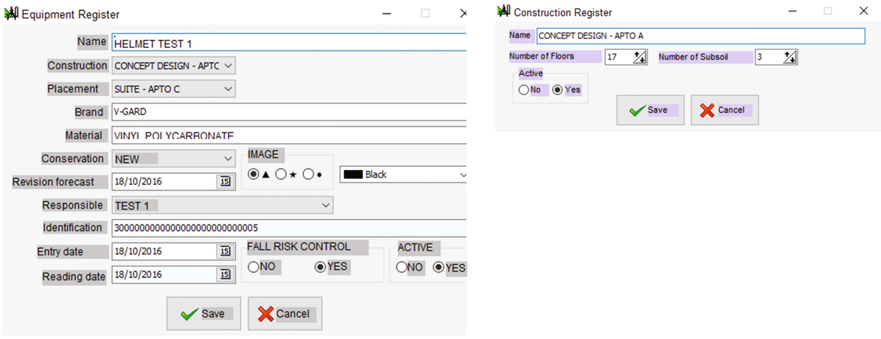



**Fig. 4.** Examples of registration windows in the software database

The numerical and text information must be typed or selected in the options menu of each registration box. The information registration follows an established order that organizes and provides the inserted information to the next registration stage.

The images of the plants are uploaded to the database in image format (.bmp). These archives must be stored in the computer where the software is being used.

The set of information that makes up the database includes the equipment type (name), name of the work, the construction site where the equipment will be used, the equipment brand, constituent material, equipment condition, prediction of the date for the next maintenance revision, and name of person responsible for the equipment.

During the configurations, the user can also define specifically which data he/she desires to get through the formatting of the data filtering menu. Thus, the results are organized so that they can be sorted by the characteristics of the equipment, or the area of application, for example.

## 6 Results

All the interactions of the system consisted of crossing and comparing data. In this way, the program was able to locate each registered element, indicating whether it was in the correct location (read – identified in green), in the wrong place (orange) or absent (not read-red color), according to Fig. 5. The readings carried through and pre-stored in the tablet were transferred to the master computer when paired up in the net, using the same IP address. The synchronization of the equipment with the database of the system works continuously, thus updating its placement in the plant.

Another resource of the system presents the equipment registers data. This resource describes, beside its placement, its characteristics according to registration. Figure 6 shows an example of the image of the graphical result considered by the system. In this example, the equipment “LatticeTray 2”, subtitled with a black triangle surrounded by a red circle, is being used in the Concept Design job, it is located in apartment “C” balcony, the equipment brand is the same as it is manufactured by the same company, metal profile is the manufacturing material, the conservation state is new; the forecast for the next revision is 18/12/2016; and the person responsible for the equipment is employee “Test 1”.

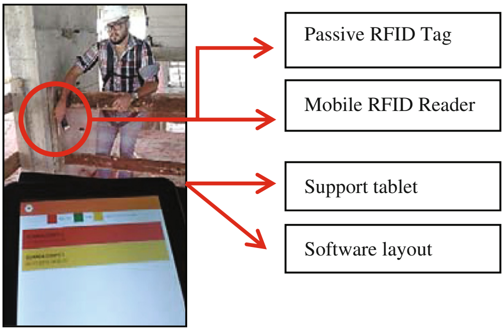



**Fig. 5.** Reading interface for the software in an Android operating system on tablet.

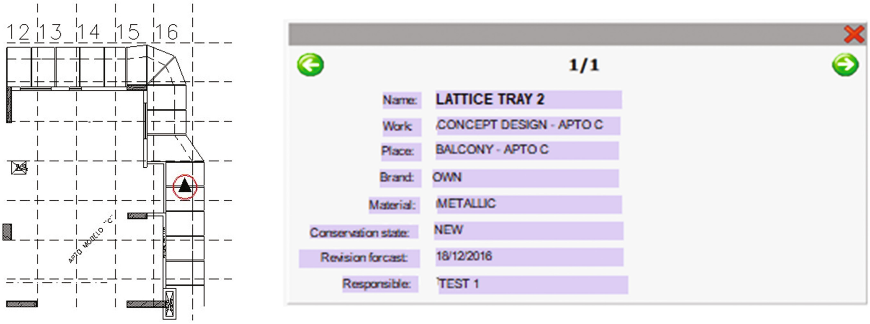



**Fig. 6.** Images of the identification graphical result, description and placement of a CPE installed in the construction site.

Figure 7 shows one more resource of the system. All the information contained in the program database can be made available as report spreadsheets. In this example, the report describes what the filters used to delimit the information are and makes the reading dates, the types of equipment and all other relevant information to the requested report available.

In all the readings made during the simulations, the results indicated the correct condition of the equipment, as planned in the initially proposed register. In addition to the equipment condition, in 100% of the readings, the system has defined and presented the data set pertaining to each equipment correctly. The results have also shown that the Tag model used operated successfully regardless of the constituent material of the monitored equipment (metal or wood).

| OCURRENCES REPORT | | | | | 01/11/2016 18:24:57 |
|---|---|---|---|---|---|
| Filters<br>Date from 01/10/2016 to 01/11/2016<br>Order: Construction<br>Section: Construction | | | | | |
| Time | Condiction | Floor | Equipment | Placement | Responsible |
| CONSTRUCTION: CONCEPT DESIGN - APARTMENT A | | | | | |
| 01/11/2016 13:52:30 | ABSENT | 13 | LATTICE TRAY | BALCONY - APT A | TEST 1 |
| 01/11/2016 13:53:05 | BEING | 13 | LATTICE TRAY | BALCONY - APT A | TEST 1 |
| | | | | Subtotal of Readings: | 2 |

**Fig. 7.** Report of a set of readings and database information

# 7 Conclusion

RFID technology has been the content of a series of research aimed at the construction industry. This research presented RFID application results with the specific purpose of constituting a system destined to the remote monitoring of security equipment. Throughout the work, the structure and functioning of a management method directed to the construction industry were described.

The tests that have determined the functionality of the system and the development of the software were conducted at the same time. The environment that hosted the trials in the construction site featured a series of interferences, such as elements of concrete, metal profile, and wood panels. Even in face of these obstacles common to a daily routine of a construction site, the set formed by the RFID equipment and the software succeeded in the readings performed, with the consequent identification and location of the monitored equipment. The use of Tags with specific attributes, protected against the action and interference of metallic elements and weather, was fundamental in reaching the gotten results.

The results have produced a tool with functions that completely modify the way to administer the equipment management. Innovations such as real-time monitoring, remote monitoring without the necessity of submitting to the existing security risks when moving around the construction site, control of supply promoted by the necessity of registering all the equipment used in the construction site and its constant updating, reduction of accidents risk due to the control of the maintenance period of the equipment, creation of a databank and using track record are just some of the benefits and contributions of this research.

Simplicity in the system operation was a purpose pursued over the course of its development. The expectation is to stimulate the workers to use it. In this sense, the design of the interface using the Android operating system has brought a great contribution: the use of the system through smartphones or tablets approximates the workforce to the technology because these are tools they are used by and belong to their routine, which humanizes the adoption of this technology.

The value of a database creation was evident when it provided that specific data were selected and stored by automated means. This easiness in the attainment of data, besides constructing a historical information base, substituted the manual register carried through by the CPE control workers. Automation of data register and analysis has reduced the work, time and flaws in the process. Moreover, it generated information for the development of production and operational performance indicators for the company.

The filtering data tool turned up to be an important function of the computational system developed. Through data filtering it was possible to reduce and/or group the amount of information contained in the reports, thus eliminating redundancies.

The results of the readings and the database organized in form of reports and spreadsheets with filters for the choice of information to be transmitted have enriched the information presentation. Moreover, the graphical results in the form of plants with the identification of the equipment therein have simplified and invigorated the way operators and managers had access to the information generated by the system.

The contributions to the continuity of new research are extensive. A straightforward example for a future application of the system would be to extend the monitoring to other types of equipment and tools, such as drills, circular saws, screwdrivers, etc., usually present in construction sites.

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# Comparative Study of the Application of RCM and Risk Matrix for Risk Assessment of Collaborative Robots

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**Abstract.** This paper is focused on the study and analysis of risks associated with collaborative robots. Currently, collaborative robots are in full development with application in different sectors of activity. However, for these new working situations the adoption of suitable risk assessment approaches is necessary to deal with all new parameters and risks generated by the collaborative work involving a machine and human beings.

In this sense, it is important to assess the risks associated with the use of this type of machines, and different methodology of risk assessment can be used in these new and complex cases.

A comparative study of two risk assessment methodologies was carried out to evaluate their suitability for risk management and thus to support the manufacturers and users of these machines in the use of appropriate and reliable risk assessment methodologies. The two methodologies, Reliability Centered Maintenance (RCM) and Risk Matrix, and the quality of the results obtained by their application are compared.

**Keywords:** Human-machine interactions · Risk assessment methodologies
Safety of machinery

## 1 Introduction

Currently, robots are part of everyday life of everyone. It is possible to find them in simple tasks such as cooking or vacuuming, but also in more complex tasks such as assembly or welding operations in different organizations.

Industry 4.0 has further encouraged the use of this type of complex machine. Present in different industries, from the food industry to the footwear industry, and also in the metalworking industry and others, the robots became essential in our day-to-day.

However, their use and interaction with humans raise some issues, especially safety issues. In the projects in which the robots are present it is necessary to check some aspects related to security, namely the study of the reliability of the robots, that is, what is the probability of failure of the robots? And in case of failure what possible damages?


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For example, robots operating in extreme situations (nuclear power stations, aerospace activities, etc.) can have a major impact if they do not fulfill their function. On the other hand, there are robots that perform activities in the industries, which imply situations of risk for the employees. In this way, it is imperative to ensure the safety conditions and to guarantee the minimal or nonexistent risk in the execution of the tasks and that human-machine (robots) interaction is safe and efficient [1].

In this paper, two approaches are presented and analyzed to evaluate the inherent risks of the robot under study: Reliability Centered Maintenance methodology (RCM) and Risk Matrix. RCM is a methodology for the development of preventive maintenance plans, in order to guarantee the inherent reliability of the system design. This methodology is focused on reliability and aims to reduce maintenance costs taking into account the functions of the equipment, but without neglecting aspects related to safety. Although not a risk assessment method, part of the RCM steps will be used to verify its applicability for this purpose. It is intended to identify the most significant aspects of each methodology and to perform a comparative analysis for the case of complex machines, such as robots. This study will evaluate the quality of the results in relation to the application of the RCM methodology, tested and recognized in different sectors. On the other hand, the quality of the information obtained from a simple methodology and frequently used between manufacturers and users of these complex machines, the Risk Matrix will also be evaluated.

This article is organized in six sections. The first defines the scope and paper objective. The second section presents a review of the literature on collaborative robots and risk assessment. The risk assessment methodologies to be compared are presented in the third section. The fourth section describes the application of the two assessment methodologies in a case study. Section 5 presents the results and the comparative analysis of the evaluation methodologies. The last section presents the conclusions and suggestions for future developments.

## 2 Literature Review

The subject under study is presented in scientific articles and normative references. The most relevant international standards in the safety of machinery, which is the subject of analysis during the case study are:

– ISO/TR 14121:2012 - Safety of machinery - Risk assessment - Part 2: Practical guidance and examples of methods [2]
– ISO 13849:2015 - Safety of machinery - Safety-related parts of control systems - Part 1: General principles for design [3]
– ISO 13849:2012 - Safety of machinery - Safety-related parts of control systems - Part 2: Validation [4]
– ISO 12100:2010 - Safety of Machinery - General principles for design - Risk assessment and risk reduction [5]
– ISO 14120:2002 - Safety of machinery. Guards [6]
– ISO/TS 15066:2016 - Robots and robotic devices – Collaborative robots [7]

In addition, it is important to mention the international standard ISO 13482:2014 [9] which reports dangerous situations or events. This reference warns about the dangers related to the human-machine impact, which are currently not known, because there are no recognized and validated standard data on this situation until the moment of publication. This situation should therefore be considered when assessing risks.

Regarding methodologies for risk assessment, in addition to ISO 12100 which presents a set of methodologies stands out the SAE JA 1012: 2011 [8], which describes the RCM - Reliability-Centered Maintenance.

Different authors also addressed the issue. In [10] the authors present a prediction model for studying the severity of the robot's impact on man, for safety assessment of collaborative robot design. In [11], the authors integrate several approaches related to risk estimation and safe design of human centered robotic workcell. The design and development of the safety strategy for a human-robot collaboration system is presented by [12].

## 3 Risk Assessment Methodologies

The process of risk assessment involves a set of actions in order to ensure success and also that measures identified in this process do not cause new risks.

According to [5] to implement risk assessment and risk reduction the designer shall follow a sequence of actions (Fig. 1).

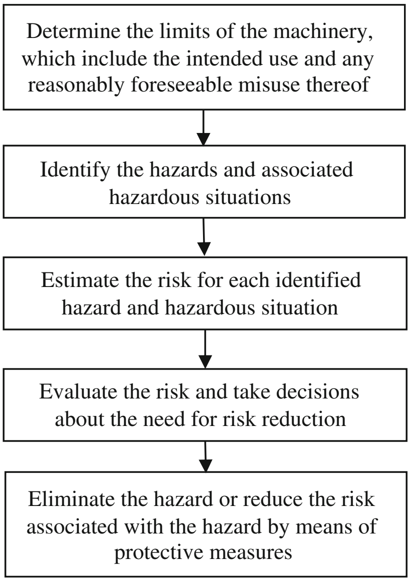


**Fig. 1.** Risk assessment and risk reduction – ISO 12100:2010

The reliability of "Safety Related Parts of Control Systems (SRP/CS)" is treated by the EN ISO 13849-1 [3], which defines 5 Performance Levels (PL) a, b, c, d, e. The PL is a «discrete level used to specify the ability of safety related parts of control systems to perform a safety» graduated from the lowest "a", suitable for safety functions related with lowest risks, to "e", the highest, applicable to protective measures of high risks. PL can be quantified by the «Average Probability of Dangerous Failure per Hour (PFHD)». Another important concept is the "Required Performance Level (PLr) - «Performance level applied in order to achieve the required risk reduction for each safety function».

There are different methodologies that can be used for risk assessment, among them it is possible to highlight two, the "Risk Matrix", a simple methodology currently in use for the safety of machines and work equipment and the RCM - Reliability Centered Maintenance, complex and exigent one usually used in the airspace industry.

### 3.1 Risk Matrix

A risk matrix is based on the construction of a multidimensional table (usually two-dimensional) where it is possible to combine any kind of severity of a damage with any class of probability of occurrence of that harm [2].

Figure 2 shows an example of risk matrix widely used in the evaluations of complex machines, including robots.

| Probability of occurrence of harm | Severity of harm | | | |
|---|---|---|---|---|
| | Catastrophic | Serious | Moderate | Minor |
| Very likely | High | High | High | Medium |
| Likely | High | High | Medium | Low |
| Unlikely | Medium | Medium | Low | Negligible |
| Remote | Low | Low | Negligible | Negligible |

**Fig. 2.** Risk estimation matrix (example) - ISO/TR 14121:2012

In which the severity of harm can be [2]:

- Catastrophic: death or permanent disabling injury or illness (unable to return to work);
- Serious: severe debilitating injury or illness (able to return to work at some point);
- Moderate: significant injury or illness requiring more than first aid (able to return to same job);
- Minor: no injury or slight injury requiring no more than first aid (little or no lost work time).

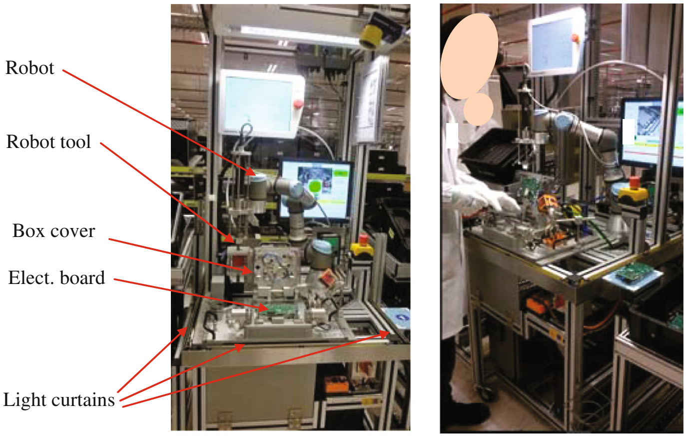


**Fig. 3.** Working cell

And for the probability of occurrence [2]:

– Very likely: near certain to occur;
– Likely: can occur;
– Unlikely: not likely to occur;
– Remote: so unlikely as to be near zero.

Its use is very simple, but technical knowledge is necessary to correctly define the probability of a given event occurring and its severity.

### 3.2 RCM - Reliability Centered Maintenance

The RCM methodology is defined in normative reference [8] and has as principle the guarantee of the function for which the equipment is intended. Thus, the application of RCM aims to determine what should be done for each system to function as defined.

To implement the methodology, it is necessary to answer a set of questions about the system under study [8]:

– What are the functions and associated desired standards of performance of the asset in its present operating context (functions)?
– In what ways can it fail to fulfill its functions (functional failures)?
– What causes each functional failure (failure modes)?
– What happens when failure occurs (failure effects)?
– What can be the consequences of failure occurrence?
– What can be done to detect or prevent the failure?

With these questions answered it is possible to comply with the following stages of the methodology:

– Determination of functions and analysis of functional failures;
– Analysis of failure modes and their effects;
– Definition of the actions to be implemented and their priority.

It is possible to use other methodologies to support the implementation of RCM, such as FTA - Failure Tree Analysis. This tool, used in the analysis of system security, has been adopted in many reliability applications. It consists of identifying possible failures of the system or undesirable events and the so-called basic faults (basic events) that leads to these failures.

# 4 Case Study

## 4.1 Case Study Description

The study has been carried out in a working cell equipped with a small "collaborative" robot. The robot and the operator do not have to perform simultaneous tasks in the working area of the robot (so called dangerous area).

Robot characteristics:

- Payload: 3.0 kg
- Weight: 15 kg
- Degrees of freedom: 6 rotation joints
- Reach: 500 mm
- Working range: 360°
- Maximum speeds: 180–360°/s; Typical tool: 1 m/s
- 15 advanced adjustable safety functions
- Performance Level: PL d (according to EN ISO 13849-1 [3]).

**Robot and worker tasks**

The robot task is to apply and tighten small screws on an electronic board, previously placed by the worker inside a box and, at the end of tightening, open that box for the operator to place a new electronic board.

The worker tasks are to place, by hand, the electronic board inside the box and, at the end of robot operation, to take it out and replace it by a new one. For that, the hands of the worker must go to the working area of the robot (dangerous area).

The access to the dangerous area is protected by light curtains, which detect any intrusion in it and stop all robot movements.

In normal work conditions, the worker needs to access the dangerous area only after the robot has performed its task and stopped at its park position, sufficiently far from the box where the worker has to take out the electronic boards and place a new one to be screwed by the robot. The robot only restarts to move after the worker hands are out of the dangerous area.

## 4.2 Risk Assessment Applying the Risk Matrix

The first step to apply the Risk Matrix is to identify the hazards associated with each phase of the life cycle of the machine. The second is to define the hazardous situation and the hazardous events and third is to estimate the risks related to each identified hazard. This methodology is based on the effects/consequences of the accident (severity of the harm) and on the probability of the occurrence of the harm. Estimating and combining these two parameters, the risk can be graduated from Negligible to High (risk level). According to the results of the risk assessment the machine manufacturer will be able to define the adequate protective measures to reduce each risk from the original level to an acceptable level.

Concepts of failure and reliability appear in the final step, when the manufacturer needs to define, design and construct those protective measures. For example, to select the light curtains to avoid the access of the robot working (dangerous) area, and to design the "safety function" of the control system related with the light curtains, he must ensure that both (light curtains and "safety function") have the adequate reliability to achieve the PLr, in other words this means the adequate «Average Probability of Dangerous Failure per Hour ($PFH_D$)» [3]. In a simple way it can be said that using this methodology he "first take the risk" and after must decide what must be the adequate reliability of the solution to reduce the risk to an acceptable level.

Table 1 shows the results of risk assessment for two situations of the working cell taken as examples. It is important to say that in the beginning of risk assessment process (preferably done at the very beginning of machine design) the identified hazards and associated risks are not treated so far.

The information taken from this table is the reliability associated with the solution adopted to reduce those risks. In this case, it is $10^{-7} \leq PFH_D \leq 10^{-6}$, which correspond to the «Average Probability of Dangerous Failure per Hour» associated to PL d level [3]. In the Risk Matrix, no detail is required about "failure modes" and their "effects".

### 4.3 RCM - Reliability Centered Maintenance

The RCM methodology has a different approach to the same situation. This approach encompasses three steps:

- Identify the function (what the manufacturer or the user of the machine wants it to do) and analysis of functional failures.
- Analysis of the failure modes and their effects.
- Definition of the action to be implemented and their priority.

Taking the same working cell and the examples dealt with in the previous section: Function Identification (robot):

1. Tighten small screws on an electronic board.
2. Open the box.

Parameters of Table 2 are based on the FMEA (Potential Failure Mode and Effects Analysis) from the Chrysler, Ford and General Motors Guide. This table shows the "failure modes" and their "effects". Each parameter (S, O, D) must be graduated from 1 to 10, and the risk level RPN is scored from 1 to 1000. RPN values over 100 means that measures must be taken to reduce the risk.

**Table 1.** Risk assessment (simplified table) with two examples

| Task | Hazard | Risk estimation | | Adopted solution | Risk estimation | | Conclusion |
|---|---|---|---|---|---|---|---|
| | | Probability of occurrence/severity of harm | Risk level | | Probability of occurrence/severity of harm | Risk level | |
| Place the electronic board to be tighten (hands in the dangerous area) | Crash (between moving parts of the robot and fixed parts of the machine structure) | Very likely/Moderate | High | Light curtains and related safety function of control system with adequate PL (*admitted PL d*) | Remote/Moderate | Negligible | Done (see Fig. 3) |
| | Stabbing/puncture (by the tool or screw) | Very likely/Moderate | High | | Remote/Moderate | Negligible | Done (see Fig. 3) |

**Table 2.** RCM (simplified table) with two functions

| Functions | Failure modes | Effects | S | Potential causes | O | Detection (D) | | | RPN[1] | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | BLc[2] | ALc[3] | | BLc[2] | ALc[3] |
| 1. Tighten screw with specified torque, speed and distance | Tighten with less or more torque than specified | Incorrect tighten | 6 | Default on electronic board | 1 | – | Automatic torque recording by machine | – | 6 | |
| | Excessive speed | Impact worker upper members | 7 | Worker upper members in the dangerous areas | 10 | 9 | Presence light curtains | 1 | 630 | 70 |
| | No tighten | Screw was not tightened | 6 | Default on electronic board | 1 | – | Automatic torque recording by machine | 1 | 6 | |
| | | Crush | 7 | Worker upper members in the dangerous area (tighten) between robot tool and electronic board | 10 | 9 | Presence light curtains | 1 | 630 | 70 |
| 2. Open the box | Box was not opened | Impact worker upper members (worker will try to open the box) | 5 | Worker upper members in the dangerous area | 4 | 9 | Presence light curtains | 1 | 180 | 20 |

Key:
[1]S = Severity; O = Occurrence; D = Detection; RPN (Risk Priority Number) = S × O × D
[2]BLc – Before Light curtains
[3]ALc – After Light curtains

## 5 Discussion

Results of the of risk assessment with both methodologies are (more or less) the same (Table 3).

**Table 3.** Results of risk assessment with both methodologies

| | Risk estimation before protective measures | Protective measures | Risk estimation after protective measures |
|---|---|---|---|
| Risk matrix (risk level) | High | Light curtains; PL d | Negligible |
| RCM (RPN) | 630/180 | Light curtains; PL d | 70/20<br>No additional measures needed to reduce the risks |

Both methodologies demonstrate that the level of assessed risks are high and so, protective measures must be implemented to reduce them to tolerable levels. These methodologies also achieved the same results after the implementation of protective measures (light curtains): risks fell to acceptable levels.

However, there are some details that can make the difference between the use of Risk Matrix or RCM on risk assessment process:

- RCM is centered on the analyses of the failures of the equipment function which may be associated with a probability of occurrence, but the failure of the function may not always lead to a safety fault. For example (in this case study) the probability of the worker getting hurt since the box is closed is different from the probability that the box will not open.
- RCM gives more possibilities of exploration, at the design phase of the main parameters involved in the functionality and safety of the working cell - probability, severity, occurrence and detection. This methodology has advantages at the design level because it allows to compare different solutions and to verify the risk level for each one. In addition, the information taken from the analysis of every single parameter will guide the designer to select which one must be the first to deal with and act to reduce the risk and achieve safety and functionality objectives.

On the other hand, the RCM presents tables with more levels (up to 10), which allows to obtain much more detailed final results.

However, the RCM is not the fastest approach since we have to look at all the functions of the system, independently of how small it may be, and identify potential risks, related to safety issues, but also reliability of the system. In summary, it provides more, and detailed information.

Thus, the Risk Matrix presents itself as a good alternative, considering that it only deals with safety issues and since it has a more simplified matrix of analysis ($4 \times 4$) facilitates the task of risk estimation by technicians.

Risk Matrix appears as an efficient tool to assess the safety of these kind of complex machines. However, the RCM clearly demonstrates its usefulness and versatility, as it also can be applied to this type of systems (collaborative robots), with obvious contributions to safety and reliability of them.

## 6 Conclusions

Both methodologies are suitable to identify the Hazards and assess the risks associated with this kind of machines.

Risk Matrix is simple and easy to apply but, apparently, the quality of the results may be slightly lower than those obtained with RCM because the information that justifies and supports each step of risk assessment is more detailed than with Risk Matrix. But this advantage of the RCM can also be seen as disadvantage, since the detail it requires makes it time-consuming and not so easy to use.

Although the results are similar, they may mean that RCM should be adapted for risk assessment so that the risk could be minimized, functional failures that have a safety consequence can be highlighted and the probability of the problem arise being determined.

## 7 Future Works

Future work will involve the study and analysis of the design, since the very beginning, of work cells with collaborative robots and the risk assessment during their life cycle, applying Risk Matrix and RCM, as well as the comparison of the results. For that purpose an adequate adaptation of RCM to do the risk assessment of this kind of machines must be developed.

For this study the document «ISO 21260 Safety of Machinery - Mechanical safety data for physical contacts between moving machinery and people» will be taken as reference to assess the risks associated with the contact between robots and humans. This document is under development and should be published by early 2019.

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# Development of Enterprise Accident Early Warning System Based on IOT

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**Abstract.** Safety rules and regulations for various groups of organizations are required along with security education, safety supervision and inspection. These measures can improve the level of safety management to a certain extent, and because the employees are disturbed by anxiety and impulsive irrational psychological factors in production and technology and other social activities, their behavior is more difficult to be predicted. This study aims at introducing an enterprise accident and safety early warning system by infusing human factors with respect to physical and the environmental aspects of the behavior, and with respect to safety management needs, and proposes the application of the Internet of things technology to the construction of enterprise early warning system. The accident warning system architecture uses IOT framework as a model, the three-layer structure includes perception layer, transport layer and application layer. The proposed system can help address several issues and can shift the enterprise focus form accident treatment to a more proper and effective accident warning system, and fundamentally help prevent accidents at first.

**Keywords:** Safe production · IOT (Internet of thing) · Accident early warning system · Sensor · Behavior analysis · Environmental monitoring

## 1 Introduction

The production process is complex, operation length and has strong continuity. In the process of production, the working environment is characterized by high temperature, high pressure and high energy. And there are toxic, harmful, flammable and explosive materials. In the working environment of high building and mechanical processing, there are mechanical injuries such as falling objects and striking objects [1, 2]. With the acceleration of the process of modernization, the enterprise has been developing rapidly. But at the same time, the probability of major accidents, such as fire, explosion, poisoning, leakage, and so on, is increasing year by year. According to the law of accident, early warning of accident signs has become an important measure to reduce the accident loss. With the rapid development of science and technology, people are paying more and


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more attention to the Internet of things [3]. In 2011, the Internet of Things was included in the national "Twelfth Five-Year plan". At present, IOT has played an active role in demonstration projects in areas such as national defense military, smart grid, intelligent transportation, smart home, and healthcare [4, 5]. The IOT technology applied to enterprise accident warning system, to play his technical advantages. Establish a set of fast and scientific accident early warning system for enterprises, thoroughly change the backward management situation, reduce the probability of accidents to the greatest extent, and ensure the safe production of enterprises [3, 6–8].

## 2 Overview and Framework of IOT

In this section, the origin of IOT is introduced. And the IOT is clearly divided into three layers. The origin of the Internet of Things is the Automatic Identification Center of the Massachusetts Institute of Technology In the United States in 1990. Kevin Ashton proposed a network radio frequency identification (RFID) system. Usually people think that the Internet of things used sensors, radio frequency identification(RFID), GPS positioning and other sensing technologies. All kinds of items are connected to the Internet through the communication network. Data storage and processing technologies, such as cloud computing, data mining, etc., are also applied to the Internet of things. Finally, a complete connected physical network system is constructed [9]. Objects in this Internet of things system can be intelligently identified, positioned, monitored, controlled, and managed. The low-cost sensor for large-scale deployment is used as the nerve end of the Internet of things network. A large number of spatial distributed sensor nodes interconnected. A large number of spatially distributed sensor nodes are interconnected by communication and network technology. The information collected by the sensor is collected. After that, the information is processed and analyzed accordingly. Finally, the physical world is clear and transparent to people [10]. Next, this paper will introduce the three-layer architecture of the Internet of things.

To make a clear framework for the key aspects of the IOT, the complex structure of the IOT can be divided into three layers, including the perception layer, the transport layer, and the application layer [6]. The three-layer structure is shown in Fig. 1. These three layers cover the various technologies involved in the technology of the Internet of things.

**The Perception Layer** is made up of various hardware devices, including sensors, RFID, camera, global positioning system (GPS), remote sensing equipment, infrared sensor and so on. In the Internet of things system, the perception layer is responsible for collecting information, which is the source of information.

**The Transport Layer** can also be referred to as the network layer. Transmission layers is fusion of various networks. It securely transfers the information obtained by the perceptual layer to the application layer. The transport layer mainly uses 2G/3G mobile networks, the Internet and private networks. The key technologies of the transport layer are wireless communication technology, IP bearer technology, network transmission technology, network security technology, self-organizing communication and network convergence technology.

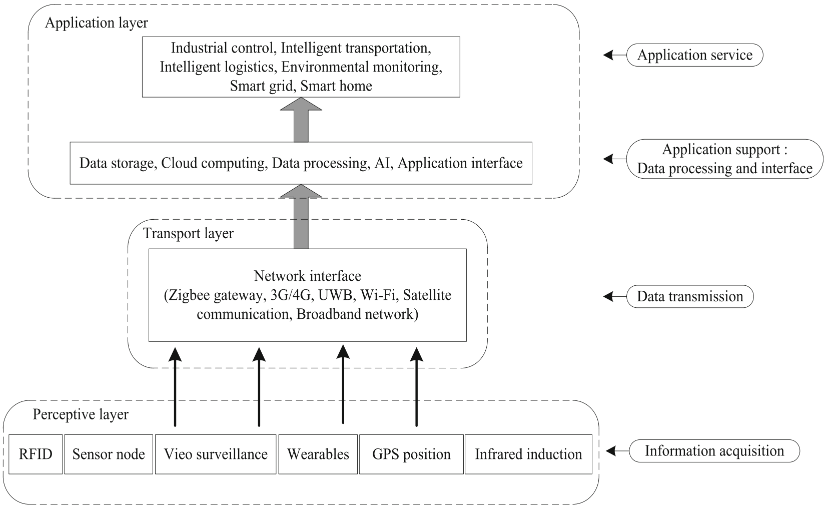


**Fig. 1.** Architecture of Internet of things

**The Application Layer** is responsible for the summary, transformation, analysis and processing of data. Application layer can be subdivided into application support layer and application service layer. The application support layer provides basic services, such as processing, sharing exchange of data, and provides a resource call interface for the application service layer. Application service layer is an application in a specific field, including industrial control, intelligent transportation, intelligent logistics, environmental monitoring, smart grid, smart home.

## 3 Enterprise Accident Early Warning System Architecture Based on IOT

In this section, the architecture of enterprise accident warning system will be introduced, it is based on the technology of the Internet of things. And establish an early-warning subsystem for unsafe behavior of employees, focus on the analysis and early warning of the unsafe behavior of the employees. Next, the unsafe behavior definition, the early warning rules and processes for unsafe behavior will be introduced.

The accident warning system is a timely forecast and warning for the omen of the accident. It can take countermeasures to solve the danger and prevent the eventual happening of the accident. At present, most enterprises have not established a scientific and effective accident warning system. The existing early warning system lacks online dynamic monitoring technology. Accident warning is overly dependent on artificial experience and it is difficult to detect the omen of the accident. Therefore, accidents cannot be strangled in the budding stage. In the event of an accident, enterprises are often caught out of hand, causing irreparable casualties and loss of property. The IOT is the product of the information age. It can provide new ideological guidance and strong technical support for enterprise accident warning system. The enterprise accident early warning system based on the IOT is shown in Fig. 2.

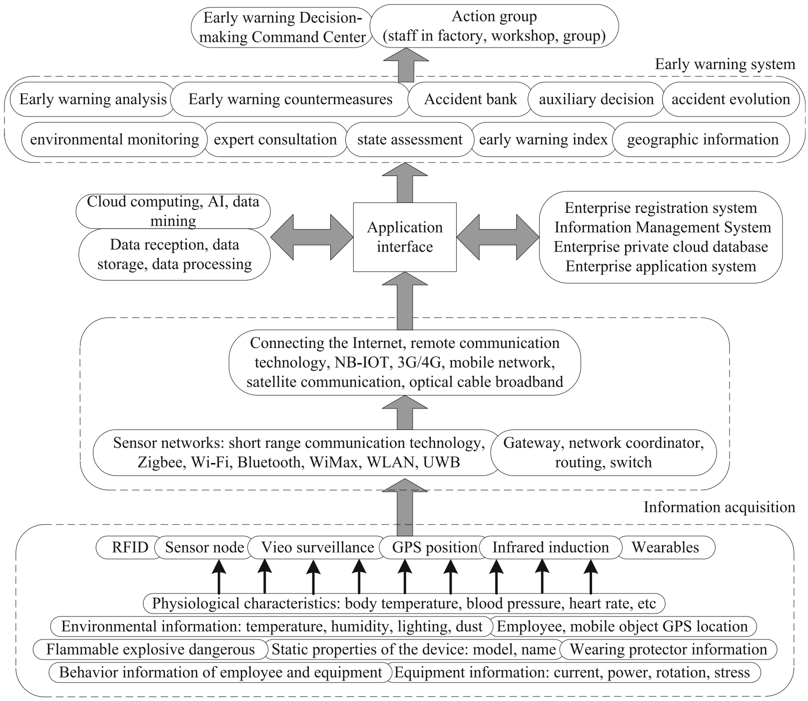


**Fig. 2.** Infrastructure of accident early-warning system for enterprises based on IOT

### 3.1 Perception Layer of Early-Warning System

The perceptual layer is the basis of the entire early warning system and the source of information. In this paper, based on the source of information, the perceived object is divided into personnel, machinery equipment and operating environment [10]. The perceptual layer can dynamically monitor, identify and locate them in real time and realize the overall perception of the enterprise.

**Perception of People**: The physiological and behavioral characteristics of the workers are collected in real time. The main contents include the following aspects: (1) Employees wear RFID Tags. The collector collects staff's post information and safety supplies information, including the permissions to enter the operation area and the permissions of the operating equipment. (2) Install video surveillance in every place of the workshop. Monitoring covers the entire production workshop. The unsafe behavior of the staff is monitored. Employees' unsafe actions include illegal operations, closing to dangerous areas, and working without safety protectors. (3) There are frequent staff flow problems in the production workshop. The perceptive layer tracks the people in real time and accurately through GPS. Establish the GIS (geographic information system) and space information system of the enterprise production workshop.

**Perception of Machine Equipment**: The process of the enterprise is complex, and the equipment and facilities are scattered. Non-contact automatic identification technology RFID and the sensor detection technology are used to detect equipment information. The device information includes the running status parameter information and the control parameter information. Device status information is divided into static and dynamic properties. The static property is the name of the device, the type of the device, and so on. Dynamic properties are vibration, rotation, etc. The dynamic properties of the device can be measured directly, or it is calculated by other parameters that can be measured directly. The device status parameter reflects the current running status of the device; The control parameter information of the device is set by the operator. The operator changes the control parameters to adjust the operation of the equipment

**Perception of the Operating Environment**: The sensor tests Harmful gas, dust concentration, humidity, temperature, noise, and lighting in the sensor detection operating environment. Real-time environmental information is uploaded to the application layer through the transport layer. Establishing GIS system in the application layer to realize the remote sensing image display of the environment.

### 3.2 Transport Layer of Early-Warning System

The transport layer is the transfer station of the early warning system which transfers the information obtained by perceptual layer to the application layer. The factors that affect the accident are multiple factors. Under certain conditions, the unsafe behavior of a person and the unsafe state of a thing cause the occurrence of an accident. So the full and multifaceted data is important when the data is collected and transmitted. At the same time, data transmission rate and transmission cycle are also important. In addition, The layout of the transmission line and the placement of the wireless receiver in the workshop should be fully considered.

First of all, the transmission layer uses short distance wireless transmission technology, including ZigBee, Wi-Fi, Bluetooth, WLAN, UWB wireless communication technology. Through the ad hoc network and middleware, all kinds of equipment are connected into network [10, 11]. The raw data can be transformed into processed data that is conducive to transmission or application. Then, the data collected from the perception layer can be transmitted to the application layer accurately through mobile network, satellite communication and broadband communication.

### 3.3 Application Layer of Early-Warning System

The application layer is the core support layer of the accident early warning system. It mainly uses cloud computing, data mining, AI, and other background intelligent platform to analyze, process and feedback massive raw data, and plays the role of early warning decision and control. The core content of application layer is to predict the security status of the system ahead of time based on the dynamic data collected online and carry out active defense against the hidden danger of the system. The highest goal of application layer is to prevent it from happening.

The function of the application layer is mainly shown in the following aspects.

(1) Establish incident management base. Collect the typical accident or attempted accident of the enterprise, establishing enterprise accident database with data warehouse. Using data mining to study the relevance of warehouse accidents and find out the characteristics of the law of the accident. So, provide strong technical support for the establishment of early warning. And provide the basis for the early warning countermeasure Library.
(2) Evolutionary simulation system. Based on the background of production condition and operation environment, this system calculate the incoming data scientifically, simulate the development trend of the police intelligence, and give quantitative evaluation.
(3) Early warning indicators. Setting up early warning indicators and early warning thresholds by assembling professional knowledge and related safety standards. Establish data resource computing group by cloud computing. According to the current state of alert, determine the alert level.
(4) Early warning Countermeasures. When the data parameters uploaded by the perceptual layer exceed the early warning threshold and the parameter has a continuous growth trend. The sound and light alarm is given by the sensor. GPS is used to locate the alarm site. The decision center informs the early warning team by phone or SMS. The early warning team puts forward practical and effective control measures based on the early warning counter and the actual police situation. At the same time, the early warning team organized the factory and workshop related personnel to prepare for emergency preparation. The alarm was lifted in time before it was transformed into an accident. If necessary, the person in charge of enterprises should prepare for contingency emergencies.
(5) 24-h expert system. Relying on AI (artificial intelligence) technology, relying on experts distributed in various enterprises and institutions, expert system provides online assistance and on-site guidance for enterprises based on quantitative analysis of test data.

## 4 Early Warning Subsystem of Employee Unsafe Behavior

In this section, the definition of unsafe behavior and the early warning process are proposed. Setting up an early warning logic process in the application layer. Hein Hilary thinks more than 85% of enterprise safety accidents are caused by human's unsafe behavior [12, 13]. A large number of accident investigation results also show that the majority of accidents are caused by human unsafe behavior. So, it's important to monitor the unsafe behavior of the employees in enterprise accident early warning system.

### 4.1 Three Kinds of Unsafe Behavior of Employees in Enterprises

There is different unsafe behavior in different specific scenes. For example, the wrong direction of walking, the parking in the forbidden area, entering the forbidden area. *GB6441-86 enterprise casualty accident classification standard* gives the definition of unsafe behavior: *Unsafe behavior is a human error that can cause an accident* [14].

In this paper, unsafe behavior is divided into three kinds in the enterprise safety production.

(1) The use of protective articles is not regulated and operation without personal safety protector.
(2) Close to dangerous areas; Work in an unsafe place; Unauthorized access to non-post area; Do not keep safe distance.
(3) Illegal operation; Erroneous operation; An act of inattention.

### 4.2 Early Warning Rules and Processes for Unsafe Behavior

Make the corresponding warning rules according to the type of unsafe behavior.

(1) Early warning rules for nonstandard use of safety protector. Different employees have different permission and wear different safety protectors. Save these information into the database. Employees and safety protectors all have identifiable tags. The tag identifier is placed at the production area entrance. The tag identifier recognizes the tags and reads the data information of tags. According to the tags information, query the information in the database. So, get the permission information for the employee to enter the area, and whether the safety protectors is used by the standard. The early warning process is shown in Fig. 3.

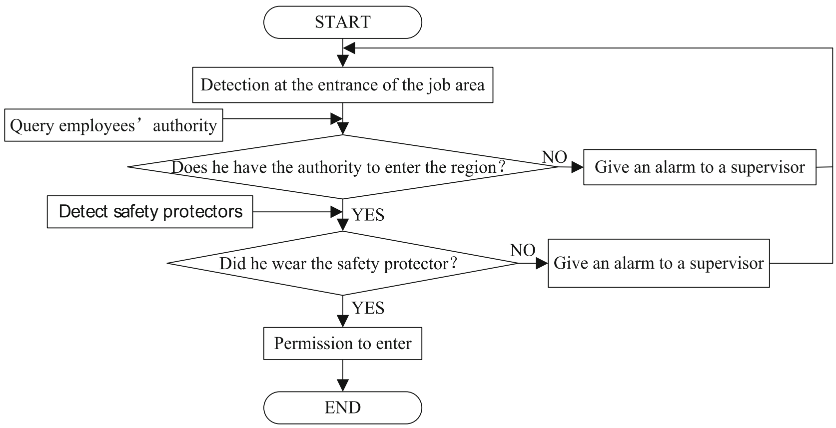


**Fig. 3.** Early warning process of non-standard safety supplies

(2) Early warning rules for close to dangerous areas. Search the location information of employees in real time through GPS positioning and tracking technology. Calculate the distance between the employee and the dangerous area, so as to determine whether the employee's position is appropriate. If the staff enter the dangerous area, the system red light warning and the alarm. The early warning process of approach to dangerous areas is shown in Fig. 4. The $d$ is the relative distance between the employee and the dangerous area.

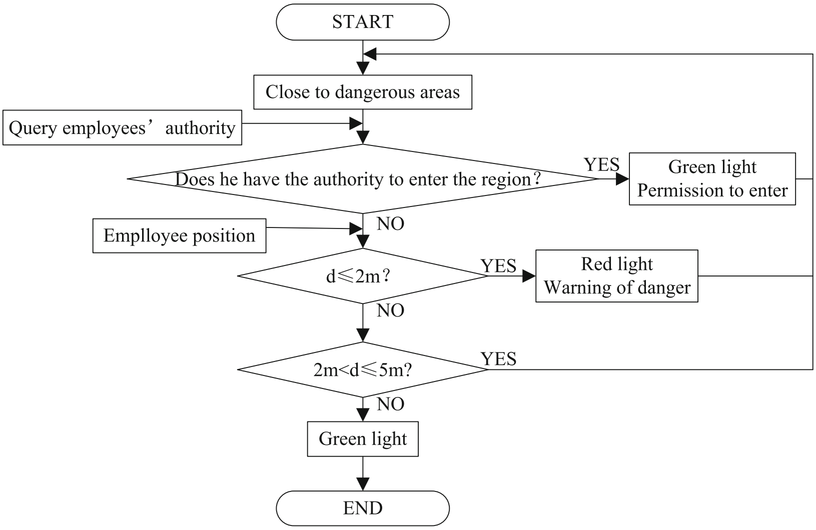


**Fig. 4.** Early warning process of approaching danger area and illegal operation

(3) Early warning rules for illegal operation. First, according to the enterprise safety operation specification, the operation behavior is defined. Design the features and behavior characteristics of the objects according to various operation specification. And build an object and behavior model library. Secondly, the action and behavior of the operator are analyzed by video surveillance and video analysis. Establishing a security behavior model library and an unsafe behavior model library. In the future process of safety production, the model library is perfected by AI. The early warning process of illegal operation is shown in Fig. 5.

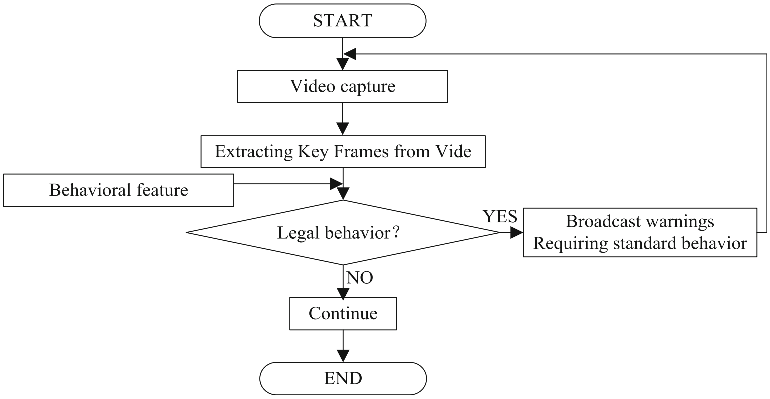


**Fig. 5.** Early warning process of illegal operation

## 5 Conclusions

With the development of science and technology, the technology of the Internet of things will become perfect. By combining the technology of IOT and the production process of modern enterprises, an effective accident warning system is established. The production process of an enterprise is monitored in real time. The early warning system will take reasonable precaution and control measures for the omen of the accident. Accident is eliminated in the embryonic stage. Furthermore, early warning system based on IOT is a long-term systematic project. There are many problems and difficulties in the construction of the project [5]. For instance, data information security and network security need to be considered; Different enterprises engage different projects, the definition of unsafe behavior of employees in each enterprise is different. So, in different enterprises, the early warning system of unsafe behavior is different. Enterprises and related research institutions should solve these problems in the future.

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# A CIT-AHP Method for Identification of Communication Skill Factors in Metro Traffic Dispatching System

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**Abstract.** Metro traffic dispatching system is a typical safety critical system. Speech communication is an important part in the task of a dispatching crew, and the quality of communication may directly affect the safety and performance of the system. The purpose of this study is to identify and determine the communication skill factors of dispatcher. Twenty dispatchers selected from Beijing Metro Company taken as the participants for CIT method and obtained 13 factors to construct a communication skill model. Through the questionnaire with 5 metro experts and group decision-making AHP method used to calculate weight of factors and importance sequence. The results show 5 most important factors are precise expression, coordination, overall awareness, multi-tasks management and avoid ambiguity. The related conclusions can be applied to the investigation of communication performance of dispatcher crew and the design of non-technical skills training programs.

**Keywords:** Communication · Metro traffic dispatcher
Group decision-making · AHP method

## 1 Introduction

Metro traffic dispatching is a typical safety critical system which the core of metro safety operation and emergency response, and plays a key role in coordination, decision-making and command. Once such an accident occurs, it will not only cause serious loss of life and property, but also lead to a huge adverse social impact beyond its own scope [1]. Therefore, the dispatching system not only has to meet the business and functional requirements, but also has to meet the security requirements. Normally, the traffic dispatcher crew consists of 2–4 people, the main task is to organize trains according to the speech communication command and adjust the train operation in time when the train deviates from the schedule. This puts forward higher requirements for the efficiency, precise and timely of speech communication.

Many serious accidents show the importance of speech communication. A train crash at Lyon station in Paris, France, killed 56 people and injured 57 in June 27, 1988. The driver cried for help to the dispatcher immediately when he found the brakes out of order, but he did not provide the train number so that the dispatcher could not


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determine the train information and location, which led to the disaster eventually. Another accident happened in September 27, 2011, a train crashed in Shanghai Metro Line 10 Yu Yuan-Old Xi Men section, causing about 40 people being slightly injured. Accident investigation showed that the dispatcher did not accurately determine the location of the train in the telephone blocking state.

Effective communication can maintain a high level of team information and situational awareness, improve team decision-making ability, and guarantee for team performance [2]. There is a large number of researches on communication in other industries, such as aviation [3], military [4], nuclear power [5], medical industry [6] and railway [7]. The factors that cause communication failure are summed as team coordination [8, 9], individual cognitive level [10], language application [11] and environment [12]. There are also many researchers proposed different solutions from different aspect, such as team structure [10], cognition difference, speech interference factors [13] and readability [14]. Metro traffic dispatcher has its professional particularity, so it is necessary to consider communication skill comprehensively.

In this study, the communication skill factors of metro traffic dispatcher were identified by critical incident technique (CIT). Afterwards, a group decision-making AHP method is combined to calculate weight of factors and to sort out the importance value. The results to some extent is explained operating time, failure probability and cognitive load in dispatching system, and provide a basis for improving team performance in further research.

## 2 Materials and Methods

This study used the CIT method for semi structured to obtain the communication skills factors and structured a "Communication skills index system for metro dispatcher" reference MBTI, SEGUE and LCSAS scales. Through the group decision-making AHP method to calculate each factor weight and get the importance sequence.

### 2.1 Critical Incident Technique (CIT)

20 Metro dispatchers were recruited as the participants, of whom, 8 from Line 1, 2 from Line 5, 13 from Line 4, and 3 from the airport line. All the participants interviewed were male, aged from 21 to 45, including the high-performance group and the general performance group. Among them, the number of dispatchers in the high-performance group was 12, who met the following criteria: ① The dispatchers with excellent performance appraisal results in the previous year or professional dispatchers who worked as acting dispatchers; ② The dispatchers have been engaged in dispatching work for over two years.

The critical incident technique (CIT) is to collect the critical incidents through interview, and to classify the text according to the content analysis [15]. CIT is a very effective method when it is necessary to study the structure of a concept, especially when it is difficult to include all variables in terms of reasoning and deduction [16]. Flanagan was the first to develop CIT in 1954, and he described it as a set of work analysis procedures to determine the key factors for the success of an American air force pilot [17]. In the process of CIT, the participants were to review the events that they considered critical. Based on the situation at the scene, the researcher finally found the tacit knowledge and skills used by the subjects [18].

In Myers Briggs Type Indicator (MBTI) [19], The Physician-Patient Communication Skills Scales (SEGUE) [20], Liverpool Brief Assessment System (LCSAS) [21] as a reference, according dispatcher's task analysis the "Interview Protocol of Metro Dispatcher" designed from three aspects: Interpersonal ability, Language application and External factors control. Adopt a semi-structured retrospective review in strict accordance with the CIT to require the subjects to state three complete safety critical incidents at work, including the following: "When did this incident occur? Would you describe the course of the event and what kind of task did you adopt? What is the importance of communication skill in a task? What difficulties did you encountered and how to overcome them when you were communicating? What are the possible causes of these difficulties?".

Interviews recorded the descriptions by tape, then compiled into written text. The researchers proofread the interview content, printed and gave each text number, coded by two people, A and B. The coders analyze the behavior events in the text, distinguishes the critical incidents from the text, and carries out formal classification. Finally, the same communication skill factors coded into one category, and the names, frequencies, average grade scores and the highest scores of each communication skill factor evaluated by each coder are calculated. The "Critical behavior" in the interview is the smallest unit of classification, which best preserves the characteristics of the event [22]. Therefore, in this study, we used the Critical behavior in the event description as the smallest classification unit. For example, "when the train enters the no power section, vacate a platform, and then I'll inform the train behind to the platform." A series of factors that may affect communication skills extracted by thematic analysis and content analysis [23].

Category Agreement (*CA*) and correlation coefficient were used as coding reliability evaluation index. *CA* refers to the proportion of communication skill factors identified by two coders when they are independently coded for the same interview data. Winter (2012) [24] gives the calculation method of *CA*:

$$CA = \frac{2S}{(T_1 + T_2)} \tag{1}$$

Where, $S$ indicates the number of the same codes encoded by two raters; $T_1$ and $T_2$ represent the number of codes encoded by the raters, respectively. $CA > 80\%$ is generally required.

## 2.2 Group Decision-Making AHP

Based on the results of CIT, a hierarchical structure model of "communication skill factors" was constructed, and the weight of each factor was determined by Group decision-making AHP. According to "communication skill factors of metro dispatcher", the result of CIT, a questionnaire on communication skill is constructed. The questionnaire is divided into three levels as Fig. 1: the Goal layer (A), the Criterion Layer

(B) and Subcriterion layer (C). The Goal layer is "Communication skill", that is, the decision problem. The Criteria Layer contain three dimensions, namely, Interpersonal skill, Language application and External factors control. The Subcriterion layer consist of the results of CIT. To edit items for each communication skill, adopt the 1–9 evaluation to judge the importance of each, 1 represent extremely unimportant, and 9 represent very important. The participants are 5 dispatchers work for more than 15 years.

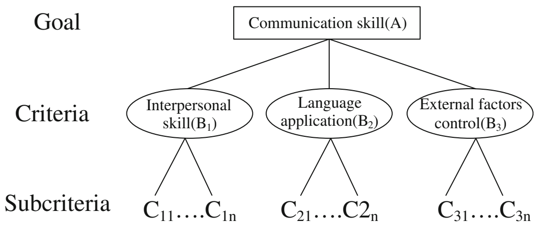


**Fig. 1.** Hierarchical structure of communication skill.

The analytic hierarchy process (AHP) was proposed by Saaty in 1970s [25], an operational research scientist from U.S. The principle of AHP is to decompose the complex problem into various factors, and then these factors are grouped into an orderly hierarchical structure according to the dominating relationship. Afterward, the relative importance in the hierarchy is determined by the comparison with expert judgment of each factors.

The basic requirement of AHP is the consistency of judgment matrix, but in actual operation, the difference of subjective evaluation of each expert often leads to the inconsistency of judgment matrix. Therefore, a novel method proposed by Shi (2014) [26] combines the "group decision" method with AHP to synthesize the opinions of all the experts. The method uses clustering analysis to give higher weights to the scores of most experts and construct a consensus matrix. Taking the consensus matrix as the basis for judging AHP, the method as follows:

Establishment of all experts to form a consensus matrix $S = (a_{ij})_{n \times n}$, determine the importance of $i$ relative to $j$ of $n$ factors as

$$S_{ij} = \left\{ \left[a_{ij}(1)\right]^{\lambda_1} \times \left[a_{ij}(2)\right]^{\lambda_2} \times \cdots \times \left[a_{ij}(n)\right]^{\lambda_m} \right\}^{1/(\lambda_1 + \lambda_2 + \cdots + \lambda_m)} \tag{2}$$

where $a_{ij}$ $(n)$ are the $n$ expert judgment matrix in row $i$ column $j$ elements.

The weight calculation of AHP and value of *R.I.* according to the literature [28]. When $C.R. < 0.1$, thought that the consistency of the judgment matrix is acceptable.

# 3 Result

## 3.1 The Word Frequency Analysis of CIT

The interview conducted from June 2 to July 7, 2017, at the Metro Dispatcher Center, where quiet, light conditions and adequate air in the environment were selected. A total of 20 dispatchers were recorded, totaling 9 h, 11 min and 25 s, and the transcribed text was 74517 words in length. Data preprocessing is divided into three segments: transcription, encoding, and document collation. First of all, the researchers input the interview record into the computer. After the content is collated, the text is collated into text data, and each text number is printed for coding. The *CA* = 88.91% shows good consistency of two coders.

A total of 60 critical incidents were collected, of which, 49 were positive events (81.7%) and 11 were regrettable events (18.3%). The subjects of 13 critical incidents were classified by coding process. The theme distribution of critical incidents is shown in Table 1. Thematic analysis of key events revealed that more critical incidents focused on Precise expression (19.8%), Time pressure management (14.1%), Information management (11.4%), and Initiative (10.6%).

**Table 1.** Analysis of CIT

| Category | Event theme | Frequency | Percentage |
|---|---|---|---|
| Interpersonal skills | Initiative | 24 | 10.6 |
| | Coordination | 18 | 7.9 |
| | Information management | 26 | 11.4 |
| | Overall awareness | 15 | 6.6 |
| Language application | Precise expression | 45 | 19.8 |
| | Avoid slip | 15 | 6.6 |
| | Avoid ambiguity | 14 | 6.2 |
| | Flexible expression | 8 | 3.5 |
| External factors control | Work load management | 9 | 4.0 |
| | Multi-tasks management | 8 | 3.5 |
| | Knowledge and information update | 6 | 2.6 |
| | Time pressure management | 32 | 14.1 |
| | Responsibility | 7 | 3.0 |
| Total | | 209 | 100 |

Notes: Since the event subject variable is set as a multiple response variable, the sum of the frequencies selected is greater than the total amount of the case.

### 3.1.1 Interpersonal Skill

The Interpersonal skill refers to the ability of individuals to deal with others' relationship with themselves. In this study, the results obtained through CIT are: Initiative (24), Coordination (18), Information management (26) and Overall awareness (15).

As the dispatchers said, if the information channel is too concentrated in one or a few persons in the disposal process, which may increase the workload of the person and cause the information blocking in the whole team. However, if the information is too dispersed in a team, it may lead to decision-making difficulties.

The individual difference may also cause the complexity of team communication. "Some people are not suitable to be a dispatcher. Willing to express is a basic criterion of one's personality. In the task of dispatchers, insufficiency of information expression or inaccurate expression often cause a critical human error." "Necessary informal communication will also eliminate the divergence in the work."

### 3.1.2 Language Application

Team communication mainly includes verbal communication and nonverbal communication (body language, written communication, etc.), and only verbal communication is considered in this study. The important purpose of verbal communication is information transfer, and the deviation of information transfer will bring about a series of negative effects. The result of a critical incident interview may include: Precise expression (45), Avoid slip (15), Avoid ambiguity (14), Flexible expression (8).

Respondent dispatchers mentioned the importance of precise expression for many times. "Precise expression can avoid slip and communication ambiguity, correctly transfer information." Spoken language is a multi-dimensional structure system constructed by many factors, such as psychology, cognition, symbol, semantics, syntax and culture, so it has the characteristics of diversity and complexity.

### 3.1.3 External Factors Control

Any communication behavior does not exist independently, and it will be subject to the impact of the part beyond the main part. These factors mainly include Work load management (9), Multi-tasks management (8), Knowledge and information update (6), Time pressure management (32), Responsibility (7).

Most of the subjects mentioned about the time pressure. Metro dispatching system is a typical safety demanding system. In the event of an accident, there will be high requirements for the time of task disposal, which may directly be related to the effect of task disposal. "We are pressed for time. When an incident is reported here (dispatching station), we should have a clear conception within 20 s to outline the event and make a scheme on how to deal with it." There are multiple forms of Responsibility. Face-to-face communication will be carried out in the dispatching team, communication with drivers by radio will be adopted and one-way communication with passengers by broadcasting will be used. Responsibility will affect the effect of communication under different intermediaries. In addition, a large number of single tasks and parallel tasks may generate a higher workload, and communication under high mental load is also one of the reasons for complex communication. The requirements for knowledge and information update also need to maintain a high level of awareness.

## 3.2 Weight Calculation Results and Importance Ranking for AHP

5 Copies of the metro dispatcher communication skill questionnaire were issued, and 5 questionnaires were collected, the recovery rate was 100%. Clustering results of experts are divided into two categories: $p_1$ is expert 1 and 5, $p_2$ is expert 2, 3 and 4. The inter categories weight is $\lambda_1 = 0.308$, and $\lambda_2 = 0.692$.

The consistency ratio calculated according to the formula (14). Criterion layer eigenvector $\lambda_{\max} = 3.000$, conformance ratio $C.R. = 0.002$. The weight ranking and Subcriterion layer consistency ratio as Table 2.

**Table 2.** Wight of communication skill

| Category | Weight | Communication skill factors | Internal weight | Total weight | Importance | $\lambda_{max}$ | *C.R.* |
|---|---|---|---|---|---|---|---|
| Interpersonal skills | 0.369 | Initiative | 0.079 | 0.029 | 10 | 4.221 | 0.083 |
| | | Coordination | 0.424 | 0.156 | 2 | | |
| | | Information management | 0.156 | 0.058 | 7 | | |
| | | Overall awareness | 0.341 | 0.126 | 3 | | |
| Language application | 0.354 | Precise expression | 0.490 | 0.173 | 1 | 4.238 | 0.089 |
| | | Avoid slip | 0.076 | 0.027 | 12 | | |
| | | Avoid ambiguity | 0.283 | 0.101 | 5 | | |
| | | Flexible expression | 0.151 | 0.053 | 8 | | |
| External factors control | 0.277 | Work load management | 0.105 | 0.029 | 10 | 5.367 | 0.082 |
| | | Multi-tasks management | 0.416 | 0.115 | 4 | | |
| | | Knowledge and information update | 0.108 | 0.030 | 9 | | |
| | | Time pressure management | 0.284 | 0.079 | 6 | | |
| | | Responsibility | 0.087 | 0.024 | 13 | | |

## 4 Discussion

Through the critical incident interviews, this study extracted 13 factors that affect the communication skill of metro dispatching crew, includes three categories: Interpersonal skills (n = 4), Language application (n = 4) and External factors control (n = 5).

Interpersonal skills refer to the ability of communication and cooperation between people. Cooperation tends to describe the awareness of interpersonal, and communication is the behavior of this awareness. The composition of the team is often characterized by diversity and heterogeneity, it is possible to cause communication problems when the individual lack of interpersonal skills. Team diversity refers to the different degree of team members in all aspects, and is a concept relative to homogeneity, also known as “team heterogeneity”, “team diversification”, “team diversity” and so on [27]. Jackson (1993) [28] considered diversity should include demographic diversity (age, gender, race, etc.), diversity of individual characteristics (personality, status, experience, style, etc.). Tsui (1999) [29] divided diversity into task-related diversity (functional knowledge, professional background, etc.) and relationship-related diversity (gender, age, experience, etc.). Withams (1998) [30] divided team diversity into five categories: tenure, background, race and ethnicity, age and gender. Guzzo (1992) [31] and Guzzo (1996) [32] considered the personality characteristics of team members as the main variables of team diversity. More than 60% of interviewed dispatchers mentioned that the team diversity may cause barriers to formal and informal communication. They believe that the greater the number of people involved in a team, the complexity of communication increased. At the same time, if the information is control in part of the members may lead to the failure of the whole communication network. Park (2011) [33] investigated the characteristics of information transfer structure of the main control operation team in the nuclear power station from three aspects, the network centrality, network connectivity and network density. In dense networks, the frequent exchange of information among the members may increase the complexity of communication. However, with the increase of information resources and the enhancement of information mobility, it can also enhance the efficiency of network operation and improve the performance of tasks under the action of individual initiative and coordination skill. Initiative is the impetus of communication awareness. It has been mentioned many times (n = 24) in CIT, and the weight coefficient is 0.029. The task of dispatchers is to organize the train operation according to schedule, these characteristics determine the dispatcher's leading position in the metro system, so the coordination skill have a strong influence for a dispatcher. The weight of coordination ability is 0.424, and the total weight is 0.156, ranking second. The importance of this skill can be explained from data. Krackhardt (2006) [34] proposed the concept of "organizational viscosity", pointing out that a little bit "viscous" but "not too viscous" network structure is suitable for rapid transfer of information, which means that a network of moderate density is the most ideal. The concentration of the network represents the centralization of power in a team, that is, the information transfer occurs only among a few members. There are two points of views at present: the concentration is negatively correlated with team performance, and the communication occurs among a few members, resulting in unsmooth information transfer [35]; from another point of view, decentralized network is easy to make information in a mess and may result in action incoordination [36]. Leenders (2003) [37] found that members maintaining these interactive relations in high density networks may disperse the time and effort necessary for creative activity, and the frequency of communication within the team has an inverted U-shaped relationship with the team performance. If the crew members have a high overall awareness, the communication network can be kept smooth. The weight of overall awareness is 0.126, which shows the third importance of all. There are few dispatchers mentioned the importance of integration of a team. Similarly, the controversy solving is the reflection of information management skill in a communication process.

The weight of language application is 0.354, which is located in the second position of all. Dispatchers are required to use standard phrases when carrying out their tasks, also called "standardized communication". 19.8% dispatchers mentioned the importance of precise expression, with the weight is 0.173, on the top of all. "Standardized communication" can enhance effective communication among team members, correctly and timely transfer critical information to reduce the occurrence of accidents [38, 39]. In medical care industry, standardized communication (SBAR) is widely used in ICU patient handover [40], operating room tour [41], and surgical anesthesia implementation [42] with its standardized, structured and concise characteristics to dramatically reduce the communication error rate, shorten the communication time, and improve the task performance. When emergencies occur, communication in dispatcher crew also needs a certain degree of improvisation. Therefore, flexible expression (weight coefficient 0.053) is also the skill of a dispatchers. Bao (2017) [43] examines the use of words, grammar and syntax from the readability of a text to reflect the quality of communication language. Therefore, not only to complete the "Dispatcher Technological procedure" strictly, but also enhance the skills of speech readability in the novice training, so as to avoid ambiguity and slip.

The metro is a critical safety system, and the environment also bring many external unreliable factors often cause obstacles to communication. The weight of External factors control was 0.277, at the third of all. When a sudden event is encountered, the transmission and exchange of information is required to be completed in a short time. As a result, many dispatchers (14.1%) mentioned the impact of time pressure management on communication effects, with a total weight of 0.079 at the fourth of all. Liu (2016) [44] believed that the task complexity generate time pressure has a significant impact on the team performance in the main control room of nuclear power station. Parallel tasks or sub-tasks raise an important challenge against the task implementers [45]. We can also think that the time pressure and the workload are two related factors. It is found that, the parallel tasks almost exist in all. The dispatchers need to synchronously perform the parallel tasks such as visual search and hardware control while implementing speech demand. The weight of parallel task management is 0.115, which is located at fourth of the whole and is very high in the level.

## 5 Conclusion

The CIT method is used to extract the factors that influence the communication skill of Metro dispatchers. The AHP method is used to weight all factors, and the importance ranking is carried out, which are include Interpersonal skill, Language application and External factors control. Further research is needed to seek the relatively important factors by using experimental and control variables. The related conclusions can be applied to the investigation of communication performance of dispatcher crew and the design of non-technical skills training programs.

Based on the results of CIT, a hierarchical structure model of "communication skill factors" was constructed, and the weight of each factor was determined by Group decision-making.

## 6 Ethical Approval

This study was approved by the Beijing Jiaotong University, School of Psychology ethics committee, China (approved June 2017).

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# Expert Elicitation Methodology in the Risk Analysis of an Industrial Machine

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**Abstract.** Calculation of the probability of occurrence of an accident involving an industrial machine such as a metal bending press requires knowledge of the failure rates. Specifically, what is needed are the failure rate of the protective device and, the failure rate associated with the human action consisting in having one's hands between the press dies while the operator is bending a part. The first data could, in principle be obtained from the manufacturer of the device. However, in reality, this data involves knowledge of the reliability of not only the protective device but also of the associated command circuitry. In reality, such data may be difficult to obtain. Also, many important statistics relating to human performance are not collected by workplaces. So, another way to obtain the data is through expert elicitation, that is consulting people knowledgeable with the problem at hand and asking them to estimate, based on their judgement, the probabilities or failure rates that are sought. This process is often used in the literature but is seldom described in detail. In this paper, expert elicitation is used and described in order to gather relevant data for the purpose of probability estimation. Thus, eight bending press operators in a large manufacturing plant, the health and safety coordinator as well as the workers' supervisor were solicited.

A questionnaire was handed to them consisting of a set of brief instructions followed by three questions which were provided with multiple possible qualitative probability estimates to choose from. In order to improve the quality of the probability estimates, the suggested probabilities were associated with typical accidental events which serve as a comparison basis for the participants. A general introduction was given by the author to the participants in a group meeting on the shop floor which consisted of presentation the research project, its purpose. The questions and the choice of answers were read and explained to the group. The questionnaire was then handed to them. The whole process took little time to complete. These estimates represent the experts' estimates of the probability of occurrence of the events in question, expressed in linguistic, qualitative terms. These estimates were translated in quantitative terms through fuzzy logic technique. More specifically, a scale composed of qualitative statements and their corresponding triangular fuzzy number was established with two main simple guiding principles in mind. Firstly, the scale should reflect


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the probability scales found in often-used safety standards. Secondly, the fuzzy triangular numbers should not overlap so that there is no need to invert any of their components as required by the rules of fuzzy number arithmetic.

**Keywords:** Expert elicitation · Industrial machines · Brake press safety

## 1 Introduction

Calculation of the probability of occurrence of an accident involving an industrial machine such as a metal bending press requires knowledge of the failure rates. The probability of occurrence P of the accident requires knowledge of the failure rates (expressed as fuzzy numbers). Specifically, what is needed are: the failure rate of the protective device and, the failure rate associated with the human action consisting in having one's hands between the press dies while the operator is bending a part. The first data could, in principle be obtained from the manufacturer of the device. However, in practice, this data may not necessarily exist. In the same manner, the number of times a press brake operator places his hands between the dies of a press is not a statistic that is collected by workplaces. So, another way to obtain the data is through expert elicitation, that is consulting people knowledgeable with the problem at hand and asking them to estimate, based on their judgement, the probabilities or failure rates that are sought.

## 2 Expert Elicitation

Expert elicitation can be defined as a structured process by which experts are consulted on a subject where there is insufficient knowledge or data [1]. It is widely used in fields such as public health [2], environmental health [3], in particular. Published risk assessments studies of industrial equipment's and processes such as oil and gas pipeline operation [4], chemical plants [5] and nuclear engineering systems [6], on the other hand, revert to expert's judgements for data gathering but this process is poorly described.

In this study, an effort is being made to apply expert elicitation in a structured manner.

The quality of the knowledge derived from experts depends on a number of factors [1, 3, 7].

Choice of experts. What constitutes an expert is not a clearly defined notion in the literature [8]. Should one consider scientists, professionals, managers, or field people? To answer these types of questions, the literature often adopts a broad definition of experts based on the experience, training and knowledge of the individuals [3].

Number of experts. The literature offers no specific advice on this issue. The number chosen seems to be dictated mostly by time/cost and availability constraints [3].

However according to a panel of expert elicitation practitioners, as reported in [1], at least six experts should be included; otherwise the robustness of the results might be doubted. The feeling of the practitioners was that beyond 12 experts (in one elicitation session), the benefit of including additional experts seem to diminish.

Elicitation process format. An elicitation session can be conducted individually in face-to-face interviews with a prepared questionnaire or in a group meeting. Surveys or questionnaires can be mailed to participants as well. Mailed-in surveys usually have low response rates [9]. Face-to-face interview is preferred as it allows for explanations [1] and for easier engagement on the part of the participants. On the other hand, the interviewer must be careful not to influence the participants.

Experts' biases. Research [1] has shown that people use various heuristics (learned rules or hard-coded by evolution) when judging uncertain information. Some of these ([10]) may introduce bias in the judging process that may affect the outcome. It has also been shown that individuals consistently overestimate the likelihood of events similar to those they have recently experienced (or read about) and underestimate the probabilities of less familiar events.

Reference [3] suggests five specific elements designed to address these issues and improve the accuracy of the elicitation process. First, the questionnaire used in the individual interview should include an introduction which explains the aim of the exercise and the methodology that will be followed. Second, specific baseline information should be included at the beginning of the process, so all the experts have a common knowledge of the issues considered. Third, technical terms and words with unclear or potentially confusing meanings must be avoided. Similarly, a plausible and specific scenario should always be given when experts have to estimate probabilities. Fourth, after giving an initial estimate, experts were required to think about one reason that could "make it wrong" (i.e., disconfirming information) and decide whether this would lead them to change their answer. Finally, and most importantly according to the authors, experts had to express their assessments of probability through simple and commonly used words (e.g., likely, high).

Once the experts' judgements gathered, they should be aggregated according to well-defined scheme. In risk assessment studies, such as the ones cited above on industrial systems, fuzzy numbers are often recommended for this purpose.

## 3 Case Study

Before presenting the expert elicitation process that was followed in this study, brake press operation will be consider. A press brake is a machine commonly found in the metal manufacturing industry. It is used to bend sheet metal in different shapes. A typical press brake is illustrated here (Fig. 1).

The machine is composed of two main structural components, a top beam mounted on a plate and a bottom table. These two parts are usually connected by two C-frames on each side of the machine. Dies are clamped on the top and bottom parts. Either the top or the bottom half of the press then closes in (via a hydraulically-powered mechanism) on the stationary part. The operator holds the piece-part and actuates the closing motion with a foot pedal, in most applications. A hazardous situation is thus created from the proximity of the workers hands to the press closing motion. A possible undesirable event (often called a hazardous event) in such a situation is then that the


**Fig. 1.** A Press brake

worker gets his hands caught between the closing dies (the hazardous zone of the machine).

Safety regulations and standards require that such machines be equipped with protective devices which either prevent entry of the operator in the hazardous zone or stop the hazardous motion when parts of the workers body are in the hazardous zone. The protective device often utilized with press brake takes the form of a light (laser) sensor beam which spans the length of the press and is mounted between the two dies. Such a device is shown in the above picture of a press brake (1 is the sensor beam and 2 refers to the emitting and receiving components of the device).

From this general description, a simple fault tree can be drawn (Fig. 2).

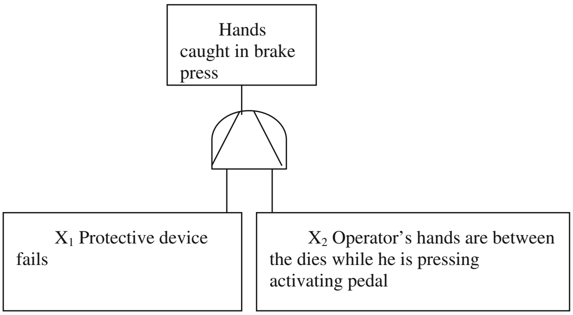


**Fig. 2.** Fault tree

In this example, the top event occurs if two events arise. One of these consists of the worker not withdrawing his hands from between the dies. In practice, such accidents have occurred due to contributing factors such as, for example, worker fatigue due to high job repetition leading to loss of concentration, stressful work situations, very noisy or hot and humid work environment. These factors would appear in the fault tree below event $X_2$.

The data needed for the probability calculation were obtained from participants who were solicited for this purpose. These were eight bending press operators in a large manufacturing plant. The health and safety coordinator as well as the workers' supervisor were also solicited.

A questionnaire was handed to them which consisted of a set of brief instructions followed by three questions which were provided with multiple possible answers to choose from. The three questions posed were the following:

1. A bending sequence requires the worker to turn off a protective device in order to complete a certain bend due to the complexity of the shape. The worker must then turn the protective device back on to resume the bending sequence. What is your estimate of the probability that a worker forgets turn the protective device back on?
2. What is your estimate of the probability that the protective device fails while the worker is bending a part?
3. What is the probability that a worker has his hands between the dies of the press while operating the machine?

The participants were given a choice of answers phrased in this manner:

(1) Very probable
(2) Probable
(3) Not too probable
(4) Improbable
(5) Very improbable

The questionnaire also contained examples corresponding to each of these probability statements to serve as comparison points.

A general introduction was given by the author to the participants in a group meeting on the shop floor which consisted of presentation the thesis and its purpose. The questions and the choice of answers were read to the group. The questionnaire was then handed to them. The whole process took little time to complete.

The following table summarizes the results (Fig. 3).

These data represent the experts' estimates of the probability of occurrence of the events in question, expressed in linguistic, qualitative terms. In order for us to calculate a probability, we need to first transform these qualitative statements into quantitative, fuzzy numbers. Then, these probabilities of failure can be used to obtain failure rates. Then, the fuzzy estimates must be aggregated in order to obtain one final fuzzy estimate. In the literature, various methods are used to accomplish this process. In [9], the linguistic estimates are related to fuzzy numbers expressed mathematically in the form of an equation representing a triangular fuzzy number. The final aggregated estimate is then a weighted average of these fuzzy numbers. In [11–14] translate the linguistic estimates of the experts into fuzzy numbers expressed as a triplet of numbers. The aggregation is then taken as a weighted average of the experts' opinions, the weighing method taking into account various factors.

In this work, we adopted a scale which combines the direct fuzzy number translation approach with a probability level from recognized safety standards such as [15].

| Participant # | Title/Function | Years of experience | Questions # | | |
|---|---|---|---|---|---|
| | | | | | |
| 1 | Brake Press Operator | 23 | Probable | Very improbable | Very improbable |
| 2 | Id. | 30 | Improbable | Very probable | Improbable |
| 3 | Id. | 37 | Very probable | Very improbable | Improbable |
| 4 | Id. | 36 | Probable | Very probable | Improbable |
| 5 | Id. | 28 | Probable | Probable | Improbable |
| 6 | Id. | 2,5 | Not to probable | Not too Improbable | Not too Probable |
| 7 | EHS Coordinator | 20 | Improbable | Very improbable | Improbable |
| 8 | Supervisor | 10 | Probable | Probable | Not too probable |

**Fig. 3.** Results from elicitation exercise

We translate the linguistic statements into fuzzy numbers by establishing a fuzzy scale which consists in associating a fuzzy number with each qualitative statement (Fig. 4):

| | |
|---|---|
| Very improbable | <0, 1, 10>x$10^{-6}$ |
| Improbable | <1, 5, 10> x$10^{-4}$ |
| Not too probable | <1, 5, 10> x$10^{-3}$ |
| Probable | <1, 5, 10> x$10^{-2}$ |
| Very probable | <1, 5, 10> x$10^{-1}$ |

**Fig. 4.** Linguistic terms and fuzzy numbers

The final aggregated fuzzy estimate of the probabilities is obtained by simply taking the average of the experts' estimates for each of the three components of the fuzzy numbers corresponding to the expert's linguistic probability estimate, as given in the scale. No weighing has been done for the following reasons. All workers have extensive experience except for one worker who had 2.5 years' experience. However, all workers get thorough technical training on all aspects of press brake operation. In addition, specific health and safety training sessions are periodically given to all workers. The company in question is a large, unionized, well-structured enterprise which performs extensive, on-going, health and safety monitoring and preventive activities.

Probability of occurrence can be related to failure rates using reliability theory and assuming that the failure rates are constant, the probability of occurrence of the accidental event considered in the constructed fault tree can then be calculated.

## 4 Conclusion

In this paper we presented an expert elicitation method for extracting the required daa needed for probability calculations related to an accidental event in an industrial machine such as a metal brake press. An expert elicitation exercise was conducted in a large manufacturing plant. Linguistic judgement of probabilities was obtained. The data was quantified and aggregated so that the final probability of occurence of an accidental event could be estimated.

**Acknowledgment.** The authors acknowledge financial support from ÉREST.

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# Improvement Plan of Fall Risk Assessment in Medical Institution

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**Abstract.** Today, due to the development of medical technology and the efforts of medical staff, safety at hospital is increasing. On the other hand, Japan's declining birthrate and an aging population will impede the improvement of the quality of medical services in the future. Therefore, it is desirable to introduce technology to replace people. In this research, we focus on patient falling and improve ways to assess risk of patients as a first step.

**Keywords:** Risk assessment · Medical safety · Fall risk

## 1 Introduction

In medical institutions such as hospitals, medical services are directly related to the lives of patients, and a great deal of attention is paid to safety activities. In the "Medical Safety Promotion Summary Report" submitted by the Ministry of Health, Labor and Welfare in April 2002, "Medical care should be performed with the highest priority on patient life-saving and health recovery, originally, under the trust relationship between patients and healthcare workers, and furthermore with confidence in medical care. (Somewhat) Currently, in medical policy in our country, it is urgent to raise public confidence in prevention of accidents and medical care. "In other words, in order to conduct a medical practice, a relationship of trust between the medical staff and the patient is indispensable. In hospitals that cannot be relieved, it is impossible to realize the "provision of medical services" that is the purpose of medical institutions. Therefore, it is an accident that it thinks that patients and families do not want to use the hospital, it can be said that it is an event to avoid.

There are two possible types of events that are thought to be "not wanted to be used": instantaneously occurring and those caused by explosion of chronically accumulated anxiety. The former mainly includes mistakes in diagnosis, mistakes in surgery, misdirected medicines and the like. These have the common point that the act itself directly harms the patient's life and health. In other words, it is easy for hospitals and patients to understand. So, hospitals want to prevent even if they inject costs. On the other hand, the latter takes place over a relatively long period of time, for example, hospitalized life. "Nurse is not kind hearted" "Although she needs help with toilet, she will not come soon", "Handrail is broken", etc. Although it does not harm directly the patient's life and health, it is easy to imagine that it turns into a feeling that


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dissatisfaction accumulated in the pellet does not want to use the hospital. These dissatisfactions cannot be observed immediately. Also, as it is not directly harmful, it is the current situation that it is likely to be postponed as a subject to be costly.

## 2 Problems in the Medical Field Due to Aging

Aging in Japan is progressing, and its impact extends to hospitals. Figure 1 shows the transition when hospitalized patients are viewed by age. The number of patients has not changed much. However, this breakdown indicates that the proportion of patients over 65 years of age is increasing year by year.

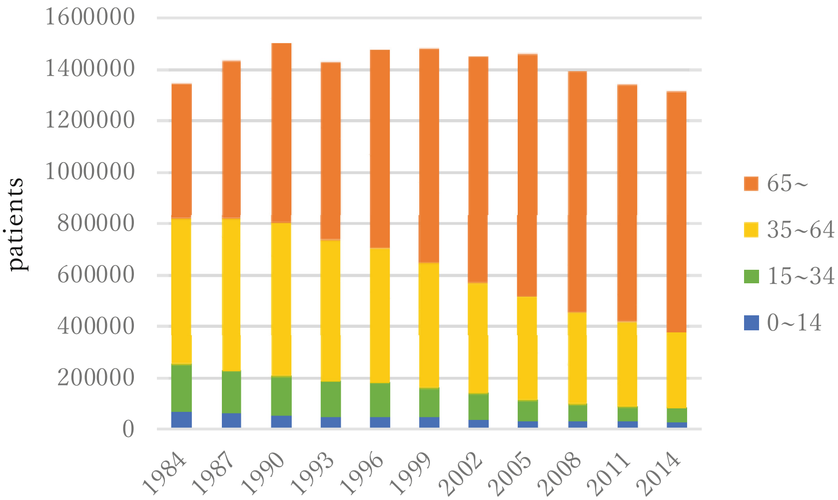


**Fig. 1.** Trends in hospitalized patients

On the other hand, the aging of nurses is progressing as well. Figure 2 shows the age-specific proportion of nurses. It can be seen that the number of people over the age of 50 years has increased from 90,000 to 210,000 in the decade from Heisei 24 to 24. In the decade from 2004 to 2014, you can see that the population over the age of 50 has increased from 90,000 to 210,000. In addition, it can be seen that the number of people under 30 is decreasing from 240 thousand to 220 thousand, and they are being fed up by the declining birthrate and aging population. Young people try to fill the hole as skilled people after the 50th come to retirement. However, because skills and experience differ between skilled and young people, it is considered impossible to completely cover the missing holes.

The competence required of nurses will rise, but rather than keeping up with the rise, the situation that it will be difficult to maintain the current situation is expected in the future. I think that patients and their families do not want to use a hospital when the quality of medical services declines. In order to avoid this accident, we have to

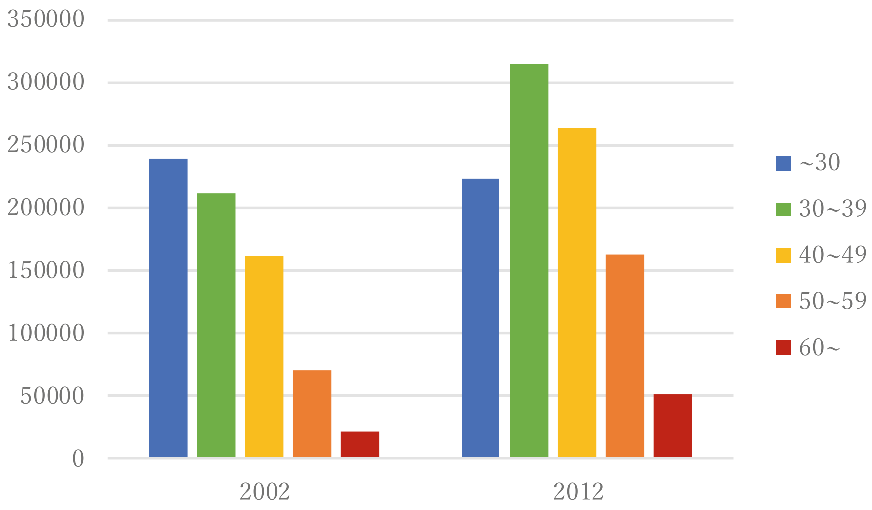


**Fig. 2.** Trends in number of nurses by age

introduce technology to replace people. However, it is not possible to invest in new technology because it tends to be postponed to put costs on the field of hospitalized living. Therefore, it can be said that it is necessary to devise measures to help nurses without spending money.

## 3 Purpose of the Study

It is a challenge to prevent accidents that you do not want to use hospitals for patients and their families without compromising the quality of medical services provided in hospitalized living. Among them, for both hospitals and patients, there are incidents that are relatively easy to understand that lead to the above accident. It is a fall of the patient. Events of falling can be observed, so by watching the frequency and degree, it is possible to worry the user. Therefore, it is necessary to advance safe and secure hospital making by preventing falling fall.

What is required of hospitals is to allow risks and to fulfill their mission within that range. It is very difficult to draw this acceptable risk. Because it is impossible to accurately grasp the magnitude of the risk. Therefore, the standard is not determined by people. Therefore, in this research, we focus on the falling fall, study the method of evaluating the magnitude of the risk, and aim to provide the risk in a visible way.

## 4 Information Necessary for Risk Assessment

The assessment sheet is the evaluation method recommended by the Japan Nursing Association. It is defined as “an evaluation table that allows one patient to comprehensively judge the risk of the patient” [1]. In the field, it is used as a means of grasping patients who are likely to fall down. Therefore, it is done for all patients when hospitalized.

In order to know the true risk, it is the easiest way to collect and analyze all the information of the world. However, it is impossible to cover everything. For example, it is impossible to record the psychological state of human beings one by one. Therefore, it can be said that it is the limit to predict true risk using incomplete data.

Among the information collected, there are mixed factors (promoting factors) that increase the possibility of a falling fall and, conversely, factors that lower the possibility of falling fall (suppressing factors). If both of them are complete, you can know the true risk, as I mentioned earlier, we cannot find out all the factors. Therefore, for example, if suppression factors are small in collected information, the possibility that promotion factors that are not so influential will be activated if they are supposed to be activated and give errors to the obtained prediction cannot be denied. Therefore, in order to estimate the risk closer to true, it is necessary to gather balance of suppression factors and promotion factors in a well-balanced manner and to eliminate factors that give errors to prediction results.

However, there is no definite criterion for this suppression factor and promotion factor. I cannot grasp why that factor gives a good impact on falling falls or a bad influence. Therefore, at this stage, it is assumed that all the factors described in the Incident Report and Assessment Sheet are promoting factors. Because both are pursuing the cause of falling fall, it seems that there is a high possibility of being a promoting factor.

If it is an extraction from the event that the promoting factor is gathered falling down, it can be considered that the method of gathering the suppressing factors can be extracted from the event “not falling down”. However, it is difficult to observe the phenomenon that “falls did not fall”. Because this event is lost in the usual life. In the event of a fall, it is the moment when the body falls on something, at the beginning, the body falls forward, the end is a moment when it completely collapses and stops. Therefore, it is easy to understand from where to where “falls” is the event. On the other hand, if you do not fall over, it is difficult to clearly distinguish its beginning and end. Therefore, it turns out that it is not easy to collect the “not fallen” event. Consider using the assessment sheet for another purpose. The assessment sheet originally judges the patient’s danger. Under this judgment, by observing whether the patient has fallen or failed to fall over a certain period of time, it may be possible to collect the two events “falling over” and “not falling down” at the same time Thought.

## 5 Improvement of Assessment Method

The primary purpose of the assessment sheet is to measure the risk of the patient and to grasp the patient with a high risk of falling. In this method, first of all, each patient is checked from the viewpoint of nine items: age, gender, past history, sensation, dysfunction, activity area, cognitive ability, medication, excretion. Characteristics are described in detail in each item, and those that apply to that feature are listed. These features are marked with points, and the total points are calculated when all the checks are completed. Patients whose total score is 0 to 5 are classified into level 1, patients with 6 to 15 points are at level 2, and patients with 16 or more points are classified as level 3. The hospital risk managers tend to implement countermeasures based on the risk level.

Based on this flow, we gathered data at a hospital using this assessment sheet. The data collected is the patient's assessment sheet and whether or not the patient had fallen over the course of a month. The results are shown below.

Figure 3 shows how many patients are in each class when the vertical axis is the risk level. Red shows patients who have fallen, and green shows patients who did not fall over. When comparing the number of people, we can see that there are only a few patients classified as Danger Level I and most of them are classified as Danger Level III. The cause is in the way of classifying the score and risk of the feature in the assessment sheet.

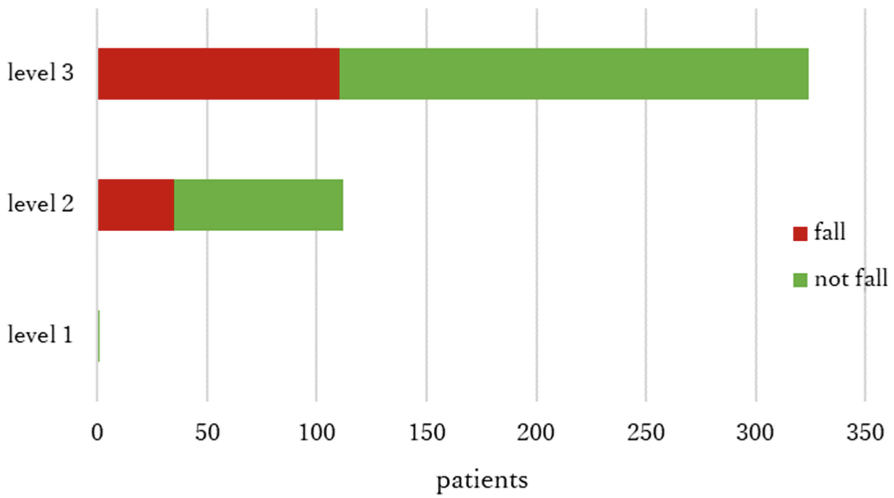


**Fig. 3.** Number of patients per risk

First of all, it is a score of features, but points are different for each feature. One point when it corresponds to sensation "vision impairment", and three points if it corresponds to "functional problems" with "problems in bone joints". This score is based on the fact that the nurse who made this assessment sheet relies on that sense reliably, so there is no basis. The way to divide the risk is also the same, and the reasoning is ambiguous here as well. Also, the interval between risks is small with respect to the score of features. For example, in the case of "a 70-year-old man, weakness of the legs and weakness of the muscle strength", the score is 6 points and it is classified as risk level II. Since it is an elderly person of 70 years old, it is inevitable that the muscle strength will be lowered. That is, nearly all male elderly will be classified as riskiness II or more. In addition to the above conditions, if it falls into three categories of cognitive ability it will be classified as risk III.

Figure 4 shows how many patients have fallen at each risk. The fall rate on the vertical axis shows the proportion of fallen patients to the number of people at each risk level. The fall rate for each degree of risk is greatly different between I and II, and there

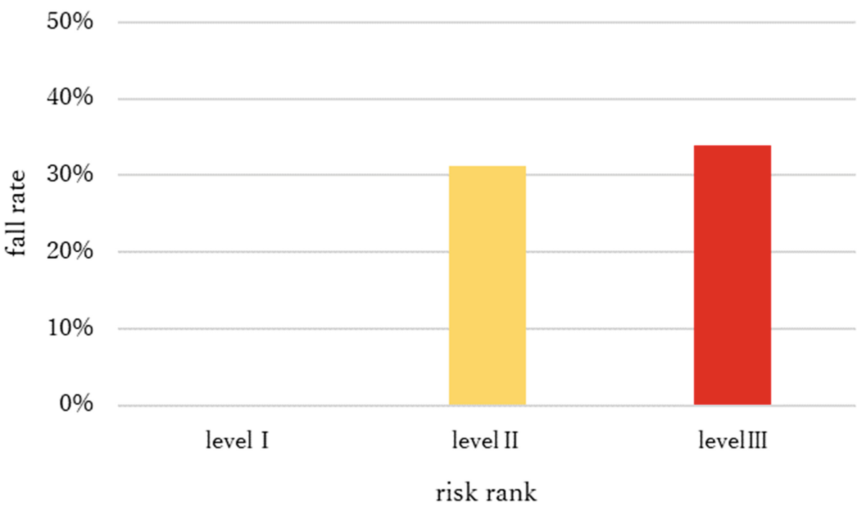


**Fig. 4.** Fall rate by risk rank

is little difference between II and III. From this also it can be seen that the classification of the degree of risk is not good.

There is no basis for classification of points of each feature and how to classify risks, and it is difficult to compare how the suppression factor and the promotion factor affect each other in this state. Therefore, first of all, we will consider how to gather information and how to process information gathered.

What the Nihon Nursing Association has decided within the assessment sheet is only 9 items of age to excretion, and each hospital leaves features that are its contents. For that reason, there are also grounds for question items and they are not listening. Therefore, it is necessary to review from the contents of the question items. Also, the purpose of proposing another way of using the assessment sheet is to find out factors that affect falling fall. There is a possibility that it will not be possible to grasp which item was checked as it is. Therefore, we also review how to ask questions.

Regarding question contents, we decided by consultation with a few nurses who are receiving training seminars for medical safety which the hospital is doing, among nurses actually working in hospitals. The results are shown below.

As a result of carefully examining the contents of the question, as shown in Table 1, we changed the form to listen to 30 items. Also, in order to grasp which item is selected, list the questions and make changes so that all answers can be answered in two ways, “applicable” or “not applicable”.

**Table 1.** Question item

| | |
|---|---|
| Age | Lower judgment |
| Sex | Restless behavior |
| Experience of falling | Declining memory |
| Syncope | Analgesic |
| Blurred vision | Anti Parkinson's agent |
| Hearing disorder | Antipsychotic |
| Paralysis | Diuretic |
| Abnormality in bone joint | Sleep stabilizer |
| Numbness | Enema laxative |
| Muscle weakness | chemical treatment |
| Use of wheelchair, cane, walker | Helping the toilet |
| Mobility assistance | Urinary frequency |
| Wobble | Urethral catheter |
| Bedridden | Incontinence |
| Confusion | Night toilet |
| Dementia | Long distance to the toilet |

## 6 Implementation of Improvement Plan

We conducted an experiment to actually operate the improvement devised in Chapter 5. First of all, in collecting samples using new question items, we cooperated with two hospitals (450 beds and 175 beds, respectively), collecting data on patients hospitalized there, totaling 1170 cases Samples were collected.

First of all, in order to judge whether the analysis result is valid or not, 570 out of 1170 cases collected were taken out and the remaining 600 cases were used for analysis.In conducting multiple regression analysis on 600 subjects, work to determine the number of explanatory variables is necessary. In the variable reduction method this time, items deleted that seemed to have little influence on falling were deleted in order. The following items are left.

- Use of wheelchair, cane, walker
- Wobble
- Lower judgment
- Declining memory
- Blurred vision
- Sleep stabilizer

This time we will proceed with these 6 items as factors. Next, because it is necessary to add each score, multiple regression analysis was carried out again and the respective coefficients were calculated. Based on the obtained results, we create a new mathematical model to calculate the risk score. As a point to note, adjustments were made to each coefficient so that the output risk score is represented by 0 to 100 points. Specifically, the proportion of each item to the total score of 6 items is used. We will assign 1 if it corresponds to each item, 0 if it does not, and that the higher the output risk score is, the more likely the patient will fall. As a result, the following model could be created.

$$\begin{aligned} \text{Risk score} = & \ 32 \times (\text{Use of wheelchair, cane, walker}) \\ & + 5 \times (\text{Wobble}) \\ & + 23 \times (\text{Lower judgment}) \\ & + 14 \times (\text{Declining memory}) \\ & + 10 \times (\text{Blurred vision}) \\ & + 16 \times (\text{Blurred vision}) \end{aligned} \quad (1)$$

Using the obtained mathematical model, we apply it to 570 cases that we kept to verify. This gives all patients a risk score. Next, we classify this patient by risk score, but first of all we do three classifications as well as existing assessment sheets. In addition, we adopted 0 to 33 points as risk criteria, 34 to 66 points as danger level II ‘, and 67 to 100 points as danger level III′ as the criteria for each class. The results are shown below (Fig. 5).

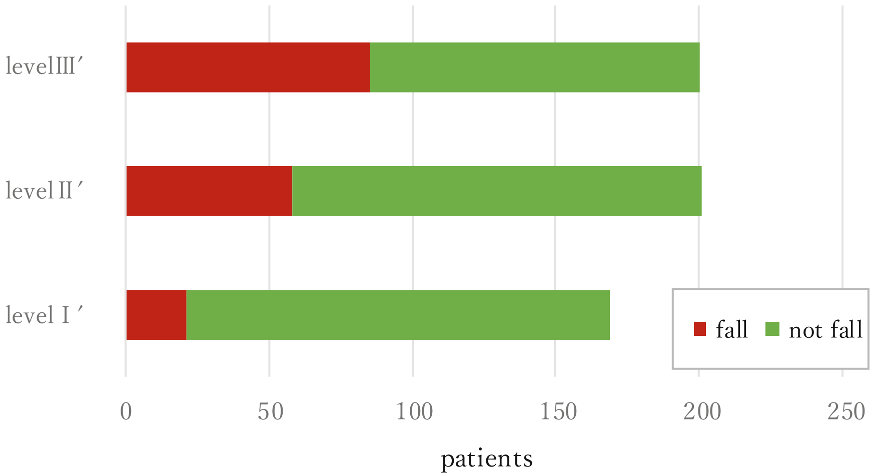


**Fig. 5.** Classification after improvement

Fig. 6 shows the difference in each falling rate when classes are divided by the new standard. The difference between classes is 17% between I ‘and II’, 14% between II ‘and III’. Compared to Fig. 6, we see that the disparities between classes are even.

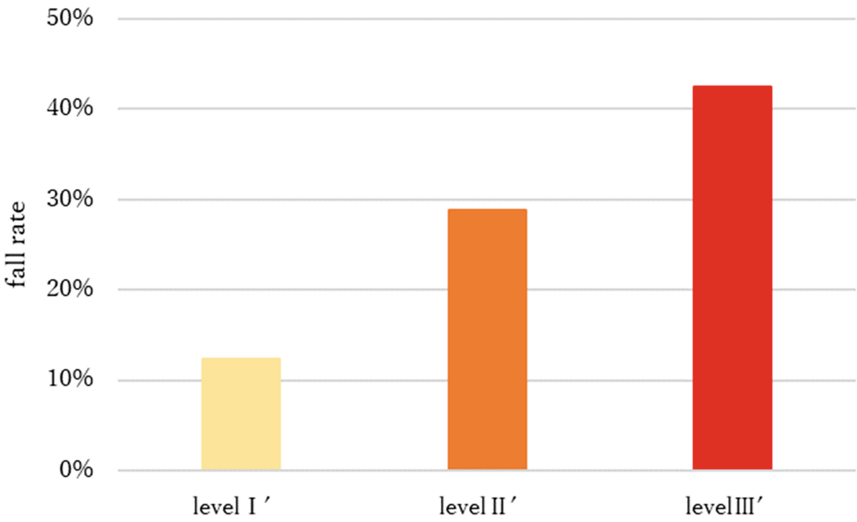


**Fig. 6.** Fall rate after improvement

## 7 Consideration

In this research, we have studied improvement proposals for risk assessment with reference to the existing assessment sheet. By improving the data collection method and processing method, it seems that it was possible to make it easier to compare the factor and the risk score of each item as to how the factor influences the fall. The next thing to do is to find out the two factors, a factor that promotes falling fall and a factor that suppresses falling fall, using this method as a cornerstone. By evaluating the patient from both the risk of falling and the ability not to overthrow, it is considered that the probability of falling of the patient can be judged comprehensively. It will also be necessary to verify the interaction between the suppression factor and the promoting factor.

If you try to do all these things, it is expected that the number of data collection will be enormous. In the future, in order to develop research on falling falls, it is necessary to overcome the information gathering barrier. One such example is a database that can collectively manage information on hospital facility data, patient charts, incident reports, and the like. It is important that the problems of how to gather information and what information should be gathered, these two develop together.

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# Proposal of Field-Oriented System to Medical Risk Management. Support of Risk Managers in Hospital

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**Abstract.** The activity of safety management in medical institutions has been positively performed for problems directly related to patients' lives. However, the Risk Manager in the hospital who performs the field-oriented safety management also have regularly works as field workers. Therefore, we made and commanded the new system which supports those Risk Managers in the hospital.

**Keywords:** Human factors · Safety management system

## 1 Introduction

The activity of safety management in medical institutions has been positively performed for problems directly related to patients' lives. In this management, preventive activities that prevent future accidents and incidents which may endanger patients' safety and confidences to doctors analyze briefly incidents happening in medical facilities and take measures. These activities are well known as necessaries. However, the Risk Manager in the hospital who performs the field-oriented safety management also have regularly works as field workers. Due to this lack of capacity of workers and time, problems that the hospital couldn't easily perform the preventive activities have been occurring recently.

Therefore, we made and commanded the new system which supports those Risk Managers in the hospital. In addition, another purpose of this system is users' safety improvement. Thus, the system would help medical risk management purposed patients' improving security.

First of all, we collect various data such as patients' chart and incident data, the data related to falling fall and finally map of the facilities from the medical treatment site. We created database that can manage these data all together, and then we can access and control these data easily rather than before. Through picking up necessary data from database and combining these, we think that it is capable for users to provide the medical safety service. Moreover, by combining the incident report and the data from employees, we predicted it could strengthen functions in terms of providing advice for staffs in the medical treatment site. We consider advice for impertinent schedule as an example. Because a worker lack in concentration, a worker works in haste, and a


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worker lacks in consideration a mistake occurs. We have to make a countermeasure for the error with time to spare.

We are planning to estimate and consider whether the system can collect useful data much more and more in the future. We hope that this plan will apply to each hospital in each Japanese prefecture.

This system will diminish the burden of the Risk Manager who was regarded that it is hard to perform safety management positively in field and is expected to lead further revitalization of medical safety as a whole activity in medical institutions. In addition to these tools, more tools relating to other factors can be incorporated to further enhance the comprehensive support system.

# 2 Methods

## 2.1 Problems in the Medical Data

I study Humanfactors which is the study to improve the quality of normal work. In medical institutions, I think that the most effective mean for improving the quality of normal work is collecting the various data. The activity of safety management is not activity that takes measures. If we will collect and share the various data can take measures, we can improve the quality of normal work. As a result, we improve an act that leads anxiety about the uses, the services and the facilities. Also the user and family of them build the trust and aim for organization to be evaluated from the local community. To make the user get the brand of the security and safety is the Fundamentals of growth strategy, we work on the activity of safety management.

In this study, we collect the various data and consider the system which provide the user relief and build the trust from the local community. In medical institutions, there are the Enormous data. For example, it is the incident data, Electronic medical records, employee data and facility data and so. However, as the present situation, incident reports are used for accident countermeasures, electronic medical record for customer information, employee data for education and personnel arrangement, and facility environment data for refurbishment of facilities only.

Although there is information like this, we can't make use of it. I thought that we should stop the vertical allocation of information and consider how to utilize information more. For example, when considering the story of falling down, we used incident report so far, but by displaying the occurrence place of the incident from the facility environment data as an image, we can omit description by word. By utilizing various kinds of information in this manner, the range is broader than the current medical safety. By thinking of this information sharing at many hospitals, I think that it is possible to find similar realities of hospitals, cooperate and to activate hospitals.

## 2.2 Advice Data

Advice data is information on incident occurrence factors from about 1000 incident reports in group hospitals centering on the Kanto area, important words from various literatures such as expert opinion and medical, nursing and ergonomics I cited it as "advice", and made advice data of 61 items last fiscal year.

As an expected effect of the advice data collection, it is possible to analyze factors in a short time, so there is an advantage that scientifically based feedback can be performed. It is thought that efficient and effective countermeasures and work improvement are carried out, the effect of submitting incident report can be felt, and as a result, safety activities will be positively carried out at the work site. There is also the possibility of standardization of guidance level of administrator of site/organization, and it is expected that citizen will be given a trusted brand as a hospital organization.

Items of existing advice data are classified into five categories: "Major factors included in Incident Report", "About work environment", "About work content" "About work transmission" "About management system" "About work environment" Has been done. Regarding the main factors, it analyzed about 1000 incident reports within a medical corporation, and it was a relatively frequent item behind it.

Provide advice data for individuals and organizations for each item, give advice based on the party and the reporter who caused the incident, and provide grounds for advice on the management of the organization to the organization. And by adding a column for reference, experts and other comments chewed up ideas so that specific content and meaning can be understood (Fig. 1).

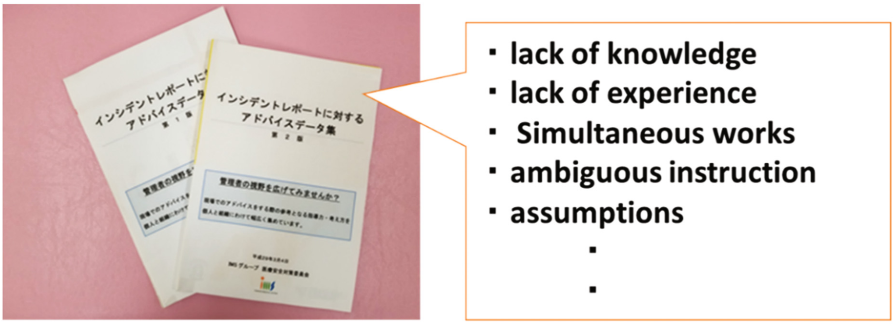


**Fig. 1.** Advice data

As a study of advice data, we focused on what is happening due to several factors, not incidents consisting of one factor. In the existing advice data, one advice data was extracted for one factor. However, if a plurality of factors is involved, it becomes huge advice data and it becomes a form not suitable for the site. Therefore, by extracting the background of the factor, major factors, indirect factors, potential factors, etc. from the advice data sentence and classifying the countermeasure, it is easy for the person who is fed back to understand, outputting outstanding advice We aimed to build a system that outputs advice involving multiple factors, thinking that it could not be done.

It is a method of extracting a system that can give examples of countermeasures to be derived from the background of factors from the advice data collection and connecting to countermeasures.

This is based on the experience of healthcare workers actually working in hospitals. Medical care workers are reading the advice data mentioned above, and words in advice data came up at the time of guidance to subordinates. Factors of advice made subordinates and factors in the advice data were different when reading advice data later. However, keywords in that were extracted and became one advice.

## 3 Discussion

The next figure shows the new medical safety system (Fig. 2).

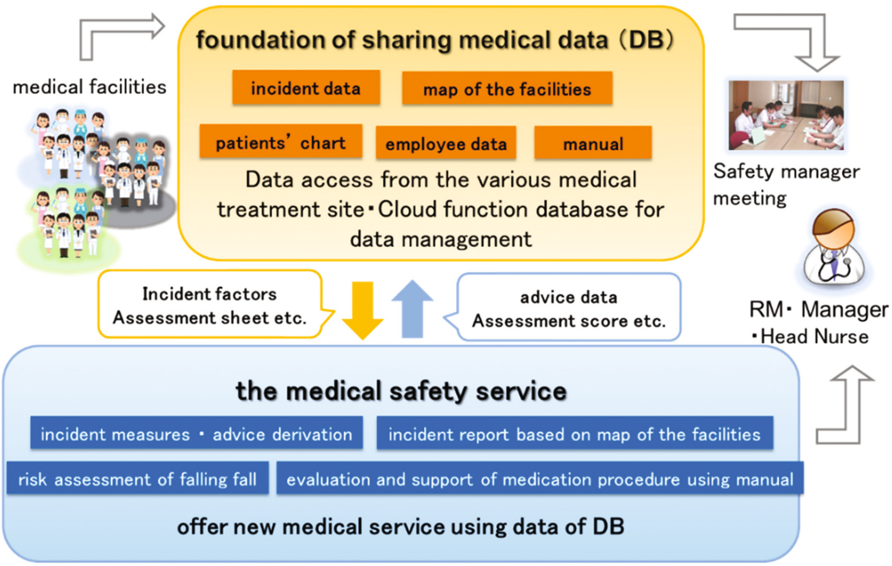


**Fig. 2.** The new medical safety system

We use data such as incident report, hospital floor map, advice data and so on. By using the incident report and the floor map, aggregate points where fall accidents occur frequently for each floor in the past, and output what is displayed on the floor map.

As a conclusion of this research, we will discuss about the study of "medical safety system" which was the research purpose, the future task of the creation, the prospect of research.

First of all, regarding the consideration of purpose. By considering existing data advice data, data on falling falls, and how to utilize medication data, we believe that medical safety systems can be put into the spot immediately. To that end, considering the construction of a medical safety system, it is possible to use the data immediately at the work site by considering the method of utilizing data in various ways in parallel.

Next, with regard to problems and tasks. It is expected that it will take some time for data to come out as we are in the midst of exploring which data is handled and which data is to be collected and the utilization of each data. In utilizing data, it is under consideration how long it will take to handle each data on what site.

Regarding advice data, since the extraction method of advice involving multiple factors is still in the concept stage, we will consider other concepts and extract advice of incidents of multiple factors, so we want to make it possible to lead to on-site support.

Regarding the falling fall data, since there are many undecided parts as to how to supplement the technology part, which tool to use and what kind of statistical data to use, consider it there next year I will go.

## 4 Conclusions

By utilizing various existing data in this manner, there is a possibility that many services can be provided. I would like to increase the quality of medical safety by utilizing a lot of data, reduce the burden of risk managers, and aim for medical safety of on-site support according to the workplace.

This system will diminish the burden of the Risk Manager who was regarded that it is hard to perform safety management positively in field and is expected to lead further revitalization of medical safety as a whole activity in medical institutions. In addition to these tools, more tools relating to other factors can be incorporated to further enhance the comprehensive support system.

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# Application of Fuzzy Evaluation Methods on Safety Management of Industrial Enterprise

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**Abstract.** The safety evaluation index system for safety management was established according to the current condition and problems of the safety management in the industrial enterprise, and by taking behavior-based safety theory as the framework. Twenty-seven measuring indices were selected. A petrochemical enterprise in Shan Dong province of China was first selected as a demonstrative research object, then field investigation, questionnaire survey and interviews were carried out in this enterprise, and finally the safety management evaluation of the enterprise was conducted by using behavior-based safety theory and the fuzzy comprehensive evaluation method.

**Keywords:** Safety management · Behavior-based safety theory
The fuzzy comprehensive evaluation method

## 1 Introduction

In recent years, more and more accidents occurred in industrial enterprises. Issues in safety management are an important cause for these issues. Safety management evaluating is the foundation and basis of safety management for industrial enterprises, however, traditional safety evaluating methods, many of which depend on the qualitative conclusion from the experience of some experts and safety management staff, is not only short of scientific basis, but also with great limitations in their application. At present, the commonly used methods of enterprise safety evaluation include analytic hierarchy process, risk index evaluation, cluster analysis, grey evaluation, etc. Analytic hierarchy process (AHP) is a combination of quantitative and qualitative method, which can simulate the process of human decision thinking. However, when the judgment matrix does not have consistency, the elements of the judgement matrix need to be adjusted, it has to be repeated through several adjustments and tests. The grey evaluation method is suitable for the loss of some data, but the subjectivity of the


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evaluation is relatively strong. Other methods of evaluation use less interdisciplinary knowledge, more subjective, and excessive reliance on expert experience.

The main direction of enterprise safety evaluation is factory equipment, rewards and punishment standards, rules and regulations, management methods, etc. In addition to the harm caused by natural disasters and engineering equipment design, installation, debugging and other errors, caused by the unsafe behavior of casualties [1] and disaster be too numerous to enumerate. BBS is the systematic application of psychological research on human behavior to the problems of safety (Cooper 1994). Heinrich (1959) estimated that 85% of accidents can be attributed to unsafe acts. Blackmon and Gramopadhye (1995) stated that 98% of all accidents are caused by unsafe behavior. HSE (2002) revealed that 80–90% of all work-place accidents and incidents are attributed to unsafe behaviors. With the development of science and technology and the improvement of production technology, the enterprise has made great progress in the realization of security [2]. There are many factors affecting the security situation of enterprises, and there are uncertainties and fuzziness among each other. Therefore, when the enterprise is evaluated, it is necessary to take a comprehensive consideration of several related factors. Enterprise security is a fuzzy problem in many cases. The occurrence of enterprise safety accidents is uncertain, and the factors and indexes of enterprise safety evaluation are also fuzzy. For example, people's attention, psychological quality, fatigue degree of working hours and even the evaluation result also have certain fuzziness [5]. Therefore, the fuzzy mathematical theory has been introduced to overcome the limitations of the analytic hierarchy process and the subjectivity of human thinking, thus forming a fuzzy analytic hierarchy process.

The results show that the evaluation model is suitable for the industrial enterprises safety management evaluation [3], and also provides a new idea for other enterprises to make safety management evaluation. Finally, the promotion counter measures are proposed for the petrochemical enterprise from safety management in 5 levels based on the evaluation results [4]. Through such a method, it can provide reference for the government departments and the enterprise administrators to improve the safety management of the industrial enterprises.

## 2 Fuzzy Evaluation Method

### 2.1 Evaluation Factor Sets

$$U = \{u_1, u_2 \ldots, u_n\}$$

There are n evaluation indexes, indicating that the object to be evaluated will be judged and described [8].

### 2.2 The Establishment of Evaluation Result Sets

$$V = \{v_1, v_2 \ldots, v_n\}$$

The safety evaluation index system for safety management can be divided into five grades: very good, relatively good, general, not good, worst. Thus, the evaluation result sets can be expressed as below:

$v_1$ –very good $v_2$ –relatively good $v_3$ –general $v_4$ –not good $v_5$- worst

### 2.3 Determining the Weight of Indexes Using AHP Method

The analytic hierarchy process (AHP) is a famous multi-criteria decision-making method developed by Thomas L. Saaty, a renowned American operational research expert, in the 1970s. AHP combines qualitative and quantitative analysis and could solve complicated multi-factor problems. Therefore, this paper adopts the analytic hierarchy process to construct the enterprise security situation system.

(1) Structural hierarchy model
The evaluation index system of petrochemical plants security situation can be divided to three layers: target layer, criterion layer and scheme layer.
(2) Build judgment matrix of pairing comparison.

The method of analytic hierarchy process(AHP) is used to seek the weights of various factors. Evaluation indexes in the same factor set are pairwise compared by panel of experts for their importance to the upper criterion or target based on the 1–9 scale in Table 1 in order to establish the judgement matrix of the factor set [8].

**Table 1.** Table for the relative importance values of various factors.

| Scale | Meaning |
|---|---|
| 1 | The pth factor and the qth factor are of equal importance |
| 3 | The pth factor is a little important than the qth factor |
| 5 | The pth factor is more important than the qth factor |
| 7 | The pth factor is much more important than the qth factor |
| 9 | The pth factor is absolutely much more important than the qth factor |
| 2, 4, 6, 8 | The comparative result of the pth factor and the qth factor for their importance is between two adjacent scales |
| $\frac{1}{2}, \cdots, \frac{1}{9}$ | The comparative results of the pth factor and the qth factor for their importance is the reciprocal of the above scales |

The relative importance values of $u_{\mathrm{i}}$ to $u_{\mathrm{j}}$ are expressed by $u_{\mathrm{ij}}$. The judgment matrix T is established.

$$T = \begin{pmatrix} C_{11} & C_{12} & \cdots & C_{1n} \\ C_{21} & C_{22} & \cdots & C_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ C_{m1} & C_{m2} & \cdots & C_{mm} \end{pmatrix}$$

(3) The weight calculation procedure is as follows:

1. The sum of each column of the judgement matrix is calculated

$$M_i = \sum_{j=1}^{n} a_i (i = 1, 2, \ldots n)$$

2. Each colum of the judgment matrix can be normalized

$$W_{ij} = \frac{a_{ij}}{M_i} (i = 1, 2, \ldots n, j = 1, 2, \ldots n)$$

3. The average of each row of the judgment matrix is calculated $\bar{w}_i$:

$$\bar{w}_i = \frac{W_{ij}}{\sum_{j=1}^{n} W_{ij}}$$

$\bar{w}_i$ is the weight of each index.

4. Solving maximum eigenvalues of judgment matrix in the following formula:

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{(BW)_i}{nW_i}$$

5. Calculate consistency index:

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$

Test Testing randomness and consistency of judgment matrix, to determine whether the eigenvectors are reasonable, the empirical formula of test is:

$$CR = \frac{CI}{RI}$$

Among the formula, CR is the random consistency ratio of the judgment matrix; CI is the consistency index of the judgment matrix.

RI is average random consistency index of judgment matrix. when the judgment matrix has complete consistency, CI = 0; When CR < 0.10, it is considered that judgment matrix is with satisfactory consistency. Otherwise the judgment matrix needs to be re-adjusted.

### 2.4 Single Factor Evaluation, Fuzzy Relation Matrix R

Judging by a single factor and determining the membership degree of the evaluation object to the element, it is called the single factor fuzzy evaluation. It is necessary to establish a fuzzy relation matrix R for single factor evaluation.

$$R = \begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{pmatrix}$$

### 2.5 Comprehensive Fuzzy Evaluation

The weight set A and fuzzy relation matrix R are obtained by analytic hierarchy process, and a comprehensive risk evaluation model is established.

$$B = A \bullet R = (a_1, a_2, \cdots a_m) \begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{pmatrix} = (b_1, \quad b_2, \quad \cdots, \quad b_n)$$

## 3 Empirical Analysis

There are certain dangers in the production process of the petrochemical plant. In the production process, there are categories of casualty accidents: object attack, vehicle injury, mechanical injury, electric shock, drowning, burning, high altitude depravity, poisoning and asphyxia, and so on. There are sintering, coking, mine, refractory, heat supply, gas supply, gas, power supply and other auxiliary production on each process [7]. Casualty accident reasons include: the defects of safety facilities, poor working environment, lack of personal protective equipment, safety operation regulation is not perfect, in violation of labor discipline, labor organization is not reasonable, safety education and training is not enough, the lack of knowledge of safe operation, etc.

### 3.1 Model Establishment of Fuzzy Comprehensive Evaluation

Based on analyzing the petrochemical plants safety status and investigating the employees as well as following the BBS theory and in the ways of man- machine-environment system analysis [6], There are five first-grade evaluation indicators and twenty second-grade evaluation indicators included in this study [9, 10]. This can be seen in Table 2.

**Table 2.** Evaluation index set of the petrochemical plants security situation system

| | Factor subset | | Factor |
|---|---|---|---|
| $U_1$ | Psychological factors of employees and managers | $u_{11}$ | The degree of fatigue of individual working hours |
| | | $u_{12}$ | The attention of individual working hours |
| | | $u_{13}$ | Personal psychological quality |
| | | $u_{14}$ | The degree of identification of safe operation production |
| $U_2$ | Operating equipment factors | $u_{21}$ | Capital investment in safety production |
| | | $u_{22}$ | Wear degree of production equipment |
| | | $u_{23}$ | Proficiency in safe operation skills |
| | | $u_{24}$ | The degree of perfection of safety regulations |
| $U_3$ | Management factors | $u_{31}$ | Perfection of safety production plan |
| | | $u_{32}$ | Rewards and punishments for safety production |
| | | $u_{33}$ | The importance of leadership to safety production |
| | | $u_{34}$ | Enterprise safety supervision |
| $U_4$ | Working environmental factors | $u_{41}$ | The performance of the workers in the daily safety production |
| | | $u_{42}$ | The comfort of daily work |
| | | $u_{43}$ | The strong cultural atmosphere of the enterprise |
| | | $u_{44}$ | Frequency and strength of enterprise safety training |
| $U_5$ | Employee factors | $u_{51}$ | Personal health |
| | | $u_{52}$ | The degree of personal experience |
| | | $u_{53}$ | The degree of understanding of job risk and hidden danger |
| | | $u_{54}$ | Awareness of safety rules and regulations |

## 3.2 Weight Calculation

The evaluation index weights are obtained by Analytic Hierarchy Process as shown in Table 3.

## 3.3 Single Factor Evaluation Matrix

Making a comprehensive assessment by using five-level division method, that is very important, important, general unimportant and no influence, the worst in five grades [11]. Additionally, twenty-three Chinese individuals, including manager, academics, and staff members, were invited to evaluate the petrochemical plants security situation, Statistical evaluation results as shown in Table 4.

**Table 3.** Evaluation index weight form.

| First grade indexes | | Second grade indexes | |
|---|---|---|---|
| Code | Weight | Code | Weight |
| $U_1$ | 0.1360 | $u_{11}$ | 0.5148 |
| | | $u_{12}$ | 0.1452 |
| | | $u_{13}$ | 0.0735 |
| | | $u_{14}$ | 0.2665 |
| $U_2$ | 0.1721 | $u_{21}$ | 0.2927 |
| | | $u_{22}$ | 0.0734 |
| | | $u_{23}$ | 0.4787 |
| | | $u_{24}$ | 0.1552 |
| $U_3$ | 0.3712 | $u_{31}$ | 0.2926 |
| | | $u_{32}$ | 0.1070 |
| | | $u_{33}$ | 0.4155 |
| | | $u_{34}$ | 0.1849 |
| $U_4$ | 0.0900 | $u_{41}$ | 0.4853 |
| | | $u_{42}$ | 0.0833 |
| | | $u_{43}$ | 0.2750 |
| | | $u_{44}$ | 0.1564 |
| $U_5$ | 0.2308 | $u_{51}$ | 0.1545 |
| | | $u_{52}$ | 0.4434 |
| | | $u_{53}$ | 0.2798 |
| | | $u_{54}$ | 0.1223 |

**Table 4.** Index evaluation form.

| Evaluation indicator number | Very good | Relatively good | General | Not good | Worst |
|---|---|---|---|---|---|
| $u_{11}$ | 5 | 12 | 6 | 0 | 0 |
| $u_{12}$ | 7 | 7 | 9 | 0 | 0 |
| $u_{13}$ | 7 | 9 | 7 | 0 | 0 |
| $u_{14}$ | 8 | 10 | 5 | 0 | 0 |
| $u_{21}$ | 8 | 11 | 4 | 0 | 0 |
| $u_{22}$ | 3 | 11 | 8 | 1 | 0 |
| $u_{23}$ | 5 | 10 | 7 | 1 | 0 |
| $u_{24}$ | 6 | 14 | 3 | 0 | 0 |
| $u_{31}$ | 6 | 13 | 2 | 2 | 0 |
| $u_{32}$ | 12 | 11 | 0 | 0 | 0 |
| $u_{33}$ | 4 | 15 | 3 | 1 | 0 |
| $u_{34}$ | 2 | 14 | 6 | 1 | 0 |
| $u_{41}$ | 2 | 16 | 5 | 0 | 0 |
| $u_{42}$ | 5 | 13 | 4 | 1 | 0 |

(*continued*)

**Table 4.** (*continued*)

| Evaluation indicator number | Very good | Relatively good | General | Not good | Worst |
|---|---|---|---|---|---|
| $u_{43}$ | 9 | 9 | 2 | 3 | 0 |
| $u_{44}$ | 9 | 11 | 2 | 1 | 0 |
| $u_{51}$ | 9 | 11 | 4 | 0 | 0 |
| $u_{52}$ | 8 | 13 | 2 | 0 | 0 |
| $u_{53}$ | 8 | 13 | 1 | 1 | 0 |
| $u_{54}$ | 7 | 11 | 4 | 1 | 0 |

### 3.4 Fuzzy Comprehensive Evaluation

(1) First order fuzzy comprehensive evaluation

First-Grade indicator fuzzy comprehensive evaluation of the petrochemical plants security situation as follow:

$$B_1 = A_1 \circ R_1$$
$$= (0.5148, 0.1452, 0.0735, 0.2665) \bullet \begin{bmatrix} 0.217 & 0.522 & 0.261 & 0 & 0 \\ 0.304 & 0.304 & 0.392 & 0 & 0 \\ 0.304 & 0.392 & 0.304 & 0 & 0 \\ 0.348 & 0.435 & 0.217 & 0 & 0 \end{bmatrix}$$

In which $A_1$ is weight of factors psychological factors of employees and managers, $R_1$ is first order evaluation matrix of psychological factors of employees and managers subset. Similarly, first fuzzy comprehensive evaluation of other factor subsets $B_2$, $B_3$, $B_4$, $B_5$ are obtained.

$$B_2 = (0.2558,\ 0.4777,\ 0.2422,\ 0.0243,\ 0)$$
$$B_3 = (0.2206,\ 0.6000,\ 0.1277,\ 0.0519,\ 0)$$
$$B_4 = (0.2294,\ 0.5674,\ 0.1573,\ 0.0463,\ 0)$$
$$B_5 = (0.3494,\ 0.5343,\ 0.0991,\ 0.0177,\ 0)$$

(2) Second order fuzzy comprehensive evaluation

$$B = A \circ R = (a_1, a_2, a_3, a_4, a_5) \circ \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = (0.1360,\ 0.1721,\ 0.3712,\ 0.0900,\ 0.2308) \circ$$
$$\begin{bmatrix} 0.2709, & 0.4576, & 0.2715, & 0, & 0 \\ 0.2558, & 0.4777, & 0.2422, & 0.0243, & 0 \\ 0.2206, & 0.6000, & 0.1277, & 0.0519, & 0 \\ 0.2294, & 0.5674, & 0.1573, & 0.0463, & 0 \\ 0.3494, & 0.5343, & 0.0991, & 0.0177, & 0 \end{bmatrix} = (0.2640,\ 0.5415,\ 0.1630,\ 0.0317,\ 0)$$

According to the comprehensive evaluation result, the petrochemical plants in China achieves a 0.2640 probability of very good security situation, a 0.5415 probability of relatively good, a 0.1630 probability of general, a 0.0317 probability of not good, and a 0 probability of worst. According to the maximum membership degree [7], the final result is that the petrochemical plants security situation is good.

## 4 Conclusion

The process of evaluating safety of petrochemical plants is made difficult by influential factors that are intangible, dynamic or man-made. Fuzzy sets can quantitatively describe these uncertain factors, therefore we introduced the theory of fuzzy mathematics for this application [12].

First, the hierarchy structure evaluation index system of petrochemical plants is established from the point of view of BBS theory, complex system theory and system engineering thought. The analytic hierarchy process and group decision method are used to determine the weight of the indicators at all levels, and the subjective influence of the experts is reduced. Secondly, the fuzzy comprehensive evaluation method was applied to the comprehensive evaluation of the safety production status of the plants and proved having feasible outcomes. The evaluation results are in line with the operation status of the enterprise. According to the evaluation value of various safety factors, the plants can put forward the Countermeasures of potential risk.

Because of the complexity and diversity of the safety evaluation, the method of safety evaluation for the petrochemical enterprise is not limited to this kind of method proposed in this paper. Only a variety of methods can be used to evaluate the petrochemical enterprises effectively and reduce the occurrence of dangerous accidents. It has a certain guiding significance for the safety production of the industrial enterprises.

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# Improvement of Safety Culture in Industry: A Systematic Review

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**Abstract.** This article aims to explore and analyze the evidences of the studies about SC improvement in the industrial field. A bibliographic search was made at different databases using the terms "Safety Culture" and "Improvement". Following the exclusion of the duplicates and applying the inclusion criteria, thirteen articles were reviewed by the authors, which allowed to assess mainly common themes to summarize the main conclusions. This review shows that communication is a key element for developing SC, and also that the fear of punishment and the difficulties in managing a reporting system are the main difficulties to improve it. To outline, this systematic review showed that despite a diversity of conceptions and practices related to the improvement of the Safety Culture, it is possible to identify some common elements. However, further research should be developed to deepen the knowledge about the topics discussed in this paper.

**Keywords:** Safety culture · Industry · Improvement · Systematic review

## 1 Introduction

According to Van Nunen *et al.* [1], studies made about Safety Culture (SC) are recent, and despite many efforts to develop the models and theories that the SC field needed, there is not yet any consensus about the definition of his content, or on the causes and consequences related to it [2]. In order to overcome this gap, many researchers have published literature reviews, in which they synthesized evidences about the nature, the theoretical frame, the link with the safety performance and the impact of SC on organizational culture [1–6].

In this context, it is verified that there are studies focused specifically to analyze the improvement of CS, however only one review was found that specifically addressed this issue, which was developed in the area of health [7]. Therefore, this framework presents a gap with regard to the systematization of knowledge focused on improvement of safety culture in industry.


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The importance of this systematization is due to the fact that industrial accidents have a great human, ecological, financial and social impact [8, 9]. Thus, by analyzing how the improvement of safety culture has been approached in studies developed in the industrial area, this article aims to contribute to a greater understanding of the aspects that facilitate or hinder the development of SC, providing subsidies for the improvement of the SC assessment and intervention programs. In this sense this article aims to explore and analyze the evidences of the studies about SC improvement in the industrial field.

## 2 Method

This article presents a systematic review of the literature on the development and improvement of safety culture carried out from the following databases: Web of Science, PsycNET, Scientific Electronic Library Online (Scielo) and Ebsco. The choice of the systematic review has been made because it applies to research strategies seeking to limit the bias in the selection of articles and critically assessing them to synthesize relevant studies in a specific topic [10].

The guiding question for this review was: what evidence has been produced by studies that have investigated the development and improvement of safety culture in industries? The inclusion criteria used were: peer-reviewed published studies written in Portuguese, French, Spanish and English, without date limitation and that indicated in their results the improvement of the safety culture in industry. The exclusion criteria took into account: the place where the studies were carried out and the type of document. Thus, articles from research carried out in other fields than industry, such as safety culture in health or food safety, as well as essays, debates, literature reviews, reports, were excluded.

Therefore, a comprehensive and exhaustive search was performed in the databases using the terms "Safety Culture" and "Improvement" which were combined using the Boolean operator "AND" and excluding with the operator "NOT" the terms "FOOD" and "HEALTH". This search strategy found 294 articles and Fig. 1 shows the flow diagram of study search and selection.

This result has been exported to the RAYYAN® application which "helps expedite the initial screening of abstracts and titles using a semi-automation process while incorporating high level of usability" [11]. Thus, after the exclusion of 61 duplicate documents, the process of document tracking was performed blindly by the four authors of this study, in order to minimize bias resulting from the realization of this process by a unique evaluator. The data collection form was created to extract the following data from each study: Author(s), Year of publication, Title, Journal, Study Setting, Study Objective and Improvement Safety Culture Main Outcomes.

The thirteen articles included in this review were analyzed in order to identify: (a) common themes and main differences between their results; (b) main conclusions; (c) relationship between key concepts; (d) classification of themes and sub-themes; (e) interpretation of content; (f) consistencies and incongruities.

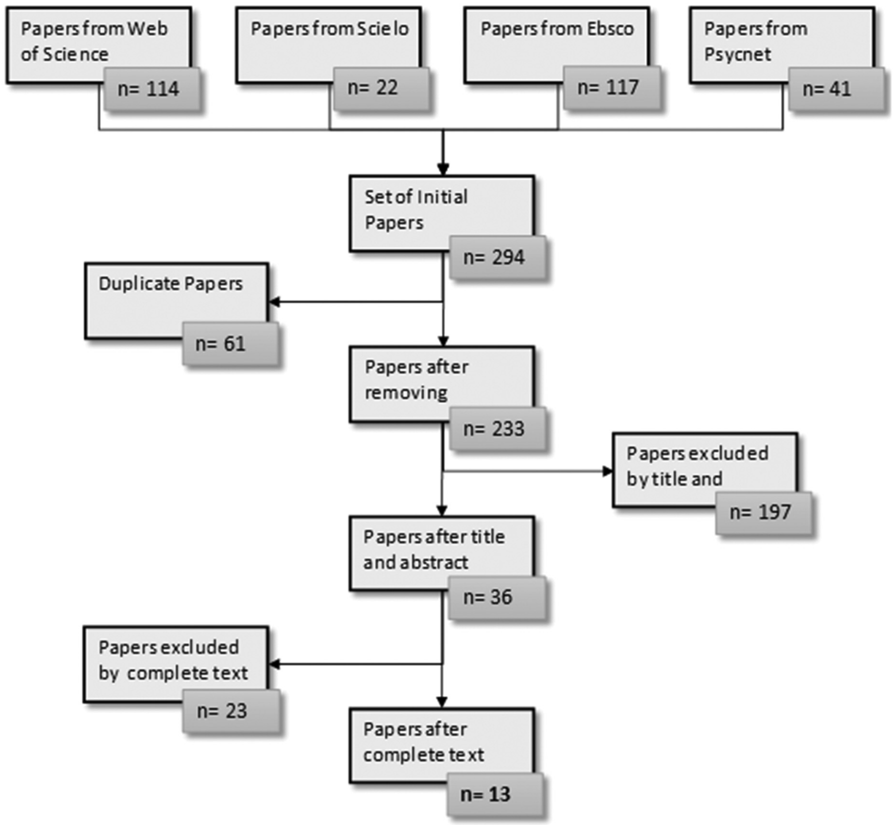


**Fig. 1.** Flowchart of study search and inclusion. Prepared by the authors.

# 3 Results

## 3.1 Characteristics of Studies Included in This Systematic Review

The studies included in this systematic review were conducted in the following countries: one in Australia, one in Belgium, one in Denmark, three in the Netherlands, three in the USA, two in the United Kingdom, one in Sweden, one in United Arab Emirates, and one article didn't specify where the study was made. It is observed that none of the studies that specifically address the improvement of safety culture was developed in Africa or South America and only one was conducted in Asia.

A bibliometric study on SC that was carried out by Van Nunen et al. [1] pointed out that Europe and Asia are the regions where more research is carried out on this topic, and that South America, Africa and Oceania are the regions that publish less on safety culture. This frame indicates that South America and Africa are regions where SC in general needs to be better understood. However, in Asia this research raises the hypothesis that although there is a significant academic production on SC in this region this production is not specifically focused on the evaluation of SC improvement.

In what concerns the publication date, the oldest article was published in 1998 and the most recent in 2016. Thus, it is noticed that the publications focused on the process of improving the Safety Culture occurred about a decade after the accident of Chernobyl (1986) that originated the term [9]. According to the bibliometric study of Van Nunen et al. [1], SC publications generally began in 1991. Therefore, it appears that an initial period of discussion about the definition of the term was needed as well as the spread of this idea among researchers, so that more focused discussions on improving the SC was developed.

As shown in Fig. 2 concerning industry type, three studies were made in the nuclear industry, three in railway, and the others in oil and gas, electric systems, metallurgy, mining, construction, industrial lifts and chemistry.

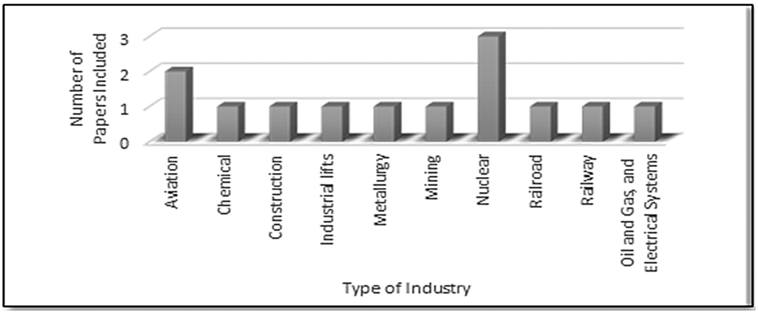


**Fig. 2.** Type of Industry where studies were conducted.

This shows that although the term “safety culture” arose through the analysis of an accident in the nuclear industry, the importance of this topic has come to be discussed in other industries, mainly because of the great catastrophes that have occurred throughout history in several types of industries, as synthesized by Daniellou et al. [9]. In summary, the data on the 13 studies included in this systematic review is presented in the Table 1. The analysis of the results and conclusions of the included studies in this paper pointed out factors that facilitate or hinder the improvement of safety culture, that which will be detailed next.

### 3.2 Facilitating Factors for the Improvement of Safety Culture

**Reinforcing the Safety Management System**

As a general departing point for the improvement of safety culture, the authors agree to better prioritize safety in front of economic pressure and productivity issues [12–15].

A good Safety Management System, as pointed by Bahn [16] and Remawi [17], is required to impulse an adequate safety culture. It includes clear and consistent procedures [16], the ability to distinguish and understand the different sub-cultures, [14], to

**Table 1.** Papers included in this systematic review

| Author/Authors | Year | Country/Region | Type of Industry | Journal |
|---|---|---|---|---|
| Alm H., et al. | 2012 | Sweden | Railway | Work |
| Bahn S. | 2013 | Australia | Mining | Employee Relations |
| Carroll J.S. | 1998 | United States | Nuclear | Work & Stress |
| Chen Q.<br>Jin R. | 2013 | United States | Construction | Journal of Construction Engineering and Management |
| Fitzgerald M.K. | 2005 | United Kingdom | Oil and Gas, and Electrical Systems | Process safety and environmental protection |
| Lallemand C. | 2012 | *not cited* | Metallurgy | Work |
| Mearns K. et al. | 2013 | United Kingdom | Aviation | Safety Science |
| Mengolini A.<br>Debarberis L. | 2012 | Netherlands | Nuclear | Safety Science |
| Mengolini A.<br>Debarberis L. | 2007 | Netherlands | Nuclear | Reliability Engineering & System Safety |
| Nielsen K.J. | 2014 | Denmark | Industrial lifts | Journal of safety research |
| Remawi H.<br>Bates P.<br>Dix I. | 2011 | United Arab Emirates | Aviation | Safety Science |
| Reniers G.L.L.<br>Cremer K.<br>Buytaert J. | 2011 | Belgium | Chemical | Safety Science |
| Zuschlag M.<br>Ranney J.M.<br>Coplen M. | 2016 | United States | Railroad | Safety Science |

be patient during the cultural change process [14, 18], an efficient safety training system to motivate the personnel [14] with a mentoring system for Bahn [16], a reinforcement of the supervisory role for Carroll [13], to keep the staff workload in an acceptable range. According to Reniers [19], a good safety management system designed to improve safety culture combines actions on technology, procedures and people in the short and long term, integrating performance and quality management in a continuous improvement model.

In the case study of Alm [12], a field worker was trained to work with safety only, what is the exact opposite of training more and more the HSE specialists or to reinforce the safety management system from the top, here the safety management system was reinforced from the bottom.

**Doing the Necessary Actions Before Changing the Cultural Assumptions**
The authors stress the necessity of allocating resources for effective improvement actions next to the safety culture assessment [18, 20, 21], as a condition for motivation and trust of the workforce in the safety management system.

But the simple actions and consequent changes in behaviors are not sufficient to claim a change in safety culture. As stressed by Nielsen [15], this has to be obtained by a double loop learning process [15] "which is defined as a strategy where the governing values behind actions are questioned and changed when actions fails and stand in contrast to single-loop learning where new actions are chosen within the same governing values". For Nielsen [15], the complexity of the Safety Culture requires a multi-method approach to be able to assess the multiple changes that a cultural change implicates. On the contrary, the limitation of a single factor assessment doesn't possibilitate a cultural change in safety. That is also the reason why Mengolini [22] argues for a combination of top-down with a bottom-up approach.

**Involving the Workers in the Assessment to Improve Safety Culture**
The assessment of safety culture in itself has an improving effect, by two mechanisms linked to the participation of the workforce. The first mechanism is coherent with the top-down approach and consists in the motivation originated by the involvement of the workers, in the reflexion about safety [20]. This participation is mechanical and doesn't require anything other than the perception to be asked and considered on safety issues. This psychological motivation helps to better consider the involvement of managers for safety and then to perceive a better safety culture [20]. In the same way, Mengolini [21] notes that the motivation and involvement of the staff is useful for the definition of improvement activities and is a required condition to manage safety.

The second mechanism is also related to the workers' ability to identify and solve safety issues during the assessment process [23]. But this time, the benefit of the participation is considered from a bottom-up perspective: this type of participation isn't only a way to increase the motivation and the perceptions of the workforce, but to take advantage of the workers safety knowledge and skills to address safety issues.

**Participation, Reporting and Workers-Managers Relations VS Involvement, Accountability and Communication**
As we saw, the top-down approach and the bottom-up approach diverge in the way they consider the role of the workers in the assessment phase of the safety culture improvement, but they differ also in the transformation phase and in the daily safety activities of the company.

The participation of the workers is a key factor to improve safety culture, but it is not conceived the same way between the authors. For Mengolini [22] and Lallemand [20], the involvement of the workers allows a greater motivation from their part and provides a better information to help the managers to decide what actions must be implemented. At the opposite, for Mearns [23] the workers involvement in the safety culture process is determinant to identify and solve part of the safety issues.

As a guideline for improving trust and safety climate, Chen and Jin [14] and Carroll [13] list the accountability system as a key element to prevent safety procedures violations. More than the self-responsibility, what is asked is a general peer screening and control on the basis of safety norms. In this case, the optimal situation is a zero-risk taken workplace where all the rules are efficient and where the workers don't have any positive role to play to improve the safety norms and behaviors.

On the other side, a "Just Culture", based on reporting, workers-managers relations and trust, as purposed by Reason [24] and implemented by Alm [12] stands for an opening of the discussion about what is to do for improving daily risky activities and ensuring the correct reward or disciplinary response regarding the necessary errors and violations needed to improve safety norms and behaviors. In the same way, Zuschlag [25] shows that an improvement in labor-management relations helps obtaining a "trust culture", "a key feature of an effective safety culture" [25]. This interaction needs to be differentiated from the top-down "communication" of some authors.

For example, according to Chen and Jin [14], the communication is viewed as a one-way top-down communication channel, in the same way that Nielsen [15] mentioned it. This repetition of the safety procedures by a specific communication effort during a safety culture program underlies the difference between valuing the workers' experience and relying only on management to address the safety issues [14, 15].

### 3.3 Limiting Factors for the Improvement of Safety Culture

**Managing Different Subcultures**

As a condition which can bother the safety management system and the resulting safety culture, a part of the authors identify the diversity of sub-cultures and the subsequent complexity of managing different safety regimes [13, 16].

**Relying only on the Managers and HSE Specialists**

The top-down approach is not exempt of defaults, as Mengolini [22] noted. First, the top-down approach is not "focused on the point of view and experience of those who act in the organization". The top-down approach is centered on the managers and the safety specialists and aims to construct a good management system to which the workforce should comply, which doesn't necessarily includes the possibility to communicate and share divergent perceptions about safety issues [22]. In a narrow sense, Carroll [13] notes that a too hierarchical and managerial approach tends to "inhibit the raising of concerns" from the bottom of the organization. Thereby, there is a lack of relevant information to manage safety.

**Using one Single Method of Assessment**

Regarding the assessment method, Mengolini [22] points out that questionnaires are more likely to present an optimistic view of the actual Safety Culture than interviews, whose results are more realistic. The accuracy of the assessment method can't be in itself a factor of improvement, but the imprecision of this method certainly is a limiting factor to identify weaknesses and monitor the safety culture. Accordingly, Nielsen [15] remembers that to obtain a change in safety culture, the basic assumptions have to change, and not only the apparent espoused values or behaviors that come from these basic assumptions. Thus, behavioral, normative or changes in perceptions, attitudes are not sufficient to claim a change of culture. In other words, a change in "safety climate" is not necessarily a change in safety culture, despite the lack of direct possibility to assess safety culture.

**Asking for an Accountability Culture at the Price of a Reporting Culture**
As another limiting factor to the improvement of safety culture is the fear to be blamed when reporting a safety violation. For Carroll [13] and Chen and Jin [14], this fear of inappropriate consequences of accountability comes together with a lack of positive reinforcement of positive behaviors. This penalization of any safety violation and the related fear of reporting brakes also the bottom-up communication channel between workers and managers [13, 14].

## 4 Discussion

This systematic literature review was probably limited because we used a simplified search strategy and analyzed only the results and conclusions of the studies. Subsequently, other studies may deepen the discussion started here by comparing methods and other dimensions of the research and thus broadening the scope of the discussion that was initiated here. Despite the aforementioned limit, the analyzed articles point to issues that can be considered central to the transformation of practices and the development of a safety culture. Changing the safety culture is a long and continuous process [14, 18, 19] in which has been underlined the role of the proximity hierarchy or supervisors, in the discussion of the daily operations of the production units, and the involvement and participation of the labor force.

Two aspects can be highlighted, which can be contradictory from the point of view of safety practice. The evolution of the safety culture demands building a trust relationship between managers and operators, which can be shaken by central components of the safety management system: accident analysis methodologies and accountability systems, often perceived as not consistent by the workforce.

## 5 Conclusion

To outline, this systematic review showed that despite a diversity of conceptions and practices related to the improvement of Safety Culture, it is possible to identify some common elements. However, further research should be developed to deepen the knowledge about the topics discussed in this paper.

In particular, a deepening of the diagnostic methodologies and the concrete actions implemented to construct a convergence of perceptions, between the different hierarchical levels and different companies normally present in the units of industrial production, seems to be central.

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# Occupational Health and Safety and Employee Engagement: Evidence from the SMEs Sector in Ghana

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**Abstract.** Occupational health and safety and employee engagement literature have been studied independently. However, the need to integrate these streams of literature has now become apparent. This paper therefore seeks to address this gap by empirically testing the impact of occupational health and safety management on employee engagement in the small and medium-scaled enterprises in Ghana. A cross-sectional data from 136 employees were analysed to (dis)-confirm our hypotheses. Results of the structural equation model revealed a positive effect of occupational health and safety on intellectual, social and affective engagement. However, among the dimensions of engagement, intellectual engagement was the criterion variable influenced most. The paper suggests that promoters of SMEs, owners and/or managers, should endeavour to treat the health and safety concerns of their employees with utmost priority in order to get the best out of them.

**Keywords:** Occupational health and safety · Intellectual engagement
Social engagement · Affective engagement · SMEs · Ghana

## 1 Introduction

Small and medium scale enterprises (SMEs) play a significant role in Ghana's economy as they make up a majority of firms in every major sector and create more new jobs than larger firms do. According to [1], SMEs in Ghana can be categorized into urban and rural enterprises with the former being further sub-divided into organised and unorganized enterprises. However, this study concentrates on 'urban-organized' SMEs since they have the highest potential for growth required to stimulate economic and social wellbeing of the country. In Ghana, the [2] defines SMEs using two criteria: fixed asset and number of employees. However, due to challenges related to the valuation of fixed assets and the continuous depreciation in the exchange rate, the second criterion is preferred in defining SMEs. As a result, this paper defines SMEs with


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potential for growth and expansion as enterprises with less than 100 employees, where a medium scale enterprise employs between 11 and 99 workers and a small business employs between 5 and 10 workers.

Despite their small-scale output and relatively lower scale economies, SMEs are significant contributors to economic growth and innovation [3]. Available statistics show that SMEs account for 92% of business establishments, 85% of employment in the manufacturing industry and 70% to Ghana's GDP [4]. However, empirical evidence shows that SMEs sector endure a greater burden of occupational illnesses, injuries and fatalities than large firms due to lack of essential resource capacity to engage in occupational health and safety activities [5]. The SMEs sector reckoned as the engine of Ghana's economic growth has received less research attention in the area of occupational health and safety management. Hence, this paper seeks to examine the extent to which occupational health and safety management affects engagement in the SMEs sector in Ghana.

Well, some theoretical and empirical research on OHS have been conducted in Ghana with emphasis on the mining sector [6, 7], timber processing sector [8], oil and gas sector [9] and psychiatric health division [10]. For instance, using a sample of 263 psychiatric nurses in Ghana, [10] found a positive relationship between OHS management and nurses' engagement and a negative relationship between OHS management and nurses' turnover intention. However, little is known in the literature about how OHS management affects employee engagement in the SMEs sector. Therefore, this paper seeks to examine OHS in the SMEs sector.

In spite of the immense economic benefits Ghana derive from SMEs, there are several impediments restraining its growth and expansion with one such obvious impediments being lack of OHS regulations to guarantee and safeguard the safety and health of workers. To this end, [10] opined that "with the exception of some statutes in Ghana including the Labour Act, 2003 (Act 651); Factories, Offices and Shops Act, 1970 (Act 328) and Workmen's Compensation Act, 1999 (Act 526) which make provisions on health and safety issues at the work environment, no bill has yet been passed into law to set and enforce health and safety standards at the workplace" (p. 2). Startling statistics from International Labour Organization [11], however, indicate that 2.3 million workers worldwide die each year due to work-related injuries with 860,000 of these deaths attributed to occupational accidents. The ILO also estimates that there are 264 million nonfatal accidents occurring each year in the work environment. In addition, technological, social and organizational changes in the workplace and rapid globalization have seen the emergence of new risks and challenges. In line with the foregoing contention, [12] opined that businesses in developing countries such as Ghana suffer colossal economic and personnel costs due to work-related injuries and diseases. This then calls for SMEs to develop health and safety strategies that encourage healthy behaviours at work and promote participation in physical activity challenges.

Some empirical studies have attempted looked at the nexus between OHS management and outcomes such as organizational commitment [7] and turnover intention [6] in sub-Saharan Africa. However, the extent to which OHS affects engagement has not received much research attention (for an exception see [10]) in the sub-region and for that matter the SMEs sector. The subject of OHS in the SMEs sector is gaining attention due to the enormous contribution of the sector to the global economy in terms of net job creation and business development. Thus, the goal of this paper is to address this gap by establishing the nexus between OHS and engagement.

## 2 Literature Review

Employee engagement is defined generally as the level of commitment and involvement employees' exhibit towards their organization. It is deemed as one of the leading subjects of interest in the fields of management. The positive attitude of employees towards their assigned tasks explains their emotional connection with the organization. Hence, engaged employees go beyond the call of duty to perform their assigned duty excellently. Empirical evidence reveals some benefits of engagement. Firstly, engagement is the key to an organization's success and competitive advantage [13, 14]. Besides, [15] opined that organizations with engaged employees have higher shareholder returns, profitability, productivity and customer satisfaction.

Despite the benefits derived from engagement, there is to date no consensus on its meaning and distinctiveness. The concept gained popularity in the 1990s after the groundbreaking work of Khan on psychological conditions of personal engagement and disengagement at work. [16, p. 694] defined engagement as "the harnessing of organisation members' selves to their work roles; in engagement, people employ and express themselves physically, cognitively, and emotionally during role performances." Another definition of engagement is by Gallup researchers' [17] who noted in their study "the right people in the right roles with the right managers drive engagement" (p. 248). Based on Gallup's conceptualization of employee engagement as a unidimensional construct, [13] identify three types of people: engaged, not engaged and actively disengaged. Engaged employees are builders who consistently strive to give excellence within their roles. Not engaged employees focus on the tasks spelt out to them rather than the goals of the organization and thus they do what they are told to do. Actively disengaged employees on the other hand are dangerous individuals who not only perform well but also demotivate performers in the organization. The concept of engagement therefore shows that an engaged employee is intellectually and emotionally bound with the organization, feels passionate about its goals and is committed to live by its values and principles.

Furthermore, although there are discrepancies in the conceptualization and measurement of employee engagement, [18] propose that engagement is a multidimensional construct encompassing intellectual engagement, affective engagement and social engagement. Given the relevance of intellectual activity to work performance and that engagement implies more than mere fulfilment of duties, they defined intellectual engagement as 'the extent to which one is intellectually absorbed in work.' Affective engagement is defined as 'the extent to which one experiences a state of positive affect relating to one's work role.' Besides, the increasing acknowledgement of the requirement for employees to work collectively [19] leads to conceptualization and operationalization of a third facet of engagement called social engagement. It is defined as 'the extent to which one is socially connected with the working environment and shares common values with colleagues' (p. 532). Consequently, [18] ISA engagement scale was adapted to assess employee engagement as the outcome variable in this study.

According to [13], employee engagement occurs naturally when leaders are inspiring. This suggests that owners/managers of SMEs who ensure safety compliance and participation are more likely to have their workers conform to safety policies and procedures at the workplace especially when workers perceive that the actions of their superiors are fair and congruent with organisational policy on safety. Hence, drawing on social exchange theory [20], this paper argues that the perception of employees about their safety and welfare determines their level of engagement in the organization. Cole [21] opines that employees who are healthy and feel safe at work are those who can fully invest their capabilities and potentials to work. Hence, to have engaged employees, promoters of SMEs in Ghana must show concern for the safety, health and wellbeing of their employees. Besides, [22] assert that when SMEs fail to address poor working conditions, their employees are more likely to judge the costs of staying and being engaged with the enterprise as exceeding the costs of quitting.

In a study on OHS management among SMEs in Thailand, [23] reported that the highest number of accident cases were from the production enterprise with about 200 employers and from the industrial sector of engineering. The authors also stated that essential safety elements for SMEs are accident reports, accident investigation and safety inspections. Similarly, using a sample of 263 psychiatric nurses from Ghana, [10] reported a positive correlation between OHS management and employee engagement. Among the dimensions of OHS, safety leadership was found to be the strongest predictor of mental health nurses' engagement. The authors concluded that promoting an OHS policy through proper monitoring and supervision strengthens and energizes mental health nurses to work hard to achieve the organization's goals. In Spain, [24] reported a positive nexus between OHS management and firm performance. In addition, OHS management has been reported as a key determinant of firm reputation and image among stakeholders [25]. Using a sample of 300 woodworkers from a Timber Company in Ghana, [8] found a positive nexus between woodworkers' willingness to use personal protective equipments and their awareness of safety and health implications on their job. Amponsah-Tawiah and Mensah [7] also found a positive relationship between OHS management and affective, normative and continuance commitment. In the US, [43], in a case study described four ways to reach SMEs with occupational safety and health assistance. They include trenching safety training for construction, basic compliance and hazard recognition for general industry, expanded safety and health training for restaurants, and fall prevention and respirator training for boat repair contractors. Based on the preceding discussions, the primary objective of this study is to examine the link between OHS management and engagement in the SMEs sector in Ghana. Specifically, *the study hypothesized that OHS management will have a positive effect on the dimensions of ISA engagement scale: intellectual engagement, social engagement and affective engagement*.

# 3 Materials and Methods

## 3.1 Research Design, Sample and Procedure

The underpinning research design for this study was cross-sectional survey design. It is considered appropriate because it is the most frequently used descriptive design in most business research [26]. The design is used because it involves the collection of information from any given sample of population elements once. The design is also imperative because it serves as a starting point for hypothesis and theory generation around a piece of research. Furthermore, the study used data from small and medium enterprises operating the capital city of Ghana. Out of the 109 SMEs registered under the National Board for Small Scale Industry (NBSSI) with 549 employees, eighty-six of them with a corresponding staff strength of 214 were selected based on [27] mathematical formula. Of the 214 questionnaires administered to employees in the selected SMEs, 136 completed surveys were received which accounted for a response rate of 63.55% after uncompleted surveys were eliminated. The demographics of respondents are presented in Table 1.

**Table 1.** Demographic characteristics of respondents

| Variable | Characteristics | Frequency | Percent |
|---|---|---|---|
| Gender | Male | 96 | 70.6 |
| | Female | 40 | 29.4 |
| Age | 23–31 year | 73 | 53.7 |
| | 32–40 year | 36 | 26.5 |
| | 41–49 year | 23 | 16.9 |
| | 50–58 year | 04 | 02.9 |
| Marital status | Single | 68 | 50.0 |
| | Married | 61 | 44.9 |
| | Divorced/separated | 07 | 05.1 |
| Education attainment | Certificate | 19 | 14.0 |
| | Diploma | 54 | 39.7 |
| | First degree | 59 | 43.4 |
| | Master's degree | 04 | 02.9 |
| Organisational tenure | 01–07 years | 98 | 72.1 |
| | 08–14 years | 28 | 20.6 |
| | 15–21 years | 08 | 05.9 |
| | 22–28 years | 02 | 01.5 |

## 3.2 Measures

### 3.2.1 Occupational Health and Safety

Employees' perception of occupational health and safety was measured using 12-items from the Occupational Health and Safety Vulnerability Measure developed by the Institute for Work and Health [28]. The items were selected from the workplace policies and procedures, and participation in occupational health and safety dimensions of the scale as this taps into the heart of the issue in the SMEs sector. Sample items include "Systems are in place to identify, prevent and deal with health hazards at work" and "I have enough time to complete my work tasks safely." Responses were anchored on a 5-point Likert scale ranging from *1 or strongly disagree* to *5 or strongly agree*. High scores represent high perceptions of employees about their health and safety at the workplace whereas low scores signify low perception of health and safety of the working environment. The alpha value for this measure is shown in Table 2.

**Table 2.** Confirmatory factor analysis for measurement model

| Constructs and indicators | Mean | SD | Factor loadings | t-values | SMC | AVE | CR | α |
|---|---|---|---|---|---|---|---|---|
| *Occupational health and safety* | | | | | | | | |
| OHS1 | 4.93 | 1.48 | 0.53 | Fixed | 0.28 | 0.59 | 0.74 | 0.73 |
| OHS2 | 5.07 | 1.41 | 0.73 | 5.16 | 0.53 | | | |
| OHS3 | 4.93 | 1.45 | 0.64 | 4.90 | 0.41 | | | |
| OHS4 | 4.99 | 1.48 | 0.56 | 4.55 | 0.32 | | | |
| OHS5 | 5.12 | 1.50 | 0.52 | 4.33 | 0.27 | | | |
| *Intellectual engagement* | | | | | | | | |
| IE1 | 4.09 | 0.93 | 0.63 | Fixed | 0.40 | 0.65 | 0.75 | 0.74 |
| IE2 | 4.04 | 0.91 | 0.80 | 6.35 | 0.64 | | | |
| IE3 | 4.03 | 0.94 | 0.67 | 5.92 | 0.45 | | | |
| *Social engagement* | | | | | | | | |
| SE1 | 3.18 | 1.20 | 0.59 | Fixed | 0.34 | 0.56 | 0.73 | 0.70 |
| SE2 | 3.10 | 1.20 | 0.70 | 5.04 | 0.48 | | | |
| SE3 | 3.14 | 1.23 | 0.69 | 5.04 | 0.48 | | | |
| *Affective engagement* | | | | | | | | |
| AE1 | 3.90 | 0.87 | 0.96 | Fixed | 0.93 | 0.62 | 0.77 | 0.71 |
| AE2 | 4.00 | 0.84 | 0.57 | 4.55 | 0.32 | | | |

***Note***. $n$ = 136. SMC = squared multiple correlation; AVE = average variance extracted; CR = composite reliability. All $t$-values greater than 1.96.

### 3.2.2 Employee Engagement

The ISA engagement scale is used to measure employee engagement [18]. The scale which was built on [16] theory of engagement has three dimensions that are empirically distinct and focuses on intellectual, social and affective engagement. The ISA engagement scale is a nine-item, three-dimensional measure. Intellectual engagement is defined as the extent to which one is intellectually absorbed in work. Sample item include "I pay a lot of attention to my work." Affective engagement on the other hand is define as the extent to which one experiences a state of positive affect relating to one's work role. Sample item is "I feel energetic in my work" Whereas social engagement refers to the extent to which one is socially connected with the working environment and shares common values with colleagues with a sample item of "I share the same work values as my colleagues." Responses were anchored on a 5-point Likert scale ranging from *1 or strongly disagree* to *5 or strongly agree*. Higher scores on each dimension indicate higher levels of intellectual, social and affective engagement. The Cronbach alpha for each dimension is reported in Table 2.

#### 3.2.3 Control Variables

Consistent with previous research, age, gender and tenure were consider as controls in this study [10, 18]. Gender was a dichotomous variable (0 = female, 1 = male) whereas age and tenure were treated as continuous measures.

#### 3.2.4 Controlling for Common Method Bias

To minimize the likelihood of common method bias due to the self-report measures used, the study followed some procedural and statistical remedies recommended by Podsakoff *et al.* [29]. First, the scale items were carefully purified by defining unfamiliar terms, avoiding ambiguous concepts as well as double-barreled items. Next, the study also used temporal, proximal or psychological separation to reduce the participant's ability and/or motivation to use previous answers to fill in gaps in what is recalled or answer subsequent questions. For the statistical remedy, after the scale purification, a Harman's one-factor test with a confirmatory factor analysis was conducted to check for the presence of common method bias. After all the manifest variables have been loaded onto a single latent factor, the CFA model revealed extremely poor fit to the data ($\chi^2(65) = 245.56$, RMSEA = 0.14, SRMR = 0.11, NNFI = 0.58, CFI = 0.63) suggesting that common method bias was not a concern in this study. Hence, the hypothesized four-factor model was used in the subsequent analysis.

## 4 Results

The data analysis followed [32] two-step modelling approach, which involves a CFA to test the distinctiveness of the study constructs using LISREL 8.50 [30] and an examination of the hypothesized relationship using structural equation modelling.

### 4.1 Confirmatory Factor Analysis

A confirmatory factor analysis was carried out for the overall measurement model in which all the key latent variables were allowed to estimate freely. The fit of the CFA model was evaluated with chi-square ($\chi^2$) goodness-of-fit test and five other fit indices suggested by [34] including root mean error of approximation (RMSEA $\leq$ 0.07), standardized root mean square residual (SRMR $\leq$ 0.07), non-normed fit index (NNFI $\geq$ 0.92), comparative fit index (CFI $\geq$ 0.95) and goodness of fit index (GFI $\geq$.0.90). In order to test for discriminant validity, the four-factor model was compared to three alternative CFA models. The hypothesized four factor model ($\chi^2$ (59) = 69.45, $\chi^2$/df = 1.18, RMSEA = 0.04, SRMR = 0.06, NNFI = 0.95, CFI = 0.96, GFI = 0.93) provided a better fit than the alternative models shown in Table 3. Hence, establishing the discriminant validity. Furthermore, discriminant validity was established by comparing squared correlations with average variance extracted. The squared correlations among the constructs range from 0.03 to 0.19 whereas the average variance extracted was from 0.56 to 0.65 and the results revealed that average variance extracted for all constructs is higher than the squared correlations thereby proving the distinctiveness of the constructs.

**Table 3.** Model summary of fit indices

| CFA model | $\chi^2$ | df | $\chi^2$/df | RMSEA | SRMR | NNFI | CFI | GFI |
|---|---|---|---|---|---|---|---|---|
| Hypothesized four factor model (OHS, IE, SE, AE) | 69.45 | 59 | 1.18 | 0.04 | 0.06 | 0.95 | 0.96 | 0.93 |
| Three factor model (OHS, IE, SE +AE) | 121.95 | 63 | 1.94 | 0.08 | 0.08 | 0.82 | 0.86 | 0.88 |
| Two factor model (OHS, IE+SE +AE) | 156.31 | 64 | 2.44 | 0.10 | 0.09 | 0.73 | 0.78 | 0.85 |
| One factor model (OHS+IE+SE +AE) | 245.56 | 65 | 3.78 | 0.14 | 0.11 | 0.56 | 0.63 | 0.78 |

**Table 4.** Descriptive statistics and correlations among study constructs

| | Variable | Mean | SD | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Gender | 1.29 | 0.46 | – | | | | | | |
| 2. | Age | 32.78 | 7.82 | 0.10 | – | | | | | |
| 3. | Organisational tenure | 5.83 | 4.44 | 0.18* | 0.87*** | – | | | | |
| 4. | Occupational safety and health | 5.01 | 1.02 | 0.02 | 0.18* | 0.16 | – | | | |
| 5 | Intellectual engagement | 4.05 | 0.75 | 0.08 | 0.21* | 0.19* | 0.40*** | – | | |
| 6 | Social engagement | 3.14 | 0.95 | 0.11 | 0.24** | 0.10 | 0.18* | 0.29** | – | |
| 7. | Affective engagement | 3.95 | 0.81 | 0.01 | 0.32*** | 0.20* | 0.31*** | 0.44*** | 0.34*** | – |

***Note***. $n = 136$; *$p < .05$, **$p < .01$, ***$p < .001$.

Composite reliabilities (CR) were used to assess the degree of consistency between multiple measurements of a construct [26] whereas average variance extracted (AVE) was used to measure the convergent validity [32]. The CR values as shown in Table 2 exceeded 0.70 which is the acceptable threshold suggested by [33]. The values for AVE also exceeded the threshold of 0.50 as suggested by [26, 34]. All item loadings ranging from 0.52 to 0.96 were significant at the 5% significance level, indicating convergent validity [34]. To check the internal consistency, Cronbach's alpha was used and as shown in Table 2, all the alpha values were above the threshold of 0.70 as recommended by [35]. The descriptive statistics and the inter-correlation among the study variables are shown in Table 4. The nexus between OHS management and intellectual, social and affective engagement were analyzed using Pearson's product moment correlation coefficient. OHS was positively related to intellectual engagement ($r = 0.40$, $p < 0.001$), social engagement ($r = 0.18$, $p < 0.05$) and affective engagement ($r = 0.31$, $p < 0.001$).

### 4.2 Structural Equation Modelling

Structural modelling was used to examine the overall fit of the proposed model after confirmatory factor analysis and to test the estimated paths. Consistent with [31] and [36] recommendation, the chi-square statistic and five other fit indices were used to assess the fitness of our proposed structural model. The five fit indices used included root mean square error of approximation (RMSEA), standardized root mean square residual (SRMR), non-normed fit index (NNFI), comparative fit index (CFI) and Goodness of fit index (GFI). Drawing on the social exchange theory with a sample of 136 employees from the SMEs sector in Ghana, results of the study showed that the hypothesized structural model provided a reasonable fit to the data ($\chi^2$ (62) = 117.27, $\chi^2$/df = 1.89, RMSEA = 0.08, SRMR = 0.09, NNFI = 0.85, CFI = 0.88, GFI = 0.88). However, in assessing the unique contribution of OHS management in each of the dimensions of employee engagement, the standardized estimates were used. Results from Table 5 show that all the hypothesized direct paths were supported by the field data with OHS management accounting for 31% of the variation in employee engagement. Hence, in line with previous research (e.g., [10]), the study found that OHS management has a positive effect on intellectual ($\gamma = 0.64$, $t = 3.92$, $p < 0.01$), social ($\gamma = 0.29$, $t = 2.19$, $p < 0.05$) and affective engagement ($\gamma = 0.52$, $t = 4.03$, $p < 0.001$). Thus, the results of the study lend support to *H1*, *H2* and *H3*.

**Table 5.** Structural path estimates for proposed model

| Hyp. | Hypothesized relationship | Sign | Std. estimate | *t*-value | $R^2$ | Result |
|---|---|---|---|---|---|---|
| H1 | OHS → Intellectual engagement | + | 0.64 | 3.92 | 0.31 | Supported |
| H2 | OHS → Social engagement | + | 0.29 | 2.19 | | Supported |
| H3 | OHS → Affective engagement | + | 0.52 | 4.03 | | Supported |
| ***Goodness-of- fit statistics***<br>Chi-squared ($\chi^2$) = 117.27, $p < 0.001$; df = 62;<br>Root Mean Squared Error of Approximation (RMSEA) = 0.05;<br>Standardized Root Mean Square Residual (SRMR) = 0.06;<br>Non-Normed Fit Index (NNFI) = 0.95;<br>Composite Fit Index (CFI) = 0.94;<br>Goodness-of-Fit Index (GFI) = 0.92. | | | | | | |

***Note***. OHS = occupational health and safety. Standardized coefficients are significant at t > 1.96.

## 5 Discussion

It is imperative to note that most accidents, injuries and deaths that occur at the workplace result from continuous exposure to hazardous substances such as chemicals, flammable liquids and gases as well as faulty equipment and machines. The study examined the relationship between OHS management and engagement in the SMEs sector in Ghana. The correlation estimates revealed a positive relationship between

OHS management and intellectual engagement. Similarly, the structural path estimates also showed a positive effect of OHS management on intellectual engagement. This finding indicates that given the importance of intellectual activity to work performance, the perception of employees towards health and safety management issues in the workplace is likely to affect the extent to which they become absorbed into their work. This is consistent with an earlier study by [37] who stressed that employees' perception of health and safety related issues at work play a major role in their engagement and performance. Thus, whereas OHS management has a significant relationship with intellectual engagement, [38] are of the view that intellectual engagement also has relevance to performance as well as other outcomes such as innovation. Furthermore, [13] opined that a desirable work environment devoid of health and safety issues is likely to motivate employees to be engaged at work. Hence, it is appropriate for owner/managers to deem it a responsibility to offer a working environment that protects the safety and wellbeing of their employees.

Furthermore, results of the structural model also revealed a significant positive effect of OHS management on social engagement. According to [18], social engagement is defined as the extent to which one is socially connected with the working environment and shares common values with colleagues. Hence, the perception of employees about their health and safety at work will likely influence their relationship with the working environment and the extent to which they share common values with their coworkers. This finding corroborates the assertion of [39] that social engagement can be particularly relevant to organizational change when physical working environment is perceived as safe and healthy by employees. Gyensare et al. [10] also reported a positive relationship between occupational health and safety and engagement in the mental health sector. Thus, the more safe and secure employees are on the job, the happier they are to share with their colleagues the same work attitudes, goals and values.

The findings of this study also revealed a significant positive relationship between OHS management and affective engagement. This implies that employees' perception about the management of their health and safety in the SMEs affect the extent to which they experience a state of positive feelings about their work roles and the organization at large. Affective engagement is relevant to a range of positive outcomes related to improvement in building personal resources [40] as in initiating good health and safety policies and programmes to safeguard employees in the workplace. This finding is consistent with [41], who found a positive relationship between the physical wellbeing of employees and the affective commitment. In addition, [7] found a positive relationship between occupational health and safety management affective commitment which when properly nurtured results in engagement. According to [18], employees with high affective engagement experience a state of positive affect in relations to their in-role performance and as such are less likely to engage in withdrawal reaction behaviours such as lateness, absenteeism and possibly turnover.

### 5.1 Implications for Policy and Theory

The contribution of OHS management in engagement in SMEs cannot be underestimated. Given the gargantuan contribution of SMEs to Ghana's economic growth and development and the absence of a clear policy directive on health and safety practices, this study argues that Parliament should pass into law an OHS statute to help safeguard the wellbeing of Ghanaian workers especially those in the SMEs sector. According to [9], to attain the globally accepted standards of providing for the safety, health and welfare of workers, the Ghanaian OHS statutes and frameworks must not only reflect current needs and challenges confronting modern organizations but essentially carry resilient, firm and effortful message to investors and employers that the nation attaches supreme prominence to OHS. Therefore, there is the need for stakeholder engagement with the aim of mounting pressure on the lawmakers to pass an OHS bill into law. This will not only bring about greater awareness of occupational health and safety issues in Ghana but also awareness of stringent punitive measures to employers who fail to protect their workers against health and safety hazards.

Furthermore, findings from the study give credence to social exchange theory [20] built on the norm of reciprocity, which proposes that social behaviour is the result of an exchange process. The purpose of which is to maximize benefits and minimize costs. Social exchange theory is the tendency of employees to respond to a beneficial action by returning a benefit and to harmful action by returning a harm. Blau [20] looks at interpersonal relationship from two perspectives, economic and social exchange. To [7], the desire of employees to safeguard their safety and health will compel them to evaluate their relationship with the organization and make an informed decision as to extent to which they are absorbed in work or connected with the working environment as well as share common experience with their colleagues. Hence, when they perceive the lack of care in the area of health and safety by owners/managers of SMEs, they will reciprocate that gesture with withdrawal reaction behaviours such as lateness, absenteeism and turnover resulting in disengagement.

### 5.2 Limitations and Future Research Direction

Although the study expands knowledge of the nexus between OHS management and engagement in the SMEs in Ghana, the results should be taken as tentative given the cross-sectional nature of the data used. In addition, focusing on the SMEs sector in Ghana makes this paper a one-sector study and thus a multi-sector and comparative study could provide further nuances on the effect OHS management on employee engagement. Future research can elicit responses on the same construct from employees and SMEs owners/managers in order to establish a dyad. Besides, future longitudinal and experimental research would help confirm the causal paths investigated in the study. Consistent with [42], this study was conducted in Ghana, a developing West African country going through political, economic, social and technological transitions. Hence, it is imperative that the model is explored empirically in other emerging, developing and developed economies in order to assess the stability of the research findings. Finally, the study used employee engagement as the only outcome variable. Whereas this is a significant outcome variable in most empirical studies, future research in sub-Saharan Africa and beyond can examine diverse outcomes such as organizational citizenship behaviour and psychological climate in order to confirm the results reported in of this study. This is an important area where future research is required.

## 6 Conclusion

The study expands knowledge of the nexus between occupational health and safety management and employee engagement in the SMEs sector in Ghana. Hence, by effectively managing the health and safety issues of employee, managers of SMEs can boost the engagement of their employees. Generally, the study findings call for a pragmatic approach to safeguard and secure the health and safety of employees in Ghana and sub-Sahara Africa as whole to attract and retain employees with a strong sense of engagement, commitment and passion in performing their in-role duties in the workplace.

## Appendix: Measurement Scale

***Occupational health and safety management***

1. I have enough time to complete my work tasks safely
2. If I notice a workplace hazard, I would point it out to management
3. At my workplace, systems are in place to identify, prevent and deal with health hazards.
4. At my workplace incidents and accidents are investigated quickly in order to improve workplace health and safety
5. At my workplace communication about workplace health and safety procedures is done in a way that I can understand

***Intellectual engagement***

1. I focus hard on my work
2. I concentrate on my work
3. I pay a lot of attention to my work

***Social engagement***

1. I share the same work values as my colleagues
2. I share the same work goals as my colleagues
3. I share the same work attitudes as my colleagues

***Affective engagement***

1. I feel positive about my work
2. I feel energetic in my work

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# Dynamic Analysis of Enterprise Security System Based on Multi-level Analysis and Structural Equation Model

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**Abstract.** To explore the internal operating mechanism of unsafety enterprise behavior system, this paper use HFACS and SD model that construct the causal relationship diagram of multi-level model of unsafe behavior in HFACS. The simulation analysis by running Vensim software shows that the effect of tissue layer safety state on unsafe behavior is the most significant. This paper also conducted a survey of a enterprise in Shandong. The effective questionnaires collected will be analyzed by the structural equation model (SEM). At the organizational level, the improvement of the rules and regulations of enterprise production has an important impact on the safety of employees' behavior. In summary, the premise of safety is to ensure the safety of the organization. Enterprises should improve the relevant production rules and regulations.

**Keywords:** Unsafe behavior · Multi-level model
Analysis of system dynamics · SD model · Structural equation model
Enterprise safety management

## 1 Introduction

Security is closely related to human life. In an enterprise, security means life, time and value. In twenty-first Century, the development of science and technology has made a qualitative leap in human life, and it also makes people's life faster and faster. High efficiency enterprise production is the fundamental guarantee of high value. But while people are pursuing high efficiency and high value, the problem of safety production is ignored. Safety accidents are common. The explosion occurred in 2014 in Jiangsu city of Kunshan, because of the existence of hidden work environment, the managers for immediate benefits, regardless of employee safety production and the staff adhere to the poor safety awareness and ultimately lead to consequences, causing 260 casualties, 351 million yuan in direct losses [1]. In December of the same year, Guangdong Foshan machinery manufacturing company car workshop explosion, a total of more than 60 casualties. The analysis shows that the safety management mechanism of the enterprise is not perfect, the employees' safety consciousness is poor, and the improper operation


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of the employees caused the explosion accident [2]. The major explosion in Tianjin, which occurred in 2015, was sadder. The evening of August 12, 2015, the Tianjin Binhai New Area of Tanggu Development Zone, east of Tianjin Port Bonded Logistics Co. Ltd. Ruihai International dangerous goods storage warehouse explosion. The explosion caused 165 deaths, including public security firefighters, Tianjin firefighters and police, and the direct economic loss was up to 6 billion 866 million yuan. After the accident, the relevant meeting of the State Council's investigation group pointed out that the illegal operation of the accident enterprises and the weak sense of safety of the local governments were the main reasons for the major explosion accidents [11]. Thus, the sense of safety is very important in the management of enterprise production. In 1931, Heinrich points out that the root cause of the accident is unsafe behavior and unsafe behavior of human beings, and people's unsafe behavior accounts for more of the proportion [3, 12]. Enterprise safety can be regarded as a complex system [4]. This paper will be unsafe behavior as a starting point and explore the internal operating mechanism of unsafety enterprise behavior system.

In this paper, the multi-level analysis method and the system dynamics model are combined to simulate the unsafe behavior of the enterprise group. And it is supported by data from survey data, it shows that the perfection of enterprise production rules and regulations. It shows that the perfection of enterprise production rules and regulations has a significant impact on staff behavior safety. This paper proposes some available suggestions to guarantee enterprise safety and reduce accident frequency.

## 2 Construction of Multi-layer Model of Enterprise Unsafe Behavior Based on HFACS

### 2.1 Construction of HFACS Multi-layer Model for Enterprise Unsafe Behavior

The unsafe behavior analysis and classification system (HFACS) is based on the theory of "recessive and dominant failure" in the famous Reason model. James Reason, a professor of psychology at University of Manchester, puts forward the conceptual model in Human Error. The "cheese" model accident, the wrong decision making, improper management, the direct precondition of forming unsafe behavior, the unsafe behavior and the failure rule of the defense system are summarized [6–9]. Unsafe behavior and classification system diagrams are shown in the following diagram. The first level is the organizational safety level in the enterprise; the second level is the supervision and management level of the enterprise; the third level produces the condition for the enterprise's unsafe behavior; the fourth level is the enterprise's unsafe behavior. The stealth failure of the first three layers will lead to the dominant failure of the last path, that is, the occurrence of unsafe behavior.

### 2.2 Multi-level Model Analysis of Enterprise Unsafe Behavior HFACS

#### 2.2.1 Enterprise Organization Security

The factors that affect the security of the organization can be divided into the level of enterprise resource management, the enterprise culture and the work of the managers.

The manager's work situation is divided into the degree of safety responsibility implementation, the degree of lack of security inspection and the degree of safety system perfection. The safe state of the organization is often the source of unsafe behavior and accidents. But it is the easiest to be ignored. A firm's management of resources is a prerequisite for security. Security skills training and safety skills training are an essential way for an enterprise to reduce the incidence of accidents for every employee. Enterprise's investment in safety skill's training and skill's training more, employees work more skilled and secured. Cost saving does not mean a higher rate of return for an enterprise. Reducing safety input will increase the rate of safety accident and be not worth the loss. When enterprises find safety systems, equipment, tools and protective equipment and other safety measures to employees have problems, it should be timely strengthened to repair and update. While the level of enterprise resource management reaches the standard, we should attach importance to the development of enterprise culture. The enterprise safety culture is a process of accumulation. Let every employee understand the importance of safety from the ideological level, form good habits of operation, influence the safety work of employees around them, conduct safety education regularly, introduce safety accidents at home and abroad. Events regardless of the size of the enterprise safety culture can't be ignored, for example, enterprises can't be ignored and tolerate small errors, no communication, the lower the formation of bad good atmosphere, to safeguard their own interests. These things must be eliminated. The manager's work situation is a factor of the most adulteration. The administrator should improve the safety system, carry out the safety responsibility to each group, and regularly carry out the lack of safety inspection.

### 2.2.2 Enterprise Supervision and Management

The influencing factors of enterprise safety management include the problem-solving situation of safety feedback, the inadequate state of supervision, the state of safety accident supervision and the frequency of safety education. The security problem reported by employees is the most important warning, and attention should be paid to the supervision and management process. At work, try not to miss, to enforce the law to correct violations of regulatory intervention, more can't be forced to work at risk. Regulators do not strictly supervise the inspection of miners' work in accordance with relevant safety regulations and standards, which is a state of inadequate supervision. In addition to adequate supervision, managers should be more reasonable in making plans and inspecting the work of employees. The plan of combining employees with the work environment is an effective plan. It is necessary to make clear division of labor in a reasonable division of labor. Improper and defective managers' work plan will lead to safety accidents, such as heavy workload, improper staffing and scheduling, and speeding up the pace of tasks for profit. The regulator rationally arranges the safety education frequency of the staff and can't ignore one of the safety education links in the absence of safety accidents. This is not only conducive to reducing the rate of safety accidents, but also conducive to the cultivation of the cultural atmosphere of the enterprise.

#### 2.2.3 Precondition for Unsafe Behavior

The precondition factors of unsafe behavior are divided into the state of safety, the insecurity of human beings and the improper operation of human beings. These three factors combine people, things and rings. The state of the equipment, the working environment and the technical environment are summarized in the safety environment. The three points complement each other together. The state of equipment and the state of work environment are closely related to the level of enterprise resource management. People are divided into willpower, attention to safety, individual body state and mental state because of unsafe state. The mental state, body, and acceptance of the employees are all different from person to person. These factors affect employee safety behavior. On the technical level, personnel should be reasonably arranged to engage in reasonable work. The task technology and operation ability exceed the employee's technical ability, which will cause the hidden danger. Employees should be trained before their homework, and they should be guided by their predecessors. It is also important to emphasize that the staff should get a good rest before they get on the job. This shows the need for a reasonable shift in the supervision of the enterprise.

#### 2.2.4 Unsafe Behavior

The emergence of unsafe behavior is inseparable from the above three points. The classification of unsafe behavior by scholars at home and abroad is different. From the above three points, it is summed up as managers' behavior factors, equipment factors, environmental factors, staff and managers' psychological factors and employee behavior factors. This paper sets three monitoring values that affect the level of unsafe behavior. They are the target value of the accident control, the rate of violation and the rate of safety accident.

## 3 Dynamic Analysis of Enterprise Unsafe Behavior System

### 3.1 Analysis of Cause and Effect Relationship of Multi-level Analysis Method for Enterprise Unsafe Behavior

The last chapter uses the multi-level analysis method and the Reason model to get the HFACS model that affects the unsafe behavior of the enterprise. This chapter combines the system dynamics to build an enterprise unsafe behavior HFACS multi-level analysis method of causality diagram, as shown in the following Fig. 1.

Three causal relationship feedback paths are summarized from the above figure, which represents the negative correlation and the + represents the positive correlation [10]:

(1) Level of organization's safety → − Level of unsafe behavior → − Level of organization's safety。
(2) Level of organization's safety → + Level of supervision and management → − Precondition state of unsafe behavior → − Level of organization's safety。
(3) Level of organization's safety → + Level of supervision and management − → Level of unsafe behavior → − Level of organization's safety。

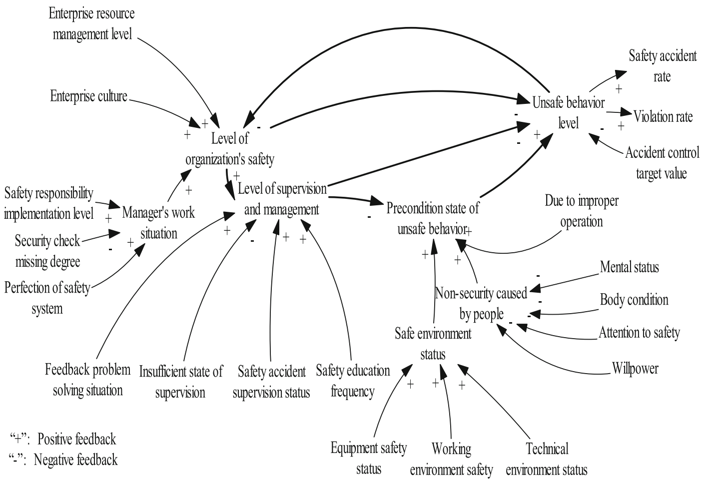


**Fig. 1.** Enterprise unsafe behavior HFACS multi-level analysis method of causality diagram

### 3.2 SD Model Simulation Construction of Enterprise Based on Multi-level Analysis of Unsafe Behavior

In the causality diagram obtained by the multi-level analysis, we summarize the three kinds of parameter types: the state variable, the flow rate variable and the auxiliary variable in the SD model diagram of the unsafe behavior.

The state variables are the state expression of the first to fourth layers of the multi-level analysis, respectively. The state variables of this paper are the level of the security state of the organization, the level of unsafe behavior supervision, the precondition state of unsafe behavior and the level of unsafe behavior.

The flow rate variables are the unsafe state variables of the organization, the increments of unsafe supervision, the increase of unsafe behavior factors and the increment of the precondition of unsafe behavior.

The auxiliary variable initial organization and enterprise resource management level and management work, enterprise culture, the implementation of security responsibilities, safety inspection, safety degree of lack of perfect system, safety accident rate, initial safety accident control target value, violation rate, supervision, feedback, solve the problem of initial safety accidents, state supervision the regulation is not fully state safety education, frequency, due to improper operation, willpower, attention to safety, physical condition, mental state, security environment, work environment, technology environment and equipment state environmental safety. There are 24 auxiliary variables in this paper. The following figure is the SD model flow chart based on the multi-level analysis of unsafe behavior (Fig. 2).

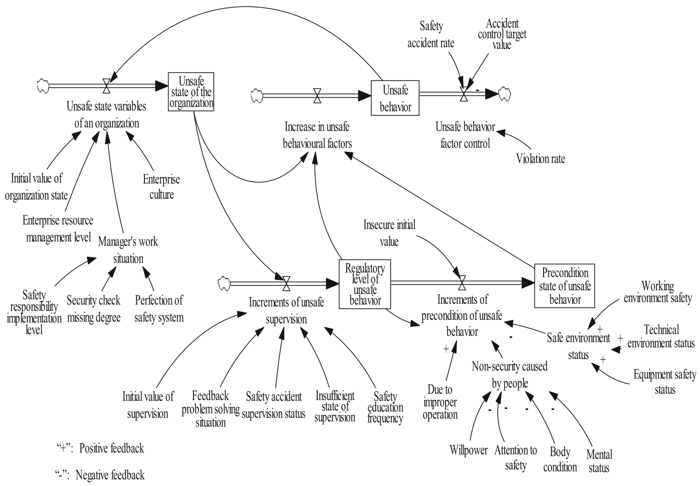


**Fig. 2.** SD model flow chart based on the multi-level analysis of unsafe behavior

## 3.3 SD Model Simulation of Enterprise Based on Multi-level Analysis of Unsafe Behavior

### 3.3.1 The Setting of the Initial Value of the Simulation Parameters of the SD Model

In the study of system dynamics, the initial values and related parameters of some auxiliary variables and factors are necessary to simplify the model. According to the established good business model SD flow chart of unsafe behavior based on AHP, determine the initial value of the state variable four: organizational insecurity, unsafe behavior, the unsafe behavior supervision level condition of state and unsafe behavior level.

In order to better investigate the influence factors of the unsafe behavior of the employees, we have also issued and collected the questionnaires in the enterprises in Shandong province of China. The results of the collection are set by statistical processing as the initial values of the state variables of this paper. A unified summary of 108 questionnaires on the leadership level was carried out, and the 0–4 scores were calculated according to the five components of Likert. The results are obtained by the proportion of the statistics. The proportion of four states is 1:3:3:2. The model is applied to DPS data processing module in Vensim. In vensim, the initial values of the model based on the proportion are 10, 30, 30 and 20. To analyze the result which state affects more effective in enterprise insecurity, this paper adopts contrastive analysis. The first case, all the conditions don't be changed and it is called enterprise safety original condition; second case, the organizational safety level in the enterprise is be changed, which increases 0.1; third case, supervision and management level of the enterprise is changed, which increases 0.1; the last case, we change the unsafe condition of state level, which will reduce the 0.1. Four cases reflect the situation, namely the simulation graph model to do comparative analysis. The conclusion can be drawn from the simulation diagram of the simulation experiment and the safety state of the organization.

The simulation time increases month by month, and the interval is 1 months. In the period of 0–3 months, the enterprise unsafe behavior showed a decline trend and the decline trend was slow, and the state of the four conditions was consistent. When the simulation was carried out in third month, the change curve of the simulation results showed a serious decline. In the meantime enterprise increased management efforts and causes of safety accidents on can be played “intervention foresight”. So employee’s unsafe behavior has inhibitory effect. From the fourth month, the staff of unsafe behavior is on the rise, which indicates that the employee has to adapt to the current management mode, or safety awareness is lax. It is also possible that the enterprise management level of loopholes or inadequate or work environment appears more difficult to cope with the problems and hidden trouble. In the simulation, one condition is changed and the other remain unchanged and the simulation experiment in the set change was 0.1 dimensionless units. It consists of 4 kinds of simulation results under the situation of dynamic curve and the organizational safety level is the most effective, followed by the enterprise supervision management level, finally the state is the unsafe condition of state level. This result is identical to previous paper. This result shows that the most fundamental is the organizational safety. The defect of tissue layers and unsafe state will affect the state of safety supervision and the formative factor of unsafe behavior and a series of conditions. Eventually all reasons lead to unsafe behavior of enterprises.

## 4 Research on the Factors Affecting Employees’ Safety Behavior

### 4.1 The Establishment of Structural Equation Model

This paper also wants to explore which factors that affect the state of organizational security in the organization state of unsafe behavior of enterprises have great influence on employee safety behavior. The questionnaire is modeled by the structural equation model (SEM), and the quantitative analysis and empirical study are carried out. The object of the survey is a staff member from a Shandong province of China. The factors that affect the safety behavior are arranged, and 20 observational variables are designed. As the observation variables of 4 latent variables, latent variables are divided into endogenous latent variables and exogenous latent variables. Three of the endogenous latent variables are employee safety literacy $(\eta_1)$, internal factors $(\eta_2)$ and enterprise management factors $(\eta_3)$. They are endogenous latent variable of this model and external environmental factors is exogenous latent variable.

The main analysis of this paper is the enterprise management factors of enterprise management factors $(\eta_3)$. Endogenous latent variables related to the state of the tissue are $X_{15,}$ $X_{16,}$ $X_{17,}$ $X_{18,}$ $X_{19}$ and $X_{20}$.

The following Table 1.

$X_{1,}$ $X_{2,}$ $X_{3,}$ $X_{4,}$ $X_5$ are endogenous observation variables related to employee safety literacy;$X_{6,}$ $X_7$, $X_8$, $X_9$ are endogenous variables related to employees; $X_{10}$, $X_{11}$, $X_{12}$, $X_{13}$, $X_{14}$ are exogenous observation variables related to the external environment; $X_{16}$, $X_{17}$, $X_{18}$, $X_{19}$, $X_{20}$ are endogenous observation variables of enterprise management factor.

**Table 1.** The variable variables related to the state of the organization.

| Variable name | Observation variable |
|---|---|
| $X_{15}$ | Degree of safety plan perfection |
| $X_{16}$ | Perfection of safety system |
| $X_{17}$ | Resource management level - rewards and punishments |
| $X_{18}$ | Resource management level - investment in production capital |
| $X_{19}$ | Safety supervision |
| $X_{20}$ | Safety education frequency |

The questionnaire was used by the Lee Kate LIKERT five component table, which was 4, 3, 2, 1, and 0. A total of 962 questionnaires were distributed in the survey. There were 657 valid questionnaires with the total number of invalid answers and the same answers. The effective rate was 68.7%. The effective questionnaire of the staff is 492. All the data of the questionnaire is completed based on SPSS19.0 software reliability test, reliability test of Cronbach coefficient and obtained the results of 0.871, said the survey results are reliable; on the endogenous variables of enterprise management factors for reliability test using SPSS19.0 software, obtained the results of reliability coefficient test results of Cronbach 0.816.

According to the latent variables and the observed variables, the measurement equation and the initial model of the structural equation are constructed respectively.

$$\begin{bmatrix} \eta_1 \\ \eta_2 \\ \eta_3 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ \alpha_{21} & 0 & \alpha_{23} \\ \alpha_{31} & 0 & 0 \end{bmatrix} \begin{bmatrix} \eta_1 \\ \eta_2 \\ \eta_3 \end{bmatrix} + \begin{bmatrix} \varphi_1 \\ \varphi_2 \\ \varphi_3 \end{bmatrix} \mu + \begin{bmatrix} \mu_1 \\ \mu_2 \\ \mu_3 \end{bmatrix} \tag{1}$$

$\xi$ and $\eta$ (i = 1, 2, 3) as exogenous latent variables and observation variables $x$ and $y$ and the endogenous latent variable, $\alpha_{21}$, $\alpha_{23}$ and $\alpha_{31}$ represents the endogenous effects between latent variables, $\phi_i$ (i = 1, 2, 3) said the effect of exogenous latent variables to endogenous' latent variables. $\mu_i$ (i = 1, 2, 3) said the error term endogenous latent variable. The measurement equation of the endogenous latent variable $y$.

$$y = \begin{bmatrix} 1 & 0 & 0 \\ \lambda_1 & 0 & 0 \\ \lambda_2 & 0 & 0 \\ \lambda_3 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & \lambda_4 & 0 \\ 0 & \lambda_5 & 0 \\ 0 & \lambda_6 & 0 \\ 0 & \lambda_7 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & \lambda_8 \\ 0 & 0 & \lambda_9 \\ 0 & 0 & \lambda_{10} \end{bmatrix} \eta + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \varepsilon_4 \\ \varepsilon_5 \\ \varepsilon_6 \\ \varepsilon_7 \\ \varepsilon_8 \\ \varepsilon_9 \\ \varepsilon_{10} \\ \varepsilon_{11} \\ \varepsilon_{12} \\ \varepsilon_{13} \end{bmatrix} \tag{2}$$

Among them, $\lambda_i$(i = 1, 2,… 10) the path coefficient between the endogenous latent variable and the endogenous observation variable, $\varepsilon_i$(i = 1, 2,…, 13) the error term of the endogenous observation variable is expressed. The measurement equation of the exogenous latent variable $x$.

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 1 \\ \lambda_{11} \\ \lambda_{12} \end{bmatrix} \mu + \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \end{bmatrix} \tag{3}$$

Among them, $\lambda_{11}$ and $\lambda_{12}$ represent the path coefficients between the exogenous latent variable and the external observation variable, and $\delta_1$ and $\delta_2$ represent the error term of the external observation variables.

The collected data were compiled by Microsoft Excel 2010, LISREL8.7 and the maximum likelihood estimation. In this paper, the parameters of RMSEA, CFI, NFI and IFI are selected to test the fitting effect of the model. After LISREL software operation, the maximum likelihood estimation fitting method is applied to standardize and correct the path coefficient and load factor. All parameters are up to the expected standard. The parameters are shown in Table 2 as follows. In the modified SEM model, the weights of the observed variables are shown in Table 3 as follows.

**Table 2.** Fitting index of modified SEM model

| Goodness of fit index | RMSEA | CFI | NFI | IFI |
|---|---|---|---|---|
| Estimated value | 0.072 | 0.91 | 0.90 | 0.91 |
| Fitting standard | $\leq 0.08$ | $\geq 0.9$ | $\geq 0.9$ | $\geq 0.9$ |

**Table 3.** Modified Variable weights

| Variable name | Weights |
|---|---|
| $X_{15}$ | 0.44 |
| $X_{16}$ | 0.46 |
| $X_{17}$ | 0.36 |
| $X_{18}$ | 0.34 |
| $X_{19}$ | 0.34 |
| $X_{20}$ | 0.40 |

## 4.2 Analysis of the Path Diagram of Structural Equation

The relationship between corporate governance factors and observation variables you can visually see the order of observation variables affect the enterprise management factor in the SEM flow chart: the degree of perfection of security system (0.46), the degree of perfection of the security plan (0.44), (0.40), the frequency of safety education resources management level of punishment (0.36), resource management the production of capital investment (0.34), safety supervision (0.34). Among them, the degree of perfection of the safety system in the organization safety state is the largest, followed by the safety plan's perfection level. This also shows that in the employee's perspective, the safety state of the organization indirectly determines the safety state of the employees. The two factors that have the greatest impact on employees can be obtained from the results.

## 5 Conclusion

This paper is based on HFACS and SD model that construct the causal relationship diagram of multi-level model of unsafe behavior in HFACS. According to SD model simulation of enterprise based on multi-level analysis of unsafe behavior, imitated diagram can be concluded that ensuring the organizational safety is the most effective way to reduce safety accident rate. In summary, the premise of safety is to ensure the safety of the organization. Enterprises should improve the relevant production rules and regulations. In formulating production plans and rules and regulations, enterprises should consider whether the production plan is reasonable and pay attention to the solution of employee feedback problems and increase the frequency of safety education.

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# Accident Prevention

# A Study on the Quality of Information in Potential Incident Report

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**Abstract.** In corporate safety activities, it is necessary to pay attention not only to the number of incident reports, but also to the quality of information of incident report. In this research, based on the experiment, we have created the evaluation axis of the information quality in the incident report. The evaluation axis is the measurement axis relating to the information amount and the measurement axis relating to the breadth of the information viewpoint. When applied to incident report collected by enterprise, relevance was observed between application result and safety activity or safety activity consciousness survey result and validity of evaluation axis was shown.

**Keywords:** Potential incident report · Safety management · PSF

## 1 Introduction

Measures against major dangers and risks that companies have been subject to safety management activities are being developed. For that reason, it is necessary for the company's management strategy to redefine events that would impair the customer's sense of security and confidence as small dangers and risks and to work on safety management activities.

Among various company's safety management activities, efforts specifically targeted by this research are "prevention of accidents and prevention of recurrence of accidents using potential incident information".

As a result of investigating the existing potential incidents information analysis method, it turned out that analysis methods using various means have been studied. At the same time, it turned out that it is a large premise that it is assumed that the information to be submitted as potential incident information shall be handled as one piece of information of the same information quality as the analyzing method of them. "Quality of information" means "Whether a wide range of factors/points are included when submitting potential incident information". The purpose of utilizing potential incident information is prevention of accidents and prevention of reoccurrence of accidents. The more root cause of how the potential incident happened, the easier it is to discover, the more useful it is for prevention of accidents and prevention of recurrence of accidents.

When the premise that the potential incident information is of the same quality is sufficiently established, the existing potential incident analysis method is effective. However, the quality of potential incident information that is actually submitted will


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differ depending on the experience and knowledge of the entrant, education received, consciousness for safety activities, etc.

In order to write potential incident information that can grasp the root cause factors, it is necessary to have a deep understanding about daily work and awareness of minor change. That is, not everyone can write such potential incident information. Therefore, it is easy to submit many incorrect information in which factors that are not root cause factors are written. For this reason, information with root cause factors is buried and it can not be used for safety management activities. Therefore, it is very important to consider the quality of potential incident information, and if you can create an axis that considers the quality of potential incident information, it will be possible to analyze potential incidents from new angles. I think that better support can be made for such utilization of potential incident information. This is the object of this research. An expert who submits potential incident information on the job site often has to submit information of high quality of information based on his extensive experience. Therefore, we try to make the difference in descriptions of potential incident information according to experience as the evaluation axis as the difference in quality of potential incident information.

## 2 Experiment

### 2.1 Experiment Reason

In order to extract the difference in descriptions of potential incident information according to the experience of the registrant, potential incident information described by a wide range of people from expert employees to young employees is necessary. However, the following problems are considered.

1. There is no clear criterion on how to judge experienced and non-experienced people.
2. When trying to extract trends and features from potential incident information, the majority of people actually submitting potential incident information are workers in the field. Because there are not many cases where experienced supervisors or people in the upper position are submitting potential incident incidents, it is highly likely that sufficient trends and features cannot be extracted.
3. In extracting the difference in the description, there is a possibility that the magnitude of the event is small in the potential incident event and it is difficult for the writer to make a difference.

The following solutions to these problems are listed.

<Solution for Problem 1>
We consider that there is a high correlation between the height of position and the degree of abundance of experience.
<Solution for Problem 2>
Ask people in a wide range of positions to participate in factorial analysis experiments that can be substituted for acts that describe potential incident information.
<Solution for Problem 3>
Make the subject of the experiment not a potential incident case but an accident case.

Based on the above, in order to extract differences in descriptions of potential incident information according to the experiences of the entrant, "Experiment analysis of accident cases for people with a wide range of positions" will be conducted as experiments.

## 2.2 Experiment Method

In this experiment why-why analysis was chosen as a method of accident factor analysis. The subjects dealt with when conducting the experiment are about familiar troubles cases in each company (Table 1).

The experiment participants are as follows. (The companies that participated in the experiment are three railway companies and one oil refining company, one system integrator, one medical hospital group).

**Table 1.** Subject's position and number of people.

| Position | Criterion | Number of people |
|---|---|---|
| Student | No experience of safety activities | 32 |
| Employee | Engaged in safety activities on site | 112 |
| Section chief | Guidance on safety activities on site | 96 |
| Chief clerk | Guidance on safety activities at multiple sites | 54 |
| Section chief | Guidance on safety activities throughout the organization | 42 |

The flow of the experiment was as follows. (About 2 h as a whole, 10 min break)

1. Have a subject of the same position have two people.
2. Distribute one imitation paper, 50 post-it and data on accident cases to each group.
3. Explain the experiment and accept questions. (10 min)
4. Read the accident case, organize the case among the two subjects, and have common recognition. (40 min)
5. After understanding about the case, write the event that most adversely affected the case as a top event, write it in post it, why analyze. (60 min)
6. As a first phase, write three factors that caused the event to the top event.
7. As a second phase, write three further factors for each factor mentioned in 7.
8. As a third phase, write three further factors for each factor mentioned in 8.

In this way, we have a total of 40 post-it on the imitation paper.

The purpose of this experiment is to extract differences in descriptions of potential incident information by job position. For that reason, we aimed to make deeper analysis possible and make it easy to extract the features and differences of the description by having two people doing experiments, not alone.

When describing it in post-it, we aimed to make it easier to extract the features and differences of the description by recommending more than 30 letters on one. (It was left to the subject himself whether or not to write more than 30 characters actually).

If we do not extract differences in descriptions from sentences written in various expressions, there is a possibility that the tendency of descriptions by accident cases as subject matter may become stronger, so we accepted not only the description of the facts, but also the description by the subject's imagination (to some extent practical).

In actual experiments, there were teams that were unable to write 40 copies within a group depending on the group, but the group submitted up to the writing as deliverables.

## 2.3 Experiment Result

As a result of the experiment, 248 sheets of imitation paper (8297 post-it) were collected. The data was divided for each job position of the subjects, and the characteristics of the description of each position were extracted for each imitation paper. Below is shown the number of imitative paper and post-it for each position (Table 2).

**Table 2.** The number of imitation paper and post-it for each position

| Position | Imitation paper | Post-it |
|---|---|---|
| Student | 86 | 3067 |
| Employee | 56 | 1853 |
| Section chief | 48 | 1610 |
| Chief clerk | 27 | 949 |
| Section chief | 21 | 818 |

When extracting features, we extracted the difference in expression (high quality of information) that appears as the position rises. The table below summarizes the experiment results listed in Level 1 to Level 5 featuring differences in expression taking account of differences in experience due to positions, with reference to Human Factors' past studies and perspectives.

**Table 3.** Summary of experiment results

| | Features on words and expressions | Features related to information volume | Items related to the field of view |
|---|---|---|---|
| Level 1 | • Many misunderstandings<br>• Abstract feelings are abundant such as troublesome and disgusting<br>• Many descriptions about physical condition such as illness and cold<br>• Represent an inconvenient event as a mistake<br>• Many factors related to the weather | • Describe the situation briefly in a single word<br>• Many factors that are not specifically written on what kind of rules or manuals<br>• Many cases where the subject of action is not written | • Few descriptions of management system and facilities<br>• Many factors related to individuals |

(*continued*)

**Table 3.** (*continued*)

| | Features on words and expressions | Features related to information volume | Items related to the field of view |
|---|---|---|---|
| Level 2 | • Many descriptions of education, experience, lack of skills<br>• Many words about equipment and environment | • Descriptions about not only the accident parties but also colleagues around them | • Few descriptions about teams and organizations as a whole<br>• A lot of descriptions about individuals<br>• Some Factors at the time of the accident<br>• Few factors written about daily work |
| Level 3 | • Many words related to others such as communication, instruction, contact<br>• Many words such as manuals and checklists | • Many factors that involve multiple stakeholders<br>• Many subjects of work<br>• The inside of the worker. | • In addition to personal description, factors related to people's cooperation are present<br>• Many descriptions about facilities and human description |
| Level 4 | • Not many factors such as human resources shortage and equipment shortage that require money<br>• Many words about information sharing such as reporting and public knowledge<br>• Factors that make it relatively easy to improve daily work have come up | • Many cases where sentences are plural<br>• Many subjects<br>• Multiple people are appearing at the same time | • Analyzing from the work flow widely rather than when the accident occurred<br>• Imagining and writing people and situations that is not in the case |
| Level 5 | • Many things represent the context of events<br>• Many reasons and backgrounds written up to the inner circumstances of workers<br>• What kind of confirmation or check is written<br>• Using [] or () for supplementary explanation<br>• Experience, age and work situation are written about the characters | | • Many of the daily tasks are described and it is not only specific situations at the time of the accident<br>• It is written on a single imitation paper with a wide perspective such as equipment, environment, communication |

The experimental results are summarized from three items.

1. **Features on words and expressions**
   Items with many specific words or specific factors appearing.
2. **Features related to information volume**
   Items related to the amount of information and the number of characters for one post-it.
3. **Items related to the field of view**
   Item on whether it is described from various viewpoints on imitation paper.

From the table summarizing the experimental results, you can see 4 points A to D.

(A) With regard to Level 1 to 4 of features relating to words and expressions
Regarding Level 1 to Level 3 related to words and expressions, since there are not many characters yet, there are many features about words rather than expression. Also, at Level 4, features related to words appear somewhat.

(B) With regard to Level 1 to 4 of features relating to information volume
Regarding the amount of information, features such as the subject, the details of stakeholders and events, the background and the feelings of the worker are written in the sentence.

(C) With regard to Level 5 of features relating to words and expressions and information amount
There are almost no features about words, and there are many features about expression. Along with that, many features that can be regarded as features related to expression and features related to information quantity are often presented.

(D) With regard to features about the field of view.

As the level goes up, it has been analyzed from various perspectives such as people, equipment, communication and organization.

Based on the experimental results, we prepare the measurement axis of quality of potential incident information as a program. First, we focus on features related to words and expressions and features related to information volume.

In Level 5 of Table 3, there were some features that can be interpreted both as features related to words and expressions and features related to information volume. Also, when measuring the quality of incomplete hat information, it is not sufficient to evaluate by simply judging whether there is a keyword or not.

Therefore, one evaluation axis reflecting two of the features related to words and expressions and the feature related to information volume is created by using the word level defined with reference to Nagata, Yukimachi (2005). For the measurement of information volume, we also use the number of characters. The evaluation axis is {0, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5} in total of 10 stages. This evaluation axis is named Level-Point.

Next, we focus on features related to the field of view. The PSF that fits each category of 4 M (Man, Machine, Media, Management) is extracted from the GAP-W type reference list (Yukimachi, Nagata 2004), and PSF of the individual and organizational PSF are added, and it is judged by the keyword list. The evaluation axis is {0, 1, 2, 3, 4} in total of 5 stages. This evaluation axis is named Balance-Point.

## 3 Application Result of Evaluation Axis

The data on companies that provided potential incident information for applying the evaluation axis created this time are as follows (Table 4).

**Table 4.** About companies

| | Industry | Number of employees |
|---|---|---|
| Company A | railway | 9,289 |
| Company B | oil refining | 363 |

Evaluation scores were calculated as "Potential incident information measurement score" = "Level-Point" + "Balance-Point".


**Fig. 1.** Application result of Company A

Company A has focused on safety activities for about 10 years ago, and about 40% of all employees participate in a workshop to think about the safety activities planned by the head office. In the workshop, we have opportunities to consult external experts regarding safety activities, we conduct factor analysis exercises against accidents, and all departments participate in the consultation meeting. It can be considered that the reason why the potential incident information measure score is increasing is because the safety activities are being promoted as such company-wide efforts (Figs. 1 and 2).

Company B lectures on young scientists directly on Human Factors and develops human resources. In the department u, there are 26 people (61 people in all, 47%) who listened to lectures, whereas 6 people (28 people in total, 23%) in the department t. The result of department u that education is beginning to penetrate is that the proportion of high quality potential incident information has increased and the department t that did not fully penetrate education seems to have not increased.


**Fig. 2.** Application result of Company B

# 4 Consideration on Application Result

## 4.1 Relationship Between Applied Results and Safety Consciousness

Company A and Company B have conducted safety consciousness surveys called Human Error Management Assessment System (HEMAS) for all employees. HEMAS is a method for employees to answer questionnaires on consciousness surveys consisting of 55 questions and to sum up the results.

The figure showing the relevance between the question items expected to be related to the improvement of the information quality of the potential incident and the actual application result is as follows.

The application result and the result of the safety consciousness survey show similar trends, and it can be confirmed that the evaluation axis created this time is valid.

In addition, in Fig. 3, the points surrounded by the orange ellipse (Company B department u 2012 → Company B department u 2014) are scored higher. This is because early education for young workers in the field who fill in potential incident information throughout the organization is penetrating.

In other words, it is suggested that it can be an indicator to measure what kind of activities are actually more effective against safety management activities.

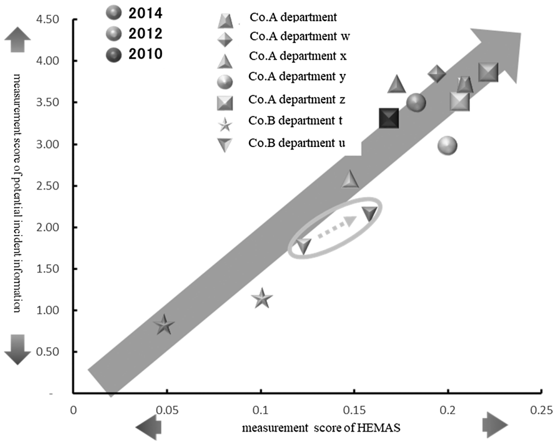


**Fig. 3.** Relationship between application results and HEMAS

## 4.2 Relationship Between Applied Results and Safety Consciousness

The figure below shows the application result after classifying the department u of Company B by length of service (Fig. 4).

Because young employees who actually receive education at department u are focused mainly on employees with less than 3 years and 5 years of service, in the results of employees with less than 3 years of service and employees with less than 5 years of service, the proportion of low quality potential incident information is decreasing. Because there is no education for people over 10 years, there are few potential incident information with low quality, but there is no change. The effectiveness of safety education has been visualized by measuring the quality of potential incidental information.

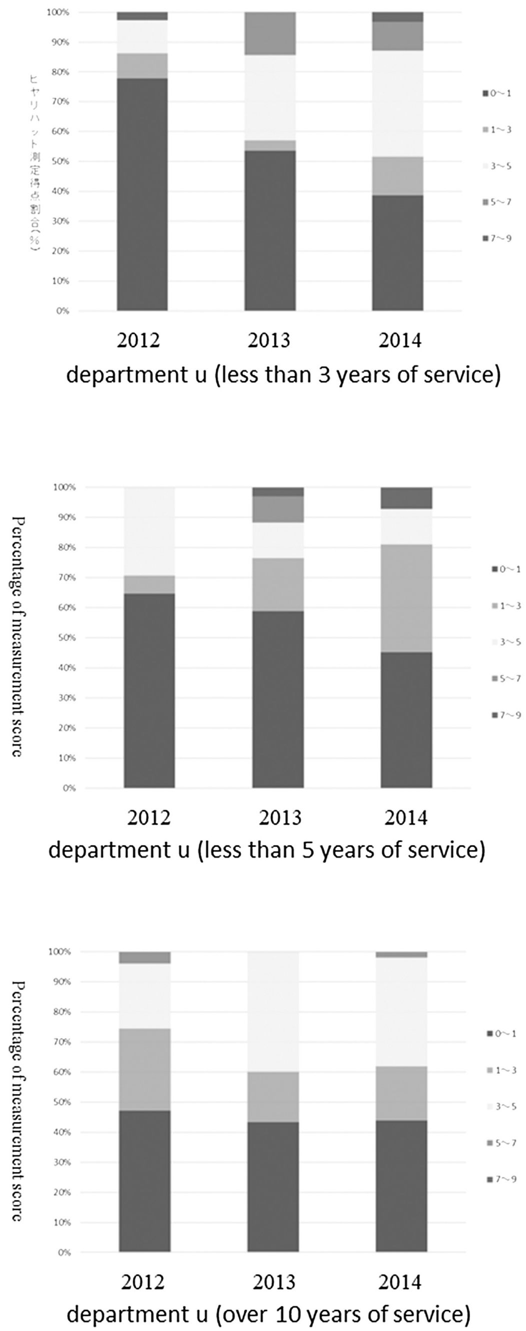


**Fig. 4.** Application results by length of service

## 5 Conclusion

We created the measurement axis of potential incident information taking into consideration the quality of potential incident information. As a result of applying the created evaluation axis to the actual potential incident information, the relevance to the questionnaire on safety consciousness survey was confirmed. Therefore, this study suggested that safety activities that could be evaluated only at conscious level until now could be evaluated at the activity level. In other words, it was possible to analyze from new angles for potential incident information.

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# Analysis and Investigation of Work Accidents at a Portuguese Municipality

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**Abstract.** This study intended to analyze and investigate a set of workplace accidents that occurred in a Portuguese Municipality. The investigation focused on the accidents that took place within the Waste Collection Division of the Department of Urban Hygiene and covered a three-year period (2014 to 2016) using a formal and structured process - the RIAAT method (Recording, Investigation and Analysis of Accidents at Work). The RIAAT process included the reclassification and recoding of 109 accidents and the in-depth investigation of 19 accidents. The most frequent type of accident and the main factors that effectively contributed to the occurrence of the accidents were highlighted. Finally, the results were compared to those reported by *Gabinete de Estratégia e Planeamento* for a similar sector. The main variables assessed showed a very similar behavior.

**Keywords:** Occupational accidents · RIAAT · Organizational learning
Accidents' investigation · Waste collection

## 1 Introduction

According to the official reports, the number of registered accidents has been increasing in Portugal since 2012. The last reported data show that in 2015, 208,457 work accidents occurred in Portugal and around 22.1% of them produced more than 30 lost days/person/year [1]. These results are in accordance with those of 2014 [2].

As reported by Fonseca et al. [3], it is recognized that accidents at work can cause, currently, damages not only to the workers but also to the State and to the organization where they occur. Then, knowing their causes demonstrates to be extremely important to prevent them [3]. Plus, as stated by Jacinto et al. [4], regardless of the occurrence of accidents at work be recognized as the oldest topic in safety science, it still is a central focus of today's agenda, probably due to the ever-increasing social pressure towards accident prevention. These authors reinforce that not many organizations investigate the occurred accidents and incidents, particularly when severity is low. Additionally, they highlight that when workplace accidents are analyzed, the investigation is usually superficial and made in an ad hoc basis [5].


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In Portugal, despite of the legal obligation of accident analysis (article 98° in Lei n° 102/2009 de 10 de setembro) its investigation is also recognized as an important matter to improve procedures and work practices associated with risk assessment and control processes [6].

During the last decades, accident causation models evolution have shown a gradual shift from the sequence of events to the representation of the whole system, which means that they no longer rely on a linear sequence of events (searching for a single immediate cause to the recognition of multiple causes) [7]. This new trend is accepted by several authors and highlights that both managerial and organizational failures and their interactions with the working activities have become an important issue for the understanding of accidents [8]. Some models, such as the one used in this study, also make a distinction between active failures and latent conditions.

This study took place in the Municipality of Oeiras (CMO), in Portugal, and intended to analyze a set of workplace accidents. The main objective of the study was to conduct an in-depth analysis of work-related accidents, in order:

- to identify trends among occupational accidents, namely find if they are within an acceptable range;
- to characterize the main accident causes (human errors, individual factors, workplace factors, and the organizational and management factors);
- to assess safety performance by comparing the results with reference patterns;
- to disseminate good working practices.

Consequently, it was aimed to go beyond the legal requirements in force in Portugal, integrating the investigation, applying formal and structured methodologies capable of systematizing research and improving communication and transparency of the process, which have been highlighted as a relevant step towards the optimization of existing control measures [5].

# 2 Methodology

## 2.1 Stages of the Study

This study comprised three fundamental stages. Table 1 shows the main objective and tasks of each stage.

## 2.2 Data Collection and Procedures

According to the specificity of the stage, different methods and tools were used for data collection. The first stage included meetings with the Health and Safety Department, documental analysis (e.g. occupational accidents reports and indexes, task procedures, risk assessment reports, etc.); workers query actions, and, conversation with workers and observations of the tasks accomplishment.

In the second stage, we resorted to the RIAAT method to analyse workplace accidents that occurred in the WCD. This method was the output of the CAPTAR project (Learn to prevent), in 2010, and was meant to be applied in the organizations,

**Table 1.** The main objectives/tasks of each stage of the study.

| Stage of the study | 1st stage | 2nd stage | 3rd stage |
|---|---|---|---|
| Main objectives | Characterization of the CMO | RIAAT application | Analysis and discussion of the results |
| Main tasks | General characterization of the institution regarding work-related accidents<br>Detection of significant changes in the number of occupational accidents and discover whether they are within an acceptable range<br>Selection and characterization of the Waste Collection Division (WCD), from the Department of Urban Hygiene (DUH) | Reclassification and recoding of the accidents that occurred in the WCD, with a formal and structured process available in the literature<br>In-depth investigation of the accidents | Characterization of the main accident causes (human errors, individual factors, workplace factors, and organizational and management factors)<br>Comparison of the results with reference patterns<br>Proposal of preventive measures such as technical and organizational ones, taking in account the identified failures |

regardless of their size or activity sector [4]. Nevertheless, its main targets are SME. The following facts supported the decision to use this particular method [6]:

- It has the ability to find causes at different levels of the organization, which makes the analysis much more realistic and robust;
- It is considered a practical and structured tool, applied to learn from accidents and develop new prevention strategies;
- The Portuguese Authority for the Working Conditions (ACT) tested it.

Moreover, according to the authors, the method should be applied by occupational safety and health professionals, which make the necessary recommendations afterwards to improve safety [9].

After a general analysis of the work-related accidents that occurred in CMO (1st stage), the WCD from the DUH was identified as the most critical area. The RIAAT method (reclassification and the in-depth investigation) was applied to the accidents registered at the WCD between 2014 and 2016.

A complete description of the RIAAT method can be found in articles written by Jacinto et al. [4, 9] and Fig. 1 shows the four parts of the process.

The first part is harmonized with the European Statistics of Accidents at Work variables (ESAW) [10] and is named Recording. In this part, the accident analysis integrates the variables resulting from the active failures that caused it, which allows defining an accident Type.

The second part integrates the identification of the latent failures, which are the causes of human errors, work place factors and management factors that contributed to

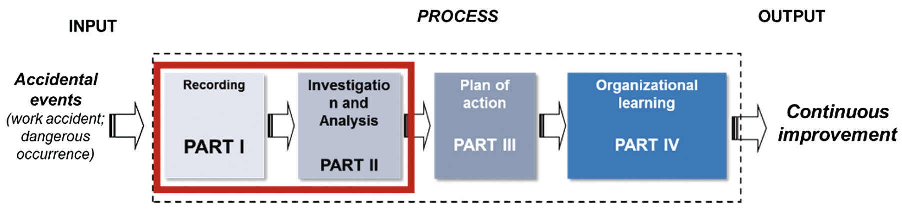



**Fig. 1.** The RIAAT process and identification of the parts applied in this study. Adapted from Jacinto et al. [4].

the accidents. In-depth level of this analysis could range from medium to high, depending on the severity of the accident.

The third part integrates the action plan, which defines where changes and improvement decisions are to be made, when and how they will be implemented and who will be responsible for them.

Finally, the fourth and last part, named Organizational learning, is the most important part to strengthening the loop of continuous improvement.

This study focused in parts I and II of the process, which are described in Table 2.

**Table 2.** Description of application of parts I and II of the RIAAT method.

| Part I | Part II |
|---|---|
| • Included the reclassification of 109 out of the 117 work accidents that happened at the DUH, particularly at the WCD | • Included the in-depth investigation of 19 work accidents, from the 109 accidents reclassified in part I<br>• The victims were informally interview and gave permission to record the conversation, facilitating the subsequent content analysis |

Note: Eight accidents were not analyzed because they did not match the criteria defined to the reclassification of RIAAT (incidents without any loss to the worker or to the organization).

Each Part of the RIAAT method (Part I and Part II) was applied with a variable in-depth level investigation, according to the learning potential of each accident analyzed. Despite this study were focused on the two first parts of the method, some suggestions for improvement are provided taking particularly in account the failures identified.

## 2.3 Data Analysis

Data processing relied on the Statistical Package for the Social Sciences (SPSS©) (version 23) and Excel 2016 and used measures of location and dispersion.

To detect significant changes in the number of occupational accidents and to ascertain whether they are within an acceptable range we used a statistical process control approach: control charts and cumulative control charts were produced. The first ones include three levels of sensitive (monthly, bimonthly and quarterly). Upper

(UCL) and lower (LCL) control limits (sometimes called “natural process limits”) were calculated with Eq. 1.

$$\overline{I_f} \pm 1.96 \times 10^3 \sqrt{\frac{\overline{I_f}}{NMHW}}. \tag{1}$$

Where:
$\overline{I_f}$ = *Previous year average Frequency Index*;
*NMHW* = *Number of Man-Hours Worked.*

The *Frequency Index* ($I_f$) was calculated considering all occurred accidents (with or without lost days) in a particular period per million of man-hours worked (Eq. 2).

$$I_f = \frac{Total\,number\,of\,work\,accidents}{NMHW} \times 10^6 \tag{2}$$

For the interpretation of data collected with RIAAT’s parts I and II, the Pareto principle was used as a reference allowing the identification of the main causes/consequences (depending on the analyzed variable) responsible/associated for/to approximately 80% of the accidents.

Due to the nature of the variables (ordinal and nominal) and the reduced dimension of the sample (N = 19) the non-parametric Kruskal-Wallis test was used, when relevant, in order to verify if there were significant differences of:

- The number of days lost between the work shifts in which the accidents occurred.
- The type of Failure among the age groups of the victims.

In all cases, a significance level of 0.05 was adopted as a criterion to reject the null hypothesis.

For the reclassification of work accidents, the following variables were considered in Part I of the RIAAT form: Victim’s age (A); Deviation (D); Contact - mode of injury (C); Part of Body injured (PB); Days Lost (DL); and Type of Injury (TI). The variable Victim’s age was analyzed taking into account the following six range groups, following the methodology adopted by GEP [1]: 18 to 24 years; 25 to 34 years; 35 to 44 years; 45 to 54 years; 55 to 64 years and over 65 years.

It is important to highlight that some variables were not considered, as they had no variation within the sample: gender, nationality; occupation, employment status and working environment.

Whenever appropriate, the obtained results were compared with data published in 2017 by GEP [1] concerning the economic activities defined as the letter E of the CAE/REV3, which include “collection, treatment and distribution of water; sanitation, waste control and remediation”.

# 3 Results and Discussion

Between 2014 and 2016, the CMO recorded 636 work accidents. From these accidents, 297 (≈47%) occurred at the DUH and 117 out of these (≈41%) happened at the WCD. In that period, the DUH had a labor force of 396 workers, of which 69% were male. The workers' age was between 35 and 54 years old and their seniority at work was above 10 years.

## 3.1 Work Accidents Data Analysis

In order to verify if the evolution of the occupational accidents frequency index was within an acceptable range, the statistical process control approach was used, as explained before.

Figure 2 shows the results obtained as control charts (left hand side) and cumulative annual control charts (right hand side). Despite of the run up of 4 that occurred in the last months of 2014, it did not turn into a trend. In fact, we can see that in 2014 and 2015 the number of accidents was according to expectations as the *monthly* $I_f$ was always between the UCL and LCL.

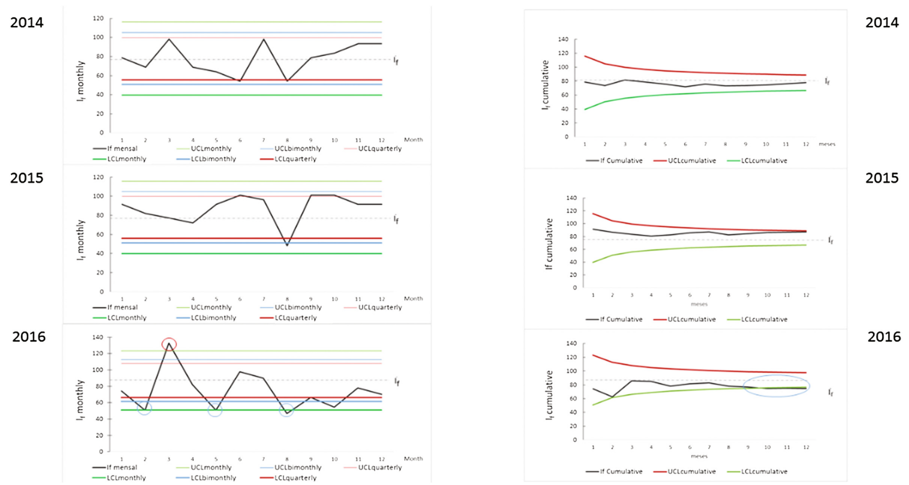



**Fig. 2.** Control charts (left hand side) and cumulative annual control charts (right hand side) per year.

In 2016 the *monthly* $I_f$ presents a more heterogeneous distribution with a peak in March, above all UCL. This result suggests that in this particular month work accidents were due to an unexpected external factor, possibly related to some sort of safety failure. Despite all investigation within the Health and Safety Department, nothing was found to explain this result. Furthermore, the *monthly* $I_f$ values were always within the control intervals or even under the LCL, which means that the adopted safety measures were effective. The results shown in the cumulative annual control chart corroborate this conclusion. From the cumulative annual control chart, it is noticeable that in the last quarter of 2016 the cumulative $I_f$ consistently lies outside LCL. Therefore one may forecast that most likely the cumulative $I_f$ will follow this trend.

### 3.2 RIAAT Results - Part I

Considering that the WCD was the area where the most severe accidents happened, it was decided that these should be the ones to be analyzed with the RIAAT method.

Figure 3 shows the distribution of the victims' age, in the WCD. The mean age of these workers was 46 years (range: 27–64 years). Compared to the data published by GEP [1], it is possible to notice that the age groups with the highest rate of accidents were the same, but with an inverted order. This distribution is in accordance with the workers' distribution by age group, in the DUH and globally in the CMO.

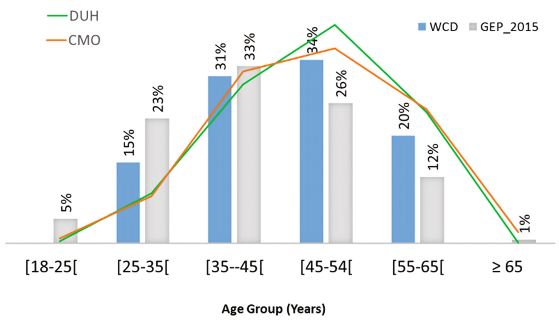


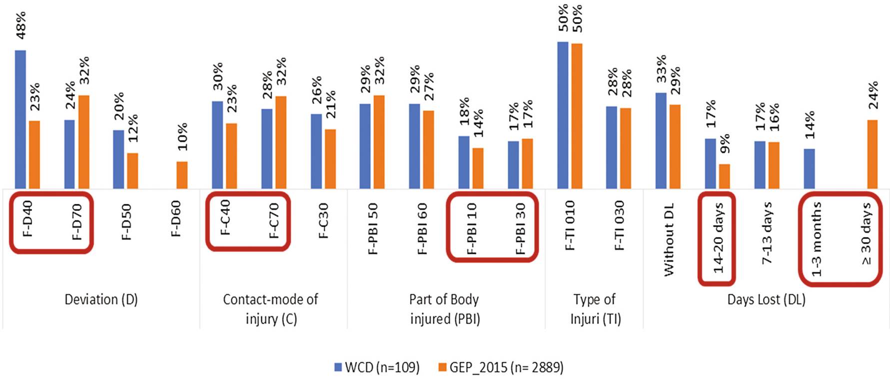

**Fig. 3.** WCD Workplace Accidents' distribution and GEP's data per age group (lines represent the workers distribution in the DUH and globally in the CMO, per age group).

The results for the variables Deviation (D), Contact - mode of injury (C), Part of Body injured (PB), Days Lost (DL) and Type of injury (TI) are summarized in Fig. 4.

To facilitate the presentation of the results, groups of variables were considered within each variable analyzed, following the methodology adopted in others studies [11, 12]. The Pareto Principle was used to analyze the obtained results.

The comparison between the results of this study and GEP's data [1] shows a similar pattern for all the assessed variables, which means that the same groups of variables were present in the majority of work accidents. Figure 4 shows the main groups considering the reclassified variables (Part I of RIAAT). Highlighted in red are the variables that appear in a slightly different order from that of the GEP's data [1].

After analyzing the results of RIAAT's part I we can say that there wasn't a well-defined accident type at the WCD. However, the typical accident can be described as the one that involved one man (100%), between 45 and 54 years old (34%), that was hit by a moving object (30%), possibly due to the loss of control of – materials, objects, products, machine parts, etc. (47%), that caused a trauma (47%), in the upper limbs (29%) and lower limbs (29%), forcing the absence of the worker from the workplace for one month.




| LEGEND | |
|---|---|
| F-D40 | *"Loss of control (total or partial) of machine, means of transport or handling equipment, hand-held tool, object, animal - not specified";* |
| F-D50 | *"Slipping - Stumbling and falling - Fall of persons - not specified";* |
| F-D60 | *"Body movement without any physical stress (generally leading to an external injury) - not specified";* |
| F-D70 | *"Body movement under or with physical stress (generally leading to an internal injury) - not specified";* |
| F-C30 | *"Horizontal or vertical impact with or against a stationary object (the victim is in motion) - not specified";* |
| F-C40 | *"Struck by object in motion, collision with - not specified";* |
| F-C70 | *"Physical or mental stress - not specified";* |
| F-PBI10 | *"Head, not further specified";* |
| F-PBI30 | *"Back, including spine and vertebra in the back";* |
| F-PBI50 | *"Upper Extremities, not further specified";* |
| F-TI 010 | *"Wounds and superficial injuries";* |
| F-TI 030 | *"Dislocations, sprains and strains".* |

**Fig. 4.** Distribution of accidents considering the reclassified variables (Part I - RIAAT).

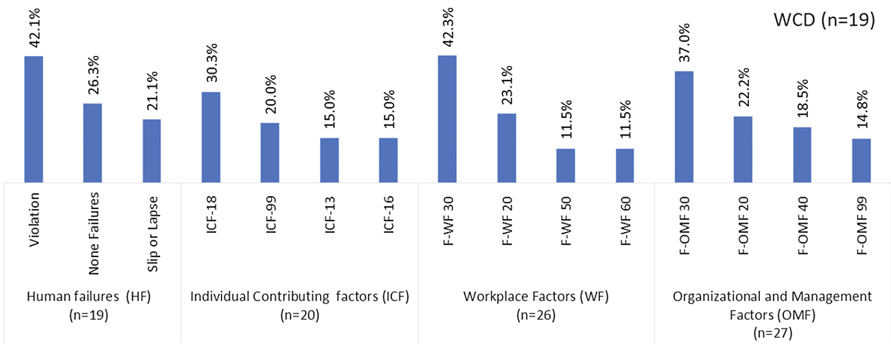
When comparing these results to those of GEP [1], it is noticeable that the variables "Contact - mode of injury", "Part of Body injured", "Type of Injury" and "Days Lost" revealed a very similar behavior.

### 3.3 RIAAT Results - Part II

Trying to identify the active and the latent failures, this part of RIAAT comprised a detailed investigation of 19 accidents at work. The Human failures (HF); Individual Contributing Factors (ICF); Workplace Factors (WF) and Organizational and Management Factors (OMF) were the items taken in consideration.

During the interviews of the victims of the 19 accidents, it was noticed that more than one item (ICF, WF and OMF) contributed for the accidents to happen and influenced the total of items that were considered for the analysis. Following the same methodology, Fig. 5 shows the key groups considering the in-depth investigation.

As for the ICF, the Psychological or Mental Stress (ICF-18) resulting from the time pressure was considered the most critical. Regarding the WF the highest rate is related




| LEGEND | |
|---|---|
| ICF-18 | *"Psychological stress, under pressure";* |
| ICF-99 | *"Other factors ICF not included this classification";* |
| ICF-13 | *"Distraction -changing pay attention";* |
| ICF-16 | *"Intrinsic human variability. It's usually always related to simple "run" errors, in "automatic" mode"";* |
| F-WF 30 | *"Task and Job";* |
| F-WF 20 | *"Safety Equipment Tools";* |
| F-WF 50 | *"Information and Communication".* |
| F-WF 60 | *"Ambient, Environment";* |
| F-OMF 30 | *"Technical Factor";* |
| F-OMF 20 | *"Procedure and Rules";* |
| F-OMF 40 | *"Training";* |
| F-OMF 99 | *None or others factors.* |

**Fig. 5.** Distribution of accidents according to contributing factors - In-depth investigation (Part II - RIAAT).

to Technical Factors, particularly poor quality of man-machine interface and/or bad equipment and structure.

In order to correlate the Type of Failure with the victim's age, it was decided to analyze the HF by age group (Fig. 6):

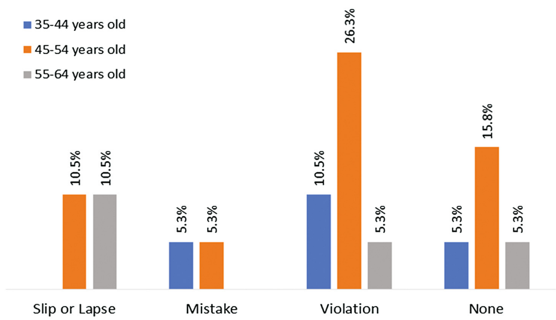



**Fig. 6.** Distribution of work accidents by Type of Failure, according to age group (N = 19).

- For the age range of 45–54 years old, HF related to Violation were the most representative (26.3%). For that same group, the second most common failure was "None", with 15.8%, followed by "Slips or Lapse" with 10.5%.
- For the group between 35 and 44 years old, Violation was also the most common (10.5%), followed by "Misunderstanding" and "None" with the same percentage (5.3%). It is important to say that for this age group "Slips or Lapse" were not documented, probably because those workers are considered to be mature and have a high cognitive ability level.
- Additionally, for the age group from 55 to 64 years old, the most common type of failure was "Slips or Lapse" (10.5%); which can be ascribed to memory loss and some slips that may affect the attention level of these workers and contribute to the accidents occurrence.

Considering the non-parametric Kruskal-Wallis test results ($\chi^2 = 0.653$; $p = 0.756$), it is possible to conclude that there were no significant differences for Type of Failure between the age groups of the victims.

Summing up the main conclusions drawn from this part of RIAAT (in-depth investigation) it can be said that:

- The most common HF was violation (42%) and it was present in all age groups. Even though there were other types of failure within the age groups of the victims, there were no significant statistical differences of the type of failure between the age groups.
- Referring to the other contributing factors (ICF, WF and OMF), Psychological/ Mental Stress (ICF-18), Task and Work (F-WF 30) and the technical factors (F-OMF 30) were identified as the most critical.

## 4 Conclusions

Using the RIAAT method to analyze the accidents that happened at the WCD allowed, not only to characterize the immediate causes, but also to find the latent causes (HF, WF and OMF) that directly contributed to the occurrence of these accidents.

The RIAAT method revealed itself as an appropriate tool to analyze and investigate work accidents and it should be applied in a consistent way in the analysis of all accidents that occurring in the CMO and in other municipalities. This would allow to benchmark within the same activity sector and between different activities sectors. Despite all efforts, we have not found any other study applying the RIAAT method in this activity sector.

The lack of a well-structured practice in the CMO to analyze the accidents, as well as the discrepancy found in different documents, made the analysis and the reclassification difficult and time-consuming.

Following the application of the RIAAT method, it was possible to present a list of suggestions for improvement. Regarding the accidents associated to failures such as few staff, damages on vehicles/containers or lack of appropriate training for some specific skills, the following measures were suggested:

- To use a hydraulic system to reduce the workers' physical effort and the time to accomplish the most physical demanding tasks.
- To improve the vehicles' maintenance management through a check-list in which the workers (drivers and garbage collectors) could report, in a more effective and systematic way, the problems found. In this way, it would be possible to check, in the beginning of each shift, the adequacy of the vehicle to be used.
- To implement periodic and effective maintenance of the garbage containers that end up being degraded, not only by their usage but also by delinquents.
- To implement an incidents' journal, in which the incidents could be reported by the workers (before ending their shifts).
- To promote actions aiming at raising the workers' awareness periodically, reinforcing the importance of complying with all safety procedures, informing and alerting the workers about the hazards and the prevention/protection measures to be adopted, and developing skills to behave safely in deviating situations (when necessary).

**Acknowledgments.** The authors thank all the workers who agreed to participate in this study.

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# Analysing Worker Exposure to WBV at the Doñana Biological Reserve (Spain). A Case Study

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**Abstract.** Work-related-musculoskeletal disorders (WMSDs) cause high costs for employers and governments. In addition, they reduce quality of life for millions of workers throughout Europe, both during their working life and retirement. One of the causes of WMSDs is exposure to Whole Body Vibration (WBV), with WMSDs usually developing over long periods of time. The Doñana Biological Reserve (DBR) in Huelva, Spain is one of the most important infrastructures in the country. Due to the ecosystem the staff must use vehicles with four-wheel drive (4 × 4). The European Directive 2002/44/EC lays down minimum requirements to protect workers from health and safety risks arising from exposure to mechanical vibration. This study analysed DBR workers' exposure to WMSD in relation to WBV when they drove the most frequently-used 4 × 4 model.

**Keywords:** Musculoskeletal disorders · Whole Body Vibration
Doñana

## 1 Introduction

Musculoskeletal disorders (MSD) caused by vibrations can develop over time and cause occupational illnesses that affect millions of workers throughout Europe, costing businesses billions of Euros [2]. Furthermore, they reduce quality of life for millions of workers throughout Europe, during their working life and retirement.

One of the causes of work-related-musculoskeletal disorders (WMSDs) is exposure to Whole Body Vibration (WBV), with WMSDs tending to develop over long periods of time. Punnett & Wegman [1] state that exposure to vibrations is one of the ergonomic characteristics of the job that represents a risk factor with regard to work-related MSD, both in the neck and the upper limbs.

Workers using machinery as part of their job are exposed to a high risk derived from WBV, particularly vehicle drivers [3].


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The majority of the vibrations transmitted to workers through machines and structures are generated as a consequence of an increase in the effort made by the workers to cushion them and the loss of energy this causes [6]. High power equipment generates greater energy that can be dissipated in the form of vibrations, which is partly transmitted to whoever is operating this machine [7].

Tiemessen et al. in 2007 [4] completely reviewed current knowledge on this subject using two sources. On the one hand, they looked at laboratory studies, identifying 19 studies that define factors with a positive effect (reduction in vibration magnitude): type of seat, seat suspension, cabin suspension, weight of driver, and posture of driver. On the other hand, the they identified 21 field studies which add other factors: experience of driver, driving speed, track condition, location of cabin, type, tyres, and load of the vehicle and vehicle maintenance. It should be mentioned that Langer [5] includes education and on the job training as a positive factor: a short training session resulted in a 22.5% average reduction in WBV exposure.

The Doñana Biological Reserve (DBR) in Huelva, Spain is one of the most important infrastructures in the country, declared a UNESCO World Heritage Site and Biosphere Reserve. The Spanish Higher Council for Scientific Research (CSIC) –the top institution dedicated to research in Spain and the third in Europe- manages the scientific infrastructure known as the Doñana Biological Station (DBS).

Covering an area of 10,008 hectares with a variety of land types, the CSIC staff (scientists, technicians and support staff) travel through the DBS using 4 × 4 vehicles. Workers make daily trips to do maintenance work on the infrastructures and tend to the flora and fauna, etc. During these trips, CSIC staff are exposed to WBV depending on the routes that they take. The combination of routes ranges widely for each working day.

The Framework Directive 89/391/EC [8] on introducing measures to promote improvements to worker health and safety in the workplace, states that employers should carry out risk assessments to prevent accidents or occupational diseases for their workers. Moreover, the European Directive 2002/44/EC [9] provides minimum requirements to protect workers from health and safety risks arising from exposure to mechanical vibrations.

This research includes the study carried out by the CSIC and the University of Granada (Spain) which analysed the exposure of workers to WBV at the DBR when driving the most frequently-used 4 × 4 model. In addition, preventive measures are defined that should be implemented after conducting the risk assessment for mechanical vibration.

## 2 Materials and Methods

### 2.1 CSIC Staff Trips Through Doñana

The DBR stands out among the important infrastructures that the CSIC manages in Spain. It was set up in 1964 to provide a shelter for endangered species, including the Iberian Linx.

It contains three large ecological systems: Marshes (dry in certain months), mobile dunes and “Cotos” (mountain, junipers, cork oaks and pine forests) (See Table 1). There are two forest tracks, one going in and one going out, which are the main access routes to the ecosystems.

**Table 1.** Different types of soil.

| Marshes | Mobile dunes | Cotos |
|---|---|---|
|  |  |  |

The geographic expanse, the types of ecosystems and their lithology mean that CSIC workers must make intensive use of 4 × 4 vehicles as they travel around the DBR.

The number of people who might travel in and/or drive 4 × 4 vehicles is, in principle, very high, as it depends on the quantity of scientific or agro-forestry maintenance activities taking place at a given time. However, the number of workers driving these vehicles can be narrowed down to 12.

## 2.2 Experimental Design

Depending on the type of land, five routes (R) have been identified: R1, R2, R3, R4 and R5. Figure 1 shows the routes. Table 2 compiles the data for each R: type of soil, distance and estimated time for the trip.

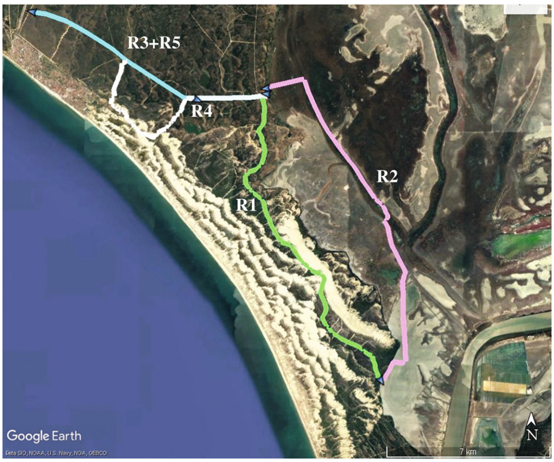


**Fig. 1.** Map showing the different Rs.

**Table 2.** Type of land, duration and estimated time for the different Rs.

| R | Land type | Distance | Estimated time |
|---|---|---|---|
| R1 | Coto | 4800 m | 39 min |
| R2 | Marsh | 16800 m | 30 min |
| R3 | Forest track | 6350 m | 6 min |
| R4 | Mobile dune | 7850 m | 18 min |
| R5 | Forest track | 3260 m | 6 min |

The workers make trips along these Rs throughout their working day. R3 and R5 will be driven on once a day as they are the forest tracks entering and leaving the work zones. To work out the different possibilities for combining the remaining Rs (R1, R2 and R4), a mathematical model is applied based on Generating Functions [10]. This involves determining the number of $x^a y^b z^c$ type monomials where:

- x, y and z will be associated with the possible Rs that DBS workers will take in the off-road vehicles to perform their daily tasks: R1, R2 and R4.
- a, b and c represent the number of times that each one carries out the aforementioned Rs in the same day.

These variables are subject to the following restrictions:

- Each route is associated with a time: R1, 39 min; R2, 30 min; and R4, 18 min.
- a, b and c should be whole numbers, greater than or equal to 0 (zero would indicate that the corresponding route was not taken).
- The maximum daily time for a worker to spend travelling has been set at 4 h (240 min). So, $(R1) \times a + (R2) \times b + (R4) \times c \leq 240$
- As a consequence of the previous point, it holds that R1 can be taken a maximum of 6 times a day (this implies that b = c = 0), R2 can be taken a maximum of 8 times and R4, 13 times.
- The different Rs can be repeated in different orders.

Knowing that the maximum number of times that a route can be repeated is 13, the possible combinations of the three Rs have been calculated, meaning that they are the combinations with repetition of m elements taken every n (m $\geq$ n) (Eq. 1):

$$CR_m^n = \binom{m+n-1}{n} = \frac{(m+n-1)!}{n!(m-1)!} \qquad (1)$$

Alongside these combinations, there is the possibility of covering the total set time, 240 min, covering R4 all 13 possible times. This means that the total possible combinations of the three Rs is 560, which is reduced to 181 considering that they meet the condition that they last 240 min or less. Figure 2 shows the number corresponding to each group of combinations.

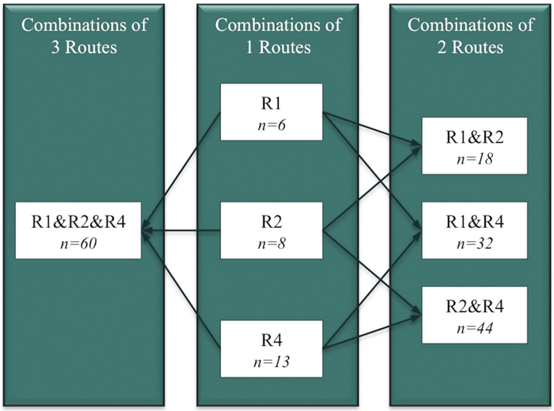


**Fig. 2.** Diagram of the different combinations.

## 2.3 Apparatus

The CSIC has different models of 4 × 4 vehicles for moving workers around the DBR. The most frequently-used model is analysed in this work and its technical characteristics are compiled in Table 3. The usual speed of the vehicle along these Rs is between 25 and 30 km/h.

**Table 3.** Technical Characteristics of the vehicle being analysed.

| Manufacturing year | Mileage | Dimensions (length × width × height) | Power (kW) |
|---|---|---|---|
| 28/6/05 | 108208 | 4713-1750-2000 | 92 |
| Motor torque (Nm) | Weight in a vacuum | Type of suspension | Type of tyres |
| 275 | 2140 | Suspension with 4 dual effect shock absorbers | 235-85-R16 |

WBV exposure during normal operations was measured with the Human Vibration Meter and Analyser SVAN 106 equipment (plus an SV 38 V accelerometer manufactured by SVANTEK) (see Fig. 3). This equipment meets the requirements of ISO 8041-1:2017, ISO 2631-1,2&5 and ISO 5349-1&2 standards.

Measuring should last long enough to ensure reasonable statistical accuracy and for the vibration to be typical of the exposure being assessed. In the event that the exposure comprises periods with different characteristics, each one will be analysed individually [11]. Given that there are no defined work cycles, the vibrations should be measured in the proposed Rs up to a minimum of 3 min [11]. To do this, the Analyser has been configured to obtain results every 3 min for each of the Rs.


**Fig. 3.** Details of the equipment used.

## 3 Data Analysis

European Directive 2002/44/EC [9], the parameter used to evaluate WBV, is the effective energy level or equivalent continuous acceleration (Aeq,t) in acceleration units $m/s^2$.

The European Directive measures exposure to vibrations using two different methods, both defined in the ISO 2631-1:1997 standard [12]. The equivalent daily exposure A(8) is expressed as equivalent continuous acceleration over an eight-hour period, calculated as the highest (rms) value (see Eq. 2), where $a_{wi}$ is the effective value of acceleration weighted in frequency according to the orthogonal axes x, y, z. $T_{exp}$ is the exposure time; $T_0$ is the reference time of 8 h; $k_i$ is the multiplication factor [12].

$$A_i(8) = k_i \cdot a_{wi}\sqrt{\frac{T_{exp}}{T_0}} \tag{2}$$

The A(8) value is calculated as the maximum of the value in the three directions (see Eq. 3).

$$A(8) = max\left[A_x(8), A_y(8), A_z(8)\right] \tag{3}$$

The other method is the Vibration Dose Value (VDV), defined as an accumulative dose based on the fourth root of the acceleration to the fourth power and its unit is $m/s^{1.75}$ (see Eq. 4). This method is defined in the UNE-ISO 2361-1 standard as being more sensitive to vibration peaks by using the fourth power instead of the acceleration time history as the basis for the average [12].

$$VDV = \left\{\int_0^T (a_w(t))^4 dt\right\}^{1/4} \tag{4}$$

Where $a_w(t)$ is the frequency-weighted instantaneous acceleration; T is the total measurement period in seconds. The daily VDV is the highest value among the calculated values in the three directions (see Eq. 5).

$$VDV = max\left[VDV_{exp,x}, VDV_{exp,y}, VDV_{exp,z}\right] \tag{5}$$

In this particular study, workers are exposed to more than one source of vibration as they complete more than two consecutive Rs along tracks with different characteristics.

UNE-ISO 2361-1 defines how to perform the calculation in the event of more than one source of exposure. To do this, the daily A(8) will be determined for each source (i) along each coordinate axis. Once these values are known, the global value is calculated for each axis using Eq. 6. In the same way, the three VDVs will be determined, weighted in each frequency for each task and the daily exposures will be determined in the three directions. To calculate the daily VDV for each direction (i) working from the partial values, Eq. 7 will be applied.

$$A_i(8) = \sqrt{(A_{i1}(8))^2 + (A_{i2}(8))^2 + (A_{i3}(8))^2 + \cdots} \tag{6}$$

$$VDV_i = \left(VDV_{i1}^4 + VDV_{i2}^4 + VDV_{i3}^4 + \cdots\right)^{1/4} \tag{7}$$

According to UNE-ISO 2361-1 [12], the established limit values are the daily Exposure Limit Values (ELV) and the daily Exposure Action Value (EAV), standardised to an eight-hour reference period. In no case should the workers be exposed to values greater than the ELV. If this value is exceeded, immediate measures should be taken to reduce exposure to “acceptable” levels. In this case, it would be necessary to establish and implement a programme of technical and/or organisational measures to reduce as much as possible the risk of exposure to mechanical vibrations (Table 4).

**Table 4.** A(8) and VDVs according to the UNE-ISO 2361-1 standard [12].

| | A(8) | VDV |
|---|---|---|
| EAV | 0.5 m/s$^2$ | 9.1 m/s$^{1.75}$ |
| ELV | 1.15 m/s$^2$ | 21 m/s$^{1.75}$ |

## 4 Results

Firstly, the A(8) and VDVs were calculated for each R. Figures 4 and 5 show the values which were obtained.

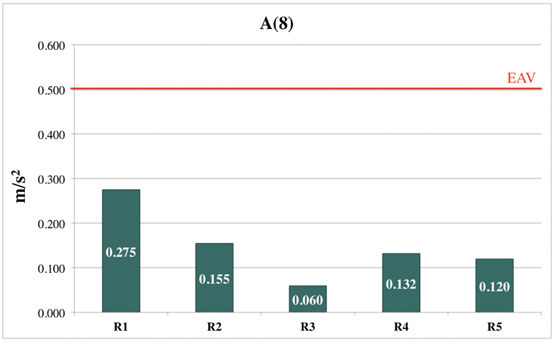


**Fig. 4.** A(8) values for each R.

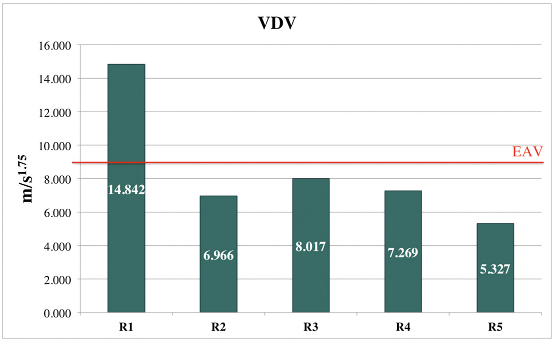


**Fig. 5.** VDVs for each R.

As can be seen in Fig. 4, all the A(8) values are below the EAV. However, Fig. 5 shows that in R1, the VDVs exceed the EAV, although they are below the ELV. This indicates that the R1 route exposes workers to the greatest WBV. Its peak values set the number of times it can be driven each day.

However, these values will increase if, as mentioned in Sect. 2.2, the workers take more than one route in their working day. Consequently, working from the values obtained in each of the axes (Table 5) and after applying the Eqs. (6) and (7), the A(8) and VDVs have been calculated for each of the 181 combinations of the Rs, including R3 and R5 in all of them.

**Table 5.** A(8) and VDVs for each R.

| R | A(8) $m/s^2$ | | | VDV $m/s^{1.75}$ | | |
|---|---|---|---|---|---|---|
| | Total exposure | | | Total exposure | | |
| | (x) | (y) | (z) | (x) | (y) | (z) |
| R1 | 0.041 | 0.039 | 0.076 | 4988.204 | 4304.672 | 48525.465 |
| R2 | 0.008 | 0.007 | 0.033 | 178.659 | 109.115 | 2354.691 |
| R3 | 0.001 | 0.001 | 0.007 | 33.902 | 16.453 | 805.250 |
| R4 | 0.017 | 0.017 | 0.030 | 1300.325 | 1306.399 | 4130.927 |
| R5 | 0.004 | 0.004 | 0.022 | 107.104 | 89.992 | 2791.892 |

As an example, if the A(8) and VDVs are calculated for a trip that covers R1 once and R2 three times, (R1-R2-R2-R2), the value obtained for each direction (i) is calculated according to Eqs. (8) and (9), giving the values compiled in Table 6.

$$A_i(8) = \sqrt{(A_{iR3}(8))^2 + (A_{iR5}(8))^2 + (A_{iR1}(8))^2 + 3(A_{iR2}(8))^2} \tag{8}$$

$$VDV_i = \left(VDV_{iR3}^4 + VDV_{iR5}^4 + VDV_{iR1}^4 + 3VDV_{iR2}^4\right)^{1/4} \tag{9}$$

**Table 6.** A(8) and VDVs on each axis for the combination: (R3-R5-R1-R2-R2-R2)

| R3-R5-R1-R2-R2-R2 | Ax(8) | Ay(8) | Az(8) | VDVx | VDVy | VDVz |
|---|---|---|---|---|---|---|
| | 0.268 | 0.254 | 0.453 | 8.676 | 8.297 | 15.598 |

The A(8) and VDVs for this combination, in accordance with Eqs. (3) and (4), are:

$$A_{R3,R5,R1,3R2}(8) = 0.454 \tag{10}$$

$$VDV_{R3,R5,R1,3R2} = 15.598 \tag{11}$$

After carrying out the aforementioned calculations for each of the 181 combinations, the number of them with values equal to or greater than EAV and ELV are compiled in Table 7.

**Table 7.** Number of combinations with values higher than EAV and ELV.

| Value | A(8) | Number of combinations |
|---|---|---|
| EAV | 0.5 m/s$^2$ | 128 |
| ELV | 1.15 m/s$^2$ | 0 |
| Value | VDV | Number of combinations |
| EAV | 9.1 m/s$^{1.75}$ | 179 |
| ELV | 21 m/s$^{1.75}$ | 15 |

70.7% of the combinations have an A(8) value greater than the EAV, with 0% of values higher than the ELV. In the case of VDV, more sensitive to peak vibration values, the values over the EAV rise to 98.9%, where 8.3% are higher than the ELV.

Figures 6 and 7 show the maximum and minimum values of A(8) and VDV for the different combinations of the Rs: repetitions of the same R (R1, R2 or R4), combinations of different numbers of two Rs (R1 & R2, R1 & R4, R2 & R4) and different combinations of the three R (R1 & R2 & R4).

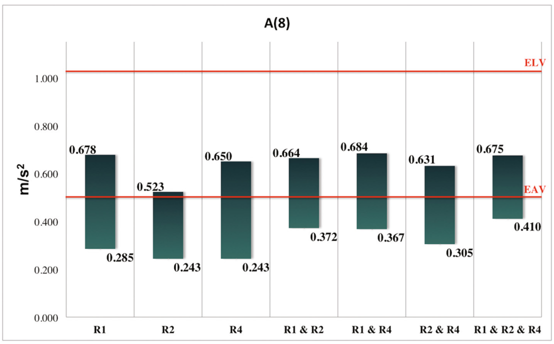


**Fig. 6.** Maximum and minimum values of A(8) according to the different combinations of the Rs.

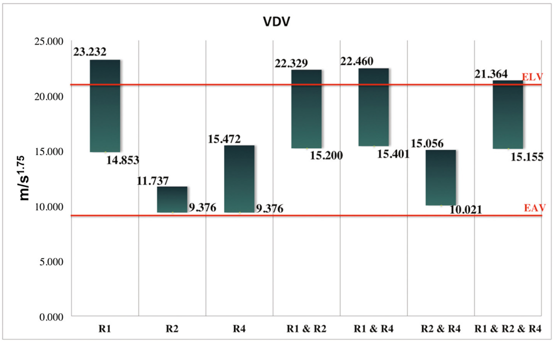


**Fig. 7.** Maximum and minimum VDVs according to the different combinations of the Rs.

In this study, the VDVs give us the combinations with EAV and ELV where the CSIC should take preventive measures, as the different surfaces produce a range of peak vibration values.

Given that the VDVs are high, measures should be set to reduce the daily exposure level until the value drops below the EAV.

Table 8 shows the combinations of Rs with values over the ELV. In general, these combinations of Rs should not be covered with the vehicle being analysed.

**Table 8.** Number of combinations with values higher than EAV and ELV.

| | No. | VDV | No. | VDV | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R1 | 5 | 22.197 | 6 | 23.232 | | | | | | | | |
| | No. | VDV | No. | VDV | No. | VDV | | | | | | |
| R1<br>R2 | 4<br>1 | 21.149 | 4<br>2 | 21.120 | 5<br>1 | 22.329 | | | | | | |
| | No. | VDV | No. | VDV | No. | VDV | No. | VDV | No. | VDV | No. | VDV |
| R1<br>R4 | 4<br>1 | 21.196 | 4<br>2 | 21.303 | 4<br>3 | 21.409 | 4<br>4 | 21.514 | 5<br>1 | 22.369 | 5<br>2 | 22.460 |
| | No. | VDV | No. | VDV | No. | VDV | No. | VDV | | | | |
| R1<br>R2<br>R4 | 4<br>1<br>1 | 21.257 | 4<br>1<br>2 | 21.364 | 4<br>1<br>3 | 21.103 | 4<br>2<br>1 | 21.318 | | | | |

## 5 Conclusion

This paper shows the WBV risk assessment for workers (scientists, technicians and support staff) working for the CSIC in the Doñana Biological Reserve. The scientific or agro-forestry maintenance activities are carried out using several 4 × 4 vehicles. The vehicle model being analysed in this work was the most frequently-used because the CSIC owns more units of this model than any other. Five Rs have been defined depending on the type of soil and all the possible combinations of these routes have been calculated, subjecting them to several restrictions, limiting them to 181.

The results show that, due to the type of terrain, there are high peaks in the WBV values so the VDVs should be considered when assessing the risk. 98.9% of the VDVs calculated are above the EAV so the CSIC should organise actions to reduce the level of daily exposure to WBV for its workers.

On the other hand, 8.3% of the VDVs are above the ELV. The vehicle being studied should not be used on these combinations of Rs. Consequently, it is necessary to run a similar study on the rest of the fleet of vehicles available in the DRB.

With regard to the design and layout of work places and jobs, whenever possible the CSIC should make efforts to eliminate rough spots on the two existing forest paths and eliminate or prevent obstacles from appearing in the driving area.

In addition, workers should be informed about the existing risks of WBV exposure and this information will extend to the applicable prevention and protection measures and activities. DBR workers should also undergo specific health checks as values might occasionally exceed the daily ELV, $A(8) = 0.5\ m/s^2$.

A work plan could also be designed to minimise the problem of having the same workers exposed to high WBV values, encouraging staff rotation and defining routes that should be carried out every day.

Finally, the CSIC should consider WBV exposure when purchasing new vehicles.

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# Reliability Analysis of Operations in the DCS of a Nuclear Power Plant Based on Accident Simulation

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**Abstract.** With the development of computer technology, the operation environment of main control rooms in modern nuclear power plants (NPP) has considerably changed over the years, namely the use of advanced Digital Control System (DCS). In this paper, the accident of steam generator tube rupture (SGTR) of a DCS in a nuclear power plant is simulated and the task analysis method is used to explore the reliability of the secondary side cooling and depressurization operation of the operators. The effect of the man-machine interface changes on operators is studied on the basis of SGTR accident simulation. An event tree is built to model the operators' activities of handling the accident. Operators' behaviors in a DCS are determined and a quantitative calculation of operators' reliability is then conducted.

**Keywords:** Digital control system · Steam generator tube rupture
Mission analysis method · Quantitative calculation

## 1 Introduction

Compared with the traditional control system, the flexibility of the operation of nuclear power plants are more advantageous and DCS is getting more and more widely used in the nuclear power plants. DCS operators monitor the plant system and perform operations mainly through the mouse on the computer screens instead of manual activities on instrument panels, signal lamps, buttons and switches in an old control room. The new man-machine interface may bring changes to operators on cognition, resulting in new human errors. The reliability of DCS has a significant impact on the safety and availability of nuclear power plants. Therefore, the safety impact of nuclear power plant DCS must be systematically evaluated and verified. Human reliability analysis plays an important role in the safety analysis of NPP operation. With the application of the digital control system in modern nuclear power plants, the operating environment of the main control room has undergone major changes, thus changing the operator's cognitive process, behavior patterns and task characteristics, mainly on the information display, man-machine interface interaction and management, operating procedures, control and input facilities, as well as alarm systems, operator decision-making and


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support systems. DCS has many technical advantages, but the combination of potential human factors and DCS will produce new human error.

# 2 DCS Control Process Error Mode

## 2.1 DCS Control Features

The traditional main control room has a very large work space, with a space-specific man-machine interface. Alarms, display and control, man-machine interface components have their own unique and easy-to-see spatial location. Operators walk to the panels with different functions to perform tasks. In the DCS, the information is displayed on the video display unit (VDU) and the large display system (LDS), with the controls being operated by the mouse and the keyboard. Man-machine interfaces on DCS tend to lack physical sense of space. Operators work before computers. All these lead to the change of the cognitive process of the operators. New human error should be considered in the human reliability analysis of DCS.

The primary tasks of nuclear power plant operators are monitoring and control, such as monitoring flow, starting pumps and switching valves. The primary tasks involve four cognitive processes: monitoring and testing, situation assessment, response planning and response implementation [1]. Operators in the DCS perform the appropriate auxiliary tasks to complete the primary tasks. These auxiliary tasks are called “interface management tasks.” NUREG/CR-6690 states the general interface management tasks include the following items [2] :

(1) Configuration: Set the man-machine interface of the computer workstation to the desired arrangement, for example by assigning software functions on the multi-purpose display.
(2) Browse: Accessing and retrieving specific aspects of man-machine interfaces on computer workstations, such as monitors or controllers.
(3) Arrangement: Adjust the operator’s perception of the information. It can happen on several levels, inside and inside the display, such as arranging items within a display page or window.
(4) Access: Access the human-machine interface to determine information about its status, such as the current display’s relationship to the rest of the display network or the most recent file date. This category also includes the use of help systems.
(5) Automation: Set shortcuts to simplify interface management tasks.

In a DCS, operators can only see part of the information at any time through the VDU on the DCS. The limited viewing area is a feature called “keyhole effect” [3]. Operators must perform interface management tasks to accessing information through the limited windows. Interface management tasks may affect the cognitive reliability of the operator. When operators conduct primary tasks, they need some attention resources to perform interface management task. Due to limited attention resources, the performance of the primary tasks maybe impaired. Slips and lapses may occur. In addition, the primary task is interrupted in a way of selection of wrong pictures, slow execution and missing steps.

### 2.2 Control Process of Human Error

In the past a large number of documents on human error have different definitions and classification, there are some people in the DCS error pattern and the traditional main control room the same, and because DCS has different characteristics, the need for other human error mode. The error is usually divided into error of omission (EOO) and error of commission (EOC) [4]. EOO said he forgot to carry out the task, but EOC said the wrong mission. Rasmussen classifies staff behaviors into three categories (SRK models): skill-based, rule-based, knowledge-based [5]. The form of information content in skill-based behavior is signal, and the performance of personnel behavior is mainly influenced by the schema of pre-memory and is represented by the similar structure in the space-time region. The content of the information content in the rule-based behavior is a sign, Personnel behavior is guided by pre-existing rules (IF-THEN rules); knowledge-based behavior in the face of the new scene action plan to be made in real time. The classification of human error caused by human behavior in SRK model is based on the difference of cognitive behavior between different behaviors. It is also based on the view that cognitive failure is the main failure mode of complex human-machine interface. Skill-based behavior basically requires no awareness, including two types of mistakes, lapse and slip. Knowledge-based personnel behavior requires relatively high cognitive behavior, rule-based second, the error caused by these two kinds of personnel actions is a mistake. From the error mechanism point of view, slip and lapse is the main attention or memory problems, and mistake mainly decision-making problems. This shows that the prevention of human factors caused by the behavior of skilled and regular personnel is mainly to prevent the operator's memory and attention problems in order to avoid slip and lapse, reduce the slip and lapse can also reduce the possibility of mistake. In addition, it is in the accident conditions to reduce the operator's decision-making errors, reduce the operator's mistake in the accident. Since the main cause of errors is not the DCS design, but the operator's misjudgment, the interface between the traditional master control room and the DCS may be the main cause of lapse and slip in the operator's operation [6]. Swain and Guttmann [7] Six patterns of human error are proposed, including omission of operation, wrong object, incorrect operation, confusion of modes, improper operation and delayed operation.

### 2.3 DCS Cognitive Behavior Model

The cognitive process of human includes sensory, perception, memory, thinking, imagination and other cognitive activities. Through these cognitive activities, we can understand the characteristics, the nature and the interrelationships of objective things. Cognitive load has a great impact on the cognitive reliability of people, cognitive overload may make people's cognitive process may be mistakes. However, the increase of cognitive load of operators on DCS is caused by the bottleneck of human cognitive resources (memory and attention, etc.) [8]. When the operator in the implementation of operational tasks cognitive resource needs and cognitive resource supply to match, cognitive tasks are likely to be better implemented, if the cognitive resource needs more than the supply or lack of cognitive information, the operator Cognitive performance will decline, resulting in errors.

In Budley-Hitch's working memory model [9], Proposed that there are two independent short-term memory buffers, one is a voice loop used to process voice information and store numbers, the other is an air-space drawing board used to process the air-space information to determine the spatial relationship, and the central actuator is responsible for completing Coordinate the work and exchange information rapidly between the two memories. Operators in the DCS in the same form (oral or visual space) encoded information easily interfere with each other, while in the traditional master control room operators can form the object and the system of spatial separation, which will enable operators to form more in the operation Lasting, more reliable, clearer and more meaningful "Skyshield." In terms of long-term memory, traditional control rooms are more "coherent" and "ecological" than DCS, and operators are able to form a "mental model" that is stronger than DCS. In terms of attention, Wickens's SEEV model [10] four factors of concern were raised: the saliency of the signal, the effort to note the signal, the operator's expectations of the signal, and the task's relevance or value of the signal.

## 3 Simulation Experiment

The simulator in the experiment was designed and researched by China Guangdong Nuclear Power Group Co., Ltd. with reference to the Daya Bay PWR nuclear power plant so that the environment of the simulation experiment is similar to that of the nuclear power plant. The experiment is based on the accident of heat transfer tube rupture (SGTR) in the steam generator of a nuclear power plant. The task analysis method is used to explore the reliability of the secondary side cooling and depressurization operation of the operator on the DCS. Steam generator heat transfer tube rupture (SGTR) refers to the rupture of the heat transfer tube between the primary side and the secondary side. When the reactor is in a power operating condition, the pressure on the primary side is much higher than the pressure on the secondary side. When the heat pipe breaks, the primary coolant leaks through the breach to the secondary side. The experiment mainly analyzed the rupture of the heat transfer tube of a steam generator and recorded the secondary side cooling and depressurization operation of the operator on the DCS in the simulation experiment.

### 3.1 Task Analysis

The control tasks in the DCS consist of the primary tasks and the interface management tasks. One or more secondary tasks in the execution of the tasks fail. If the recovery is timely, the final major tasks can also be successful. If the recovery of the secondary task fails is unsuccessful, the failure or failure of the relevant secondary task causes the primary task to fail. In order to study the reliability of the operator's secondary cooling and depressurization operation on the DCS in the background of SGTR accident, the primary tasks and interface management tasks in the DCS are analyzed and divided into observable sub-tasks to control the tasks. Human error in the primary tasks may lead to the implementation of inappropriate controls, and human error in the secondary tasks is likely to delay access control and display, hinder the operation of the operator, or select the wrong controls and displays [11]. There is no interface management task in the operation of the traditional main control room, but DCS interface management tasks occupy a large part. Analyze the primary tasks and interface management tasks in the DCS and model them as unit tasks for control tasks so that basic human error probabilities for unit tasks can be observed and calculated in simulator-based experiments or field operations studies. Unit tasks include: Operation selection, screen selection, control device selection and operation execution [12]. In this paper, the establishment of an event tree model approach, the primary tasks and interface management tasks into the event tree model, based on the results of the event tree analysis to quantify the results obtained operator DCS on the secondary side of the cooling step-down operation the reliability.

## 3.2 Establish the Event Tree Model

Under the background of experimental simulation of SGTR accident, the most important function of the operator in DCS is to obtain information and search information. Then according to the state parameter display on the VDU, combined with his own mental model to evaluate the status of the power plant, accordingly, Strategy and response to the implementation of behavior, need to develop a clear strategy. The establishment of the event tree model shown in Fig. 1.

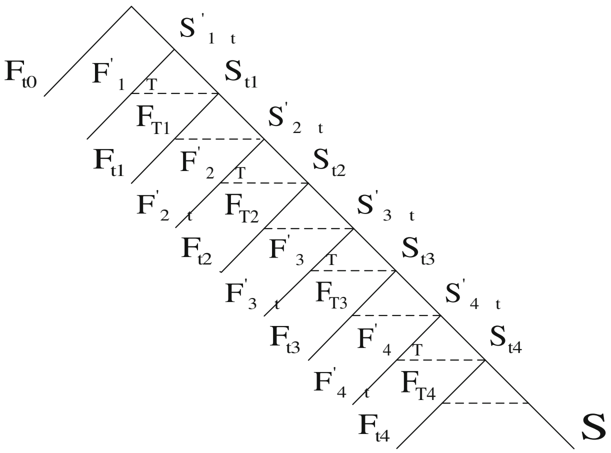


**Fig. 1.** The event tree model

| Name | Content | Task category |
|---|---|---|
| $S'_{tA}$ | Operator successfully completed the A interface operation management tasks | Interface management tasks |
| $F'_{tA}$ | The operator did not complete the pre-A interface management tasks | Interface management tasks |
| $S_{tA}$ | The operator successfully completed A operation | Primary tasks |
| $F_{tA}$ | The operator did not complete the A operation successfully | Primary tasks |
| $F'_{TA}$ | The operator successfully corrected the error and completed the pre-A interface management tasks | Interface management tasks |
| $F_{TA}$ | The operator successfully corrected the error and completed the A operation | Primary tasks |

The value of A in the table is 1, 2, 3, and 4, corresponding to the symbols in the figure, where A = 1 indicates the operation of reverting to safety injection, A = 2 means the operation of reversion of the accidental evaporator, A = 3 means A circuit cooling operation, A = 4 indicates the stability of the accident evaporator pressure operation.

for $F'_{t1}$, Check the "THERP Manual", the operator failed to complete the security before the return of the interface management tasks before the error probability of the nominal value $1 \times 10^{-3}$, Consider the impact of stress factor, amended as $5 \times 1 \times 10^{-3} = 5 \times 10^{-3}$; for $F'_{T1}$, Check the "THERP Manual", the operator failed to complete the security before the return of the interface management tasks before the error probability of the nominal value $1 \times 10^{-3}$, Consider the impact of stress factor, amended as $5 \times 1 \times 10^{-3} = 5 \times 10^{-3}$.

Similarly, consult "THERP Manual" $F'_{t1}$, $F'_{t2}$, $F'_{t3}$ The error probability correction value is $5 \times 10^{-3}$, $F'_{T2}$, $F'_{T3}$, $F'_{T4}$ The error probability correction value is $5 \times 10^{-3}$.

$F_{t0}$ for operators failing to detect SGTR alerts, the probability is very small in simulations and can be ignored.

The incident tree has nine wrong paths $F_1$, $F_2$, $F_3$, $F_4$, The probability of their mistakes are:

$$P(F_1) = F'_{t1} \times F'_{T1} = 5 \times 10^{-3} \times 5 \times 10^{-3} = 2.5 \times 10^{-5}. \quad (1)$$

$$P(F_2) = F'_{t1} \times F'_{T1} = 5 \times 10^{-3} \times 5 \times 10^{-3} = 2.5 \times 10^{-5}. \quad (2)$$

$$P(F_3) = F'_{t3} \times F'_{T3} = 5 \times 10^{-3} \times 5 \times 10^{-3} = 2.5 \times 10^{-5}. \quad (3)$$

$$P(F_4) = F'_{t4} \times F'_{T4} = 5 \times 10^{-3} \times 5 \times 10^{-3} = 2.5 \times 10^{-5}. \quad (4)$$

The total probability of a mishap on an SGTR accident is:

$$P = P(F_1) + P(F_2) + P(F_3) + P(F_4) = 1 \times 10^{-4}. \tag{5}$$

## 4 Conclusion

Compared with the traditional control system, the change of digital control system of nuclear power plant will lead to the change of cognitive activity of the operator, resulting in the new human error, which will affect the human reliability. And new human error will affect the system Bring the risk. This paper studies the reliability of the secondary side cooling and depressurization operation of the operator on the DCS in the background of the rupture of the heat transfer tube of the steam generator of the nuclear power plant and reveals the cognitive process of the operator in the SGTR accident response and the interface management tasks And the primary tasks of human error prevention and control to provide technical measures to reduce the risk and improve the safety level of nuclear power plants.

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# Airport Runway Incursions and Safety

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**Abstract.** Runway incursions are a major concern for modern airport in order to reduce accidents. When planes, vehicles or people are on the runway without approval a runway incursion may occur. Runway incursions could be a result of many different contributing factors from human errors to design flaws. Runway incursions are responsible for a majority of accidents at aerodromes and with growing traffic volumes; they have been raised to the top of many airports safety agenda.

The aim of this study was to look at the critical safety system of runway incursions to see what safety measures that are in place and also to analyze that system with the help of risk management tools. It was found that top management commitment to safety is very important. Finally, training and the proper use of signal systems was also an important factor in maintaining a safe runway.

## 1 Introduction

**Background**

During recent decades, there has been a tremendous increase in air travel. From the beginning, the industry focused on wealthy people that could afford the luxury of air travel but in recent years, air travel has been available to the public at a reasonable cost. The dramatic changes in the industry have of course put safety in another dimension. With planes taking off and landing with only minutes between them, safety is a growing concern among travelers as well as airlines and authorities. Airports have worked with safety as long as planes have been in the sky. The main concern for aerodromes are the runways where planes takeoff or land at high velocities. Minor incidents that would not have caused an accident in any other part of the airport can lead to disasters when combined with the high velocity on the runway. Runway incursions are a major concern for modern airport in order to reduce accidents. When planes, vehicles or people are on the runway without approval a runway incursion has occurred. Runway incursions are responsible for a majority of accidents at aerodromes and with growing traffic volumes they have been raised to the top of many airports safety agenda. In order to understand what runway incursions are, how they have developed during recent years and what can be done to reduce them we will look at runway incursions from a risk management perspective in this study.


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## 2 Aim of the Study

The purpose of this study is to look at a critical safety system, i.e. runway incursions, see what safety measures are in place and with the help of risk management tools analyze the mentioned system as well.

## 3 Method

This study is prepared mainly based on a project conducted in Chalmers University of Technology, Gothenburg, Sweden [1]. The method in the study will consist of information gathering, analysis and conclusion. Information gathering consisted a literature survey together with a study visit. The study visit was conducted at Landvetter, a Swedish airport along with an interview with an air traffic controller working at that airport. The study visit aimed to get a deeper understanding of the day-to-day operations concerning runway incursions as well as insight into safety measures in practice. The literature survey and study visits were followed by an analysis of the gathered information through some risk management tools such What-if analysis and VMEA (Variation Mode and Effect Analysis).

## 4 Runway Incursions

**Definition**

Runway incursions is rather descriptive and refers to a scenario where something that is not naturally present at the runway in on the runway. It is a danger for both aircrafts coming in to land, aircrafts taking off as well as the ground crew and can result is serious accidents. The definitions used by the International Civil Aviation Organization (ICAO) and the definition previously used by the United States Federal Aviation Administration (FAA) are provided as below:

*A runway incursion is defined as "any occurrence in the airport runway environment involving an aircraft, vehicle, person, or object on the ground that creates a collision hazard or results in a loss of required separation with an aircraft taking off, intending to takeoff, landing, or intending to land"* [2].

> *"Any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected area of a surface designated for the landing and takeoff of aircraft"* [3].

The U.S. Federal Aviation Administration have recently replaced their own definition with the one used by the International Civil Aviation Organization. The broader scope of the definition allows the agency to treat surface incidents that does not involve aircrafts as runway incursions [4]. ICAO's definition is well established and the European organization, EUROCONTROL, along with Transport Canada and Australian Transport Safety Bureau all have similar definitions [5].

**Severity Classification**

In order to measure the risk of a runway incursion, the authorities need information from the airports about the severity of the runway incursions. The severity classification considers facts such as the speed of the aircraft, the proximity to other aircrafts or vehicles and the extent and type of evasive maneuvers by those involved in the event [4]. The classification does not provide shortcuts in the following investigation of the event [4]. It is important that each event is thoroughly investigated in order to further improve safety. The U.S. FAA use their own severity classification system based on their previous definition. It is a system consisting of four categories (A-D). The system has according to the FAA lead to a significant reduction of category A and B events and allowed the agency to focus on the most important factors resulting in runway incursions. Table 1 illustrates the different categories used by the FAA [4].

**Table 1.** Different categories of runway incursion severity

| Increasing severity | | | |
|---|---|---|---|
| Category D | Category C | Category B | Category A |
| Little or no chance of collision but meets the definition of a runway incursion | Separation decreases but there is ample time and distance to avoid a potential collision | Separation decreases and there is a significant potential for collision | Separation decreases, and participants take extreme action to narrowly avoid a collision or the event results in a collision |

The ICAO has adopted a similar system consisting of five categories (A-E). Table 2 illustrates ICAO severity classification system [3].

**Table 2.** The ICAO severity classification system [3]

| Category A | Category B | Category C | Category D | Category E |
|---|---|---|---|---|
| A serious incident in which a collision was narrowly avoided | An incident in which separation decreases and there is a significant potential for collision, which may result in a critical corrective/evasive response to avoid a collision | An incident characterized by ample time and/or distance to avoid a collision | Incident that meets the definition of runway incursion such as incorrect presence of a single vehicle/person/aircraft on the protected area of a surface designated for the landing and take-off of aircraft but with no immediate safety consequences. Surface designated for the lauding and takeoff of aircraft but with no immediate safely consequences | Insufficient information inconclusive or conflicting evidence precludes severity assessment |

The Canadian Transport Bureau has developed their own classification system consisting of five categories. The categories are based on the severity and frequency of incursion events. The Australian Transport Safety Bureau have adopted the U.S. classification system [5].

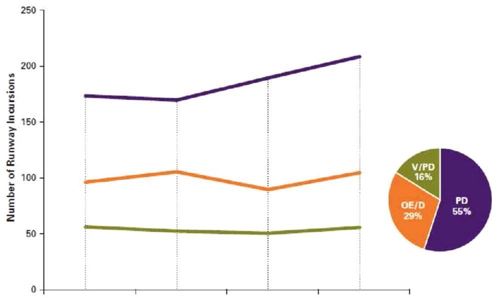
### Contributing Factors

Runway incursions are a result of many different contributing factors from human errors to design flaws.

According to the ICAO [3], the most common scenarios for runway incursions are:

(a) An aircraft or vehicle crossing in front of a landing aircraft
(b) An aircraft or vehicle crossing in front of an aircraft taking off
(c) An aircraft or vehicle crossing the runway holding position marking
(d) An aircraft or vehicle unsure of its position and inadvertently entering an active runway
(e) A breakdown of communication leading to a failure to follow an air traffic control instruction
(f) An aircraft passing behind an aircraft or vehicle that has not vacated the runway.

The U.S. FAA use a different system and categorize runway incursions into three error types: pilot deviations, operational errors and vehicle/pedestrian deviation. When a runway incursion is analyzed and assigned an error type, the error type does not reflect the cause of the accident but refers to the last event in a chain of actions that caused the runway incursion. Consequently, the focus is on the last safety measure in the safety system that did not work. Figure 1 shows the U.S. statistics of runway incursions per error type from 2004 to 2007 [4].




| | FY 2004 | | FY 2005 | | FY 2006 | | FY 2007 | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number | Rate per Million Ops | Number | Rate per Million Ops | Number | Rate per Million Ops | Number | Rate per Million Ops | Number | Rate per Million Ops |
| Pilot Deviations | 173 | 2.74 | 169 | 2.68 | 190 | 3.11 | 209 | 3.42 | 741 | 2.98 |
| Operational Errors/ Deviations | 97 | 1.54 | 105 | 1.66 | 89 | 1.46 | 105 | 1.72 | 396 | 1.59 |
| Vehicle/Pedestrian Deviations | 56 | 0.89 | 53 | 0.84 | 51 | 0.84 | 56 | 0.92 | 216 | 0.87 |
| | | | | | | | | | 1,353 | 5.45 |

**Fig. 1.** Number and rate of runway incursions per error type for the U.S. during 2004–2007 [4]

**Congestion**

*"There is strong evidence that a minor increase in traffic congestion leads to an exponential increase in the potential for runway incursions"* [5].

The U.S. Federal Aviation Administration began tracking runway incursion in 1988 and their statistics clearly show that there is an exponential relationship between traffic increase and increase in runway incursions. From 1988 to 1990, traffic grew by 4.76% and runway incursion rates grew by 43%. The following years, from 1990 to 1993, there was a decreasing in traffic by 5.34% and runway incursions were down 30%. For the following five-year period, traffic volumes increased once again followed by a sharp increase in runway incursions [5]. Transport Canada has made a similar analysis of their statistical data and concludes that runway incursions increase more rapidly than transport volume. The Australian Transport Safety Bureau has reached the same conclusion from their statistics [4].

**Preventive Measures**

Seeing the severity of and relatively frequent incidents of runway incursions, it is of interest to see what measures that can be taken in order to reduce or even eliminate these problems. A very important aspect of preventive measures is the fact that some sort of standard is put in place worldwide. If the safety systems vary significantly between aerodromes, the risk of making an error from the individual aircraft is increased. According to a presentation made on a runway, safety/incursion conference a recommendation is to introduce certification for aerodromes and to introduce safety audits [6]. Included in this standardization is to harmonize the definition of runway incursions globally. Instead of having two separate ones, which can cause confusion and cause, some aerodromes to report incursions, which others will not deem as incursions at all. If the industry does not have the same starting point, it is difficult to improve. Starting with physical preventive measures, the most obvious is to erect physical barriers protecting the perimeter of the runway and aerodrome operating theatre. For most airports in the western countries, these are already a natural part of the safety efforts. However, in the South American and Caribbean areas many runways lack these [6]. Therefore, this is a natural first step for these aerodromes. A significant portion of unauthorized people as well as land-based wildlife can be kept away from the runway. Other important factors in the safe operation of aerodromes are the numerous lightings, signs, runway markings etc. If these are malfunctioning, the probability that runway incursions occur is increased. If a sign is misplaced, an order telling an aircraft to taxi and hold might turn into an order telling the aircraft to taxi out onto the runway causing serious incidents or even accidents. In light of the necessity to maintain these factors, it is evident that the maintenance system of aerodromes is an important preventive measure. Another important conclusion from the safety conference was to make states ensure that maintenance systems were in place in all aerodromes [6]. Besides physical actions such as signs, for example there is much to gain from the managerial aspects as well. The managerial actions include safety systems for training and keeping the awareness of the problem of runway incursions. In the report "European Action Plan for the Prevention of Runway Incursions" they emphasize the necessity for special runway safety teams that are in charge of leading actions to ensure the safe operation of the runway [7]. By delegating responsibility for these specific questions and also assigning specific teams more focus can be put on these issues. Furthermore, the report stresses the importance of doing campaigns for promoting the seriousness and the safety threat of runway incursions [7]. It is important to maintain these efforts to maintain the attention to the issue in the minds of all actors involved. The implementation of the safety teams can also have synergetic effects with the campaigns by letting the safety teams in charge of doing them. Additionally, it is important to issue personnel training regarding the safety issue of runway incursions [6, 7]. Questions such as how to safely operate around the runway or in the worst case how to deal with an emergency are vital issues that the personnel of an aerodrome need to be well versed in to have a safe operating airport.

## 5 Landvetter Airport, Gothenburg Sweden

All the information in this section were gathered in an interview during a study visit to the air traffic control tower at Landvetter airport on the 11th of December 2008. Landvetter is the second largest airport in Sweden and is situated outside Gothenburg. Today it deals with about 200 movements, takeoffs and landings, per day but previously this number was bigger. The capacity of the airport is much higher at about 32–34 movements per hour for a sustained period. In addition, the airport is using ICAO's severity classification methods. Safety systems have increasingly become standardized and routines and manuals are kept to ensure safe aerodrome operations. For the specific issue of runway incursions, they are very rare but considered extremely serious and important at Landvetter. There are no official numbers, but a rough estimate left the number at around 3 incidents per year. By incident means an object on the runway that should not be there. Actual accidents are however, very rare. When it comes to possible causes for runway incursions misunderstandings was listed as a factor. The use of phraseology is a major source of misunderstanding and can cause problems. Especially since English is not the native tongue for the controllers, which also is the case for many aerodromes around the world. An example is that the air traffic controllers at Landvetter used to say "taxi to holding position" when the aircraft was supposed to hold before entering the runway. This caused problems especially with American pilots who were used to the similar phrase "taxi into position" which for them meant lining up on the runway. This caused the order to hold before entering the runway to be misinterpreted as being cleared to enter the runway. Due to this, the phraseology was changed and further standardized and now air traffic controllers instead use "Taxi to holding point" to avoid any misunderstandings and risks. Other potential causes could be poor markings and usage of signs. That they were not clear enough or they were positioned poorly. The type of signs and markings used is now standardized to make sure that the actors involved understand them clearly regardless of where they come from. The positioning of the signs, however, is something that can differ from airport to airport and which is being improved continuously. Furthermore, there is always the risk of high stress loads or people who are unfit to work which can cause problems both in the tower as well as in the aircraft or on the ground. To treat the causes for runway incursions, at Landvetter, there are numerous safety systems in place. To begin, there are specific Wigwag lights, which are very difficult to miss due to their nature, which warns of the runway ahead. This is to make sure that actors are made aware that they are about to enter the runway which without clearance can have dire consequences. Furthermore, the runway can be accessed from several taxiways spaced along the length of the runway. Mainly the ones at the northern or southern ends are used for aircrafts lining up. The central taxiways to the runway are always lit red to prevent aircrafts from accidently entering the runway through these since this could cause a runway incursion. If an aircraft demands a shorter take-off and it is cleared by the air traffic controllers, then the red lights are temporarily switched off to permit the aircraft to take that taxi route instead. During day-to-day operation of the aerodrome, many actors have to coexist with the aircraft. There are fire drills, maintenance cars and runway sweepers and plows for example that all need access to the runway at specific times. This can of course cause problems since you introduce an object to the runway, which could cause a collision. Whenever the air traffic controllers "lend" the runway to someone other than an aircraft they use specific red "strips" which block the strips for the incoming aircraft or the ones to take off. It should be noted that a "strip" is a physical piece of plastic containing the crucial information about flights that are in the system. They are organized into incoming or outbound flights and are arranged in order for the controller to plan the upcoming operations. This ensures that the controller is always reminded that something is currently occupying the runway and that no orders for landing or taking off are allowed at that moment. The seriousness of runway incursions is really depending on the weather conditions. If the skies are clear and the visibility for the air traffic controllers are good, then a runway incursion is not likely to cause any serious problems. The controller will see the object and so will the pilot which means the controller can avert the problem by telling the pilot to abort landing or if it is a vehicle radio it to call it away. This means that runway incursions during good visibility rarely results in any danger, but they are always treated as incidents and always reported. In fact, the controllers are now obligated by law to report all kinds of incidents, which are then investigated and analyzed for the purpose of improving the safety of the aerodromes. The real danger of runway incursions is during bad weather conditions when the visibility is low for example during fog or heavy snowfall. If the objects are not visible, then they are much more difficult to detect and consequently to remove from the runway. A safety measure employed during severely restricted visibility is the use of category 2 landing procedures rather than category 1 procedure. Category 2 moves the holding point for the aircraft, waiting to take off, further away from the runway so as to prevent them from accidently rolling on to the runway. Furthermore, the guide lights in the taxiways, from the holding position up to the runway, are turned off to make sure that the aircraft does not proceed further than intended. Once clearance is given to line up on the runway, the lights are again turned on. Once the aircraft is moving the recently lit lights are subsequently turned off again behind the aircraft as it moves to the runway. This is done to prevent any following aircraft from also entering the runway. One of the key elements for Landvetter's ability to operate safely is the ground radar. This radar is a so called primary radar, meaning that it is an active radar able to detect anything as small as people. With it, the air traffic controllers can detect any aircraft or vehicle moving on the taxiways or the runway. This is a crucial instrument for the safe operation when the visibility is limited.

The ground radar enables Landvetter to maintain full operations even though the visibility is heavily decreased. In the event of the ground radar breaking down the operation is immediately limited to only one moving aircraft at any time, which significantly hampers the capacity of the airport, but the safety is maintained. This was introduced after the dreadful accident at Linate airport 2001 when poor visibility combined with poor markings and signs and non-existing ground radar led to the collision of a SAS MD 80 with a Cessna Citation. All in all, runway incursions are rare at Landvetter but they are taken extremely serious. There are many systems in place to make sure that unwanted objects are not allowed on to the runway. Furthermore, the knowledge about runway incursions and the seriousness of them are constantly updated through briefings of incident reports, both from Landvetter itself but also from reports filed at other airports in Sweden.

## 6 Analysis of Runway Incursion

**Description of the Tools**

There are different hazard identification techniques that can be used for analysis of accidents including airport runway incursions. However, in our case the information is limited to reports from different aviation agencies and a study visit and interviews with air traffic controllers at a Swedish airport. Therefore, due to shortage of information and also limited time the analysis was conducted through applying What-if Study and VMEA (Variation Mode and Effect Analysis). What-if is similar to a brain storming session with a group of experienced people in the field. The group tries to identify hazardous scenarios by brainstorming about different things that can go wrong in the process. For instance, a group within a water purification plant could ask the following question: what if the electricity supply to the plant is cut off? The event is then further analyzed, and the group tries to determine what would happened and if there are any preventive measures that need to be put in place in order to prevent this scenario. Specifically, the team should start by identifying an abnormal scenario and the resulting hazard. Then, the possible consequences and current safeguards should be discussed as well as recommendations to improve the current situation. The findings are generally documented in a table similar to Table 3 [8].

**Table 3.** Table for what-if analysis [8]

| Topic Investigated: | | | Date: ##/##/## | |
|---|---|---|---|---|
| What If | Hazard | Consequence | Safeguards | Recommendation |
| | | | | |

VMEA is a statistically based method that is used to find areas where the effect of unwanted variation is critical [8]. The idea is to systematically look for noise factors (NF) affecting the Key Product Characteristic, KPC where noise factors are source of variation. The goal of conducting VMEA is to identify and prioritize those noise factors, which significantly contribute to the variation of the KPCs and might result in unwanted consequences. The result of the analysis is calculating a Variation Priority Risk Number (VPRN) that directs attention to those areas where reasonably considerable variation might be determined. This technique is a subjective one and is conducted based on experts' opinions. Several Sub-KPCs, favorably using an Ishikawa diagram should be listed, that influence the performance of the KPC. Then the analyst goes through a spreadsheet, as shown in Table 4, adding the sensitivity and variation size and finally compute the VPRN, variation risk priority number, and this gives information on what to focus on to improve safety.

**Table 4.** An example of the form used in VMEA, adapted from [9]

| No. | Sub-KPC | Weighting of sub-KPC (A) Rated 1-10 | Noise factors (NF) | Size of variation in NF (B) Rated 1-10 | Sensitivity of sub-KPC to NF (C) Rated 1-10 | VPRN (NF) $[A^2*B^2*C^2]$ | VPRN (sub-KPC) $\Sigma[A^2*B^2*C^2]$ |
|---|---|---|---|---|---|---|---|
| | | | | | | | |

# 7 Results of Analysis

**Results of What-If study**

In order to understand what can happen at an airdrome and what the important factors are, a what-if analysis was conducted (see Table 5).

**Table 5.** Results of What-if study

| Topic investigated: runway incursions | | | Date: December 2017 | |
|---|---|---|---|---|
| What if | Hazard | Consequence | Safeguards | Recommendation |
| Phraseology is unclear | Pilot, driver or person enter runway without permission | Risk for misunderstanding resulting in accidents | Standardized language, signs, wigwag lights, stop lights, visual identification, ground radar | Train operators, regular maintenance of signal lights, stop signs and markings |
| Lost radio contact with tower before landing | The traffic controller and pilot cannot communicate | Risk for misunderstanding resulting in accidents | Safety procedures: with loss of communication, specific flight patterns are used to alert the tower | Make sure the pilots and traffic controllers are trained to handle these situations |

(*continued*)

**Table 5.** (*continued*)

| Topic investigated: runway incursions | | | Date: December 2017 | |
|---|---|---|---|---|
| What if | Hazard | Consequence | Safeguards | Recommendation |
| Grotuid radar fails - Good visibility | Some sections of the airport that cannot be seen from the tower | Risks for runway incursion in parts of the airport that are not visible from the tower | Redundancy radar, positioning of tower several towers | Regular mauitenance. consider the layout, air traffic controller training |
| Ground radar fails - poor visibility | Impossible to detect moving objects near or on the runway | High risk for accidents and decreased possibility for traffic controllers to avert the situation | Redundancy radar, safety protocol: only allow one movement near the runway at a time | Regular maintenance, regular training in safety protocols, parallel and dedicated runways for takeoff and landing |
| Hardware failure - lights | Pilots may taxi to the wrong area | Risk for miscommunication | Redundant lights, safety protocols | Regular maintenance, training, standardized procedures |
| Hardware failure - computers | No communication between tower and vehicles, planes and people near the runway and no way of knowing which planes should land and takeoff | Risk for misunderstandings | Safety protocols, regular reliability check of key systems, | Have satellites phones available so other towers can be contacted, have standardized signaling system to alert a total shutdown of operations |
| Hardware failure - transponder and passive radar only | The traffic controllers are not able to detect incoming aircrafts | No way of detecting aircrafts near the airport which can result in runway incursions | Active backup radar. Safety protocols | Training, keep a backup radar |
| Unfit personnel | Poor judgment, unable to properly perform their work task | Potential risk for runway incursions due to improper behavior and poor decisions | Regular safety checks and screening of traffic controllers | Campaigns to show the consequences of tiredness or drunkenness |

(*continued*)

**Table 5.** (*continued*)

| Topic investigated: runway incursions | | | Date: December 2017 | |
|---|---|---|---|---|
| What if | Hazard | Consequence | Safeguards | Recommendation |
| Animal on the runway | Collision risk | Collision may result in the loss of thrust causing an accident | Animal fence around the airport. warning shots | Frightening sounds to keep birds away. Detection system so that animals entering the aiiport can be detected |
| Software failure | Wrong input to the traffic controller | Misunderstandings of flight paths or taxing paths which may lead to runway incursions | Safety protocols | Regular system checks |
| Heavy snowfall or fog - Poor visibility | Harder to detects vehicles, planes or people on the runway | Unable to detect errors, preventing the aversion of collisions | Ground radar, safety protocols, lights | Regular maintenance and training |

From the what-if analysis, a few key parameters have been identified as crucial to the safe operations of an airport such as regular maintenance, regular training of pilots, air traffic controllers and ground personnel. Furthermore, the ground radar is an important safeguard in order to maintain operations during poor visibility.

**Results of VMEA**

First, the KPC and the Sub-KPCs needs to be identified. The best way to do this is using an Ishikawa diagram. The KPC is obviously "number of Runway Incursion". The Sub-KPCs are identified below in Fig. 2.

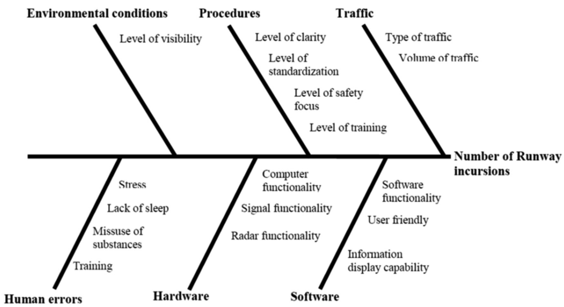



**Fig. 2.** KPCs and Sub-KPCs for use in VMEA

**Table 6.** Results of VMEA

| No. | Sub-KPC | Weighting of Sub-KPC (A) | Noise factor | Size of Variation NF (B) | Sensitivity of Sub-KPC to NF (C) | VRPN (NF) $[A^2*B^2*C^2]$ | VRPN (sub-KPC) $\Sigma[A^2*B^2*C^2]$ |
|---|---|---|---|---|---|---|---|
| 1 | Traffic | 3 | Type of traffic | 6 | 5 | 8100 | 22500 |
| | | | Volume of traffic | 5 | 8 | 14400 | |
| 2 | Procedures | 6 | Level of clarity | 7 | 5 | 44100 | 170418 |
| | | | Level of standardization | 7 | 7 | 86430 | |
| | | | Level of safety focus | 4 | 7 | 28224 | |
| | | | Level of training | 2 | 9 | 11664 | |
| 3 | Environmental conditions | 7 | Level of visibility | 9 | 9 | 321489 | 321489 |
| 4 | Human errors | 8 | Stress | 5 | 8 | 102400 | 333824 |
| | | | Lack of sleep | 4 | 8 | 65536 | |
| | | | Misuse of substances | 4 | 9 | 82944 | |
| | | | Training | 4 | 9 | 82944 | |
| 5 | Hardware | 5 | Computer functionality | 2 | 9 | 8100 | 27225 |
| | | | Signal functionality | 3 | 7 | 11025 | |
| | | | Radar functionality | 2 | 9 | 8100 | |
| 6 | Software | 5 | Software functionality | 2 | 9 | 8100 | 40600 |
| | | | User friendly | 5 | 4 | 10000 | |
| | | | Information display capability | 5 | 6 | 22500 | |

In the table below (Table 6) the contribution of each sub-KPC to the key performance indicator is calculated in order to understand how runway incursions can be prevented.

From the VMEA analysis, it is clear that the human errors, procedures and environmental conditions are of high importance in order to prevent runway incursions.

## 8 Conclusion

The analysis conducted based on the information gathered during the literature study and the study visit has identified the most important factors to work with in order to reduce runway incursions. The factors are ground radar, top management commitment to safety, standardization and procedures, effective signaling system as well as training and maintenance. Ground radar is extremely important for the safe continuation of operations at an aerodrome. It shows all movements near the runway making it easy for air traffic controllers to identify people, vehicles or planes that are present on the runway or about the enter without permission. Weather conditions that reduce the visibility of the runway from the air traffic control tower make it harder to avoid small incidents that could potentially lead to major accidents. However, with the ground radar system continuous safe operations can be assured in all weather conditions. Management plays a crucial role in the development of a good safety culture that ensures high runway safety. By being role models for safe operations, they can develop a culture that promotes safety and safety thinking. It will eventually mean that air traffic controllers, pilots and ground personnel feel confident about always putting safety first regardless of the effects of the operations of the entire airport or their own work. Standardization is important in order to reduce errors due to misunderstandings. Communications and different work procedures are potential sources of misunderstanding. By heavy standardization of communications where every word should be by the book, runway incursions can be reduced by making sure everyone understand what permission they have. Different work procedures can also be a source of misunderstandings since people may not understand each other's work patterns and cannot spot errors that others commit and help to redeem them. Signal systems with different types of lights are used to guide aircrafts that are taxiing, landing and taking off. They give everyone near the runway a clear indication of where they should go and if they deviate from their appropriate course. It is an efficient way to guide aircrafts in all weather conditions and gives the pilots a clear indication of what they should do. Furthermore, standardization among airports is very important in order to ensure consistency for pilots. Training of pilots, ground personnel and traffic controllers are important to make sure that everyone is well equipped to do perform their duties. With continuous training, everyone will follow the standardized procedures that are important to use in order to avoid misunderstandings. Through training, people can also prepare for unlikely scenarios and practice what they should do in extreme situations. This can be very valuable if an incident occurs. Regular maintenance and preventive maintenance ensures continuous operations by reducing equipment malfunctions and failures. System failures can have dire consequences and thus, maintenance reduce the risk for runway incursions. There are many different factors that influence the number of runway incursions and in order minimize them, a safety management perspective is needed in order to focus on all factors and continuously improve runway safety.

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# Accumulation of Micropollutants in Aqueous Media and Sediment, A Risk Assessment for Konya Main Drainage Channel, Turkey

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**Abstract.** Human activities increase types and numbers of synthetic pollutants and their byproducts in the course of time. Synthetic Organic Chemicals (SOCs), so called micropollutants, present in very low concentrations in aquatic ecosystem, but likely accumulate in animal and human tissues and cells because of fat solubility. These persistent micropollutants have toxic effects in very low concentrations and resistant to biodegradation. SOCs can be adsorbed to sediments in surface water sources, so sediments have an important role in the accumulation of water contaminants. In the course of time, sediments become source of new contamination for aqueous media.

In this study, it is aimed to determine concentration of two groups of SOCs; organochlorine pesticides (OCPs) and organophosphorous pesticides (OPPs) in wastewater, surface sediment and excavated sediment samples taken from Konya Main Drainage Channel (MDC) which takes the effluents of Konya Wastewater Treatment Plant and transports the treated wastewater to Salt Lake.

**Keywords:** Micropollutants · Pesticides · Water · Sediment · Risk

## 1 Introduction

Nowadays, it is hardly possible to find unpolluted water source as a result of water contamination with thousands of natural and synthetic pollutants. Synthetic Organic Chemicals (SOCs) are a numerous group of compounds including persistent organic pollutants (POPs), endocrine disrupting chemicals (EDCs), pesticides, polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), volatile organic compounds (VOCs), pharmaceutically active compounds (PhACs) etc. which can be found in all types of environmental media. Persistent, bio-accumulative and toxic characteristics of these pollutants pose a risk to ecosystem. Scientific studies demonstrate adverse health effects of SOCs exposure [1, 2]. Decreased fertility, increased breast, prostate, and testicular cancers, incidences about gender switch of fish and frog are attributed to endocrine disrupting SOCs [3]. SOCs can be found far away from their sources,


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including Antarctica, Arctic etc. despite geographical isolation and lack of industrial activities [4]. Hydrophobic or hydrophilic characteristics of compounds affect their spatial and temporal distribution in ecosystem. Hydrophobic compounds (most of the POPs) bind to the sediment particles. Halogenated and polar groups are more mobile in the environment [5].

Simultaneous occurrence of these pollutants has synergistic effects that cause higher toxicity [6]. There are still large knowledge gaps about toxic effect of different combinations of these substances in various conditions. Besides, some transformation byproducts of SOCs have higher mutagenic and carcinogenic effects. Therefore, determination and removal of these pollutants are of high importance for human health and sustainability.

Lack of regulations or failed implementation of existing legislation in many countries, insufficient inventory, and inadequate training on internationally approved analysis technologies result in unsuccessful management of SOCs.

There are various studies in the literature to determine efficient and applicable treatment methods to remove SOCs from aqueous media [7, 8]. Conventional treatment plants depend on mainly biodegradation and adsorption onto activated sludge. Only some specific bacteria capable to degrade SOCs [9]. Advanced oxidation processes, membrane technologies and adsorption methods are mostly proposed techniques for the removal of SOCs, all of which have some different constraints. Advanced oxidation processes are used to depredate micropollutans to less refractor and toxic, and more biodegradable compounds. The success of these methods is to degrade SOCs to $CO_2$ and $H_2O$, which do not have harmful effect, however, it is generally not possible to mineralize POPs. In some cases, degradation results in production of more toxic metabolites when compared with mother compound.

Pesticides are important groups of SOCs, applied to increase agricultural product quality and quantity, and have recalcitrant character. Due to their physico-chemical properties they can stay in the environment for long periods. Pesticides enter the ecosystem from non-point sources (e.g. agricultural practices) and point sources (e.g., industrial and municipal discharges) [10]. Increasing pesticide concentrations in environmental media has ecological risk, since pesticides do not only affect the target species. They can enter the food chain and bioaccumulate in tissues [11]. Pesticides cause harmful effects on the human immune, nervous, respiratory, endocrine and reproductive systems. Physical (e.g., altered temperature and wind pattern), chemical (e.g., degradation and transformation) and biological (e.g., changes in soil and water microbial activity) processes constantly affect the environmental distribution of pesticides [12].

Organochlorine pesticides (OCPs) are a group of pesticides ubiquitous in the environmental matrixes. OCPs have been widely used in the world since 1950s. There has been an extensive concern for OCPs due to their high toxicity, persistency, and bioaccumulation in the environment [13, 14]. Most of the OCPs are among the substances restricted or banned globally under the Stockholm Convention [15]. Organophosphorus pesticides (OPPs) are one of the most commonly used insecticides in the world due to their effectiveness and lower persistency in the environment when compared to OCPs. OPPs have widely substituted OCPs in many countries.

SOCs levels in sediments give a basic information about contamination of water sources with these compounds. In recent studies, Sakan et al. [16] determined OCPs in the range of < MDL-113 μg/kg in the sediment samples taken from river and artificial lakes in Serbia. 270.6 μg/kg total OCPs was reported for surface sediments taken from three main rivers in Congo; Makelele, Kalamu and Nsanga [17].

The objective of this study is to investigate occurence and distribution of OCPs (α-HCH, β-HCH, γ-HCH, δ-HCH, aldrin, dieldrin, heptachlor, heptachlor epoxide, endosulfan I, endosulfan II, endosulfan sulfate, p,p'-DDE, p,p'-DDD, p,p'-DDT, endrin, endrin aldehyde, endrin ketone, methoxychlor) and OPPs (malathion, parathion, methyl-parathion, chlorpyrifos, diazinon) in sediment, excavated sediment and wastewater throughout Konya MDC, so as to determine accumulation of these micropolutants in researched area and evaluate the risk for ecosystem. It is aimed to give an overview about the state-of-the-art of pesticides accumulation risk.

## 2 Material and Method

### 2.1 Study Area and Sampling

Konya WWTP's effluent reaches to Salt Lake via MDC with the length of 150 km. Three pumping stations are located along the MDC (named 1st pump, 2nd pumb, 3rd pump). Sediment and water samples were collected near these pumping stations. Sediments in the MDC are periodically excavated to gain better hydraulic conditions. Excavated sediment samples were taken from 1 km after Konya WWTP discharge point and from three pumping stations. Four sediment samples were taken from each sampling point. Excavated sediment samples were taken from hills in two side of MDC in the depth of 0–25 cm, 25–50 cm and 50–70 cm. All samples were stored in refrigerators at 4 °C until analysis.

### 2.2 Determination of Physico-Chemical Properties of Sediment Samples

The pH values were measured by preparing a 50 mL 0.01 M CaCl2 and distilled water (v:v, 1:1) suspension containing 5 g of sediment sample. For the determination of electrical conductivity (EC) values, 20 g sediment sample was shaken in 100 mL distilled water during 30 min and filtered. The cation exchange capacity (CEC) of sediment samples were performed according to the ammonium acetate saturation method. Organic matter was determined by standing for 20 min in the ash oven at 550 ± 50°C.

### 2.3 Extraction and Clean-up of Pesticides from Samples

Extraction of pesticides in sediment and water samples was carried out by soxhlet extraction method and liquid extraction method, respectively. Extraction of pesticides in sediment samples was carried out by soxhlet extraction method for 16 h with 150 mL n-hexane/acetone (1/1, v/v) solvent mixture. The extract was concentrated to about 2 mL with a rotary evaporator and the extract was cleaned with column included

10 g of 5% deactive silica gel. For the elution of compounds, a solvent mixture of 70 mL n-hexane and 60 mL n-hexane/ethylacetate (1/1, v/v) was used. Obtained extracts were concentrated to 1 mL and then analyzed by gas chromatograph-mass detector (GC-MS) system. Wastewater samples were extracted according to conventional liquid-liquid extraction method (US EPA 3510). 200 mL of wastewater sample was extracted by using 40 mL dichloromethane by vigorous shaking for 2 min. Sodium sulfate was used for dehydration. Rotary evaporator (Buchi B-160 Vocabox, Flawil 1, Switzerland) and gentle nitrogen stream were used to concentrate the extracts to 1 mL after clean up step (0.45 μm syringe filter). Samples were transferred into the vial for GC-MS analyses.

### 2.4 GC-MS Analyses

Analyses of OCPs and OPPs were carried out by gas chromatograph (GC, Agilent 6890 N, Agilent Technologies, Palo Alto, CA, USA) equipped with mass-selective detector (MS, Agilent 5973, Agilent Technologies, Foster City, CA, USA). Programmed temperature vaporizing (PTV) injector and HP-5 ms capillary column were used (30 m length, 0.25 mm i.d. and 0.25 μm film thickness) in GC-MS system. 1 ng/μL mix standard was used to determine optimum GC-MS conditions.

### 2.5 Quality Control Parameters

For OCPs, LOD, LOQ, linear response range and $R^2$ values were determined as 0.011–0.052 μg/L, 0.37–0.173 μg/L, 0.001–10 ng/μL, and 0.996-0.999, respectively, while LOD, LOQ, linear response range and R2 values were determined as 3–8 μg/μL, 10–27 μg/μL, 0.1–10 ng/μL and 0.990–0.998, respectively, for OPPs.

## 3 Results and Discussion

### 3.1 Physico-Chemical Properties of the Samples

pH, EC, CEC values of surface sediment samples were determined as 7.9–9.2, 99.4–572 μs/cm, 52.1–137 meq/100 g, respectively, while pH, EC, CEC values of excavated sediment samples were determined as 7.6–8.1, 848–6910 μs/cm, 65.8–126.8 meq/100 g, respectively. Sediment samples have alkaline properties. The organic matter values of the sediment samples range between 0.4%–6.4%. The higher content of organic matter increases the accumulation of pollutants.

### 3.2 Pesticide Concentrations in Surface Sediment Samples

Concentrations of OCPs and OPPs in sediments samples are given in Figs. 1 and 2, respectively. Besides, Fig. 3 shows the difference of total concentrations of two groups. OCPs were determined in the range of 0.5–54.24 μg/kg dw, while OPPs were determined in higher concentration in the range of 0.5–608 μg/kg dw. Main reason for this finding is that; while many OCPs are forbidden, OPPs are encouraged to be used by farmers. Since OPPs have shorter half-life, they are likely not accumulate in the environment. On the other hand, excessive use of these pesticides results in high concentration values in environmental matrixes. Besides, it is proved that OPPs have an inhibition effect on acetilcolinesterase (AChE) enzyme that cause neurotoxic effects [18]. This effect results in deterioration of motor activities [19]. Previous studies were also revealed carcinogenic and genotoxic effects of OPPs [20].

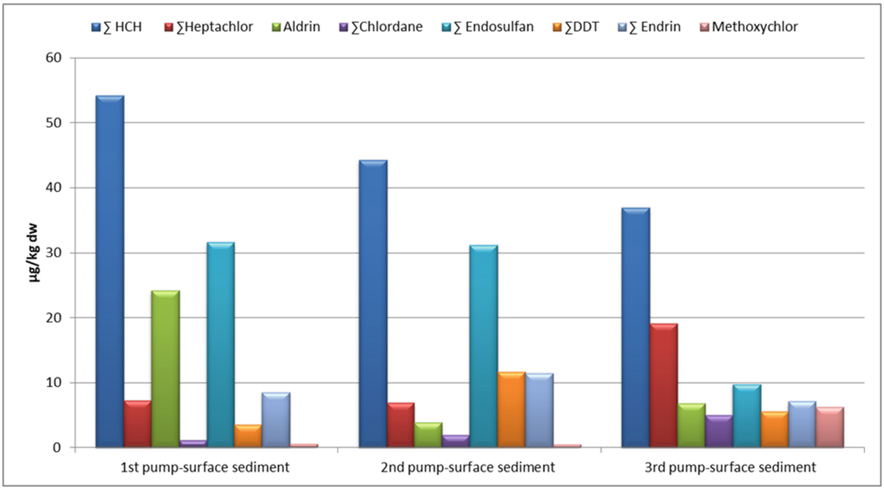


**Fig. 1.** Concentrations (*µg/kg dw*) of OCPs (*∑HCH: α-HCH, β-HCH, γ-HCH, δ-HCH, ∑DDT: p,p'-DDE p,p'-DDD p,p'-DDT, ∑Heptachlor: Heptachlor, Heptachlor epoxide, ∑Endosulfan: Endosulfan I, Endosulfan II, Endosulfane sulfate, ∑Endrin: Endrin, Endrin aldehyde, Endrin ketone in 1$^{st}$ pump-surface sediment, 2$^{nd}$ pump-surface sediment, 3$^{rd}$ pump-syrface sediment*) in surface sediment samples

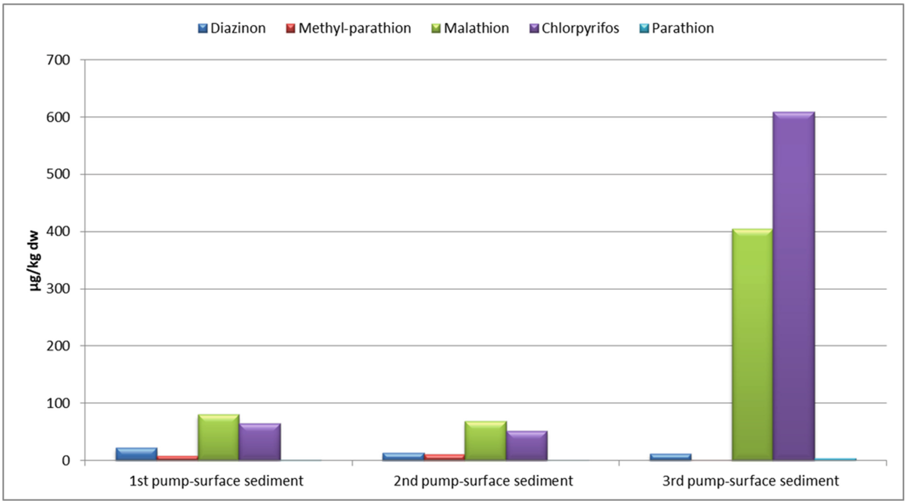


**Fig. 2.** Concentrations (*µg/kg dw*) of OPPs (*Diazinon, Methyl-parathion, Malathion, Chlorpyrifos, Parathion in 1$^{st}$ pump-surface sediment, 2$^{nd}$ pump-surface sediment, 3$^{rd}$ pump-syrface sediment*) in surface sediment samples

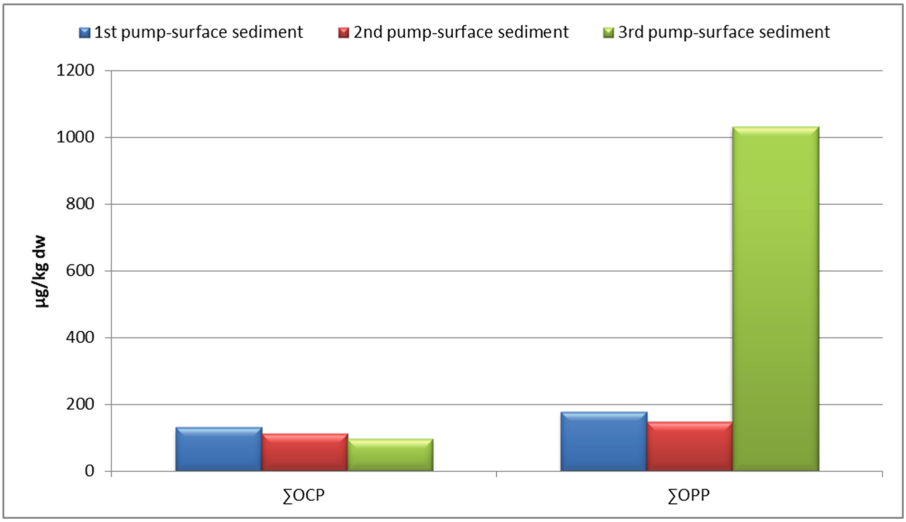


**Fig. 3.** Concentrations (*µg/kg dw*) of (∑*OCP)* and (∑*OPP)* in surface sediment samples

A decreasing trend to downstream of MDC (from 1st pump station to the 3rd pump station) was found for OCPs, while trend is opposite for OPPs. This situation can be explained by continuous application of OPPs for agricultural activities in the vicinity of MDC. ΣHCH among OCPs, and chlorpyrifos and malathion among OPPs determined in the highest concentrations.

Among investigated OPPs, parathion, metyl-parathion and diazinon are in the list of prohibited pesticides in Turkish Food Codex. These OPPs were detected at lower concentrations. Malathion and chlorpyrifos which are detected in higher concentrations are in use. Among investigated OCPs, except methoxychlor, all other compounds were prohibited. Prohibited OCPs have been still determined in high concentrations, due to their physicochemical properties.

### 3.3 Pesticide Concentrations in Excavated Sediment Samples

Similar findings were recorded for excavated sediment samples with surface sediment samples. Figure 4 shows that ΣOPPs concentrations of the excavated sediment samples are higher than ΣOCPs concentration. Pesticide pollution in excavated sediment samples is higher than pesticide pollution in surface sediment samples. No trend was obtained for samples taken from different depths, probably because of mixing during excavation.

So as to gain a better hydraulic condition, sediments accumulated in MDC are excavated and deposited in two opposite sites of the channel. These hills are source of environmental pollutants for the environment. Organic and inorganic contaminants are adsorbed to sediments, so sediments have essential environmental role in the accumulation of contaminants [21]. For determination of water pollution level, sediments can be used as indicator.

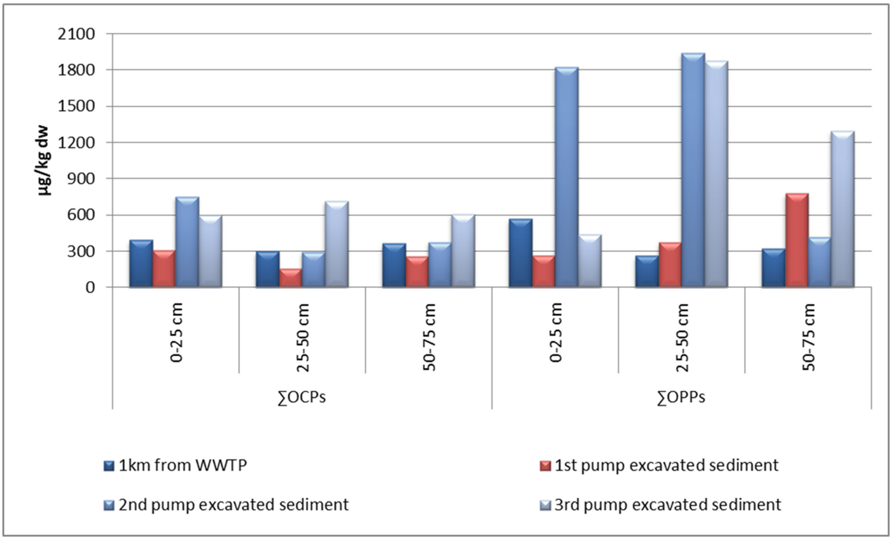


**Fig. 4.** Concentrations (*µg/kg dw*) of (∑*OCP)* and (∑*OPPs*) in excavated sediment samples (*1 km from WWTP, 1st pump excavated sediment, 2nd pump excavated sediment, 3rd pump excavated sediment*)

∑OCPs and ∑OPPs in excavated sediment samples were in the range of 307–751 µg/kg dw and 261–1821 µg/kg dw in 0–25 cm depth. 153–715 µg/kg dw ∑OCPs, 264–1942 µg/kg dw ∑OPPs were determined in 25–50 cm depth, and 254–609 µg/kg dw ∑OCPs, 324–1297 µg/kg dw ∑OPPs were determined in 50–75 cm depth. Pesticide concentrations of sediments samples in this study were higher than reported in the literature. Since sediment samples were taken from MDC, which took untreated wastewater for many years, OCPs and OPPs concentrations were higher when compared with previous studies. Hela et al. [22] investigated pesticide residues in water and sediments samples. 321 ng/g dw methyl-parathion was found in sediment samples. 50 pesticides and their transformation products in surface water, wastewater, sediment and fish samples were determined. Chlorpyrifos and diazinon were determined in the range of 0.7–15.9 ng/g dw and 0.2–175.5 ng/g dw, respectively [23]. Mohammed et al. [24] determined concentration of OCPs in surface sediment samples, taken from three points near Trinidad Island. Concentration of ∑DDT and ∑HCH were found in the range of 0.7–29 ng/g dw and 0.5–1.8 ng/g dw, respectively. Yuan et al. [25] reported 1.8–27.5 ng/g dw and 2.5–16.9 ng/g dw ∑DDT and ∑HCH in sediment samples.

### 3.4 Pesticide Concentrations in Wastewater Samples

Figure 5 shows OCPs and OPPs concentrations in wastewater treatment plant effluent, wastewater near the 2nd and 3rd pump stations. Concentration of ∑HCH, ∑heptachlor, aldrin, ∑chlordane, ∑endosulfane, ∑DDT, ∑endrin, metoxychlor, diazinon, malathion, chlorpyrifos, and parathion were determined in the range of 0.8–0.91 mg/L, 0.01–0.02 mg/L, < dl-0.05 mg/L, 0.09–0.011 mg/L, 0.01–0.04 mg/L, 0.025–0.125 mg/L, 0.09–0.25 mg/L, 1.07–1.37 mg/L, 0.008–0.12 mg/L, 0.05–0.11 mg/L, 0.05–0.085 mg/L, 0.02–0.03 mg/L, respectively. ∑HCHs and metoxychlor from OCPs were dominant pollutants in wastewater.

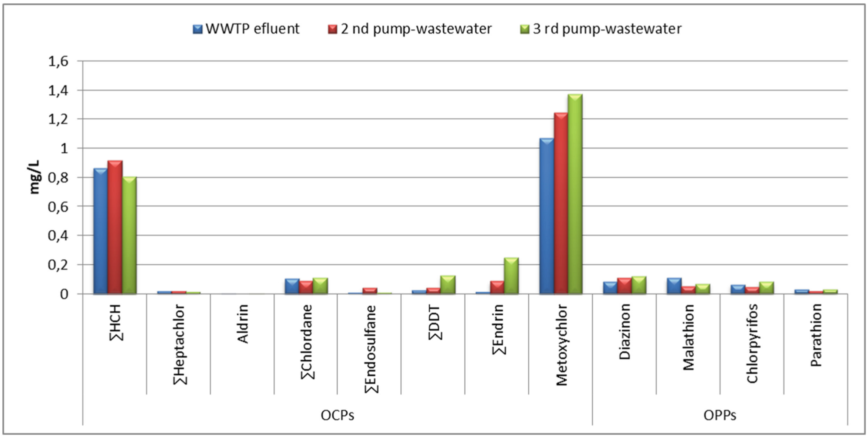


**Fig. 5.** Concentrations (*mg/L*) of (*OCP)* and (*OPP)* in wastewater samples (*WWTP effluent, 2nd pump-wastewater, 3rd pump wastewater*)

## 3.5 Risk Assessment for Konya MDC

There are different routes of pesticide contamination for MDC. While Konya WWTP's effluents consist investigated pesticides, agricultural drainages and spray applications in near areas are also contamination sources for the MDC's water. Besides, re-suspension of pesticide accumulated surface sediment and excavated sediments are sources of water contamination. Findings of this study show that excavated sediment samples contain high pesticide contamination. Excavated sediment hills in two sites of MDC pose risk of contamination in near agricultural fields.

It is known that, conventional wastewater treatment plants are insufficient to remove SOCs from wastewater. SOCs seem to be the most problematic group of pollutants for reuse of treated wastewater in water scarce Konya region. There are agricultural lands around the MDC and wastewater in the channel is sometimes used by farmers for irrigation purpose.

Konya city and its environment has a closed basin, which means that all water sources are in an interaction. It is likely that SOCs in MDC may contaminate fresh aqueous media. Besides, usage of this contaminated water for agricultural irrigation is an additional pesticide source for the cultivated products.

While waters of MDC do not meet to Salt Lake in arid season, waters of MDC discharges to the Lake in rainy seasons. MDC discharge to Salt Lake is another pesticide contamination route for the area. Salt Lake meets high percent of salt demand of Turkey. Pesticide contamination risk of salt should be determined.

## 4 Conclusion

This study shows that there is quantitative OCPs and OPPs contamination in MDC, in Konya. $\sum$HCH, $\sum$Endosulfan, malathion and chlorpyrifos were dominant contaminants in the area. OPPs were determined in higher concentrations when compared with OCPs. It was determined that the prohibited OCPs are still in the environment. Excavated sediments samples contain high concentrations of pesticides when compared with literature. Pesticides do not only accumulate in limited environments, but also distribute far away regions. Therefore, more precautions are needed to control these compounds and less permanent and harmless pesticides should be preferred.

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# Effect of Experimental and Mathematical Modeling of Spillway on Dam Safety

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**Abstract.** In this paper, hydraulic characteristics of Yedigöze Dam and Hydroelectric Power Plant (*HEPP*), which are producing energy in Turkey, were investigated experimentally by physical model studies. The 1/70-scaled physical model was used in conducting experiments. Flow depth, discharge and pressure data were recorded for different flow conditions. Serious modification was made on the original project with the experimental study. In this study, in order to evaluate the capability of the computational fluid dynamics on modeling spillway flow a comparative study was also made by using results obtained from physical modeling and computational fluid dynamics (CFD) simulation. Discharge rating curves, velocity patterns and pressures were used to compare the results of the physical model and the numerical model. It was shown that there were many modifications needed after project design with experimental and numerical study and there is reasonably good agreement between the physical and numerical models in flow characteristics.

**Keywords:** Dam safety · Spillway design · Hydraulic engineering
Experimental and numerical model · Risk management

## 1 Introduction

Spillway design is very important for dam safety and rehabilitation as inadequate spillway capacity is one of the primary reasons for dam failures. During the spillway design, a dam must safely withstand the probable maximum flood (PMF). If design analysis indicates that, a spillway may not be adequate to safely pass the probable maximum flood, resulting in overtopping the dam and possible failure with loss of life and property.

The nature of the hydraulic problems is very complex and so theories related with hydraulic science are usually based on some assumptions. Designing the hydraulic structures, which is made according to these theories, contains these assumptions (Senturk 1994). Therefore, the design results may not always reflect the reality and the designs need to be verified, improved and modified by the physical and numerical model studies. As a result, it provides economy and some problems, which will be faced after the construction, may be solved before the construction. For this reason as a part of design process for hydro-electric generating stations, hydraulic engineers


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typically conduct some form of model testing. The desired outcome from the testing can vary considerably depending on the specific situation, but often characteristics such as velocity patterns, discharge rating curves, water surface profiles, and pressures at various locations are measured.

In this paper, hydraulic characteristics of Yedigöze Dam and Hydroelectric Power Plant (*HEPP*), which are producing energy in Turkey, were investigated experimentally by physical model studies. The 1/70-scaled physical model was used in laboratory experiments. Flow depth, discharge and pressure data were measured for various design flow conditions. Serious modification was made on the original project with the experimental study. Experimental modeling studies have been used to achieve designing hardness, however, the studies take time, needs heavy labor and frequently may not be economical. With the use of high performance computers and more efficient computational fluid dynamics (CFD) codes, the behavior of hydraulic structures can be investigated numerically in reasonable time and expense and so an alternative to experimental work in civil engineering applications (Johnson and Savage 2006; Savage and Johnson 2001). For this purpose, there are many commercial or open computer programs used in various engineering fields.

In this study, in order to evaluate the capability of the computational fluid dynamics on modeling spillway flow a comparative study was also made by using results obtained from physical modeling and computational fluid dynamics (CFD) simulation. A commercially available CFD program, which solves the Reynolds-averaged Navier-Stokes (RANS) equations, was used to model the numerical model setup by defining cells where the flow is partially or completely restricted in the computational space. Discharge rating curves, velocity patterns and pressures were used to compare the results of the physical model and the numerical model. It was shown that there were many modifications needed after project design with experimental and numerical study and there is reasonably good agreement between the physical and numerical models in flow characteristics.

## 2 Physical Model

A 1/70-scaled physical model of the Yedigöze Dam spillway and stilling basin was built and tested at the Hydraulic Model Laboratory of State Hydraulic Works of Turkey (DSI). The model was constructed of plexiglas and was fabricated to conform to the distinctive shape of an ogee crest. The spillway has 66 m in width with 11 width of 6 gates. Spillway has two consecutive inclinations of 10% and 28%. During model tests, flow velocities were measured with an ultrasonic flow meter. Pressures on the spillway were measured using a piezometers board reading provided the average pressure reading at each pressure tap location. Both the upstream reservoir lake level and downstream tailwater elevations were measured using piezometers. A control valve was used to set the flow in the physical model. The model was operated for PMF = 9000 $m^3/s$ and belonging upstream reservoir elevation of 238.22 m.

The downstream tailwater elevations was adjusted by another control gate located far downstream of the model.

## 2.1 Water Surface Profiles Along the Spillway

During the spillway design, water surface depths are needed for all calculations in each section. Water surface profiles were conducted using a point gage with a vernier scale to the nearest 0.1 mm for the reservoir discharge capacities of Q = 9000 $m^3$/s, 6000 $m^3$/s, 3000 $m^3$/s and 1000 $m^3$/s considering that for spillway gates are fully open. Figure 1 shows water flow view observed from the experimental studies and water surface profiles observed from the experiments are seen in Fig. 2, respectively.

**Fig. 1.** Water surface profiles along the dam spillway

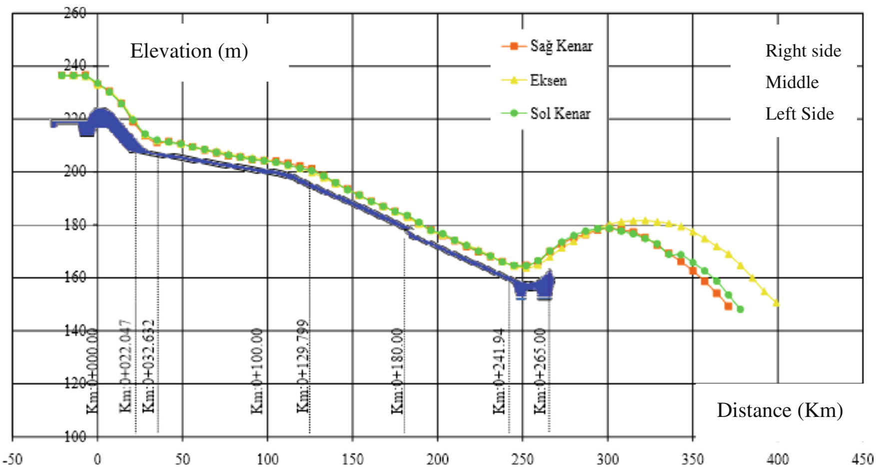



**Fig. 2.** Water surface profiles for various discharges observed by model study

## 2.2 Pressure and Velocity Measurements on Spillway

If the flow pressure drops below the vapor pressure the water begins to vaporize, just like if it was boiling (Wagner 1967). As the bubbles cannot escape they will implode. The pressures fluctuations associated with bubble collapse produce noise and vibrations and, eventually can lead to the structure failure (Vischer and Hager 1997). Cavitation can cause damage in a very short time. The cavitation risk is checked by cavitation number defined by the following equation.

$$\sigma = \frac{P - P_{\upsilon}}{\frac{1}{2}\rho U^2} \tag{1}$$

where; $\sigma$ is the dimensionless cavitation number; $P$ is the absolute pressure (N/m$^2$); $P_{\upsilon}$ is the vapor pressure of the fluid (N/m$^2$); $\rho$ is the fluid density (kg/m$^3$) and $U$ is mean flow velocity (m/s). The cavitation number at which cavitation starts is here referred as the critical cavitation number (Kokpinar and Gogus 2002). According to Falvey (1990) the critical cavitation number is $\sigma = 0.2$, and cavitation will occur if $\sigma < 0.2$.

In order to investigate the flow characteristics and to calculate the cavitation numbers; flow depths, the pressures and flow rates were measured at various distances from the spillway crest (Spillway crest is Km: 0+000.00) for the reservoir discharge capacities of Q = 9000 m$^3$/s, 6000 m$^3$/s, 3000 m$^3$/s and 1000 m$^3$/s considering that for spillway gates are fully open. Flow depths were measured directly, and pressures were measured by using manometers. The details of the experimental study and the calculations are given in the report of Hydraulic Model Studies of Yedigöze Dam and HPP (Kumcu 2008). In the original design case, when the flow discharge is 1000 m$^3$/s and 3000 m$^3$/s, some negative pressures were attended along the spillway and cavitation numbers were calculated. These results indicate that the velocities were very high and the pressure variations strongly affect the flow in this area. Flow characteristics, which were observed at these points, presented in Table 1. It is clearly seen that, cavitation number is less than the critical cavitation number, $\sigma = 0.2$ at Km: 0 + 173.00 for Q = 3000 m$^3$/s. Therefore, the cavitation risk is real. Protection of the surface from cavitation erosion is usually achieved by introducing air next to the flow structure surface. Aeration devices are designed to introduce artificially air within the flow upstream of the first location where cavitation damage might occur. Aerators are designed to deflect high velocity flow away from the chute surface. The water taking off from the deflector behaves as a free jet with a large amount of interfacial aeration. This is made by means of aeration devices located on the bottom and sometimes on the sidewalls of the structure (Chanson 2002; Chanson and Gonzalez 2005). In order to prevent cavitation, aerators were fixed when the cavitation risk is available, and aeration is not enough along the spillway. In order to increase the amount of air introduced by aerators the deflectors were placed in front of the aerators (Demiröz 1986). The plan view of experimental rearrangement of pressure measurement points, aerators and the reflectors is shown in the Fig. 3.

**Table 1.** Cavitation indexes of pressure measurement points

| Section | Distance from spillway crest (Km) | Q ($m^3/s$) | Uave (m/s) | H (m) | Cavitation index |
|---|---|---|---|---|---|
| 1 | 0+173 | 1000 | 22.84 | 0.67 | 0.40 |
| 2 | 0+166 | | 23.35 | 0.67 | 0.39 |
| 3 | 0+159 | | 22.93 | 0.71 | 0.40 |
| 4 | 0+138 | | 21.39 | 0.74 | 0.46 |
| **1** | **0+173** | **3000** | **27.44** | **1.40** | **0.18** |
| 2 | 0+166 | | 27.11 | 1.37 | 0.31 |
| 3 | 0+159 | | 26.74 | 1.42 | 0.32 |
| 4 | 0+138 | | 24.01 | 1.69 | 0.40 |
| 1 | 0+173 | 6000 | 28.40 | 2.50 | 0.31 |
| 2 | 0+166 | | 28.14 | 2.49 | 0.31 |
| 3 | 0+159 | | 27.89 | 2.43 | 0.32 |
| 4 | 0+138 | | 25.90 | 3.00 | 0.38 |
| 1 | 0+173 | 9000 | 29.29 | 4.13 | 0.32 |
| 2 | 0+166 | | 28.76 | 4.22 | 0.34 |
| 3 | 0+159 | | 28.15 | 4.28 | 0.36 |
| 4 | 0+138 | | 27.26 | 4.51 | 0.38 |

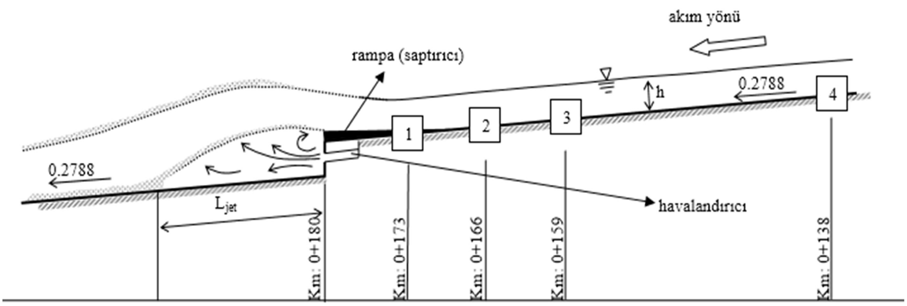
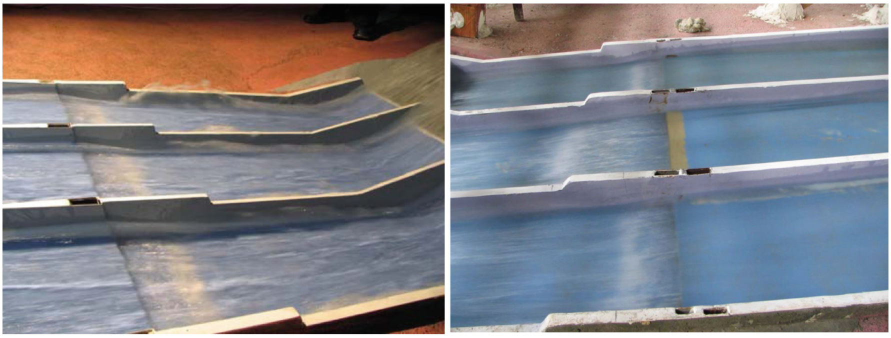



**Fig. 3.** Pressure measurement points for cavitation risk

It is clearly seen from Fig. 4 that, after rearrangement of the aerators with the reflectors, aeration amount was almost become twice. The air entrainment results from the interaction of the water flow and the air flow at the aerated areas. After final project design, all the tests were repeated, water profiles and pressure measurements were again recorded and there was no cavitation risk along the spillway. After convinced that the spillway structure is safe, numerical tests were continued with the final project.



a) Original project b) Final project

**Fig. 4.** Aeration along the spillway belonging to (a) original project and (b) final project designed after the experimental study

## 3 Numerical Simulation

After serious modification are made on the original project, a comparative study was made for flow over a spillway structure using results obtained from physical modeling and computational fluid dynamics (CFD) simulation. The commercially-available CFD package FLOW-3D Version 10.0 was used in the simulation of the flow field. The CFD package applies finite-volume method to solve the RANS equations. Free surfaces are modeled with the Volume of Fluid (VOF) technique, which was first reported in Nichols and Hirt (1975), and more completely in Hirt and Nichols (1981). Trademarked as TruVOF, this technique is one of the defining features of the program and provides three important functions for free surface flow: location and orientation of free surfaces within computational cells, tracking of free surface motion through cells, and a boundary condition applied at the free surface interface.

The location of the flow obstacles is evaluated by the program implementing a cell porosity technique called the fractional area/volume obstacle representation of FAVOR method (Hirt 1992). The free surface was computed using a modified volume-of-fluid method (Hirt and Nichols 1981). For each cell, the program calculates average values for the flow parameters (pressures and velocities) at discrete times using staggered grid technique (Vesteeg and Malalasekera 1996).

The three-dimensional solid form is recreated in AutoCAD, longitudinal cross section, plan and profile views (2D) are used to generate 3D model by series of extrude, subtract and union commands for spillway itself and wall structures.

FLOW-3D version V10.0 was used to simulate flow over the Yedigoze Dam along with the renormalized group turbulence model. Solid model used in the model study is seen in Fig. 5a and a rectangular grid was defined in the computation domain is shown in Fig. 5b. Total number of grid cells was approximately 17.0186E+06 in which only about 4.8E+06 of them were in touch with open volume. The corresponding uniform mesh size used in outer mesh was $\Delta x = \Delta y = \Delta z = 0.4$ m. While the nested inner mesh is defined as $\Delta x = \Delta y = \Delta z = 0.3$ m.

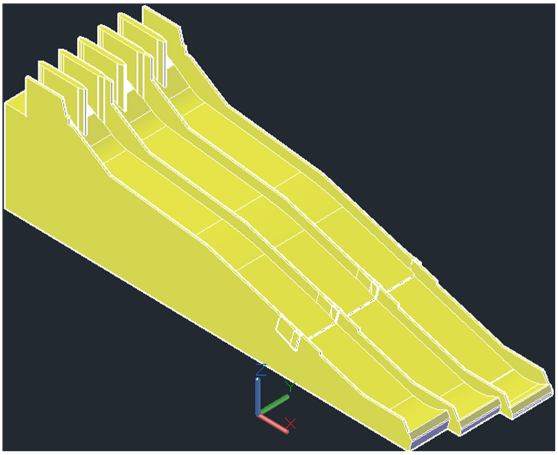



**Fig. 5a.** Solid model is recreated in AutoCAD 3D Modeling

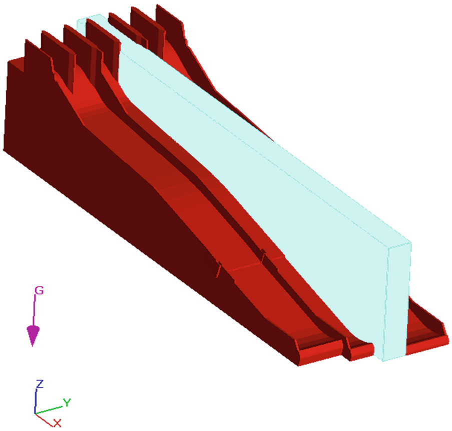



**Fig. 5b.** Solid model used in the CFD simulations (final design)

To simulate given flow, it is important that the boundary conditions accurately represent what is physically occurring. Because the flow is defined in cartesian coordinates, there are six different boundaries on the computational mesh domain. The boundary conditions on the mesh were set as follows: sidewalls y-no slip/wall; top z-wall to keep atmospheric pressure equal to zero; bottom z-no slip/wall; left x-local stagnation pressure based on upstream reservoir elevation; and right x-local outflow.

The inflow and outflow boundary conditions (left and right boundaries, x-direction) can be computed by employing a hydrostatic pressure distribution throughout the flow depth. In running the FLOW-3D CFD software, computation modules of viscosity and turbulence, gravity, air-entrainment, and density evaluation were activated for all cases studied. Since there are no prototype data available for comparison to the CFD solution, the data from the physical model have been scaled to prototype dimensions.

## 4 Discussion and Results

The main purpose of this part of the studies to compare results from a physical model with that of a CFD model for flow over an ogee crest spillway and through stilling basin. The flow rates over the spillway crest and free surface elevations, depth-averaged velocity distributions, and the pressures acting on the crest and on the stilling basin are used to compare the differences between the physical model and the CFD model.

Figure 6 shows the comparison between the water surface profiles of mathematical simulation and physical model observations for final project design of Q = 9000 $m^3$/s. It is obvious that, both simulation gives similar water depths for a given discharge and distance from the spillway crest. The water surface profiles overlap each other. This means that, numerical solution is also an alternative solution by means of water depth measurements. The effect of reflector on air entrainment is seen in Fig. 7. This figure depicts that, when the reflector is added to the aerators, as a result, aerator's efficiency increases rapidly. After replacing to reflectors on the aerators, air entrainment into spillway face increases from 17% to 28%.

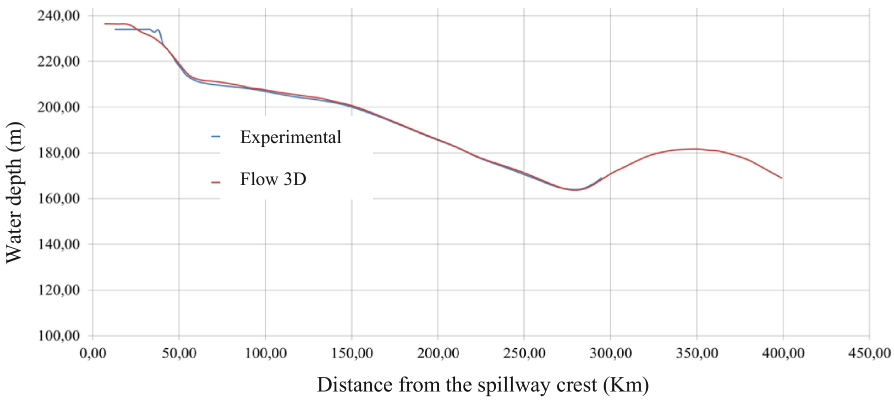
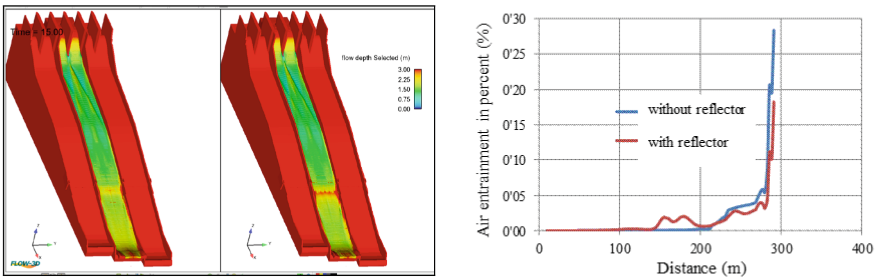



**Fig. 6.** Comparison of water surface profiles of experimental measurements and CFD observations for Q = 9000 $m^3$/s




a) b)

**Fig. 7.** CFD modeling observations with and without reflectors for Q = 9000 $m^3$/s; (a) Flow along the spillway (b) Efficiency of aerators and reflector

If the importance of the air entrainment is taken into account, it is obvious that experimental investigations are very important for the dam safety, and the results of the CFD solutions and experimental findings are very similar to each other.

## 5 Conclusions

In this study, 1/70-scaled physical model was conducted in order to investigate flow conditions of the approach channel, performance and their rating curves for full openings of the radial gates of the spillway, flow over the spillway for operation conditions in the Yedigöze Dam. A series of experiments were tested in the State Hydraulic Works Hydraulic Laboratory. Cavitation risk was tested flow along the spillway. Aerators and reflectors are added as there was cavitation risk. After observing final design for the approach channel and spillway, an attempt was made to simulate flow over a spillway structure using commercially available CFD software. Obtained results from the CFD model was compared to existing physical model data of the Yedigöze Dam and HEPP.

The flow rate results show that the CFD model provided a reasonable solution. The average relative percent difference between the CFD model and the physical model was obtained as 2.9%.

The CFD results obtained for free surface elevation and depth-averaged velocity fit generally the physical model data.

Although numerical methods offer a potential to provide solutions with increasing accuracy, physical model studies are still considered as the basis from which all other solution methods used.

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# The Effect of Fall Prevention Methods for Construction Scaffolds in Accident Prevention

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**Abstract.** Every year in Japan, approximately 300 workers are killed due to work-related accidents at construction sites. Approximately 40% of the accidents are caused by falls from heights. Therefore, Japan's Ministry of Health, Labour and Welfare has introduced and strictly enforced countermeasures with various safety guidelines to prevent fall-related accidents. In this study, the features of two typical guidelines are introduced including an evaluation of the human factor and the effects on the prevention of fall-related accidents. Based on the results of the evaluation, it was found that fatal accidents at construction sites were reduced following the "Guidelines for the Methods to Erect Scaffolds First." However, another guideline, the "Guidelines for the Methods to Erect Handrails First for the Scaffolds Erection" did not significantly reduce accidents because of a low usage rate.

**Keywords:** Fall · Accident · Construction · Scaffold · Handrail

## 1 Introduction

Every year in Japan, approximately 300 workers are killed due to construction accidents, including frequent falls from heights. Figure 1 shows classifications of the causes of fatal construction accidents in 2016 in Japan. Approximately 40% of the accidents were caused by falls from heights, with the next most common cause of accidents being due to collapses (this does not include traffic accidents).

Due to the high rate of fatal accidents from falls in the construction industry, possible countermeasures became the main issue of the Five-Year Industrial Accident Prevention Plan in Japan. To prevent these accidents, the Ministry of Health, Labour and Welfare, Japan (MHLW) instituted various safety guidelines.

Typical guidelines are as follows.

1. Guidelines for the Methods to Erect Scaffolds First
2. Guidelines for the Methods to Erect Handrails First for the Scaffolds Erection

The MHLW established committees to examine further countermeasures to reduce falls, and these guidelines were amended by the results of the committees. However,


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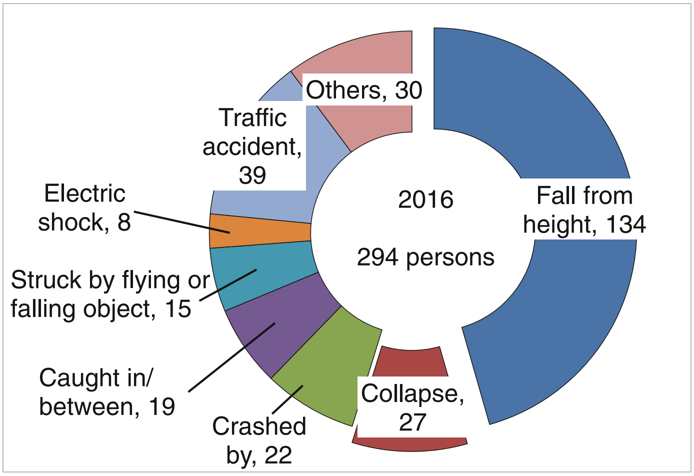


**Fig. 1.** Causes of fatal construction accidents in 2016 in Japan.

the effects of the guidelines have not been evaluated yet. Therefore, in this study, the features of these guidelines are introduced including an evaluation of the human factor and the effects on the prevention of fall-related accidents.

## 2 Features and Effects of Guidelines

### 2.1 Guidelines for the Methods to Erect Scaffolds First

Figure 2 shows a low-rise construction site from over thirty years ago in Japan. Many fall-related accidents occurred because there was no scaffold while erecting the frame.

Figure 3 shows scaffolds erected using the Methods to Erect Scaffolds First for low-rise construction. This method is applied when the height of the house is less than 10 m.

In this method, the scaffold is assembled before the frame of the house is erected and is used during all stages of construction to prevent falls from scaffold guardrails. Figure 4 shows a house constructed using this method.

In 1996, the MHLW established safety guidelines aimed at spreading the usage of this method. The guidelines were amended in 2006 to ensure improved safety at work environments. The MHLW gave subsidies for using this method, and supported activities to educate workers about this method at construction sites, as shown in Fig. 5.

Figure 6 shows the number of fatal accidents during the construction of low-rise houses in Japan from 1995 to 2014. Figure 7 shows the ratio of fatalities in low-rise construction for all construction accidents. By enforcing the guidelines, almost all low-rise construction sites used this method, and fall-related accidents at these sites were decreased drastically compared to all other construction accidents. Construction methods for low-rise houses improved safety drastically by spreading this method.

**Fig. 2.** Low-rise construction site from over thirty years ago.

**Fig. 3.** Scaffolds erected using the Methods to Erect Scaffolds First for low-rise construction.

**Fig. 4.** A house constructed using this method.

**Fig. 5.** Educating workers about the method at construction sites.

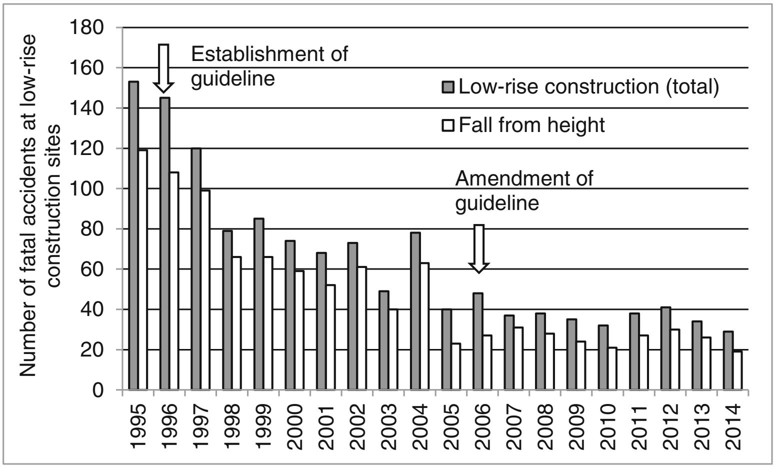


**Fig. 6.** Number of fatal accidents at low-rise construction sites in Japan from 1995 to 2014.

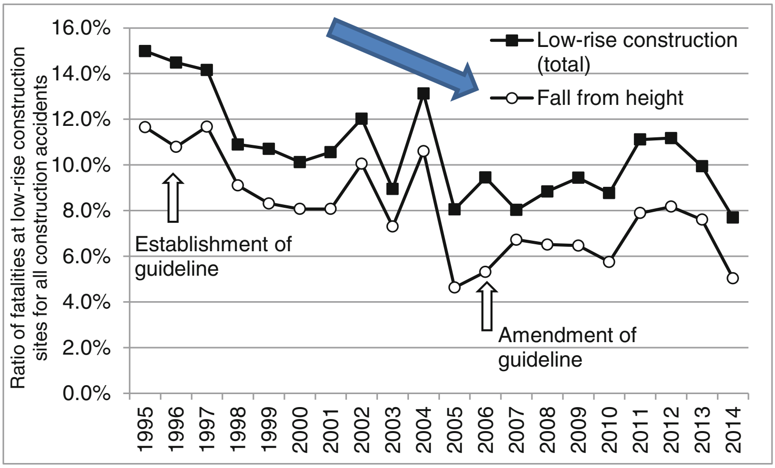


**Fig. 7.** Ratio of fatalities at low-rise construction sites for all construction accidents.

## 2.2 Guidelines for the Methods to Erect Handrails First for the Scaffolds Erection

Figure 8 shows scaffolds erection from over twenty years ago compared to the present. There was no handrail more than twenty years ago, however, today they use handrails by using the Methods to Erect Handrails First, during the scaffolds erection works.

In this method, upper handrails are always set from lower platforms using advanced handrails, as show in Fig. 9. Workers are always protected from falls thanks to the advanced handrails at the top of the previously erected scaffold.

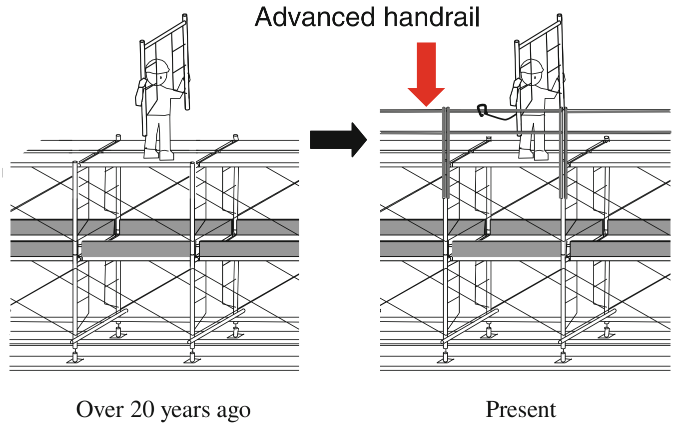


**Fig. 8.** Scaffolds erection works over twenty years ago and present.

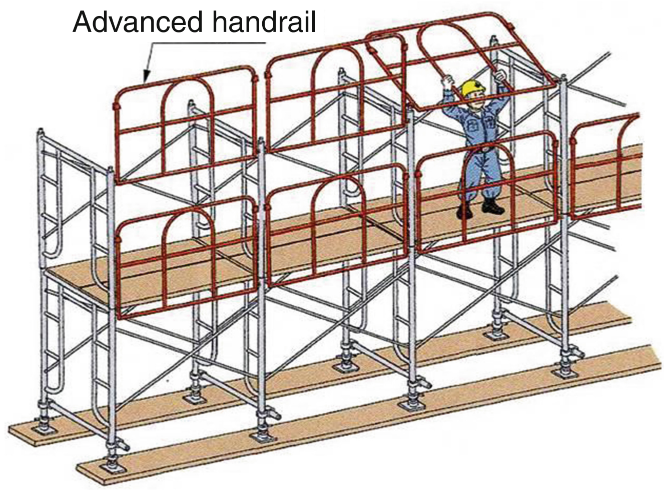


**Fig. 9.** Example of the Methods to Erect Handrails First [1].

In 2003, the MHLW established safety guidelines aimed at increasing the adoption of this method. The guidelines were amended in 2009 to improve safety at work environments.

The MHLW gave subsidies for following these guidelines and sent advisers to construction sites. Figure 10 shows the number of fatal accidents due to falls from scaffolds in Japan from 1995 to 2014. Figure 11 shows the ratio of fatalities due to falls from scaffolds compared to all construction accidents. Fatal accidents did not decrease much following these guidelines when compared with the Guidelines for the Methods to Erect Scaffolds First.

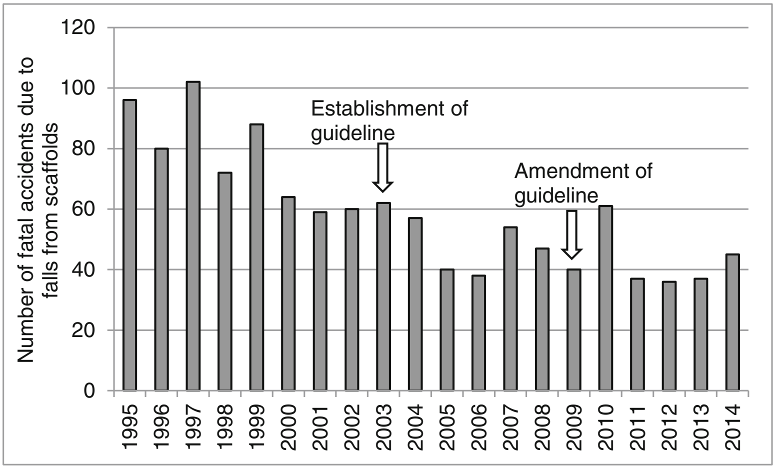


**Fig. 10.** Number of fatal accidents due to falls from scaffolds in Japan from 1995 to 2014.

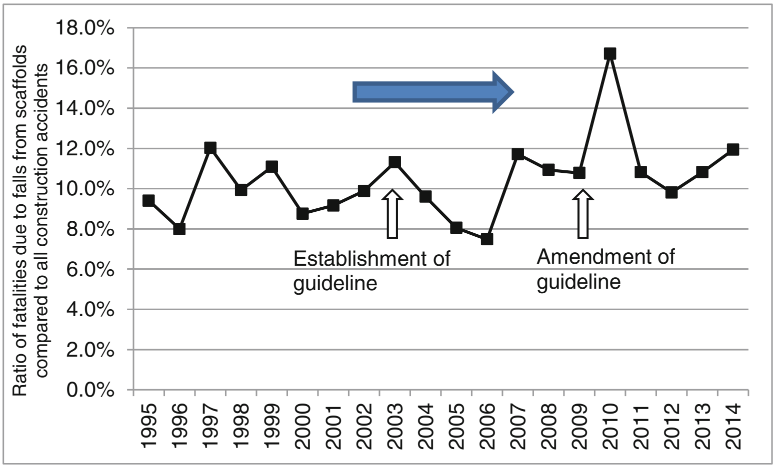


**Fig. 11.** Ratio of fatalities due to fall from scaffolds to all construction accidents

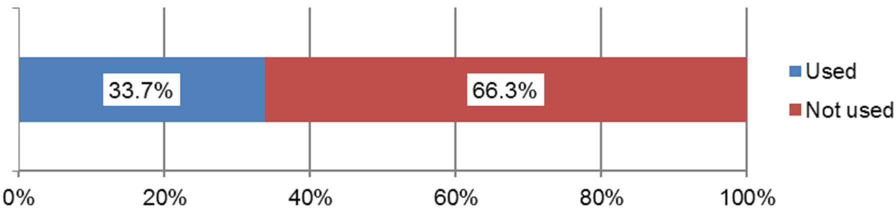


**Fig. 12.** The usage rate of the guidelines at 3,657 construction sites in 2011.

Figure 12 shows the usage rates of these guidelines at 3,657 construction sites in 2011. Only 34% of construction sites followed the guidelines. Therefore, it was found that usage of these guidelines was during expansion and did not reduce accidents because of a low usage rate.

## 3 Work Efficiency After Following the Guidelines for the Methods to Erect Handrails First for the Scaffolds Erection

The MHLW is aiming to spread this method by having construction sites follow the safety guidelines. However, the guidelines are not widely used due to their poor efficiency.

To investigate work efficiency, a questionnaire survey was carried out with 18 construction workers [2]. Figure 13 shows the results of the questionnaire survey on work efficiency using the methods shown in Fig. 9. More than 80% of the workers felt that the methods took more time, were too complex, and required moving heavy equipment to construct the scaffolds.

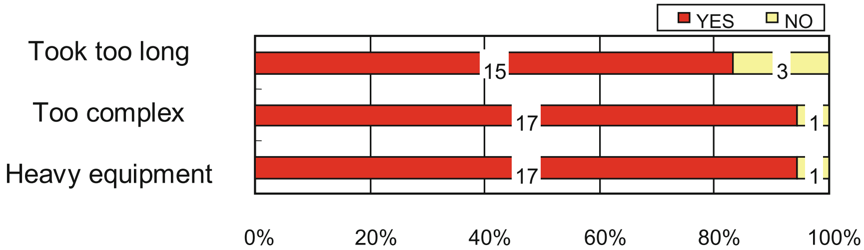


**Fig. 13.** Results of a questionnaire survey on the work efficiency of the methods.

Figures 14 and 15 show the results of the survey on safety and usage of the methods, respectively. Approximately 90% of the workers felt that the scaffolding improved safety, but more than 60% said that they did not want to use the methods because of poor work efficiency.

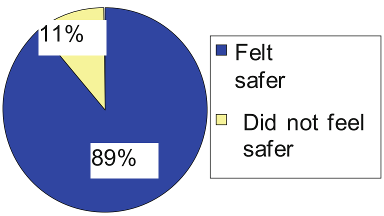


**Fig. 14.** Results of the survey on the safety of the methods.

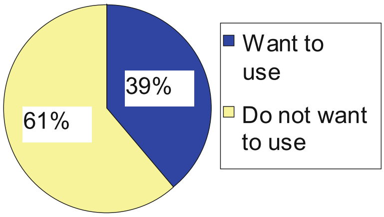


**Fig. 15.** Results of the survey on the use of the methods.

Therefore, to spread the guidelines widely for safety construction, it is suggested that advanced handrails should be made lighter and easier to use when constructing the scaffolds.

## 4 Concluding Remarks

In this paper, the fall prevention guidelines were introduced, and the effects on the prevention of fall-related accidents were evaluated. The results are summarized as follows.

1. By following the Guidelines for the Methods to Erect Scaffolds First, almost all low-rise house construction sites saw a marked decrease in fall-related accidents.
2. The Guidelines for the Methods to Erect Handrails First for the Scaffolds Erection did not result in a noticeable reduction in accidents because of a low usage rate. Therefore, it is suggested that the advanced handrails be made lighter and easier to construct.

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# Effect of the Starting Time Delay on the Confluence Pattern During Staircase Evacuation of a Multi-story Building

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**Abstract.** Pedestrian evacuation is one of the most crucial research fields in safety management. Staircase is a main escape route when pedestrians evacuate from the multi-story building. According to different priorities about evacuation, it is necessary to make a rational strategy that reducing the casualties and property damage effectively. The article makes an attempt to establish a extended network model, which is used to make further applications in more complex architectures to analyze the evacuation. The results of our study could provide individual instructions for risk avoidance and effective strategies for safety management.

**Keywords:** Starting time delay of evacuation · Network model Confluence · Drill · Data processing method · Evacuation strategy

## 1 Introduction

Buildings are among the major venues in productive life of humankind. Many multi-story buildings are built with the urban population growing and the construction area decreasing. The evacuation system in the multi-story buildings is very important and the safety evacuation is the basic requirement in evaluation of building fire safety performance.

The spreading of beginning evacuation signal has a time lag in each room on account of the randomness of human movement, we called this "starting time delay". Starting time delay is a common phenomenon in building evacuation. Since the smallest unit in spreading of building evacuation signal is room, the starting time differences in the different room are significantly longer than it in the same room. Just as in schools, the objects of the building evacuation are students, once the emergency evacuation signal appears, only after the teacher in the classroom makes sure that the evacuation begins can the whole class begins the evacuation. Since the time points of confirmation signal received by teachers are different, the rooms of starting time point in the evacuation are different.


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Many studies on the process of transferring evacuation signals has been conducted, some experiments proved that the peoples' received time point of evacuation signals at the same room is approximately the same [1]. Spearpoint [2] considered that the evacuation starting time point would have an effect on the total time of evacuation by studying the influence of the time distribution of the pre-evacuation in the same room. Kuligowski [3] got the conclusion about the influence of all features on starting time delay in evacuation by establishing a semi-empirical linear fitting model according to the environmental information, individual perception in evacuation and other kinds of factors. Also, people need time to react to the fire [4]. Proulx [5] thought that most people began their evacuation half a minute later after the alarm bell rang.

Since different conditions have different evacuation aims, in urgent situations, the safety egress time is rigid for human beings, that is to say, once the evacuation time go over the certain threshold, the casualties and property losses would be greater than before [6]. Therefore, it is hoped that the evacuation could be completed as soon as possible. While in the condition of the time is not so urgent, such as assembly and gala parade, the aim of evacuation is different. The pedestrian crowds could suddenly change from laminar to "turbulent" flows [7] since some unstable factors. So in this condition we pursue the evacuation is more orderly rather than time efficiency.

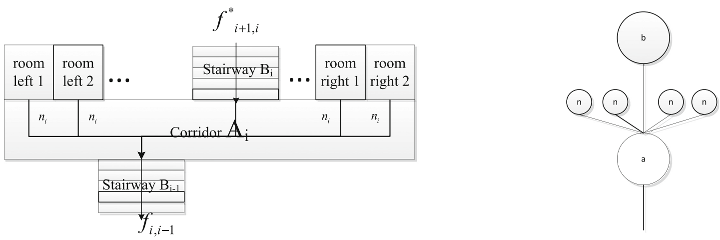
At present the study of modeling the pedestrian evacuation can be summarized in two parts according to the objects of study: the individual and the group [8]. The former studied based on individual behavior could fully consider the influence of evacuation from the relationship between the individual and the environment. While this kind of study doesn't performs comprehensive when investigating the integrity of evacuation. Such as cellular automation method [9], which is limited to the capacity of CPU, cannot get the regular pattern of the pedestrian evacuation in some complex conditions [10, 11] (e.g. the building structure is complicated or a large scale of evacuation). Moreover, since the whole evacuation is more important, it is not necessary that be taken individually into account in these conditions above. The other research method which is proposed by Chalmet, Francis, Gunnar and MacGregor [12] is converts it into a network design problem (NDP) such as EXITT [13] model and EVACNET4 [14] model. NDP method treat each evacuation area as a network node [12, 15] while setting the evacuation path and link the node by a line according to the spatial relationship among each area. The link represents the pedestrian flowing from one side to another so that the evacuation process can be seen as the information transmitting process among the network nodes. The concept that the limitation of flow is the key to the model. This method of modeling is based on the whole strategy level when consider the evacuation process without the individuals' behavior.

Staircase evacuation is the main way of evacuation when the emergency happens because the elevator is forbidden in many cases. Since the number of evacuee is huge, we could not investigate the individuals' behavior. This paper developed the method of network model and discussed how the information transmitting process effects the pedestrian evacuation when the starting time delay happened in the building evacuation. We also provided some advice in developing the strategy about different evacuation mission according to an analytical method of the simulated data processing.

# 2 Confluence Model

## 2.1 Survey Design

Generally, the basic structural unit to the stair evacuation could show in the following Fig. 1a, once the pedestrian in the $i$-th enter floor who walk into the $i$-th corridor $A_i\left(f^*_{i+1,i}\right)$ down to the $i$-th exited floor together with the pedestrian in the $i$-th corridor who walk from the room that would called a finish of evacuation confluence. Such a kind of structure could be treated as an "inversed tree" structure like Fig. 1b, while the corridor is node A, the stair is node B, the room is node N, the line among them stands for the information flow (pedestrian) from one node (area) to another. What we need to do is to determine the information transfers among each node for the simulation of the pedestrian building evacuation process.




**(a)** **(b)**

**Fig. 1.** (a) Basic structure of confluence in stairs (b) Basic unit of the tree structure

Once the occupants walk into the stair, the pedestrian traffic capacity of stairs would be determined by the density and the width of stairs whichever escaping approach be selected. Actually, the pedestrian flow may only be determined by the capacity of stairs, so we could just consider the flow in every entrance and exit of the spots rather than study individual behavior of each occupants.

At time $t$, there are $n_s(t)$ pedestrians who walk into the corridor from the room $s$ (while the time in which the people walks from room to the staircase is concluded in $n_s(t)$, so the walking speed distribution of students in the corridor is measured by the evacuation drill, as is shown in the Sect. 3.1), $a_i(t)$ is the number of pedestrians in corridor $A_i$, $b_i(t)$ is the number of pedestrians in staircase $i$, $f^*_{i+1,i}(t)$ is the exported flow in floor $i$, $f_{i,i-1}(t)$ is the pedestrian flow walk into the next staircase, therefore, the quantitative relation among the variables are above:

$$a_i(t+\Delta t) = a_i(t) + \sum_s n_s(t) + f^*_{i+1,i}(t) - f_{i,i-1}(t) \tag{1}$$

$$b_i(t+\Delta t) = b_i(t) + f_{i,i-1}(t) - f^*_{i,i-1}(t) \tag{2}$$

There is a maximum flow $f_m$ that is limited by the ratio between the width of stair and shoulder. Here, according to the evacuation drill, $f_m = 5$ namely, the maximum capacity of single step is 5. The value of $f_{i,i-1}(t)$ is affected by the number of pedestrians in next staircase $b_{i-1}(t)$. Also, this value must be smaller than the number of pedestrians in $i$-th corridor $a_i(t)$:

$$f_{i,i-1}(t) = \min(f_m \varphi(b_{i-1}(t)), a_i(t)) \tag{3}$$

When $b_{i-1}(t) = 0$, namely the next staircase is empty, the flow of entrance $f_{i,i-1}(t)$ can achieve the maximum $f_m$. While the number of pedestrians in the next staircase is saturated: $b_{i-1}(t) = b_m$, the pedestrian would stop that cannot get into the next staircase. Therefore, the larger is the value of $b_i(t)$, the more difficult is for the pedestrians to enter the staircase. Define a function as follows:

$$\varphi(b) = \begin{cases} 1 - \frac{b}{b_m} & 0 \le b \le b_m \\ 0 & b > b_m \end{cases} \tag{4}$$

The Eq. (4) expressed that when the number of pedestrians in the staircase achieves the $b_m$, $\varphi(b_m) = 0$ while the staircase is empty, $\varphi(0) = 1$. We assumed that it is a linear relation as seen in Fig. 2:

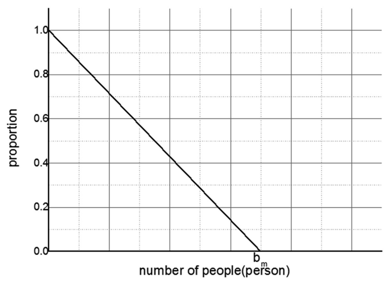



**Fig. 2.** Relationship between $\varphi = \varphi(b)$ and $b$

The flow of exit $f^*_{i+1,i}$ could be calculated as the Eq. (5):

$$f^*_{i+1,i}(t) = \min(f_m \varphi(b_i(t)), \mathrm{c}_i(t)\mathrm{B}_i(t)) \tag{5}$$

The $f_m \varphi(b_i(t))$ is the same as the flow of entrance (Eq. (3)). Meanwhile, the value of $f^*_{i+1,i}$ is also influenced by the number of pedestrians $\mathrm{B}_i(t)$ in the nearby stair exit (as seen in Fig. 3b). The iteration mode of the value $\mathrm{B}_i(t)$ can be determined as Fig. 3a. Setting the total length of staircase is $L$, whereby the $l_k$ is the moving distance of the $k$-th pedestrian in the $i$-th staircase, when the $k$-th pedestrian walks into the $i$-th staircase from the $i+1$-th corridor, if $l_k < L$, then $l_k = l_k + v\Delta t$, if $l_k \ge L$, this situation is defined as the pedestrian is in the nearby stair exit, then, $\mathrm{B}_i = \mathrm{B}_i + 1$. If the $f^*_{i+1,i}(t) > 0$, then, $f^*_{i+1,i}(t) = f^*_{i+1,i}(t) - 1$ and $\mathrm{B}_i = \mathrm{B}_i - 1$.

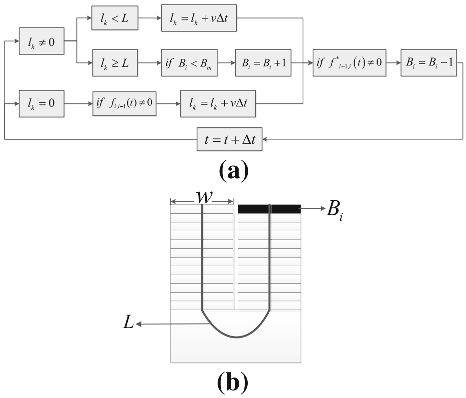



**Fig. 3.** (a) Iterative method of the number of people in the nearby staircase exit (b). The diagram of the stair structures

[16] The walking speed of the pedestrian in staircase is defined as Eq. (6), $D = \frac{nd}{wL}$. This value is between 0 and 0.92 (this is because that it is very difficultly to move on stairs while the occupants walking with the speed at $D_m = 0.92$). $L$ is the total length of the staircase, $n$ is the number of pedestrians in the staircase (here, $n = b_i(t)$), $d$ is the frontal projected area of the pedestrian, $w$ is the width of the staircase, $\mu$ is a correction factor, which is defined $\mu = \frac{2.04}{57} = 0.0358$ according to the observation in evacuation drill (the average speed for each occupant walking on stairs without anyone else is 2.04 m/s).

$$v = \mu\left(112D^4 - 380D^3 + 434D^2 - 217D + 57\right) \tag{6}$$

On the other hand, since there is a competition of the crowd between the corridor and its upper staircase, the mean flow is the dominant flow in the process of confluence, define as a "probabilistic guiding" term $c_i(t)$ as follows:

$$c_i(t) = \frac{\sum_{t_k \in (t-2s,t)} f^*_{i+1,i}(t_k)}{\sum_{t_k \in (t-2s,t)} f_{i,i-1}(t_k)} \tag{7}$$

The above Eq. (7) standing for the value of $c_i(t)$ is the ratio between the pedestrian from $i$-th floor to $i-1$-th staircase and the total pedestrians who walk into $i-1$-th staircase in two seconds. It is the probability of the pedestrians from the $i$-th to $i-1$-th staircase in next moment. Moreover, the highest floor doesn't have pedestrians who walk into its staircase from the higher staircase, namely:

$$f^*_{n+1,n} \equiv 0 \tag{8}$$

Above all, this confluence model is expressed more directly and easier to be understood as it is based only on the flow of pedestrians rather than considering the individual behavior for each person. Obviously, this confluence model could reduce the quantity of calculation when compared with other methods (lattice gas, social force, etc).

# 3 Experiment

## 3.1 Process of the Drill and the Result

In order to verify the accuracy of the model and extract the necessarily dynamic parameters in evacuating process, we carried out an evacuation drill in a high school. The scenery of the teaching building is shown in Fig. 4a, and the structure schematic diagram is shown in Fig. 4b. As shown, there is four floors in the teaching building. The first floor is the administrative office so that there is no student, and there are three classrooms in other three floors, one is on right and two is on left, that is to say, there are nine rooms which have students. Each classrooms' size is 10 m 5.6 m, and the size of the corridor is 56.4 m 1.5 m, the story height is 3 m.

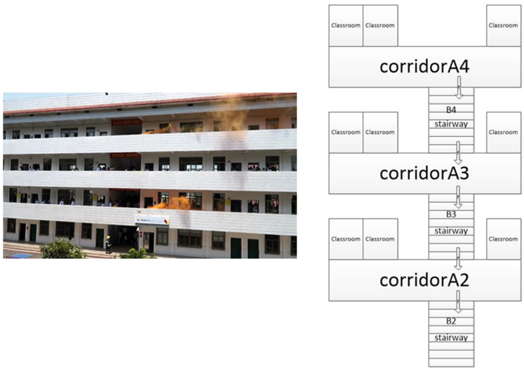



**Fig. 4.** (a). Teaching building (b). Schematic diagram

We set up the cameras at the exit of the staircase, and get the speed distribution of experimental data. It is proved that the speed distribution observes the normal distribution which the expectation is 1.63 m/s (Fig. 5) through the observation from 45 students.

The relationship between the number of people and time in staircase is shown as Fig. 6, the total number of the student is 432, and the evacuation time is 172.5 s. The starting time delay is different in different area, we set the starting time of the people in the left classroom of the third floor as no delaying. The stating time delays of the rest areas are seen in Table 1.

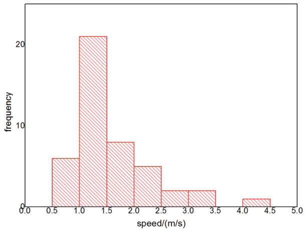



**Fig. 5.** Teaching building

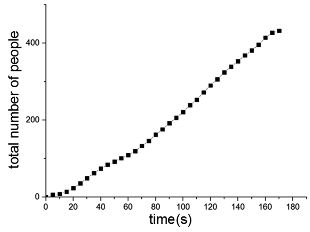



**Fig. 6.** Schematic diagram

**Table 1.** Time delay in the different classroom.

| Area | Time delay (s) |
|---|---|
| 2 left rooms | 7 |
| 3 left rooms | 0 |
| 4 left rooms | 37 |
| 2 right rooms | 53 |
| 3 right rooms | 29 |
| 4 right rooms | 35 |

We extracted a video from the experimental drill to record the link of the number of people and time for determining the pedestrians' evacuation starting time distribution (result can be seen in Table 2).

**Table 2.** Pedestrians' starting time.

| Time (s) | The number of people (person) |
|---|---|
| 0–0.5 s | 20 |
| 0.5–1 s | 9 |
| 1–1.5 s | 9 |
| 1.5–2 s | 2 |
| 2–2.5 s | 0 |
| 2.5–3 s | 1 |
| 3–3.5 s | 1 |
| 3.5–5 s | 0 |
| 5–5.5 s | 1 |

It can be found that the number of people follows a Poisson distribution with the expectation: $\lambda = 1.2558$ according to the k-s test:

$$P(x = k) = \frac{1.2558^k}{k!} e^{-1.2558}, (k = 0, 1, 2, 3\ldots) \quad (12)$$

Where $x$ is the random variable, $P(x=k)$ stands for the probability of the student getting out the door at the starting time located in the $\frac{k}{2}$ seconds and $\frac{k}{2}+0.5$ seconds.

### 3.2 Simulation

The network model introduced in Sect. 1.1 was applied on the teaching building shown in Fig. 4b. Setting the number in corridor and staircase are $a_4$, $a_3$, $a_2$, $b_4$, $b_3$, $b_2$, respectively, the pedestrian flow from the classroom the corridor are $n_1$,$n_2$ ($n_1$ is the left side and $n_2$ is the right side), both $n_1$ and $n_2$ are follow the Poisson distribution with the expectation is 1.2558, the flow from corridor to staircase is $f$ and the flow from staircase to corridor is $f^*$ (e.g. $f_{43}$ is the flow from $a_4$ to $b_4$, $f^*_{43}$ is the flow from $b_4$ to $a_3$). We can get the equations according to the conservation of people like this:

$$a_4(t+\Delta t) = a_4(t) + n_1(t) + n_1(t) + n_2(t) - f_{43}(t) \tag{13}$$

$$a_3(t+\Delta t) = a_3(t) + n_1(t) + n_1(t) + n_2(t) + f^*_{43}(t) - f_{32}(t) \tag{14}$$

$$a_2(t+\Delta t) = a_2(t) + n_1(t) + n_1(t) + n_2(t) + f^*_{32}(t) - f_{21}(t) \tag{15}$$

$$b_4(t+\Delta t) = b_4(t) + f_{43}(t) - f^*_{43}(t) \tag{16}$$

$$b_3(t+\Delta t) = b_3(t) + f_{32}(t) - f^*_{32}(t) \tag{17}$$

$$b_2(t+\Delta t) = b_2(t) + f_{21}(t) - f^*_{21}(t) \tag{18}$$

Where, the expression of evacuation flow is shown in Eqs. 1–8. Furthermore, we need a boundary term $a_1$ to record the total number of the evacuee, that is:

$$a_1(t+1) = a_1(t) + f_{21}(t) \tag{19}$$

In order to get a more stable flow data, we take 50 times for simulation in MATLAB using the network model as above with the experimental data. The results of simulation (red line) and drill (black line) are shown in the Fig. 7.

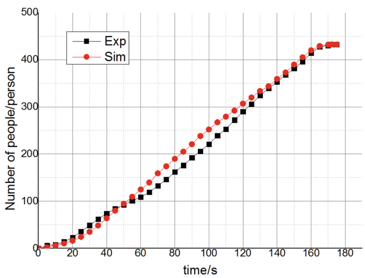



**Fig. 7.** The contrast of the result of simulation and experiment

As the randomness of human behavior in evacuation, we modified the parameter in confluence model to make the simulation result approximately agree well with the experimental result, so in this way that the confluence model is reasonable to study the starting time delay in evacuation of the teaching building.

# 4 Result and Discussion

## 4.1 Discussion About the Operation Setting in the Confluence Model

Due to the complexity of algorithm, it is impossible to traverse each kind of condition (e.g. if setting the interval were 10 s and the maximum starting time delay were 60 s, it would have $7^9$ conditions as there are nine classrooms). But this does not prevent us from getting the confluence pattern, to achieve the flowing control of evacuation process, we can use this established model to investigate the influence of starting time delay in emergency. As is shown in Fig. 8, we can traverse the classrooms' delayed evacuation condition in both horizontal and vertical two directions, which the horizontal ergodic is called floor 4, floor 3, floor 2, respectively, and the vertical ergodic is called left 1, left 2, right, respectively. The rooms was numbered I–IX. So that we would get the analog result of confluence model to discovery laws. Considering the actual situation, we set the maximum starting time delay as 1 min in the model.

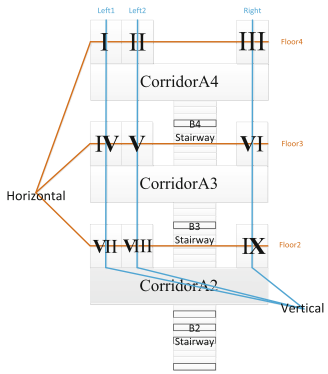



**Fig. 8.** The project of ergodic simulation about teaching building

Moreover, to study the result of simulation more easily and make the result visualized, we need to introduce a "combinatorial number": since both the horizontal and vertical ergodic has $7^3 = 343$ conditions, the time delay condition of each three-classroom is a three-dimensional vector like this $t = t(t_1, t_2, t_3)$, and the combinatorial number $H$ stands for the time vector (Eq. (20)). The relationship between the combinatorial number and time vector is shown in Table 3.

**Table 3.** Relationship between combinatorial number and time vector.

| Time vector (s) | Combinatorial number |
|---|---|
| $(0\,s, 0\,s, 0\,s)$ | 1 |
| $(0\,s, 0\,s, 10\,s)$ | 2 |
| $(0\,s, 0\,s, 20\,s)$ | 3 |
| … | … |
| $(60\,s, 60\,s, 60\,s)$ | 343 |

$$H = 7^2\left(\frac{t_1}{10}\right) + 7^1\left(\frac{t_2}{10}\right) + 7^0\left(\frac{t_3}{10} + 1\right) \tag{20}$$

## 4.2 The Influence of Starting Time Delay

The limitation of the safety evacuation time is rigid when emergency occurs, so it is a challenging work to increase the evacuation efficiently. We can solve this problem with the established network model above. According to the ergodics of each condition (every condition was simulated fifty times and took the average), we can get the relationship between the combinatorial number and total evacuation time below (Fig. 9a and b):

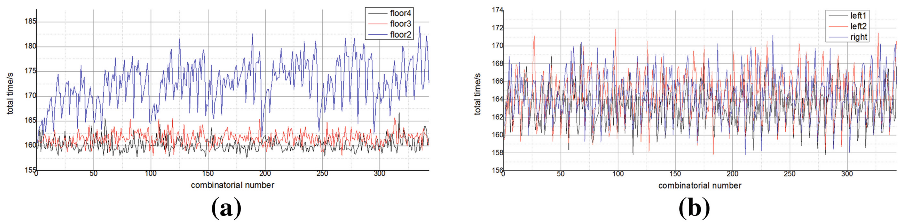



**Fig. 9.** (a) Horizontal ergodic (b) Vertical ergodic

To extract the influenced pattern in different delayed time vector from the irregularly simulated result, we use the linear separation method to process the simulated data as follows:

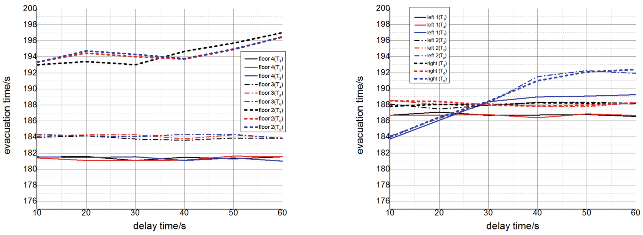
$$T_{i,j,k} = \widehat{T}_{i,j,k} + Y_{i,j,k} \tag{21}$$

$$\widehat{T}_{i,j,k} = \frac{1}{3}\left(T_i + T_j + T_k\right) \tag{22}$$

What we need to do is to extract the contribution of the trend item $\widehat{T}_{i,j,k}$ from two traverse ways as above. (When traverse in horizontal direction,$T_i$,$T_j$,$T_k$ represent the three classrooms in the same floor respectively, when traverse in vertical direction, $T_i$,$T_j$,$T_k$ represent the three classrooms in the same column respectively):

$$T_i = \frac{1}{49}\sum_{j,k} T_{i,j,k},\ T_j = \frac{1}{49}\sum_{i,k} T_{i,j,k},\ T_k = \frac{1}{49}\sum_{i,j} T_{i,j,k} \tag{23}$$

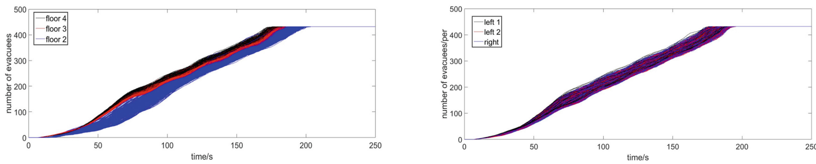
Two kinds of the traverse results are shown in Fig. 10a and b. We can find that floor 4 is not sensitive to the change of starting time delay compared with floor 2. This is mainly because the occupant retention occurred in floor 4 had a less influence on the whole evacuation (The range of starting time delay is between 0 s and 60 s). The maximum ratio of starting time delay to the total evacuation time in floor 2 is about 8.85%. So that whether the room evacuation in floor 4 is prior or not, it could hardly change the total evacuation time. So the starting time delay in floor 2 could have a great effect on it.




(a) (b)

**Fig. 10.** (a) The contribution of the trend item (horizontal ergodic). (b) The contribution of the trend item (Vertical ergodic).

The process of occupant retention caused by congestion in stairs could be obtained in the relation of N-t (see Fig. 11a and b).




(a) (b)

**Fig. 11.** (a) Evacuation process of teaching building (horizontal ergodic). (b) Evacuation process of teaching building (Vertical ergodic).

Figure 11a and b shows two ergodics results about different delay conditions as follows: the distance between the room and the evacuation exit is closer, the greater the effect of starting time delay on evacuation process. Meanwhile, the evacuation process present a 'quasi' periodicity with the combination number (the period is 60 s). With this, the effect order of nine rooms' starting time delay to the evacuation is as follows: VIII = IX>VII>V=VI>IV>II = III>I.

## 5 Conclusion

In conclusion, the starting time delay of evacuation is very common phenomenon in building evacuation and it could make a great influence on evacuation process. This paper analyzed this phenomenon by establishing a network model and made use of the experimental data from the drill to determine the model parameter. Compared with those models (such as lattice gases and social force, etc.), the confluence model which is based on flow is easier to understood and costs less computation.

Then we obtained the rational parameters to the confluence model through the experimental drill. Furthermore, we used the confluence model to analyses the evacuation process in a teaching building and got the effect order of different rooms' evacuation starting time delay. This kind of effect depends firstly on the different floors, the occupants' starting time delay at the lowest floor could most notably increase the total evacuation time. With the simulation above as an example, if the occupants at the second floor was the last who obtained the evacuation signal in emergency and the evacuation starting time delay of them was 60 s (e.g. the fire happen in the fourth floor), the congestion would severely happened at the nearby exit stairs which could made the total evacuation time increased by approximately 8.85%. However, the distance between the room and exit is also a factor at the same floor but not significant.

So that we can control the evacuation process aiming at different evacuation missions according to these four rules above. Furthermore, this confluence model can also make a further extension in analyzing the evacuation in more complex structure.

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# Applications in Safety Management and Loss Prevention

# Modeling Safety Criticality in Aviation Maintenance Operations to Support Mastery of Human Factors

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**Abstract.** Aviation maintenance (AM) represents safety critical work and has procedures for safety management. However, sometimes, the modeling of safety critical parts of this work may not be sufficiently concrete for evaluating safety risks in practice. The AM company we studied lacked concrete methods for modeling the most safety critical parts of its work and for utilizing this knowledge in occupational health services (OHS) and safety management. We modeled the safety criticality of six of its tasks using interviews, work process analysis, the Brain Work Index, Work Observation, and HF tool. We summarized the results as a 3D model, and held workshops involving managers, operative, HR and quality assurance personnel, and OHS. We utilized systemic and collaborative orientation, mixed methods and participative development. As a result, the AM company improved its mastery of safety criticality by including new procedures in OHS processes, developing work processes, and modifying recruiting processes.

**Keywords:** Human factors · HF tool · Aviation maintenance · Co-creation Cognitive demands

## 1 Introduction

Aviation is regarded as a safety critical field and often referred to as a pioneer in safety. Flight operations and air traffic management are considered prime examples of safety critical work [1, 2]. Safety criticality in aviation maintenance (AM), however, has received less attention, despite AM being a complex sociotechnical system, and mechanical engineering problems posing risks to human factors (HF). This may have a great impact on how aircrafts operate during flights [1, 3]. Although the international aviation regulatory authorities (the Federal Aviation Administration FAA in the USA, the European Aviation Safety Authority EASA in Europe) have imposed requirements for and guidelines on managing HF in AM [3, 4], the norms do not inherently guarantee safe operation in everyday work. The final responsibility for creating sufficient safety procedures to guarantee the safety of their operations and services rests with the AM companies themselves.


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The literature contains no generic definition of safety critical work that can be applied to all industries. For instance, employees such as flight engineers are potentially indirectly safety critical workers, and causes of incapacitation are relevant in terms of their effect on safety because an undetected error made by such a person could result in an adverse outcome [5]. Safety management systems have been established in several safety critical fields, and HF, i.e. the effects of human performance – both capabilities and restrictions – on the safety, efficiency and well-being of the systems, is an essential part of safety management [2]. Improving the mastery of HF at individual, work, group and organizational level by implementing HF frameworks, models and tools has great potential for improving safety culture [3, 6].

This article demonstrates how an AM company improved its ability to model safety criticality in its work processes and thus handle the risks in AM work that could harm the safety of the product (e.g. a repaired engine), and finally the safety of the flight, aircraft and pilot.

The AM company had perceived a need to further develop their preparedness to control safety criticality in cases of reduced work ability among AM personnel. The company had already applied several means to control safety criticality in operations (qualification requirements, occupational safety and health practices, regular HF training, inspection points in maintenance work processes), but needed to incorporate more accurate means and methods, to (1) identify safety critical tasks and work phases, (2) establish a criterion to assess and monitor the workers' ability to perform safety critical work, (3) establish recruitment criteria for evaluating applicants' suitability for safety critical work, and (4) improve the occupational health service (OHS) center's practices for supporting the work ability of personnel who execute safety critical work.

This required the development of tools to provide OHS with sufficient information on the characteristics and challenges of the safety critical parts of work, as well as practices for utilizing the information in, for example, occupational health controls and workplace inspections. Despite searches, no holistic model for modeling the safety criticality of the AM tasks was found. Thus, a new model had to be created through joint co-operation among external experts (Finnish Institute of Occupational Health), different parts/actors of the AM company, and OHS, thus bringing features of co-creation into the project [7, 8].

An essential, guiding principle in the project was that 'the worker is the best expert of his work', based on the participative work development framework, which was implemented in several Finnish workplace interventions in the 1990s–2000s [9, 10]. We also applied mixed methods to illustrate work processes, their critical points and cognitive demands, to increase the company's capability to improve safety culture and to provide OHS with easily applicable data on the demands of the safety critical parts of work. From the beginning, the aim was to include methods in the company's processes such as workplace inspections, to enable the future accumulation of data and its availability for various uses in the company.

In this article, we describe the framework and methods that we used to model the safety criticality of AM work, and how the results of the modeling were summarized and used in the AM company and by the company's OHS. We utilized systemic and collaborative orientation, mixed methods and participative development in the implementation of the project.

## 2 Materials and Methods

This study was conducted in the AM company from May 2016 to May 2017. It was an intervention which engaged all organization levels (employees, experts, management) of the AM company. The study participants were operation employees, HR, OSH officers, quality assurance personnel, and top and middle management. Three of the company's operational units participated.

The project targeted six work processes representing different phases of the overall AM work process (from mechanical engine repair work to the inspection of mechanical engine repair work, test run and test flight) to obtain an appropriate sample of the most safety critical work tasks of the AM company. The project was executed in three phases. In phase one, we tested and verified tools for identifying and gathering information from safety critical work phases. In phase two, we identified and analyzed safety critical phases in the targeted processes. In phase three, we developed the company's safety management practices to better support risk management in safety critical processes (Fig. 1).

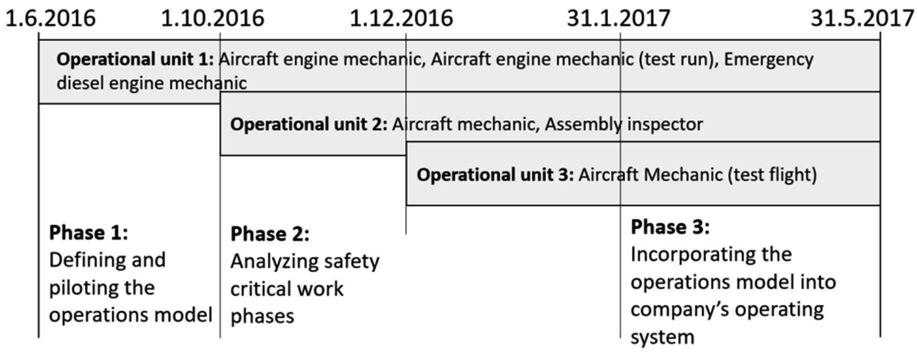


**Fig. 1.** Phases of the project (Phases 1–3) in three operational units.

In Phases 1–2, the project organization worked as working groups and steering groups in each of the three operational units (Fig. 1). In Phase 3, we formed the recruiting and work ability working groups to implement the results in the processes.

The methods applied in this study had been developed previously by the Finnish Institute of Occupational Health (FIOH), but were customized to meet the specific needs of the project through co-creation [7, 8] with the AM company and OHS.

### 2.1 Interviews

We started the project by interviewing key actors of the company (n = 24) and OHS (n = 3), to obtain an overall picture of the company and its safety management system and the most critical factors of the targeted tasks.

The interviews sought answers to the following questions: What are your goals for this project? Can you describe this organization? What kind of safety management systems do you have in use? Do you have an incident reporting system? What kind of incidents are reported? What kind of incident investigations have been conducted? Can you describe the (selected/targeted) task; which factors could lead to success or errors in conducting this task? Which work phases are especially challenging from the competence perspective? Where can errors occur, what are the risks? Is there a risk of overload? How do you deal with complacency or lack of vigilance at work? How do you evaluate the mastery of work processes?

## 2.2 Work Process Analysis

The next step in evaluating the safety criticality of the selected six tasks was a work process analysis of each task (see tasks in Fig. 1). The operative personnel representing each task ('process group') met for one to two days to model the basic contents of their work processes, using Post-it notes® on a large brown sheet of paper which was stuck to a wall. The process group analyzed their work from four viewpoints: (a) outcomes of the work process ('output'), (b) competence and knowledge needed at work ('input'), (c) safety critical phases of the work process in which risks can arise and errors can occur, and (d) co-operation needed at work (in the work process and the related work processes).

The method used in the analysis of the work process is based on the frameworks of participative planning and work process development [9, 11] and has been tested earlier in safety critical air traffic management [10].

After modeling the basic contents of the work processes, the process group members were asked to state the most important development needs in their work, and these were marked in the model. Supervisors, managers, the OSH officer, the OHS representative and the quality manager participated in the final meeting and commented on the model. They were able to add issues to the model to make it more accurate, and to include all the different viewpoints regarding the task. The development needs produced during the modelling were collected, to be coordinated and implemented by the company.

As the interviews and work process analysis highlighted the most safety critical points of the evaluated tasks, they were proceeded by more detailed methods: the Brain Work Index (BWI) and Work Observation (WO).

## 2.3 Brain Work Index

The Brain Work Index is a brief questionnaire developed at FIOH and designed to measure the cognitive demands of work [12, 13]. The core of the BWI is composed of 39 questions, divided into 11 cognitive domains with three variables each. Each variable has two dimensions: frequency and the subjective experience of energization or strain. The variables are concrete questions regarding work-related demands. For example: 'How often does your work require you to read or write instructions, messages or documents; remember agreed appointments, meetings or tasks; or think creatively, form ideas, and innovate?'

The frequency dimension is first queried via five levels of occurrences within a timeframe: 'Several times a day', 'Daily', 'Weekly', 'Monthly', 'More rarely'.

Although a subjective estimate, a scale with a real-world reference is easier to interpret than, for example, a scale with fully subjective levels, such as ‘Often’ and ‘Rarely’. The second dimension has two directions: energization and strain. These directions force the respondent to take a stand on whether they regard the variable as motivating or strenuous. The question, ‘How do you feel about these things? Do they motivate/energize you, or do they cause you strain?’, is asked regarding the variables that appear monthly or more often. The response scale has seven levels: ‘Somewhat’, ‘Quite a lot’ and ‘Very much’ for both directions, and ‘Neither’ for neutral.

### 2.4 Work Observation

We conducted Work Observation using a semi-structured method also developed at the FIOH. WO was originally designed to be an elaborative work and work environment investigation method that can be applied together with BWI. BWI provides group-level questionnaire-based information on work-related cognitive demands and subjectively experienced strain, which can both provide signals for more focused work inspection. Moreover, the BWI results of this project helped us focus WO on the issues that were considered most relevant among the different occupations. WO is slightly different to the classical observation methods applied in social sciences and psychology that typically aim to provide an unobtrusive picture of real world actions. Our semi-structured WO is less strict in terms of observer’s activity and visibility. WO starts with a brief interview in which the observer and subject decide together on the most essential work tasks for observation. In addition, during the observation, the observer can talk freely with operator/worker and ask definitive questions when needed. Typically, WO takes roughly two hours per subject, and a minimum of two subjects per work task are observed. In our study, an experienced psychologist trained in the method carried out WO.

### 2.5 HF Tool

In the project, we chose an HF tool as a framework for analyzing human contribution in the AM company, because user experiences of the HF tool had already been studied in another field of aviation, namely air traffic management [6]. The tool had been an established part of the safety management system since 2008, and used for HF-training and incident reporting and analysis, to discover which factors in one’s own actions or in work or organizational factors (i.e. human factors) weakened or strengthened safety in a particular case [14].

The HF tool consists of individual, work, group and organizational characteristics that may contribute to the success of the work. The basic idea of the tool is that both the successes and failures of everyday work must be recognized and analyzed to avoid creating or strengthening a blame culture: focusing on HF can easily lead to a focus on individual or error-based aspects, which in turn can result in individuals being blamed for operative events. As is widely known, incidents or accidents are rarely due to violations or intended harm [15]; they are mostly the results of chains of events, which are more often weaknesses of some part of the system: for example, restrictions in work processes, system design or a lack of mutual information flow among different actors in the system [16, 17].

This project formed a working group representing different partners of the company (HR, quality assurance, the OSH manager, unit managers, operative personnel), to modify the HF tool for AM purposes and to form a joint picture of the current HF procedures of the company. The working group was run by a FIOH researcher and met nine times. As a result of the modification, some items of the HF tool were slightly changed and some items were added (e.g. disturbances during work) as they were accurate in the AM work, but not included in the original version of the HF tool.

### 2.6 Workshops to Define Safety Culture and Safety Criticality

The organization was committed to the project through meetings and workshops held during the process as a whole. One task of the executive team and work groups in three units was to formulate joint definitions of two essential terms, namely 'safety criticality in our company' and 'safety culture in our company'.

## 3 Results

Interviews conducted at the beginning of the project offered an overall picture of which issues to tackle or focus on in more detail, while other methods were used to model the tasks. The most often mentioned views were that safety issues are essential, and that extensive efforts are made for maintaining safety. The main procedures for assuring safety were compliance and function according to safety rules and the norms of the company and aviation legislation. A reporting system, auditing, safety meetings and different kinds of quality checks were in use. An open atmosphere and careful work orientation were highlighted. Continuous learning and being able to adapt work in cases of overload were also mentioned. The challenges to safety were recognizing and openly raising concerns about work ability, especially on the 'invisible' mental side. These were not currently followed up, and supervisors had to rely on their own or their colleagues' perceptions of weakened work performance or well-being, and the openness of the operative employees themselves. Occupational health checks were conducted, but the methods used in these did not focus on psychological (emotional, cognitive, behavioral, or physical characteristics) in detail. Recruiting appropriate and suitable employees was also considered a challenge. Some interviewees mentioned the flexibility of personnel during changes as a challenge.

Work process analysis provided a visual depiction of the most safety critical phases and development needs of the work processes and work environment (Fig. 2). It also facilitated the conversation between staff in different positions (mechanics, assembly inspectors, foremen, OHS) on identifying the most critical work phases, what these demand of staff, and how the risks they involve could be contained.

The BWI questionnaire was administered to 379 employees to elicit cognitive demands and experienced burden in the AM occupations studied. The BWI results clearly indicated that different cognitive demands were emphasized in different jobs. As all the studied jobs included safety critical features, the BWI results helped us detect the occupation-specific cognitive features that were most common and relevant for preventing work-related cognitive errors. Knowledge of occupation-specific cognitive

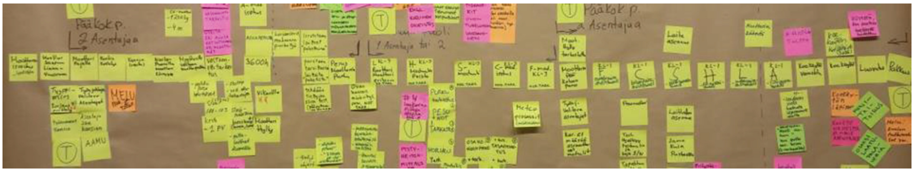

**Fig. 2.** Depiction of work process analysis (work process phases on yellow, development needs on pink, solutions on orange, successes on green colored Post-it® notes)

demands could be utilized directly in work development and in OHS collaboration. Figure 3 illustrates the BWI results in the pooled sample of employees working in aviation mechanic occupations (n = 83). The results showed that in this employee group, perceptual, hand motoric, verbal and attention-requiring demands were the most common cognitive demands. The BWI results also indicated that work-related distractions/disruptions, time pressure, multitasking, and conflicting instructions were considered the most strenuous cognitive domains.

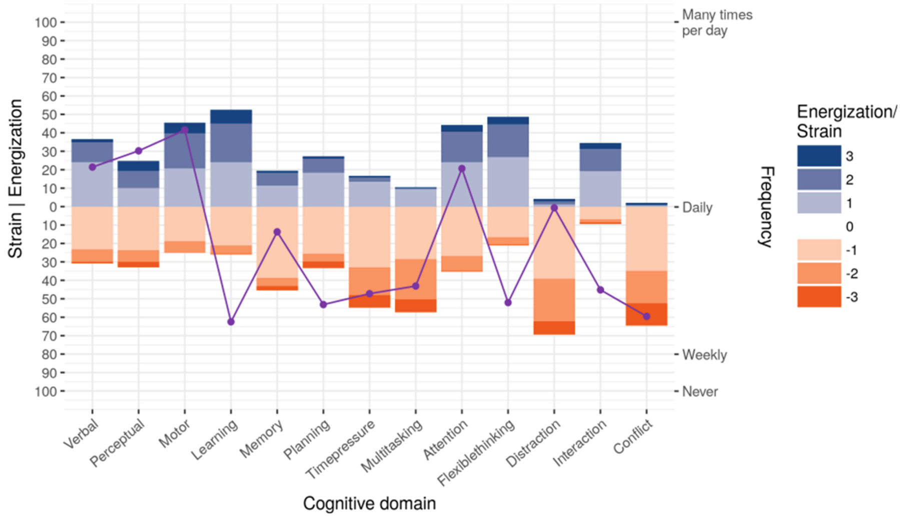


**Fig. 3.** Brain Work Index results of pooled sample of employees working in different aviation mechanic occupations.

We used WO as an elaborative method in addition to work process analysis and BWI. WO produced information on four main themes: (1) the work environment, (2) work demands (including challenging and inspiring work tasks), (3) work equipment, and (4) work-related cooperation/interaction. WO was especially beneficial for detecting work-related developmental targets at the practice level. In general, work instructions and equipment were highly regulated, and work environments were clean and clear, which indicated a high safety critical culture in the investigated AM company. However, WO also revealed several targets for development, such as insufficient lighting and distractive factors in the work environment, which could further improve cognitive ergonomics. We also found that the cognitive demands of work evaluated using BWI did not always present a full picture of the work, because many of the work tasks were overlearned, which meant that their requirements were not easily verbalized in the questionnaire. However, WO conducted by a trained psychologist indicated that observed work tasks could, for example, include memory requirements that were not explicitly recognized at first hand. In several such cases, the experienced employees had developed courses of actions that significantly helped their work tasks. In general, WO proved to be an applicable method for revealing experts' tacit knowledge.

An HF tool modified for AM company purposes was to be used as part of HF-training, and there were plans to implement it in the reporting system and for analyzing incidents. It was seen to have potential as a part of PR, especially for raising awareness of HF as a part of safety management.

Workshops for defining safety culture and safety criticality increased joint understanding and shared commitment to project goals. At the end of this process, the company actors formulated their safety culture as: 'Each of us is responsible for safety. Safety management is a part of our daily activity. We operate according to instructions and requirements, identify risks and strive to eliminate them. We learn from our mistakes and successes by handling safety-related issues openly and honestly. We maintain high expertise and expect high-quality performance from ourselves.'

**End Result – 3D Model.** The 3D model was designed to tie together all the information produced by the use of the aforementioned methods. It functions as an easily adoptable visual description of a work task or process (1) critical features and (2) human requirements, and the company's (3) ability to prevent/mitigate the potential risks inherent in the critical features. A compact picture offers OHS the chance to, for example, quickly adjust to the central aspects of a given task. A large amount of data was labeled under these categories to also allow a more detailed examination (Fig. 4).

On the basis of all the material described above, safety critical work phases were identified in all of the targeted AM work processes. However, the factors that made the phases safety critical varied depending on the task. Furthermore, safety procedures in aviation maintenance turned out to be less clear than those in, for example, flight operations or air traffic management. All in all, safety criticality in AM is a complex, task-specific issue that poses challenges to safety management. This highlights the need for a task-specific and adaptive approach to managing safety risks, as well as a strong safety culture. This in turn requires improvement of a unified understanding of the holistic impact of human action on safety at the individual, work, group and organizational levels.

**Practical Implications and Added Value for the AM Company.** The project was a notable investment for the company: 88 company employees worked altogether 4226 h on the project, 68% of company personnel replied to the BWI questionnaire, and 56 improvement initiatives were implemented, 33% of which were executed by the end of the project.

As a result of the project, the company incorporated interviews, work process analysis, BWI and WO into the regular workplace inspection process, which also includes risk-evaluation based on the information gathered through the aforementioned

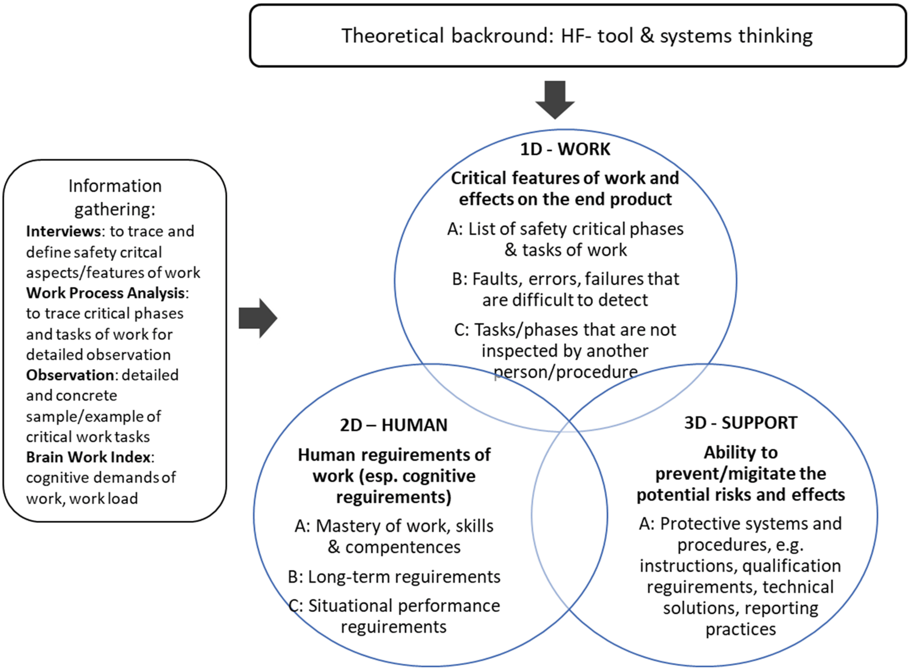


**Fig. 4.** Dimensions of safety critical work depicted using the 3D model.

methods. Workplace inspection reports thus became informative sources of information for managing the human risks related to safety critical parts of work.

The information that was produced in the project of the previously unrealized demands of safety critical parts of work, such as cognitive demands, also allowed the company to re-evaluate their recruitment processes. Practical tests, in which applicants performed the actual maintenance work phases, were included to allow production and HR specialists to evaluate the applicants' technical skills and personal working styles with regards to the safety critical nature of work tasks. Similarly, the process of managing cases of reduced work ability was updated and communicated to the staff. The process highlights the shared responsibility for raising concerns about one's own or others' work ability, and includes, for example, alternative work until work ability is restored. Emphasis is placed on communicating that the company will actively support employees returning to their original jobs as soon as this is possible.

## 4 Discussion

At the start of the project, the goal of the AM company was to develop a system for managing safety criticality. Although the company already administered advanced safety management procedures, establishing an extensive system for safety criticality management was a challenging target, especially as suitable local benchmark companies with that kind of system could not be found. The project set out to build a system through close collaboration among FIOH, the AM company and OHS. By the end of the project, the AM company had administered a comprehensive management system to control the safety critical factors of its work tasks, comprising tools for gathering information on the safety critical parts of work, summing up, visualizing, and managing the gathered information, and applying it to various processes in and between the company and OHS.

The FIOH team consisted of specialists in work, organizational, social and cognitive psychology, as well as in medicine and engineering. As OHS also provided wide-ranging expertise (doctors, nurses, physiotherapist, psychologist), and the company involved staff of all organizational levels and different positions, the project was truly multi-skilled and multidisciplinary. Due to a lack of ready-made models for meeting the project targets, FIOH, the company and the company's OHS had to work in close co-operation throughout the project. The working model had several characteristics of co-creation [7], such as close collaboration with the customer organization, joint problem-solving and continuous dialogue [8]. FIOH had previously applied all the qualitative and quantitative methods that were used in different development projects, but combining and revising the methods resulted in a novel and innovative approach to safety management.

The HF tool [6, 14] provided a good starting point for creating a common understanding of the subject matter of the project among all participants, especially as HF training was regularly provided throughout the company, which meant that the HF viewpoint was commonly known. Finding common ground with the central terms (safety culture, safety critical task), and convincing the employees on all organization levels of their importance required active communication and discussions. The language used in all communications was clear and easily understandable for all parties.

The combination of the methods presented in Sect. 2 proved capable of identifying safety critical phases in a work process and providing information on their demands. Making the methods a part of the regular workplace inspection process and storing the information in WPI reports enables the data to cumulate and be applied to safety management and, for instance, work development. The 3D model helped in the use of the data, as it offered an easily applicable overview of the demands of a given task or work phase, while also structuring the data for more detailed analyses.

The project covered delicate and private matters, namely work ability and the related health issues. The work processes of the operative personnel were also researched in detail. This required trustful collaboration with the staff whose work-tasks were under scrutiny, especially as the methods used relied heavily on employees as producers of information. Establishing and maintaining a trusting relationship with the staff was extremely important for the success of this project. Similarly, involving staff and workers' union representatives in the project planning, evaluation and follow-up was important to ensure that the project genuinely acknowledged and served the needs of the operative personnel.

**Acknowledgments.** We would like to express our heartfelt thanks to all the stakeholders and participants of the different phases of the intervention. The Finnish Work Environmental Fund provided financial support for conducting the intervention.

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# Back Flexion and Extension: The Effects of Static Posture on Children Using Mobile Devices

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**Abstract.** In 2016, smartphone sales grew five percent, with nearly 1.5 billion smartphones sold worldwide. In the United States (US), there were 220 million users. These 220 million users represent the 77% of American households who own a smartphone. A large number of the smartphone users are children. The intent of this study is to understand the effect smartphone use might have on the musculoskeletal system of young children. Eighteen participants, 11 males and 7 females, ages 10–12, were interviewed. The participants were observed and quantitative data was collected as 17 trials were performed; noting back posture while children used a smartphone and tablet. A goniometer was used to measure back flexion and extension. Measured back flexion ranged from 8.5 to 54° and back extension ranged from 12 to 24°. Results indicate that back support and/or correct posture are important when using mobile devices.

**Keywords:** Smartphones · Tablets · Musculoskeletal disorders
Awkward posture · Trunk inclination

## 1 Introduction

The use of mobile devices, cell phones and tablets, is predominant in the workplace, homes, and schools. Once in most every home in the United States (US), landlines have been replaced by cell phones. In the latter half of 2016, only 45.9% of US households still had landlines, while 50.8% of homes and apartments had only cell phone service; more than 39% had both. The remaining had no phone service at all [1]. While the sale of tablets (iPads, Android, or other devices) has slowed, in 2016, smartphone sales grew five percent, with nearly 1.5 billion smartphones sold worldwide. In the US, there were 220 million users. These 220 million users represent the 77% of American households who own a smartphone [2–4]. Adults purchase these devices for themselves and their children. A high percentage of users are children; as greater than 75% of American children under eight had access to a smartphone or tablet, in 2013 [5]. The average age of children getting their own smartphone is ten [6, 7].

Viewing the small screens of smartphones necessitates close working distances which may induce various symptoms such as dry eyes, fatigue, headaches, eyestrain (asthenopia), presbyopia, etc. [8–12]. Berolo et al. [13] and Pope-Ford [12] studied the


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musculoskeletal symptoms and neck and back posture of users of mobile hand-held devices and smart phones, respectively. Both found that a neutral posture was altered. Per the international standard, ISO 11226 which evaluates the static working postures, trunk inclination (back flexion) of 0° to 20° and 20° to 60° with full trunk support is acceptable. However, trunk inclination of 20° to 60° without full trunk support is acceptable only under specific conditions. For example, for a trunk inclination of 20°, without full trunk support, the holding time should be a maximum of four minutes and one minute at 60° [14]. Even when trunk inclination is acceptable, it is important for there to be variation in task.

The physical demands of electronic games and the portable or mobile devices, especially as they pertain to children are often overlooked, and more time is spent discussing some of the other hazards of cell phone use; distraction and cell phone addiction [15–19]. Some have, however, warned of the symptoms of overuse from playing electronic games and even suggested teaching children about the basic principles of posture [20]. The purpose of this study is to understand the effect smartphone use might have on the musculoskeletal system of young children – specifically the back.

## 2 Methods

### 2.1 Experimental Design

The research focuses on the use of two mobile devices - the smartphone and the tablet. Participants were supplied with a smartphone and tablet to use for the 17 experimental trials. the independent variables device (smartphone) and position (seated on sofa (SS), seated in a chair (SC) at a desk, and seated on the floor (SF) on a rug). An additional position was called personal choice. For personal choice, the participant could select any of the three seated positions. Personal choices with the smartphone and tablet, were always performed first. The order of all other trials were randomly generated using the Microsoft Excel version 15.31 RAND() function. The dependent is back flexion/extension.

### 2.2 Participants

Eighteen children, ages 10 – 12, participated in the study. There were 11 males and seven females, with a mean age and standard deviation (SD) of 11.4 years (±0.6). Mean height of the participants was 60.5 in (±3.79) and the mean weight was 102.8 lb (±34). The mean grade of 5.9 in (±0.78). All participants were in good to excellent health and none were currently under or previously under a doctor's care for a musculoskeletal disorder in the last 12 months. Both participants and their parent or guardian provided written consent to participate in the study. Upon completion of the study, each participant was given $20 for compensation. The study was approved by the university's Committee on the Use of Human Subjects in Research.

### 2.3 Equipment

For this study, a plastic 12 in, 360° ISOM (international standard of measurement) goniometer with a scale of 1° increments was used to measure back flexion/extension. A 60 in/150 cm soft cloth measuring tape was used to measure the viewing distance. Viewing distance was measured as the distance from the eye to the smartphone screen. All participants were given a Nexus 5X 16 GB smartphone loaded with age appropriate games (such as Angry Birds, Subway Surfer, Jet Pack, Crossy Road, etc.) and a Samsung Galaxy Tab S2 model SM-T710 32 GB tablet to use for each trial. A questionnaire was developed for the minor by the researcher using the ©2017 Qualtrics LLC survey tool. Two Sony Handycam CX440 camcorders were used to record each session. A sofa, chair and desk, and a rug, 4 ft × 6 ft, were provided for participant seating. Microsoft Excel version 15.31 was used to perform descriptive statistics.

### 2.4 Procedure

Prior to the start of the experiment, both the parent and the participant signed the consent form and the questionnaire was administered to the participant. The questionnaire was completed on line using the Qualtrics software. Demographic data was collected from the participant and the trials were conducted in randomized order, excepting the personal choice trial. During the experiment, for each trial, participants were asked to sit in one of three different positions – a chair with high back support, a sofa with a low back support, or on a rug. Participants could select any of the preloaded games on the smartphone and tablet and could play the game(s) of his/her choice. Each trial lasted two minutes, with a recovery period of one minute between each trial. Measurements were taken at approximately the one minute mark.

## 3 Results

### 3.1 Reported Smartphone and Tablet Use

Responses to the questionnaire administered to all participants revealed that nine of the eighteen participants had their own smartphone, nine had access to a family member's phone, and two had access to a friend's phone. Two had no access to a cell phone or smartphone. A person who owned his or her own smartphone, could also have access to a family member's or a friend's smartphone. Additional information regarding user behavior was also obtained. While thirteen of 18 (72%) used a smartphone to make phone calls, the most prevalent uses of smartphones were to play games and to send text messages (78%). Sixty-seven percent used their phones for internet searches and to listen to music, with another 61% watching movies or television programs, 44% to do homework, and 28% to read. See Fig. 1.

Review of the responses regarding tablet (iPad or Android) use disclosed that fewer of the participants, six, had their own tablet. Another three had access to and use of a family member's tablet, one person used a friend's tablet, and three used their school's tablet. Five did not own a tablet nor did they have access to a tablet. As with smartphones, the most prevalent activity for users was playing games on a tablet, 61%.

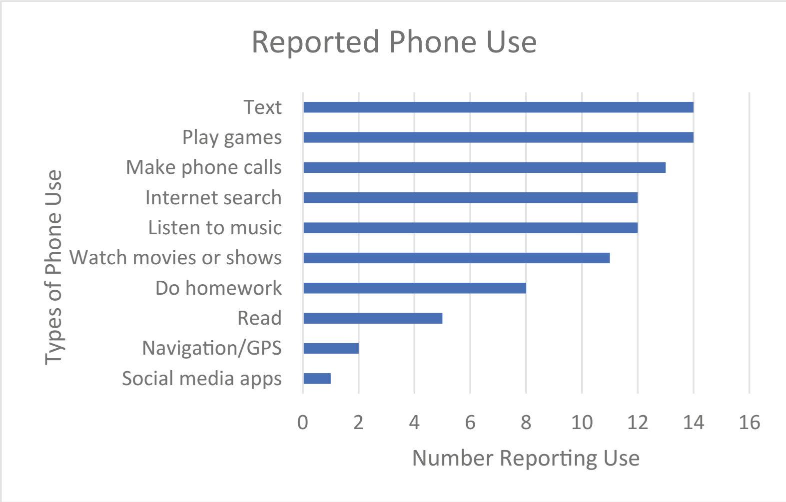


**Fig. 1.** Reported types of smartphone use (n = 18)

Another 33% used the tablet for internet searches and to watch movies or television programs. Doing homework, listening to music, and reading accounted for 22%, 17%, and 11%, respectively, of tablet use. These user behaviors are shown in Fig. 2.

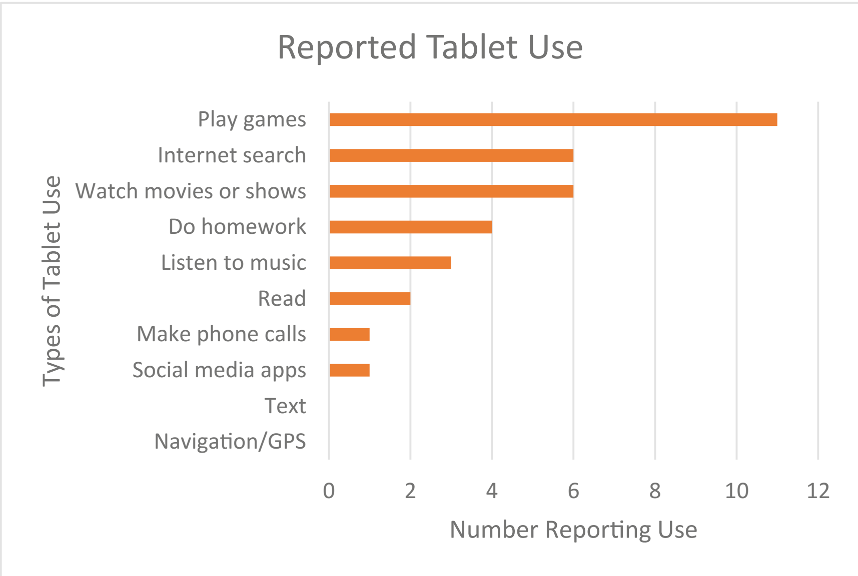


**Fig. 2.** Reported types of tablet use (n = 18)

When comparing smartphone and tablet use, in terms of hours per day, Fig. 3, participants spent fewer hours per day on tablets than on phones. The mean (and standard deviation) hours per day for tablet use was 2.6 (±3.71), while the smartphone use was 3.2 (±1.92) hours per day. Fifty percent of the participants, used a tablet less than one hour per day, compared to 22.2% of smartphone users. Fifty percent of smartphone users reported greater than one but less than 4 h of phone use each day. Four participants, 22.2%, reported using their phones four or more hours per day.

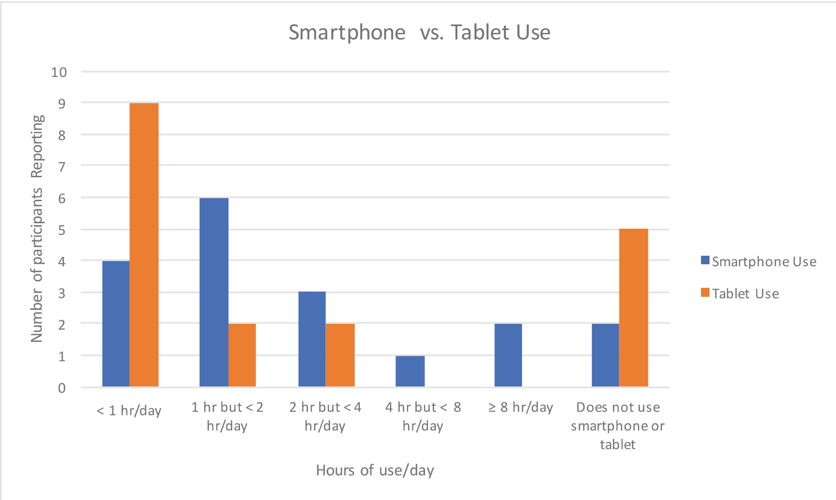


**Fig. 3.** Smartphone vs. tablet use hours per day (n = 18)

When asked if they felt any discomfort or pain, four participants (22.2%) indicated they felt discomfort or pain in certain body regions related to smartphone use and one reported discomfort or pain (5.5%) after using a tablet; shown in Fig. 4. Two people reported discomfort or pain in each of three body regions – the neck, lower back, and wrist/hands – when using a phone. The neck and wrist/hands were also reported for a region of discomfort or pain for the tablet user; in addition to head/headache. Except one case when reporting neck pain frequency of occurrence as often, frequency was stated as occasional. On a scale of 1–5, five being severe, no one reported a pain greater than level 3, moderate.

### 3.2 Back Flexion/Extension During Use of Mobile Devices

An assessment of the back posture was made for each of the three positions assumed during the experiment. In Fig. 5, a comparison of three positions is made for each participant. For all but three participants - participants 8, 11, and 17 – the maximum back flexion/extension for at least one position, exceeded 10°. (Back flexions/extensions of 10° or less are not shown.) For the fifteen participants for whom back flexion or extension exceeded 10°, fourteen occurred while seated on the floor, 12

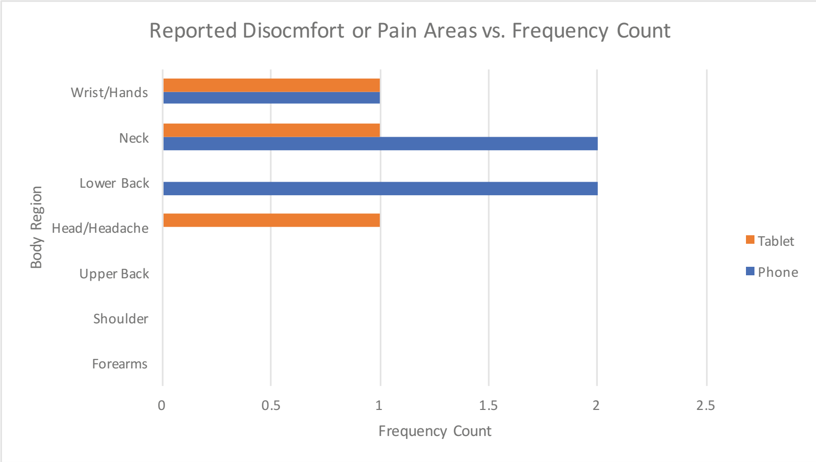


**Fig. 4.** Participant reported areas of discomfort or pain (n = 18)

when seated on the sofa, and nine occurred when seated in the chair. There were three people for whom the maximum flexion exceeded 50° and one for whom back extension exceeded 20° (shown as in Fig. 5).

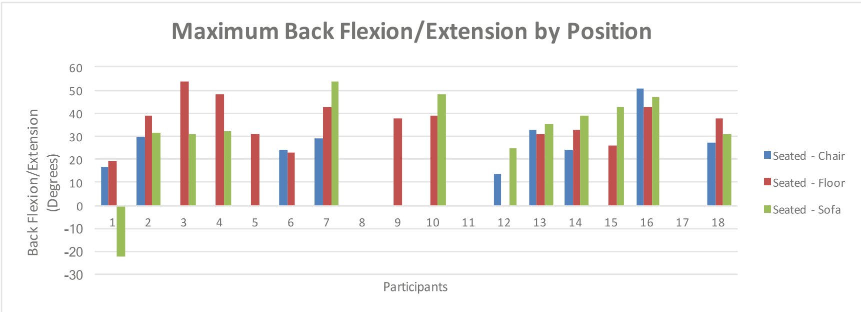


**Fig. 5.** Maximum back flexion/extension for participants when seated in chair, on sofa, or on floor

Back posture was also observed when participants used a specific device, independent of seating. See Fig. 6. For participants 3 and 7, for both smartphone and tablet use, a maximum flexion of over 50° was recorded. Fifty-six percent of the time when maximums were observed, the maximum flexion was higher for tablet use by a range of 1° to 18°. In a direct comparison of position (chair, sofa, or floor) versus device,

Figure 7, the mean flexion for all participants was least when participants sat in the chair, 25.58° for phone use and 25.8° for tablet use. Mean flexion/extension for participants seated on the sofa, was 29.9° for phone use and 30.1° for tablet use. When seated on the floor, mean back flexion/extension was 31.18° and 28.6°, for phone and tablet use, respectively

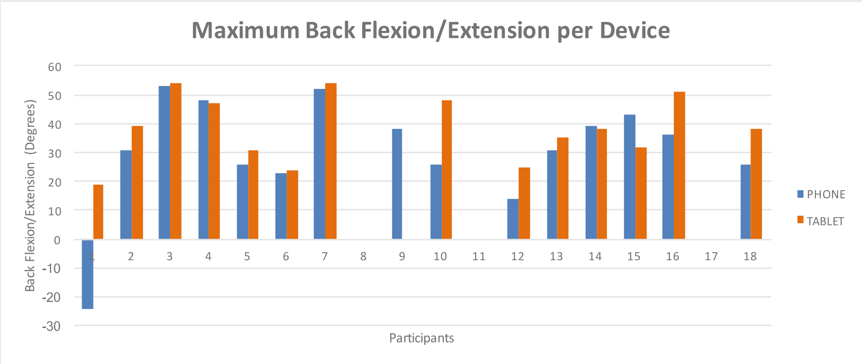


**Fig. 6.** Maximum back flexion/extension for participants when using a smartphone or tablet

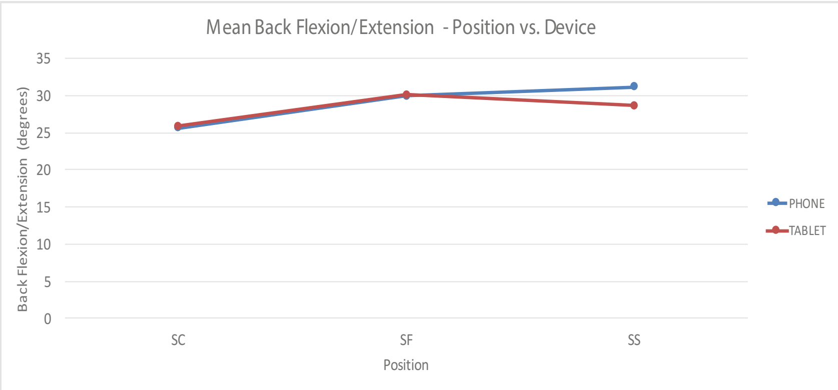


**Fig. 7.** Position vs. device mean back flexion/extension for all participants

## 4 Discussion

Eighty-nine percent of the participants of this study either owned their own smartphone or had access to a smartphone. This is in agreement with a previous report [5]. Phones and tablets were largely used to play games and send text messages, followed by making phone calls. Two of the users who reported discomfort or pain when using their smartphone between one and two hours each day. A third person reported pain and discomfort after both smartphone and tablet use, used a smartphone between two and four hours per day and a tablet less than one hour per day. The fourth person, used a smartphone eight or more hours each day. The number of pain regions reported did not appear to have a direct association with the number of hours of smartphone or tablet use.

Based on the information given, daily use of smartphones is higher ($1 < t < 2$) than the daily use of tablets ($t < 1$); where t is the number of hours per day. This translates to smaller screens being viewed and increased risk of developing dry eyes, fatigue, headaches, eyestrain (asthenopia), presbyopia, and an altered posture, discussed in the work of other researchers [8–14]. The reported daily hours of smart phone and/or tablet use, implies long periods of static, awkward postures being held by the participants. This is also validated by the collection of data which showed back extension as high as 24° for one person and high degrees of back flexion, as high as 54°, for others. No full trunk support was provided during back flexion. Combining the hours of daily use of mobile devices and degree of flexion/extension, the postural characteristics defined by ISO 11226 standard are not acceptable [14]. The postural characteristics and hours of use, point to an increased risk of developing musculoskeletal disorders.

Further review of the collected data, revealed participants often did not take advantage of furniture that could provide back support. When they did take advantage of the back support, back flexion or extension was noticeably less than 10°. In addition, there were 36% fewer occurrences of back flexion greater than 10° when participants were seated in the chair and used the desk, rather than when the person sat on the floor. The chair had a high back which provided back support.

Parents and other caretakers, must remember that school age children are likely using laptops, desktop computers, or tablets during the school day or even for homework assignments. This accounts for additional, hours of static, awkward postures. (The time children spend seated on ill fitted furniture should also be considered.) To decrease the risk of developing musculoskeletal disorders, the following ergonomic interventions are recommended:

1. Parents, teachers, administrators, and other caretakers must be cognizant of the hazards of extended and extensive use smartphones and tablets.
2. Monitor children's posture.
3. Ask children if they are experiencing any discomfort or pain in the neck, back, hands, wrists, etc.
4. Identify a sofa or chair that supports the back and promotes back support and a neutral posture. Be sure the furniture allows the shoulders to remain in a neutral posture, and not raised.
5. Provide a cushion that provides support for the forearms
6. Encourage, even insist, children take breaks, move, and change their activity.
7. Find exercise activities that promote relaxation of the shoulders and a neutral neck and back posture.

## 5 Conclusion

Use of mobile devices by children whose bodies are still developing will continue. The impact of wearable technology on users of the current technology is still to be determined. As well, the insistence on incorporation of technology in classrooms will also continue. Therefore, parents along with other caretakers must be vigilant in their observation of children and any possible discomfort they might experience. Continued use of smartphones, tablets and other electronic devices will have a cumulative effect; increasing the risk of developing musculoskeletal disorders. Enforcement of breaks when using smartphones and tablets and encouragement to participate in other activities are important in lowering the risk of developing musculoskeletal disorders.

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# Occupational Stress Inventory (OSI) for Ergonomic Evaluation of Work Stress Among VDT Operators

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**Abstract.** Workplace stress has been a major source of deterioration in well-being and performance of workers for decades now. VDTs have become an inseparable part of any workstation in the modern work world. It is important to address workplace stressors in order to achieve a better work life around the globe. The study aimed at identifying potential stressors associated with VDT work and developing a measuring instrument to assess the level of occupational stress experienced by VDT operators. The study was conducted in three phases, i.e., identification of constructs of occupational stress among VDT operators; generation of items and item analysis; and standardisation of Occupational Stress Inventory (OSI). As a test of validation, the inventory was subjected to an evaluation by 50 experts. A sample of 100 VDT operators, chosen randomly, from IT industry was taken for the pilot study and 1000 VDT operators were taken for the final administration of the inventory for its standardisation. Reliability Estimation was done by split halves and test retest method. For test retest reliability estimation, an interval of 6 months was taken for repeated administration of the inventory. The OSI was found to be valid and very reliable, in terms of both internal consistency and repeated administrations (r = 0.83 by split halves method and r = 0.92 by test retest method).

**Keywords:** Occupational stress · Workplace stressors · VDT work

## 1 Introduction

The application of computer technology and trends in information technology has brought about revolutionising changes in modern office setup. Not only the office workers have changed and evolved their working pattern and technical aptitude, but the mechanical set-up of the office has been forced to evolve with time and modify according to the need, problems and adaptability of personnel working on the VDTs. Every sector is dependent on computers and consequently new kind of problems and their remedies have evolved over time in order to capture the full benefits of technology. The use of VDTs in the workplace has resulted in automation of previously manually performed tasks and thus revolutionised the workplace. The problems or worries concerned with the use of VDTs are generally associated with physical, temporal, affective and cognitive costs of work that affect the workers in all fronts. The physical costs of work include postural stress, musculoskeletal disorders and visual


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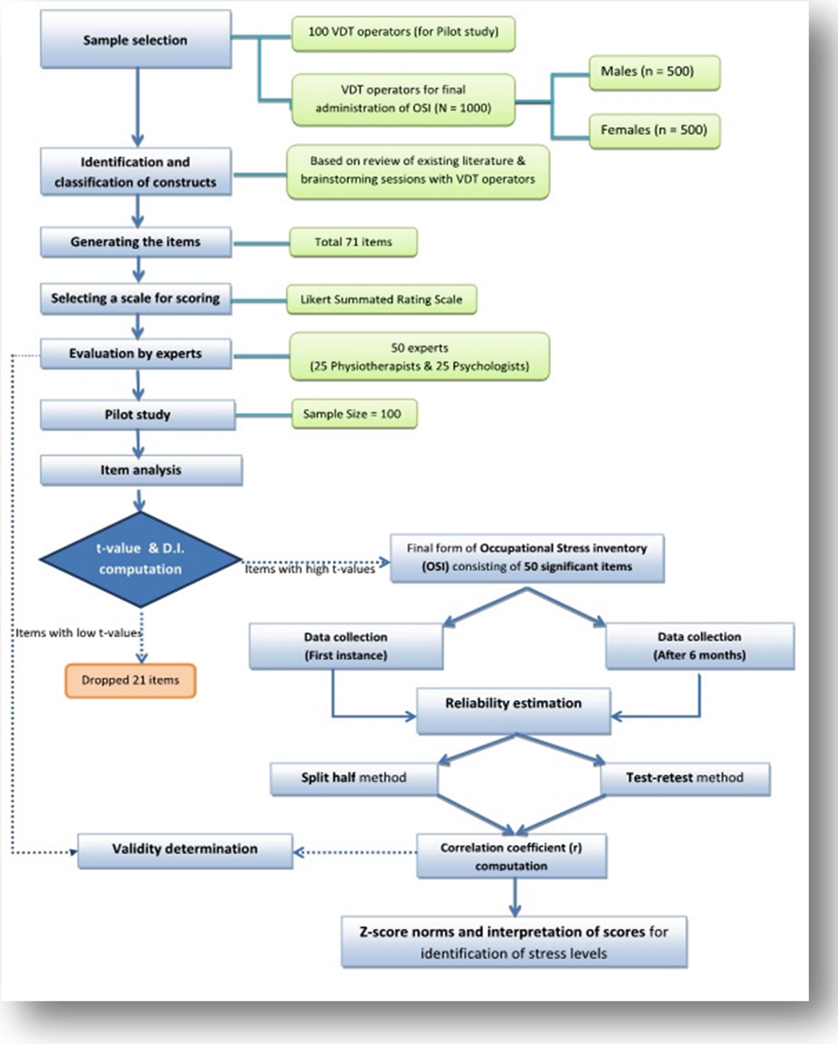
fatigue etc. Sitting with a definite restricted posture for a long time creates onerous workload, where as if the posture is flexible with reference to time interval then it helps to reduce the over-burden created by static and awkward postures. Temporal cost is the collective outflow from the employer in getting the potential output in return. Temporal cost is the little shrinkage in total output for a small duration, which helps to avoid longstanding reduction in output. Temporal cost is primarily associated with the work schedule and timing of the task allocated which includes appropriate rest breaks and leaves. Overloading reduces the efficiency of the operator in the long term. Hence, it is a kind of permanent loss in efficiency due to extending the working hours beyond the normal schedule. Affective cost is associated with attitude, feelings and interest of the workers. VDT work is considered to be monotonous and sedentary in nature; as a result, workers do not find it interesting or motivating. These stressors attain the cumulative power to harm the productivity and efficiency of the VDT operators in the workstation. Cognitive cost refers to the addition in the input column or deduction in the output column as a result of behavioural process among the workers. The cognitive cost of work is high in VDT work as the operators try to multi-task or serial-task.

## 2 Literature Review

Louis (2014) stated that musculoskeletal problems related to head and eye postures when working at a VDT are common and can often be alleviated through proper workstation adjustment. Also, inadequate viewing angles and distance of the monitor can impose the necessity for awkward postures while working on a VDT. Charpe and Kaushik (2008) concluded that workers who perform repetitive work with their bodies in fixed and static positions are more susceptible to getting work related health problems and these problems are one of the leading causes of preventable injuries in the workplaces. McCauley-Bush (2012) suggested that visual fatigue may include loss of productivity, decline in quality, increased human error, increased accident rate, visual complaints and long-term discomfort. Dembe et al. (2005) reported that long hours of work increase the exposure to psychological and physical demands and may induce fatigue and stress among workers. Lehto (2013) found that workplace layout becomes especially important when workers are repetitively doing the same activity hour after hour. Part of the issue is that workers may need to maintain the same posture or a limited set of postures most of the time they spend working. The layout determines postures, and this determines a whole cost of other factors, such as whether the job will be pleasant or unpleasant, fatiguing, or potentially harmful. An ergonomic designer must be familiar with how the human body moves, especially when designing workplace. Juul and Jensen (2005) suggested that the ergonomic equipment such as ergonomic chair, desk, arm supports, keyboard and mouse chair are very useful for protecting the discomfort related computer use.

## 3 Methodology




## 4 Study Findings

Occupational Stress Inventory (OSI) was constructed on the lines of Likert Summated Rating Scale. A total of 71 items generated after thorough review of literature were compiled and categorised as the first step towards formulating the Occupational Stress Inventory (OSI). The items were designed to measure the magnitude of occupational stress experienced VDT operators, identified to be associated with the *Physical, Psychological* and *Environmental* domains of work. In order to quantify the response set, response categories were assigned numerical values ranging from 1 to 5, on the degree of agreement or disagreement of the respondent towards each of the items. The scoring for negative items was reversed.

The tool was validated to define the accuracy with which it could measure the occupational stress levels among VDT operators by subjecting it to review by a panel of 50 subject matter experts (Fig. 1).

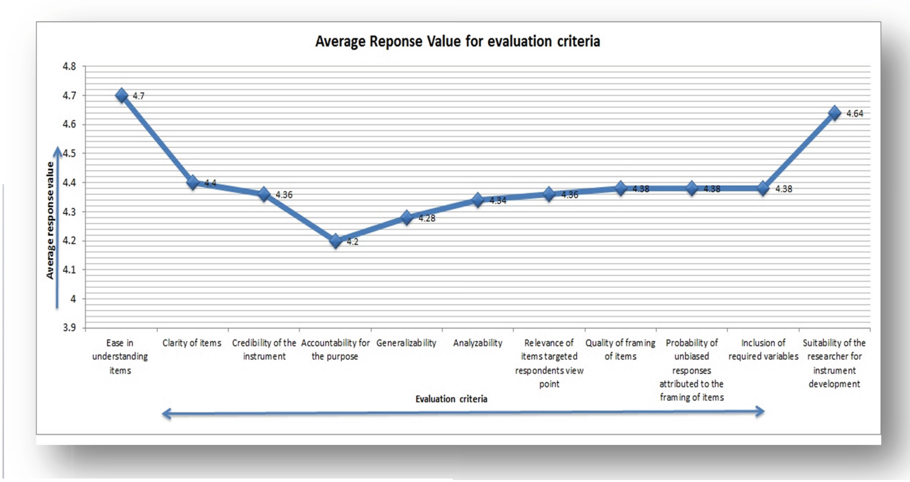



**Fig. 1.** Average response value of evaluation on different criteria

The Average Response Scores on different criteria indicates high criterion validity, high face validity, high predictive validity and high construct validity.

After the OSI was evaluated by a panel of 50 experts, it was administered on a sample of 100 randomly selected VDT operators, in order to identify the items to be retained in the final form of inventory. Item analysis was performed in order to select appropriate items for the final draft, by obtaining discriminatory power of the items to differentiate between effective and ineffective items in the set. Normally items with high t-values are considered to be possessing informal consistency and high discrimination index. Nunnally (1972) suggested that 25% of the top and 25% of bottom scores should be used for item analysis in order to identify relevant and irrelevant items. Individual items were assessed for their appropriateness in measuring the construct, by identifying *item discrimination index* (DI) and the value of *alpha if item deleted* (AID). A high *t-value* indicates here, that item is unique enough to measure a construct in a particular domain and does not interfere with other items in their domains (Tables 1 and 2).

**Table 1.** Categorical display of items with their respective mean, SD, t-values, DI and AID

| Sr. No. | Items | Mean | SD | t- value | DI | Alpha if Item Deleted (AID) |
|---|---|---|---|---|---|---|
| *Physical parameters* | | | | | | |
| 1 | My legs swell at the end of the workday | 3.90 | 0.974 | 6.63** | 0.44 | 0.931 |
| 2 | I experience ache in the left side of the head | 3.52 | 1.328 | 5.77** | 0.52 | 0.934 |
| 3 | I feel pain in shoulders | 3.32 | 1.301 | 4.99** | 0.40 | 0.933 |
| 4 | I experience dryness in eyes | 3.56 | 1.248 | 4.07** | 0.76 | 0.931 |
| 5 | I need to change posture every now and then | 3.52 | 1.403 | 3.94** | 0.44 | 0.932 |
| 6 | I feel strain in eyes while looking at the monitor | 3.96 | 0.989 | 3.74** | 0.60 | 0.932 |
| 7 | I feel strain on the shoulders | 3.52 | 1.216 | 3.44** | 0.44 | 0.931 |
| 8 | I feel soreness in the eyes | 2.98 | 1.286 | 3.34** | 0.36 | 0.935 |
| 9 | I experience ache in the right side of the head | 3.52 | 1.474 | 3.26** | 0.52 | 0.932 |
| 10 | I experience tingling in fingers | 2.72 | 1.443 | 3.23** | 0.68 | 0.933 |
| 11 | I feel pain in neck | 3.52 | 1.568 | 3.13** | 0.48 | 0.933 |
| 12 | I experience headaches | 3.52 | 1.555 | 2.81** | 0.44 | 0.931 |
| 13 | I feel strain in the mid back | 3.14 | 1.604 | 2.74** | 0.52 | 0.933 |
| 14 | I feel numbness in the hands | 2.90 | 1.568 | 2.73** | 0.40 | 0.932 |
| 15 | I experience blurred vision | 2.62 | 1.383 | 2.61** | 0.48 | 0.931 |
| 16 | I feel numbness in fingers | 2.34 | 1.722 | 2.56** | 0.44 | 0.933 |
| 17 | I feel stiffness in body | 3.04 | 1.124 | 2.50** | 0.52 | 0.932 |
| 18 | I feel strain in lower back | 3.82 | 1.561 | 2.39* | 0.64 | 0.934 |
| **19** | **I feel numbness in wrist** | **3.98** | **0.958** | **1.88*** | **0.40** | **0.933** |
| **20** | **I feel numbness in the legs** | **3.72** | **1.262** | **1.81*** | **0.36** | **0.935** |
| **21** | **I feel irritation in the eyes** | **3.74** | **1.157** | **1.79*** | **0.48** | **0.936** |
| **22** | **I feel pain in wrist** | **3.98** | **0.958** | **1.62ns** | **0.24** | **0.936** |
| **23** | **I feel strain in neck while maintaining gaze on the monitor** | **4.06** | **0.867** | **1.46ns** | **0.04** | **0.936** |
| **24** | **I experience ache in the back of the head** | **4.02** | **0.958** | **1.12ns** | **−0.08** | **0.935** |
| **25** | **I feel strain in the upper back** | **3.86** | **1.107** | **−0.19ns** | **0.12** | **0.936** |
| *Psychological parameters* | | | | | | |
| 26 | I feel monotony in workplace | 3.38 | 1.497 | 4.59** | 0.48 | 0.933 |
| 27 | I become frustrated at the end of the workday | 2.40 | 1.229 | 4.22** | 0.40 | 0.932 |
| 28 | I find my mind stressed due to work | 3.12 | 1.423 | 4.22** | 0.56 | 0.933 |
| 29 | I get bored during working hours | 2.90 | 1.282 | 4.06** | 0.64 | 0.931 |
| 30 | I try to ignore pain | 3.04 | 1.049 | 3.51** | 0.52 | 0.931 |
| 31 | I feel stressed in repetitive tasks | 3.90 | 1.313 | 3.15** | 0.48 | 0.931 |

(*continued*)

**Table 1.** (*continued*)

| Sr. No. | Items | Mean | SD | t- value | DI | Alpha if Item Deleted (AID) |
|---|---|---|---|---|---|---|
| *Physical parameters* | | | | | | |
| 32 | I experience the worries of deadlines | 3.30 | 1.282 | 2.70** | 0.40 | 0.932 |
| 33 | I feel exertion in static posture | 3.86 | 1.010 | 2.44** | 0.36 | 0.932 |
| 34 | I feel restless | 1.94 | 1.517 | 2.42** | 0.72 | 0.932 |
| 35 | I feel difficulty in concentrating on work | 2.56 | 1.248 | 2.32* | 0.68 | 0.933 |
| **36** | **I feel anxious in dealing with problems** | **4.06** | **0.867** | **1.83*** | **0.40** | **0.932** |
| **37** | **I feel that I need to meditate** | **4.06** | **0.867** | **1.68*** | **0.40** | **0.933** |
| **38** | **I have conflicts with my subordinates** | **3.90** | **1.035** | **1.36ns** | **0.56** | **0.932** |
| **39** | **I feel the requirement of self-vigilance** | **3.84** | **1.113** | **0.91ns** | **0.32** | **0.937** |
| **40** | **I have conflicts with my authorities** | **4.02** | **0.958** | **0.84ns** | **0.12** | **0.936** |
| **41** | **I get confused over petty issues** | **3.86** | **1.107** | **0.55ns** | **−0.04** | **0.936** |
| *Environmental parameters* | | | | | | |
| 42 | I find my workstation suitable for my work demands | 2.92 | 1.412 | 4.57** | 0.40 | 0.931 |
| 43 | I feel there should be more light in work area | 2.88 | 1.380 | 4.36** | 0.56 | 0.934 |
| 44 | The flicker in the work area is a source of disturbance for me | 3.14 | 1.178 | 4.29** | 0.48 | 0.933 |
| 45 | Noise in the work area leads to decline in my work efficiency | 3.62 | 1.383 | 3.69** | 0.56 | 0.934 |
| 46 | My work seat supports stable posture | 2.74 | 1.259 | 3.63** | 0.48 | 0.934 |
| 47 | My elbow gets an appropriate surface to rest upon during work | 2.62 | 1.244 | 3.57** | 0.44 | 0.934 |
| 48 | The armrest of my work chair is comfortable | 3.02 | 1.059 | 3.39** | 0.68 | 0.934 |
| 49 | I feel dryness in throat | 3.20 | 1.262 | 3.38** | 0.40 | 0.935 |
| 50 | The humidity level at the workplace is comfortable | 2.74 | 1.157 | 3.37** | 0.56 | 0.934 |
| 51 | I have to change positions on my work seat every now and then | 3.22 | 1.130 | 3.36** | 0.68 | 0.934 |
| 52 | My seat creates discomfort through unnecessary pressure under thigh | 3.00 | 1.195 | 3.31** | 0.44 | 0.934 |
| 53 | I find work related objects at a far distance from me | 3.16 | 1.267 | 3.16** | 0.64 | 0.935 |
| 54 | I experience difficulty in making adjustments in my work seat | 3.12 | 1.319 | 3.11** | 0.36 | 0.935 |
| 55 | The height of my work desk is appropriate for my work | 3.30 | 1.359 | 3.05** | 0.48 | 0.935 |

(*continued*)

**Table 1.** (*continued*)

| Sr. No. | Items | Mean | SD | t- value | DI | Alpha if Item Deleted (AID) |
|---|---|---|---|---|---|---|
| *Physical parameters* | | | | | | |
| 56 | I have to make adjustments to fit the diverse work objects together | 3.26 | 1.482 | 2.92** | 0.52 | 0.935 |
| 57 | The height of the monitor is suitable to my working height | 2.66 | 1.349 | 2.92** | 0.64 | 0.935 |
| 58 | The office workplace has a noisy environment | 2.46 | 1.216 | 2.54** | 0.36 | 0.935 |
| 59 | The work desk is large enough to create comfortable work environment | 3.16 | 1.608 | 2.30* | 0.56 | 0.935 |
| 60 | The work chair has appropriate backrest | 2.08 | 1.066 | 2.20* | 0.44 | 0.935 |
| 61 | I experience discomfort in prolonged sitting | 3.28 | 1.471 | 1.97* | 0.40 | 0.934 |
| 62 | The arm to mouse distance in my work area is appropriate | 2.42 | 1.357 | 1.89* | 0.36 | 0.934 |
| 63 | I find my workstation hotter/cooler than desirable | 3.22 | 1.582 | 1.89* | 0.36 | 0.935 |
| 64 | The footrest provided on my work table supports stable posture | 3.70 | 1.233 | 1.40ns | 0.16 | 0.936 |
| **65** | **The surface provided for keyboard is appropriate** | **3.68** | **1.220** | **1.39ns** | **0.24** | **0.936** |
| **66** | **The width of the seat pan in my work chair is appropriate** | **3.60** | **1.262** | **1.39ns** | **0.20** | **0.936** |
| **67** | **Castors in my work chair allow it to swivel smoothly** | **3.68** | **1.220** | **1.26ns** | **0.16** | **0.936** |
| **68** | **The indoor climate of my work area is never a cause of exertion** | **3.54** | **1.313** | **1.21ns** | **0.08** | **0.936** |
| **69** | **The work area has considerable amount of glare** | **3.74** | **1.157** | **0.53ns** | **−0.04** | **0.935** |
| **70** | **My work pace get affected by the indoor climate of the workstation** | **3.80** | **1.088** | **0.30ns** | **0.12** | **0.936** |
| **71** | **I experience excessive brightness in the workplace** | **3.90** | **1.015** | **0.10ns** | **−0.16** | **0.936** |

**Significant at 1%, *Significant at 5%
ns -non-significant

**Table 2.** Reliability estimation by split halves method

| Split halves | Mean | Pearson's r | Cronbach's Alpha |
|---|---|---|---|
| Odd numbered items (25 items) | 3583.68 | 0.83 | 0.817 |
| Even numbered items (25 items) | 3548.96 | | |

t-value for the items varied between 6.63 as maximum to −0.19 as minimum. Edwards (1975) suggested that items with high t-values (normally $\geq 1.75$) are regarded as items possessing informal consistency and high discrimination power. Based on t-values obtained, the relevant items were retained in the inventory and items with lower t-values were removed. To obtain an appropriate size of the instrument, 3 items with t-value >1.75 were also removed; the t-values being 1.88, 1.81 and 1.79. The Occupational Stress Inventory (OSI) in its final form comprised 50 items with high item discrimination index ($\geq 0.32$) and t-values ranging from 6.33 to 1.89, after dropping 21 items with low t-values; and was administered on a large sample of 1000 respondents selected randomly, under the age group of 25–30 years with a working experience of at least one year in the same work setup; working at least 6 h per day on a VDT. The data was collected twice with an interval of six months to establish its reliability in repeated administrations. The response sets of both administrations were tabulated and data was statistically analysed for the reliability estimation of the instrument. Reliability of OSI was estimated by Split-Halves method and Test Retest method.

In the Split Halves Method, the value of **r** (0.83) indicated that the instrument was highly consistent and strong enough to measure the construct effectively (Table 3).

**Table 3.** Test retest reliability statistics

| | Mean (for 50 items) | Pearson's r | Cronbach's Alpha |
|---|---|---|---|
| Data collected (First Instance) | 3566.32 | 0.92 | 0.950 |
| Data collected (After 6 months) | 3493.38 | | |

The value of **r** as calculated for the two set of scores was 0.92; indicating a very high correlation, which shows that the instrument was very much consistent and reliable over time. After assuring the validity and reliability of Occupational Stress Inventory (OSI), z-score norms were developed for assessing the occupational stress levels among VDT operators. This was done to make the instrument applicable in any VDT workstation setup, where VDT work is performed under a standard set of situations and be used to assess the levels of occupational stress at the workplace. z-score corresponding to each raw score was calculated and norms were developed for the interpretation of Occupational Stress Inventory (OSI) scores. The raw scores of OSI lie in the range 50 to 250 and the corresponding z-scores vary between −1.72 to +1.72.

If the raw score of a respondent lies in the range 50 to 90; the subject is experiencing negligible stress at the workplace. If the raw score falls in between 91 and 130, the stress level can be considered low. Raw score in the range 131 to 170 indicates mild levels of stress. If the raw score exceeds 170 and range up to 210, the stress level should be considered high and if it exceeds beyond 210, the stress level is severely high, which indicates a need to bring about change in the work environment to protect the worker's efficiency at work (Table 4).

**Table 4.** z-score norms for interpretation of levels of occupational stress

| Occupational stress level | Raw scores | z-scores | Occupational stress severity level |
|---|---|---|---|
| A | 50–90 | −1.72 to −1.03 | Negligible |
| B | 91–130 | −1.02 to −0.34 | Low |
| C | 131–170 | −0.33 to +0.34 | Mild |
| D | 171–210 | +0.35 to +1.03 | High |
| E | 211–250 | +1.04 to +1.72 | Severe |

*Mean = 150, SD = ±58.168, N = 1000*

The study aimed at examining the overall VDT work structure and thereafter identification of physical, psychological and environmental sources of stress among VDT operators. The prime objective of the study was to develop an inventory which can be used as a standard to assess the level of occupational stress among VDT operators. The administration of Occupational Stress Inventory (OSI) in any VDT workstation can assist the management and all those interested in the welfare of the workers at the workplace. It can be helpful for the employers for assessing the stress level for each worker in the organisation and taking appropriate counter measures and defining appropriate stress management programs to reduce stress level at the workplace for enhancing the overall performance.

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# OHSAS 18001 Certification as Leadership Commitment Factor for Improvement of the Safety Management Performance in a Mining Company

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**Abstract.** Mining was one of the first activities developed by humankind and it has been one of the pillars of the Brazil's economy for years. Studies show that mining is responsible for the highest mortality rates related to working accidents among the economic activities from Brazil. This work consists of a case study which the aim is to analyze the impact of the OHSAS 18001 certification in the performance of workplace safety management in a gold mining company. For this purpose, were made bibliographic researches, technical visits in field, collection and critical analyze of data. The results showed that the certification process contributed significantly for the evolution of the performance of the safety management system. However, the key element to unleash the improvements was the human factor, through the high commitment level of the managers with the issue, which were reflected on the other organizational levels, providing several gains for the company.

**Keywords:** Safety management · OHSAS 18001 · Human factor
Leadership · Continuous improvement

## 1 Introduction

Mining was one of the first activities developed by humanity. According to Hartman [1] the beginnings of mining refer possibly to the year 300,000 BC, when the "cavemen" performed the extraction of rocks for the use of these as tools and weapons.

Nowadays Mining is reported by Ibram [2] as one of the pillars of the Brazil's economy. The Brazilian ore production is one of the biggest of the world, so that turns the country an important global player of the sector.

The problem of accidents and work diseases has followed the history of mining. According to USP [3], the appearance of workers exposed to lead, mercury and dust was reported by Pliny (23-79 AD) after he had visited some mines galleries, who impressed, mentioned the initiative of slaves to use in front of face, cloths or membranes (ram's bladder) to minimize the inhalation of dust.


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Among the activities listed in the national register of activities (CNAE), mining is among those at greatest risk of work accidents. Candia [4] said that although in recent years significant reductions have been observed in the rate of injuries and fatal accidents in mining, the number of accidents and their degree of severity are still high when mining is compared with other industrial activities. Lima [5] shows that mining has one of the highest rates of accidentally, as well as one of the highest rates of mortality related to industrial accidents among all economic activities. Therefore, it is fundamental an effective management of the dangerous conditions in these workplaces, which is possible through the adoption of systematized actions, which must be properly planned, implemented, verified, corrected and/or improved by skilled people.

During the period of the Industrial Revolution, according to USP [3], there was already a concern about the repair of damage to physical integrity and health of the workers, but only around 1926, from the studies developed by Heinrich, a series of ideas began to be developed in order to manage this problem.

Then, in the midst of a context of major accidents, and, consequently, the growing pressure for greater clarity in the actions of companies regarding ethics and social responsibility, the concept of occupational health and safety (OHS) management system emerged, which was later strengthened through the publication of standards such as OHSAS 18001.

OHS management system is defined by OHSAS [6] as part of the organization's management system used to develop and implement its OHS policy and manage OHS risks.

OHSAS 18001 aims to provide organizations with the elements of an effective OHS management system, which can be integrated with other management requirements, and assist them to achieve their goals of OHS and economic ones [6].

This paper consists of a case study related to the performance of workplace safety management system of a gold mine after the certification by OHSAS 18001.

The general objective of this study is to analyze the impact caused by the OHSAS 18001 certification in the performance of the occupational health and safety management system (OHS) of a gold mine work located in Brazil.

Thus, this study sought to answer the following question: Has OHSAS 18001 certification contributed to the improvement of the occupational health and safety management system of the company under study?

## 2 Materials and Methods

### 2.1 Characterization of the Enterprise in Study

This work consists of a case study related to the performance of the OHS management system of a gold mine, located in Brazil. To preserve the identity of the company under study was adopted the pseudonym NX Mine. The main activity developed by NX Mine is characterized as precious metal ore extraction, and the risk level of this activity is number 4, classified as high risk, according to the Regulatory Norm 4 (NR-4) [7]. During the study the workforce numbered 864 employees (298 own and 566 permanent third parties). All activities of this site are performed on the surface of the land, which characterizes it as an open pit mine. In short, the production processes developed there are: ore extraction, crushing, gravimetry, leaching and casting, as shown in the Fig. 1.

In addition to the processes mentioned before, there are those of support, such as administration, finance, logistics, mechanical maintenance, infrastructure and physical-chemical laboratory.

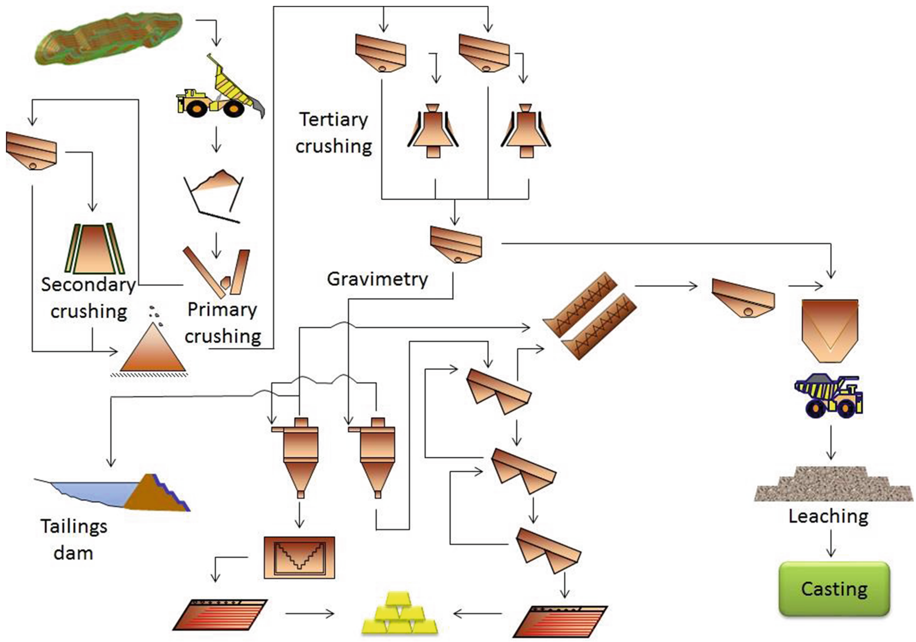



**Fig. 1.** Flowchart of macro processes of the NX Mine.

### 2.2 Methodology

This work was developed through the survey and technical analysis of documents and data related to the OHS management system of the NX Mine. Some performance indicators of the occupational safety management were selected from the years 2011, 2012 and 2013, which were statistically compared to each other, allowing the conclusion about the behavior of the system before and after the Standard OHSAS 18001 certification.

## 3 Results and Discussion

### 3.1 The Management System of Mine

NX Mine has an integrated management system of health, safety, and environment (HSE) certified in accordance with international standards such as ISO 14001 and OHSAS 18001.

During the study, he OHS Department had a cadre of eleven professionals, being 01 Coordinator; 01 occupational safety engineer; 03 occupational safety technicians; 01 ergonomist; 02 nurses and 03 nursing assistants.

For this study, were selected some of the main performance indicators of OHS management system to investigate the system performance before (baseline – year 1), during (year 2) and after (year 3) the OHSAS 18001 certification process. The performance indicators selected were:

- Legal compliance management;
- Incidents management;
- Security approaches management;
- Objectives and goals management;
- $FAP^{i}$ × RAT[1] index.

## 3.2 Analysis of OHS Management Performance

**Legal Compliance Management**

NX Mine has an electronic system of legal requirements management, where users (NX Mine employees) and external consultant law experts hired are responsible for the assessment and update of system. System monitoring is done by means of internal audits that happens annually. Figure 2 demonstrates the performance of the management of legal requirements over the past few years.

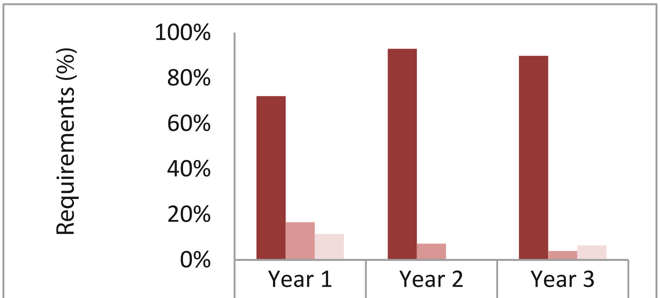
Figure 2 shows there has been an increase of approximately 20% in the number of legal requirements applicable to the activities of the company registered in the system. The percentage of compliant requirements jumped from 72% in year 1, to 93% in year 2, and had a small fall in year 3, with 90% of legal compliance. The analysis of the non-compliant requirements demonstrates a continuous evolution in the studied period. The percentage went from 17% in year 1, fell to 7% in year 2 and reached the lower index in the third year, with 4% of non-compliance. Finally it is possible to assign the percentage drop of compliant requirements in year 3 to the increased requirements index, which were not assessed in the same year, that is, it's noticed a need to improve the commitment of responsible users for evaluation and updating of the system.

Data reviewed here include all applicable legal requirements, and not only those related to OHS.

**Incident Management**

The system standard named "Analysis of Incidents and Communication" defines the systematic of communication, classification and investigation of the incidents that have occurred in NX Mine. According to this standard, the incidents must be investigated by a skilled team, which must identify the causes of the events and establish preventative

[1] Environmental Risks at Work (RAT) represents the contribution of the company, provided for in item II of article 22 of Brazilian Law 8212/91, and consists of a percentage that measures the risk of economic activity, based on which the contribution is paid to finance the social security benefits arising from the degree of incidence of incapacity (GIIL-RAT) [8].




| | Year 1 | Year 2 | Year 3 |
|---|---|---|---|
| Compliant | 72% | 93% | 90% |
| non-compliant | 17% | 7% | 4% |
| unevaluated | 11% | 0% | 6% |

**Fig. 2.** Performance of legal compliance

and/or corrective action plans. The investigations of incidents and the respective plans of action are registered in an electronic system.

The key performance indicators of the NX Mine incidents management are the statistics related of the incident frequency rates, which is calculated on the basis of the number of incidents per one million man hours worked. In this section there are presented loss-time accidents rate (ACPT), severity rate (G), non loss-time accident rate (ASPT) and near accidents rate.

**Incidents Statistics**

The following graphs show the evolution of statistics of incidents in the studied period (Fig. 3, 4, 5 and 6).

The data show a continuing reduction in the frequency rate of ACPT, severity and ASPT. It is noticed a sharp reduction in year 1 rates for year 2. Near accidents denote an opposite phenomenon, because in year 2 have occurred the highest rate of near-accidents, showing a significant drop in year 3.

The Accident Prevention Factor (FAP) (see Footnote 1), effective since 2010, is a *bonus* × *malus* system, in which the contribution rate of one, two or three percent, destined to the financing of the special retirement benefit or those granted due to the level of occupational incapacity caused by environmental risks at work, may be reduced by up to fifty percent or increased by up to one hundred percent, according to the regulations, due to the performance of the company in relation to the respective economic activity, calculated in accordance with the results obtained from the accidents frequency, severity and cost indices, calculated according to methodology approved by the National Social Security Council [8].

**Safety Approaches**

Safety approach is a tool applied by NX Mine leadership day by day to verify and report the behavior of the employees regarding the safety at work and the hazard conditions in the workplace.

Figure 7 shows the data related to the application of the safety approaches.

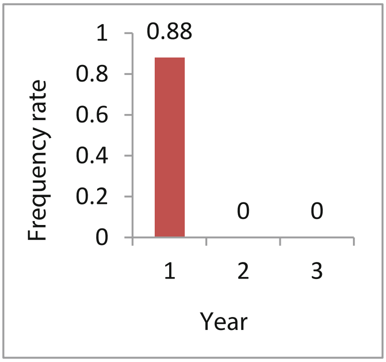



**Fig. 3.** Loss-time accidents frequency rate in each year studied.

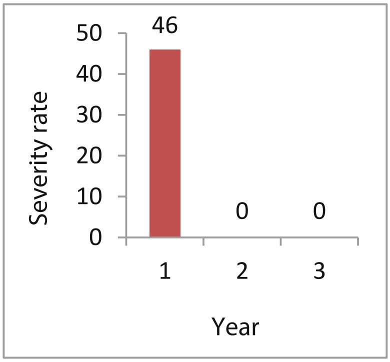



**Fig. 4.** Severity accidents rate in each year studied.

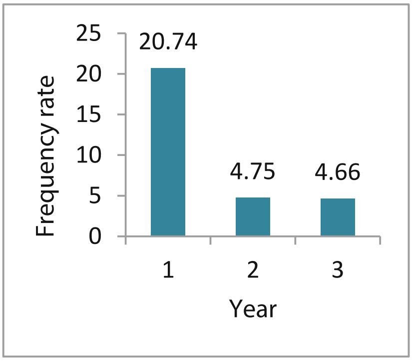



**Fig. 5.** Non loss-time accidents frequency rate in each year studied.

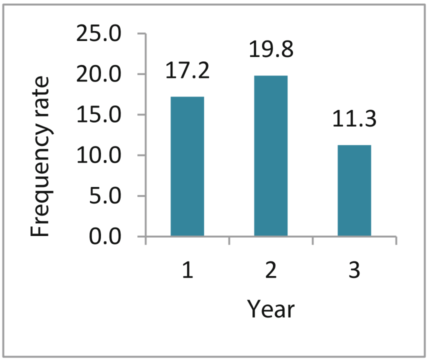



**Fig. 6.** Near accidents frequency rate in each year studied.

Data indicate that there was a significant and continuous increase in the total and in the specific quantity (approaches/worker) of approaches over the studied years. In addition, there is a 13% reduction in the percentage of negative approaches, while showing a 12% increase in the percentage of positive approaches.

This results can represents the beginning of a possible culture changing in the company, because it demonstrates a higher commitment of the leadership and others employees with the OHS issues.

**Strategic Targets and Goals of OHS**

Figure 8 shows the performance related to the fulfillment of the HSO goals and targets established for the years 1, 2 and 3.

As illustrated by Fig. 8 there was a gradual evolution in performance related to the reaching of targets and goals of the company. Despite of the Fig. 8 shows only the percentage of targets and goals have been reached, it is important to comment that it is also noted the improvement of the quantity and quality of the targets and goals

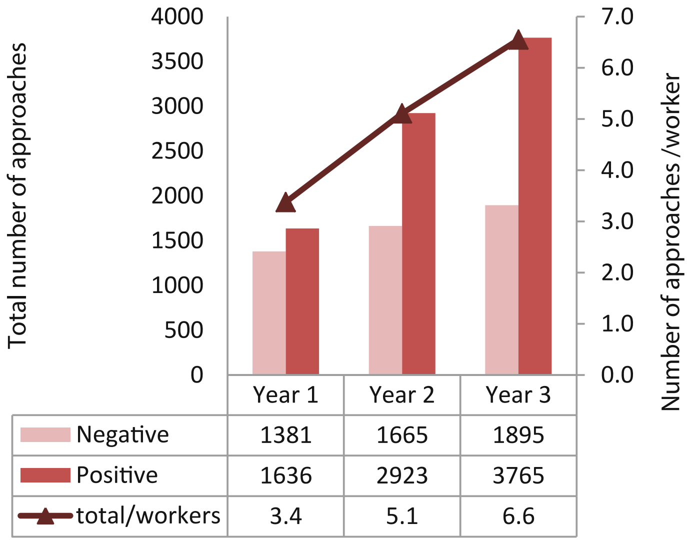



**Fig. 7.** Amount of safety approaches conducted in in each studied year.

established (especially between years 1 to 2), in order to make them more specific and daring over the years. It is observed that OHS objectives and goals have been treated in a systematic manner, from year 2, with the establishment of programs and performance indicators, in order to meet the requirements of OHSAS 18001. So, it is possible to say, through the Fig. 8, that the effort expended to meet the goals became greater from year 2, demonstrating that OHS issues have become more relevant for the organization.

**Accident Prevention Factor (FAP) and Environmental Risks of Work (RAT)**
According to the Ministry of Social Security [9], the index that results in the FAP is composed of frequency indices (incidence of accidents in each company), severity (cases of accidental removal for more than 15 days, incidents of accidental disability and death, illness aid and accident aid) and cost (amounts paid by the Pension Plan in monthly benefit rents). The final calculation is called “RAT set” = RAT × FAP.

The results related to the reduction of frequency and severity rates of accidents, impacted on the gradual decrease percentage of social security contribution the company payroll (FAP × RAT), as Fig. 9 illustrates.

The drop of FAP implies directly in significant reduction of financial costs of NX Mine, in addition to reflect indirectly in the production, through the gains related to minimizing time loss due to accidents, as well as in improving OHS conditions of its employees.

Fernandes [10] states that FAP as an indicator of HSO performance of the company, in addition to reflecting the result of other management subsystems, determines its profitability and its competitive position with regard to other companies in its economic segment.

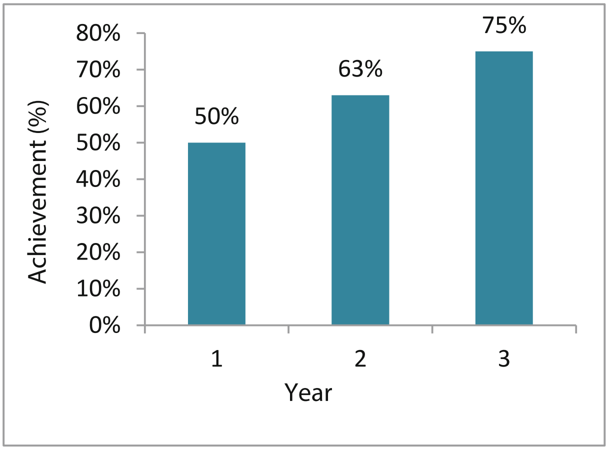



**Fig. 8.** Achievement of OHS targets and goals established in NX Mine.

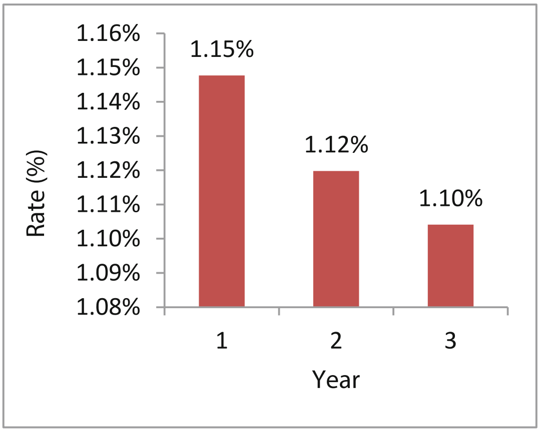



**Fig. 9.** Rate of social security contribution (FAP × RAT) of NX Mine.

## 4 Conclusion

OHSAS 18001 certification process contributed directly and indirectly to the improvement of OHS management performance of NX Mine. Directly because it is noted that from year 2 (year of the certification), OHS management has become performed in a more systematized manner, with establishment and monitoring of objectives, goals and programs, performance indicators, and all other OHSAS 18001 requirements, which are important to the efficiency and effectiveness of any OHS management system. In addition, it can be said that the third-party audit process, although it is a sampling, acts in a way, as an inspection agent of practices and performance of OHS in the company, so, the audits influence directly on discipline and priority which these issues are dealt in the company.

A lot of NX Mine key performance indicators that have been demonstrated the improvement of OHS management performance from year 1 to 3. The highlights were the following ones: non loss-time accidents frequency rate, which reduced around to 77%, loss-time accidents frequency rate and severity rate, which both reduced by 100%, rate of social security contribution, which dropped around 4%, number of safety approaches, which increased around 56%, compliance with objectives and goals, which increased around 25% and legal compliance, which increased around 18%.

Despite direct benefits promoted by system certification, it can be said that the major contributions occurred indirectly, particularly due to the high degree of commitment from senior management with OHS issues, which culminated in financial investments for appropriateness of physical structures, several trainings for employees, review of important documents and implementation of OHS programs, among several other improvements. In addition, the posture adopted by the senior management reflected in other leadership positions in the company, because, once the OHSAS 18001 became a goal, OHS went on to be one of the priorities for all the company's employees.

Therefore, it was concluded that the commitment of senior management was the key element that unleashed the improvement of the performance of OHS management mentioned, and OHSAS 18001 was the tool that helped the company to achieve these results, thus, it is confirmed that statement: "the leadership constitutes a condition for success. Any preventive approach can bear fruit only if it is supported by the direction" [11].

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# A Study on Preventing Runaway Reaction of Batch Reactor by Installing the Safety Instrumented System (SIS)

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**Abstract.** There have been multiple chemical incidents which involved runaway reaction in the exothermic batch reactors (e.g. synthetic polymer reaction). Runaway reaction commonly refers to the abnormal exothermic reaction when cooling water fails to operate and the temperature inside the reactor increases rapidly. Most commonly, synthetic polymer reactors are operated and controlled by the Basic Process Control System (BPCS) and the safety valve or/and rupture disks are installed for the protection and safety. These measures, however, are limiting in terms of detecting abrupt changes in temperature (and pressure) in advance when a runaway reaction takes place. This research suggests the use of batch reactor along with Safety Instrumented System (SIS) in addition to the current practice of BPCS. As for the Safety Instrumented Functions (SIF) of the SIS, a 2oo3 voting is installed as a sensor, 2 channels as a logic solver, and a 1oo2 voting is utilized as final elements.

**Keywords:** Batch reactor · Runaway reaction
Basic Process Control System (BPCS) · Safety Instrumented System (SIS)
Safety Integrity Level (SIL)

## 1 Introduction

The batch reactor (included semi-batch reactor) is a commonly used type of reactors in the fine and pharmaceutical chemical industries (i.e. synthetic medicines, adhesives, coatings manufactures, etc.) and there have been multiple chemical incidents which involved 'runaway reaction' or 'thermal explosion' in the exothermic batch reactors (e.g. synthetic polymer reaction). The number of fatalities and injuries as a result as a result of thermal runaway incidents has increased by ~325% and ~279%, respectively, in the last 25 years even though the number of incidents was significantly decreasing [1]. In recent years in Korea, 3 cases were reported in 2014, 5 cases in 2105, 4 cases in 2016, and up until August 2017, 2 incidents have been documented [2].

The accumulation of reactants or intermediates in the reactor is a main factor of hazard for exothermic reactions, undesirable reacting control conditions, such as


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temperature or conversion jump during the reaction, leading to well high temperature at which decomposition reaction may be triggered [3].

For example of some synthetic polymer reactions, the result from thermal risk assessment indicated that there was a rapid increase in the adiabatic temperature and this resulted in the damage to the reactor as well as the loss of reactants from safety valves or/and rupture disks.

As a case study, this research examines the incident in the epoxy resin reactor which took place in a paint manufacturing factory in Korea in September, 2014 [4].

This research intends to empirically explain and assess the thermal risk of abnormal exothermic reaction during the homopolymerization of epoxy resin. A MultiMax Reaction Calorimeter is used an experimental test for homopolymerization reaction of epoxy resin. For preventing runaway reaction, this research suggests that the Safety Instrumented System (SIS) be additionally installed to the current practice of Basic Process Control System (BPCS) for reducing thermal risk before runaway reaction is occurred.

## 2 Theoretical Assessment of Runaway Reaction's Thermal Risk

### 2.1 Assessment of Severity

The adiabatic temperature rise ($\Delta T_{ad}$) can be calculated by dividing the energy of the reaction (Q′) by the specific heat capacity ($C'_p$), show as Eq. (1). Q′(kJ/kg) represents the heat energy of reaction which can be obtained by reaction calorimetry. The specific heat capacity of organic liquids is 1.8– 2.0 kJ/kg.K.

$$\Delta T_{ad} = Q'/C'_p \tag{1}$$

A proposal for the assessment criteria on a four levels scale is presented in Table 1. This four levels scale for the severity (or consequence) is commonly used in the fine chemicals industry. It has its roots in the Zurich Hazard Analysis (ZHA) developed by the Zurich Insurance Company [5]. If the assessment is performed on a three levels scale, the upper levels "critical" and "catastrophic" may be merged into one level, "high".

**Table 1.** Assessment criteria for the severity of a runaway reaction.

| Simplified | Extended | $\Delta T_{ad}$ (K) | Order of magnitude of Q′(kJ/kg) |
|---|---|---|---|
| High | Catastrophic | >400 | >800 |
| | Critical | 200–400 | 400–800 |
| Medium | Medium | 50–200 | 100–400 |
| Low | Negligible | <50 and no pressure | <100 |

## 2.2 Assessment of Probability

The cooling failure scenario was developed by Gygax (1988, 1993) which presented uses the temperature scale for the assessment of severity and the time - scale for the probability assessment. Starting from the process temperature ($T_p$), in the case of a failure, the temperature first increases to the Maximum Temperature of the Synthesis Reaction (MTSR). The concept of Maximum Temperature of the Synthesis Reaction was developed for this purpose, show as Eq. (2). At this point, a check must be made to see if a further increase due to secondary reactions could occur [6].

$$\mathrm{MTSR} = T_p + X_{ac} \cdot \Delta \mathrm{T}_{\mathrm{ad,rx}}. \tag{2}$$

For this purpose, the concept of Time to Maximum Rate under adiabatic conditions ($TMR_{ad}$) is very useful. Since $TMR_{ad}$ is a function of temperature it may also be represented on the temperature scale. For this, we can consider the variation of $TMR_{ad}$ with temperature and look for the temperature at which $TMR_{ad}$ reaches a certain value [6]. The duration of the main reaction runaway may be estimated using the initial heat release rate of reaction and concept of $TMR_{ad}$, show as Eq. (3) [6].

$$TMR_{ad} = \frac{C'_p \cdot R \cdot T_p^2}{q_{(Tp)} \cdot E} \tag{3}$$

The integration of the heat release rate can be used to determine the thermal conversion and the thermal accumulation ($X_{ac}$). The accumulation may also be obtained from analytical data [6].

For the assessment of probabilities, a six levels scale is often used, as proposed by the ZHA method [5]. Assessment criteria based on such a scale is presented in Table 2. If a simple three levels scale is to be used, the levels “frequent” and “probable” are merged in one level “high” and the levels “seldom”, “remote”, and “almost impossible” are merged in one level “low”. The intermediate level “occasional” then becomes “medium.” For chemical reactions on an industrial scale, we can consider a probability to be low if the time to maximum rate of a runaway reaction under adiabatic conditions is longer than 1 day. The probability becomes high if the time to maximum rate ($TMR_{ad}$) becomes less than 8 h (1 shift).

**Table 2.** Assessment criteria for the probability of a runaway reaction.

| Simplified | Extended | $TMR_{ad}$ (hr) |
|---|---|---|
| High | Frequent | **< 1** |
| | Probable | **1–8** |
| Medium | Occasional | **8–24** |
| Low | Seldom | 24–50 |
| | Remote | 24–50 |
| | Almost impossible | **>100** |

### 2.3 Risk Assessment

Generally, risk (R) is multiplying of the probability(p) of risk with the severity(s) (or consequence) of risk (s), show as Eq. (4).

$$R = p \times s \tag{4}$$

The four severity levels and the six probability levels described above can be arranged in a risk matrix. The below matrix (Fig. 1) is derived from the IEC 61508-5, 2nd ed., part 5 Annex C, table C.1(2010) [7]. It was adapted to the assessment of runaway reactions with the criteria as defined above [8]. In such a risk matrix, the different fields corresponding to negligible (white), tolerable (yellow and grey), intolerable risk (black) can be identified.

| Probability | Severity | | | |
|---|---|---|---|---|
| | Negligible | Medium | Critical | Catastrophic |
| Frequent | SIL 2 | SIL 4 | | |
| Probable | SIL 1 | SIL 3 | | |
| Occasional | | SIL 2 | SIL 3 | SIL 4 |
| Low | | SIL 1 | SIL 2 | SIL 3 |
| Remote | | | SIL 1 | SIL 2 |
| Not credible | | | | SIL 1 |

**Fig. 1.** Risk matrix adapted from IEC 61508-5 standard for runaway reaction

The black field corresponds to risks that cannot be reduced by a safety instrumented system (SIS) alone. The intermediate field (yellow and grey) is used corresponding to the risk that should be reduced as far as the costs are in relation with the risk reduction, following the ALARP principle (as low as reasonably possible) [8].

The thermal risk of batch reaction (or process) will be considered unacceptable unless the probability of the incident severity (or consequence) s is lower than the acceptable risk; otherwise, additional protections or measures should be considered to reduce the risk. The design of a protection system against runaway comprises the definition of the nature of the system as well as its reliability. Let us consider that the probability decreases by one order of magnitude, from each level to the level below (Table 2), e.g. "probable" means a ten times higher probability than "occasional" and so forth. Then a risk that should be reduced from "probable" to "remote" corresponds to a reduction by a factor $10^{-3}$ and requires a SIL 3 reliability. This may also be realized as two IPLs with a SIL 2 and a SIL 1. If more than one IPL is used to achieve a higher reliability, they must be strictly independent [8].

# 3 Experimental Test of Runaway Reaction of Epoxy Resin's Homopolymerization

## 3.1 Objectives of Experimental Test

This research intends to empirically explain for the reasons of abnormal exothermic reaction during the homopolymerization of epoxy resin. To create the same scenario, the experiment followed the procedures of the incident and the same rate of mass was input into the reactor. A MultiMax Reaction Calorimeter is used an experimental test for runaway reaction. The thermal risk (i.e. runaway reaction) is administered by stirring velocity and failure of stirring control. The reactant materials included YD-011(Diglycidyl ether of bisphenol A) (98%), 4-Methoxyphenol (stabilizer or inhibitor) (1.5%), Tris-2,4,6-Tris(dimethylaminomethyl)phenol (amine catalyst) (0.5%) (Table 3).

**Table 3.** Reactor spec. and experimental conditions.

| | | | |
|---|---|---|---|
| Reactor material | Glass | | |
| Stirrer type | Pitched paddle | | |
| Stirring velocity | 600, 300, 100 rpm | | |
| Reaction operating temperature | 100 °C | | |
| Reaction time | 3 h | | |
| Total Reactant materials: 40 g | YD-011 | Stabilizer | Amine catalyst |
| | 98% | 1.5% | 0.5% |

The experiment followed the procedures of the incident and the same rate of mass was input into the reactor. In addition, a stirrer, which had a pitched paddle form with a reaction temperature of 100 °C, was in place operating at the stirring velocity of 600 rpm, 300 rpm and 100 rpm.

## 3.2 Results of Experimental Test

The comprehensive results of this experiment can be found in Figs. 2 and 3.

According to Fig. 2, it indicates that when the stirring velocity is at 300 rpm, the adiabatic temperature rise ($\Delta T_{ad}$) is calculated 186 °C and the maximum temperature of the synthesis reaction (MTSR) is calculated 286 °C which will be met within 1 h if a runaway reaction occurs due to the failure of stirring or cooling water system after the input of the catalysts. Moreover, it shows a rather slow rise of temperature until 15 min yet a rapid rise after 15 min. The reaction temperature at the rapid rise was recorded to be around 130 °C. Figure 3 indicates to reduce for the rapid temperature rise, which leads to a runaway reaction, safety measures must be implement before the reactor temperature reaches 130 °C.

Figure 3 indicates the different heat flows (W/kg) when the stirring velocity is at 100 rpm, 300 rpm, and 600 rpm. It indicates the reaction patterns of homopolymerization reaction based on the different stirring velocity. The stirring velocity is one of the critical factors that determine the reaction rate. The proper stirring velocity is below 100 rpm and if this velocity is not under control, the epoxy reaction leads to a runaway reaction.

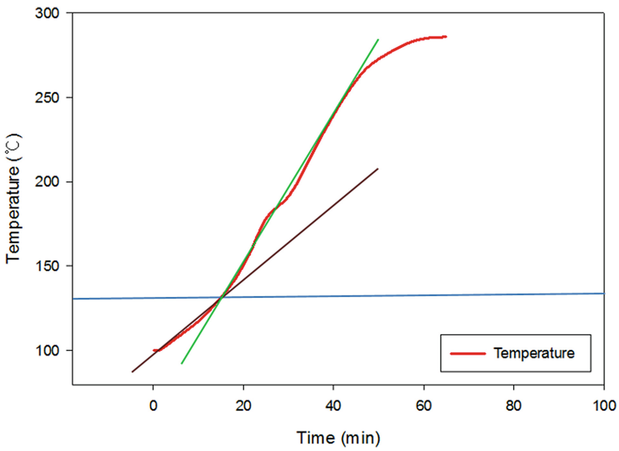


**Fig. 2.** Temperature trend of reactor by runaway reaction at 300 rpm stirring velocity with time (min).

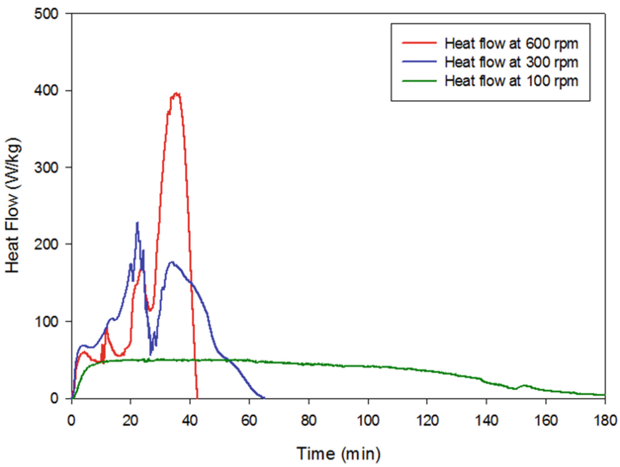


**Fig. 3.** Comparison of heat flow at 3 different stirring velocities with time (min)

To summarize the result of the epoxy resin's homopolymerization reaction, the adiabatic temperature rise ($\Delta T_{ad}$) is 186 °C and MTSR is 286 °C which indicates during the section of the desired reaction.

The severity is "Medium" (Please see Table 1 assessment criteria for the severity of a runaway reaction). The $TMR_{ad}$ is within an hour thus from the assessment criteria for the probability of a runaway reaction (Table 2), it falls under the category of "High" and "Frequent". The thermal risk according to Fig. 1 is "SIL 4". The epoxy resin's homopolymerization reaction should conclude that protection systems (IPLs) install to reduce the thermal risk.

### 3.3 Preventing Measures of Undesirable Reaction

**Stop the Agitation When Cases of an Unexpected Temperature Rise**
Findings above indicated that the measures must be taken before 130 °C to prevent from the undesirable temperature rise. As part of the BPCS measure, when there is a 5% rise (approximately 10 °C) of the adiabatic temperature rise($\Delta T_{ad}$) 186 °C, the agitation must be ceased and an interlock must accompany that automatically stops the stirrer when the reaction temperature (Reaction Temp. High) hits 110 °C.

**In Case of a Temperature Rise Even after the Agitation is stopped**
Firstly, a protection system (device) must be installed that automatically adds an inhibitor into the reactor to cease the reaction immediately before initial runaway reaction (reaction temp. High, High) reaches 130 °C. The inhibitor needs to have a higher boiling point than the reaction temperature. Additionally, considering the high viscosity of reactants, input a brine chiller inside coil can help to stop reaction when the reaction temperature reaches 130 °C.

## 4 Preventing Runaway Reaction by Installing Safety Integrity System (SIS)

### 4.1 Technology of SIS

The SIS is the instrument system for the SIF (Safety Instrumented Functions) of chemical processes and/or other industries that safely shut down the process when the operation occurs outside of the safety criteria. According to IEC 61511-1 part 1(2004), it is called SIS, and in API (American Petroleum Institute) 521 6$^{th}$ ed., it is introduced as HIPS (High-integrity Protection System) [9]. Currently, SIS has been used as a protection system to improve the safety integrity of petrochemical process and has been installed as a back-up system of pressure relief system, reducing flare load, $CO_2$ emission and to prevent the contamination of environment. A SIS is consisted of Sensor(s), Logic Solver(s), and Final Element(s) and it requires a high level of safety integrity Level (SIL) likely Level 3 and over. Sensors are used to measure the process operating condition and/or abnormality. Logic Solver(s) include control devices that plays more than one function of logic and its connecting devices (e.g. input cards, output cards, processor), and Final Element(s) include devices that allow process to operate safely such as valves, switch gear, motors and their relevant pieces such as shutdown valve(UV), solenoid(UY), relay for trip machinery [10].

### 4.2 Safety Integrity Level

When the allocation has sufficiently progressed, the E/E/PE (Electrical/Electronic/Programmable Electronic) Safety Related System(s), shall be specified in terms of Safety Integrity Level (SIL). The IEC 61508-1 2$^{nd}$ ed. (2010) specified the 4 discontinuous steps probability of a dangerous failure on demand($PFD_{avg.}$) for a low demand mode of operation (See Table 4) [11].

**Table 4.** Safety Integrity Levels- target failure measures for a safety function (IEC 61508-1, 2nd ed., 2010)

| Safety integrity level | Probability of failure on Demand (PFD) | Risk reduction factor (1/PFD = RRF) |
|---|---|---|
| SIL 1 | 0.1 to 0.01 | 10 to 100 |
| SIL 2 | 0.01 to 0.001 | 100 to 1,000 |
| SIL 3 | 0.001 to 0.0001 | 1,000 to 10,000 |
| SIL 4 | 0.0001 to 0.00001 | 10,000 to 100,000 |

## 4.3 Preventing Measures to Runaway Reaction

**Installation of SIS**

The thermal risk is "SIL 4 level". The epoxy resin reaction should conclude that protection systems (IPLs) install to reduce the thermal risk of the epoxy resin's homopolymerization reaction.

This research suggests the next step, the use of batch reactor along with SIS for stopping the reaction immediately. As for the temperature's sensors, 2003 voting is installed and 2 channels logic solver and 1002 voting (valves, safety position: open) are installed for final elements (inhibitor input valves and brine chiller input valves) respectively. With regard to the Probability of Failure on Demand (PFD) complete SIS, a SIL 4 is required. The each SIF's reliability data such as failure rate (λ), Safety Failure fraction (SFF), and $PFD_{avg.}$ are obtained from manufactures and vendors. The data are certainly verified by official third party certification body. The each SIF should be performed to partial stroke and a proof test must be administered periodically according to manufacturer's manual in order to maintain the high level of safety integrity. The adopted elements and the reliability (or failure) data of SIF are presented in Table 5. The SIS's diagram of batch reactor with installed sensors, logic solver and final elements for reducing risk is showed as Fig. 4.

Firstly, as part of BPCS, the agitator can be stopped, if the reaction temperature reaches to 110 °C. However, there is a temperature rise even after the agitation is ceased, the temperature rise reaches on the level (High, High, 130 °C), the temperature (HH) must be detected. In advance, an inhibitor (IPL 1) can be input into the reactor by nitrogen opening valves and/or a cooling medium (brine chiller, IPL 2) can be input inside the cooling coil additionally.

**Verifying Safety Improvement by FTA Method**

A fault tree is a graphical model that illustrates combinations of failures that will cause one specific failure of interest, called a top event. FTA is a deductive technique that uses Boolean logic symbols (i.e., AND gates, OR gates) to break down the causes of a top event into basic equipment failures (called basic or root events). The resulting fault tree model displays the logical relationships between basic events and selected top event. A fault tree model can be used to generate a list of the failure combinations (failure mode) that can cause the top event of interest. These failures modes are known as cut sets [12]. As can be referred from Fig. 5, the total $PFD_{avg.}$ of SIS, which is the

**Table 5.** The Reliability (or Failure) Data of Safety Instrument Function (unit: $10^{-9}$ h)

| SIF's device | $\lambda_{sd}$ | $\lambda_{su}$ | $\lambda_{dd}$ | $\lambda_{du}$ | SFF | $PFD_{avg.}$ | Remark |
|---|---|---|---|---|---|---|---|
| Temp. Tr[a] | 0 | 149 | 460 | 59 | 92.0% | 2.3E–05 | 2003, partial test 6 month, proof test interval 1/yr. |
| PLC[b] | | | | | | 6.7E–06 | 2002 input/2002 output Proof test interval 1/yr |
| Solenoid valve[c] | 0 | 216 | 0 | 188 | | 1.2E–03 | De-energize to trip |
| Actuator[d] | – | – | – | – | | 1.31E–04 | Partial test 6 month, proof test interval 1/yr. |
| Top entry ball valve[e] | | | 91.1 | | | 1.13E–04 | Partial test 6 month, proof test interval 1/yr. |

Sources: [a] Temp. Tr. single RTD configuration (YTA), YOKOGAYA Electric
[b] PLC, Prosafe-RS, YOKOGAYA Electric
[c] Solenoid valve, ACSO sol v/v 327B1/2
[d] Actuator, Emerson PM Series G
[e] Top entry ball valve, Pibiviesse S.R.L Series T1

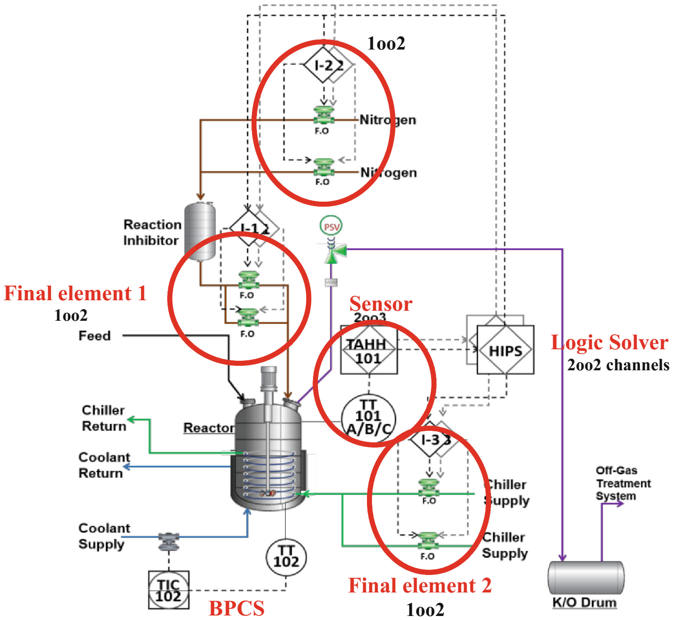


**Fig. 4.** The SIS's diagram of batch reactor with installed sensors, logic solver and final elements

Top event of FTA calculated from the root (basic) events of SIS elements. Total of SIS's $PFD_{sys.avg.}$ is calculated Eq. (5).

$$\text{Total of SIS's}\, PFD_{sys.avg.} = PFD_{sensors} + PFD_{logic\,solver} + PFD_{final\,elements}. \tag{5}$$

In the development of fault trees, it is generally assumed that the probability of failure of equipment (device) is independent of each other. However, it becomes necessary to consider the impact of common cause failures when assessing the reliability of systems with redundant equipment (device). Redundancy is typically applied to equipment to achieve a significant improvement in system reliability. Common cause failures result in dependent failures between redundant equipment. Typical causes of common failures include: inadequate design (e.g. underrated equipment), manufacturing defects, system configuration (e.g. common power supplies), external factors (e.g. fire, weather events, temperature, humidity). Common cause failure

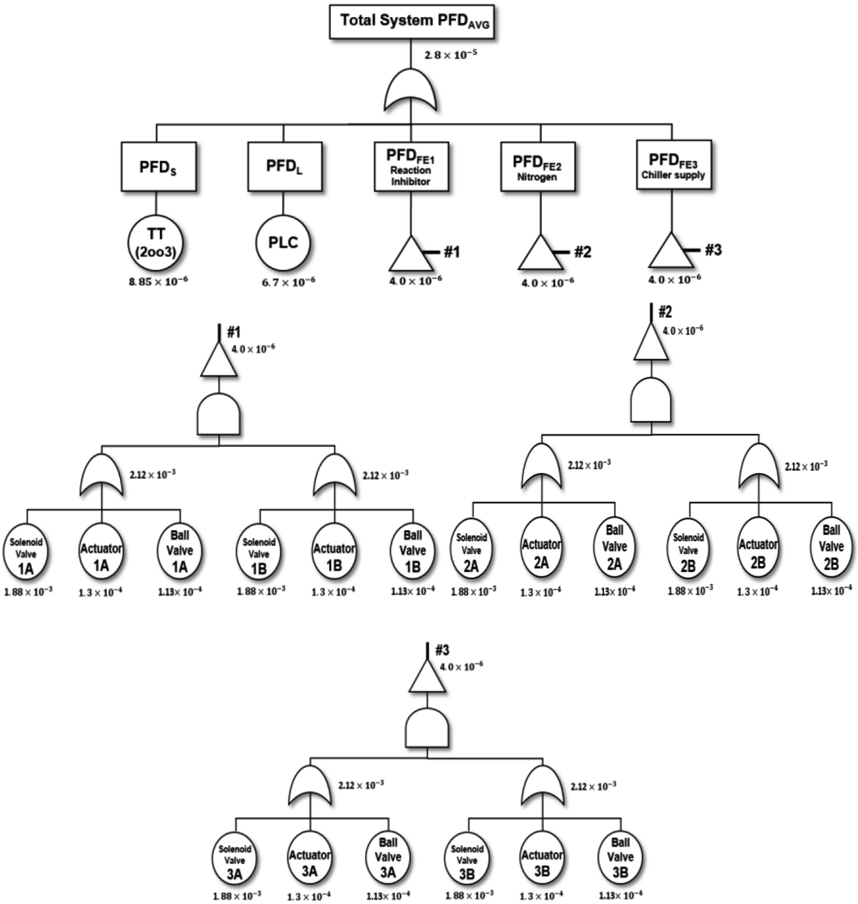


**Fig. 5.** Verifying safety improvement by FTA

becomes a more critical issue to meet SIL 4, because even a small increase of common cause failures can degrade the SIL in the $PFD_{avg.}$ range of SIL 4. The common cause failure's values (ß) are converted to 0.03(valves) and 0.01(sensors) [13].

The total $PFD_{sys.avg.}$ is calculated 2.8E–05 to verify which the SIS design should be met and satisfied the target SIL 4.

## 5 Conclusion

In case of when the adiabatic temperature rise ($\Delta T_{ad}$) is 186 °C and the maximum temperature of the synthesis reaction (MTSR) is 286 °C. It will take within 1 h for the temperature of the reactor to reach MTSR if a runaway reaction proceeds due to the failure of stirring or cooling water system. Firstly the agitator must be stopped as part of BPCS. If the reaction temperature reaches on 130 °C, it is detected by the temperature sensors. Immediately, an inhibitor (IPL 1) input of the epoxy resin's homoplymerization reactor, and/or a cooling medium (brine chiller, IPL 2) can be input inside the cooling coil. The total $PFD_{sys.avg.}$ of SIS, which is the Top event of FTA calculated from the root (basic) events (each SIF element), is 2.8E–05 to verify which the SIS design should be met and satisfied the target SIL 4. The verification is conducted under each SIF must be performed partial stroke and a proof test periodically according to manufacturer's manual.

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# Visibilization of Hidden Characteristics of Firefighting Tasks and Factors Predictive of Firefighters' Work-Related Musculoskeletal Disorders

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**Abstract.** Based on the notion that the Fire-service profession is a strenuous and hazardous occupation, this study explored and identified the hidden characteristics of firefighting tasks, and factors predictive of firefighters' work-related musculoskeletal disorders in the Ghana Fire Service. Quantitative data was collected from three hundred and six firefighters and analyzed using both factor and correlation analysis. It was found that the firefighters experience several traumas characterized by exposure to human entrapment and loss in fires accidents, and personal terrible sensory experiences, the enormity of which increase with increasing years of firefighting-task performance. The firefighters are also exposed to several WMSDs whose enormity is felt irrespective of years of task performance. It is concluded that the identified hidden aspects of the firefighting-task characteristics provide insights into the enormity of trauma and WMSD associated with the task performance, which could be used to optimize the future design and management of the firefighting-task.

**Keywords:** Firefighters · Firefighting · Firefighting task characteristic
Work-Related musculoskeletal disorder · Ghana fire service

## 1 Introduction

Annually, the Ghana National Fire Service (GNFS) fights thousands of fires. For instance, it is reported by [1] that in 2015 the GNFS contended with 6214 fire outbreaks. Generally, the Ghana National Fire Service was established as the main Ghana National Fire management institution by the Ghana National Fire Service (GNFS) Act of 1997 (Act 537) with a comprehensive goal of prevention and management of undesired fires and other related matters. However, the nature of works performed by fire service personnel can expose them to a lot of speed, boring, repetitive tasks and work-related musculoskeletal disorders (WMSDs). It is however presumed that the task characteristics of firefighters can contribute to their development of WMSDs. The skill of firefighting is divided into three central segments, namely; fire prevention, rescue,


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and firefighting. The prevention aspect institutes principles and procedures for the avoidance of inadvertent fires. Regular surveys and inspections are employed to regulate such principles and procedures. Rescue involves salvaging victims ensnared in all forms of disasters, especially fire infernos. In firefighting task performance, firefighters, upon getting to a fire scene, are required to identify the specific location of the fire and immediately began to rescue people, prevent exposures, sequester the fire, and afterwards quench the fire [1]. In addition, firefighter use several tools, equipment and clothing such as water hose, fire trucks, proximity suit, fire resistant suit, breathing apparatus, turn-table ladder, firefighting tunic, safety boots, safety helmets, fire engines and many more which usually require much exertion [1].

The Fire-service profession is among the most strenuous and hazardous occupations around the world. This is because in the process of preventing, rescuing and fighting fire, fire service personnel are exposed to speed, long hours of standing, repetitive bending, over exertion, extreme heat conditions, burns, falls, exposure to biological hazards such as blood of victims being rescued, traumatic scenes like burnt or dead bodies and long term effects such as burnout, cardiovascular and cancer diseases and alcohol or substance addictions. Like other fire service institutions in other developing countries, the Ghana Fire Service appears to be characterized by non-predictive, inflexible tasks and speed (task characteristics) and Work-related musculoskeletal disorders. The purpose of this study therefore, was to identify factors that significantly represent the hidden characteristics of the firefighting tasks, as well as factors that are predictive of firefighters' work-related musculoskeletal disorders in the Ghana Fire Service.

## 2 Work Dynamics and Implications on Performers' Health

The nature or dynamics in every work can have implications for various health and job outcomes. When workers are given tasks that exceed their capabilities in the absence of flexibility, they are likely to develop repetitive injuries. Some studies have reported incidences of work-related musculoskeletal disorders among firefighters. For example, [1] examined the levels of work-related musculoskeletal disorders among twenty one thousand, four hundred and sixty-six (21,466) Korean male fire service workers. In the study, [2] assessed work-related musculoskeletal disorders using the Korean NIOSH Symptom Survey developed by [3], which consists of questions regarding the presence of work-related symptoms in any of 6 body regions (neck, shoulders, arms, hands/wrists, lower back, and legs/feet) in the prior year, and symptom severity (frequency, duration, and intensity). The outcome of the study by [2] suggests that inadequate work control and relational conflict were not associated to the manifestation of WMSDs [2].

A review was carried by out [4] of previous works on upper extremity musculoskeletal disorders and psychosocial work factors (e.g., [5, 6]) with the intention of identifying possible influential factors. This review by [4] revealed that excessive shock in the upper limit was significantly attributed to less decision opportunity at work; neck and shoulder complaints were attributable to work demand whereas control over time was related to neck complaints. It is noted by [4] that the addition of high demands and low decision opportunity significantly predicted shoulder and neck complaints among the female respondents. It is therefore suggested by [4] that further studies should be conducted to clarify the association between psychosocial factors and upper extremity musculoskeletal disorders and possibly work characteristics.

In Brazil, [7] identified factors that are related with musculoskeletal disorders among three hundred and eight (308) female workers. Using a cross-sectional design with respondents sampled randomly, [7] adapted the job content questionnaire by [8] and the Nordic musculoskeletal questionnaire by [9] to measure work demands and work-related musculoskeletal disorders respectively. It was found by [7] that work-related musculoskeletal complaints in neck, shoulder or upper back and the lower back are due to physical work demands (handling heavy materials, poor back position and repetitive tasks), psychosocial demands and hazardous physical fitness. Musculoskeletal complaints in distal upper parts were caused by physical work demands (repetitive and energetic tasks) as well as number of years in service [7]. The findings by [7] pointed to the necessity for intervention approaches by fitting in both the organizational elements of work and adaptations in the physical environment and in the characteristics of work assignments.

The incidences of back and neck ache, physical workload, ergonomic complaints, and growing work demands was assessed by [10] among nine hundred and forty-one (941) subjects in the US. It was found by [10] that the occurrence of extreme bodily aches was 47% in general, 43% (neck), 59% (upper back) and 63% (low back pain). According to [10], respondents who fell within the uppermost exposure quartiles for physical workload and ergonomic complaints were 3.24–5.42 times more probable to report extreme aches than those in the lowermost quartile. It was further noted by [10] that adjusted odds ratios for work increase was between 1.74 (upper back) to 2.33 (neck).

## 3 Methodology

### 3.1 Sampling

A multistage sampling approach was used. A purposive sampling was employed to select the Greater Accra Region due to the rampant fire outbreaks in the Region, while convenient sampling was used to select nine (9) fire stations due to time and resource constraints. By this technique, the first nine (9) fire stations that granted access were used. The stations that granted access were the Legon Fire Station, Madina Fire Station, Adenta Fire Station, Accra City Fire Station, the National Head Office, the Greater Accra Regional Head Office, Korle-Bu Fire Station, Industrial Fire Station and Dansoman Fire Station. In addition, all respondents were conveniently sampled, in that firefighters who were available and willing to answer the questionnaire were selected to form part of the study.

Krejcie and Morgan's (1970) sampling size determination table was employed in determining a representative sample size for the 1367 firefighters working in the Greater Accra Regional Fire Command. Using [11] sample size determination guide, a sample size of 306 study participants was deemed appropriate from a population of 1367 firefighters, However 320 firefighters were sampled for the study in order to enhance the response rate.

### 3.2 Data Collection Approach

Data was collected using a questionnaire which consisted of three sections. Section A measured the demographic characteristic of the firefighters, which included, gender, age, rank, years of working and number of working hours. Section B measured the task characteristics using the Experience of Work and Life Circumstances Questionnaire subscale [12]. The sub-scale items were rated on a 5-point Likert scale ranging from 1 (very low) to 5 (very high) with reliabilities ranging from 0.83 to 0.92 [12]. Section C measured work-related musculoskeletal disorders using a subscale adapted from the Standardized Nordic Questionnaire [9]. The Nordic questionnaire comprises of items on nine (9) body parts, joints and tendons. This scale sought to find out whether a firefighter had experienced pains, hurts or aches for the last 12 months in any of the nine (9) body parts (neck, shoulder, elbow, wrist, upper back, lower back, hip, knee, and ankle). Items for this measure were also rated on a 5-point Likert scale ranging from 1 (very unlikely) to 5 (very likely).

Before administering the questionnaire, its reliability was tested by piloting among thirty (30) firefighters. The reliability estimate for task characteristics was 0.72 while that for work-related musculoskeletal disorders was 0.92. Since both estimates were greater than 0.70 as recommended by [13], the questionnaire was deemed reliable and was thus used to collect the data.

In the data collection approach, introductory letters from the Department of Organization and Human Resource Management, University of Ghana Business School were sent to the National Chief Fire Officer and the Greater Accra Regional Fire Service Commander respectively for authorization. Upon approval, consent of participants was sought by making them aware that participation is voluntary explaining. Participants were also assured of anonymity and confidentiality.

### 3.3 Data Analysis Approach

The data was firstly collated and then analyzed descriptively. In the descriptive analysis, the respondents demographic factors were firstly analyzed using frequencies and percentages. Factor analysis was then performed to firstly, identify factors that significantly represent the hidden characteristics of the firefighting tasks, and secondly, identify factors predictive of firefighters' work-related musculoskeletal disorders. Factor significance and/or predictiveness were established using factor loading of 0.7 or above as recommended by [14]. The statistical package for social sciences (SPSS) version 22.0 was used as the analytical tool.

## 4 Results and Discussion

### 4.1 Analysis of Respondents Demography

The distribution of the respondents' demography showed male respondents to be 234 (73.1%), while female respondents were 86 (26.9%). This shows that the firefighting profession is dominated by males. In terms of age, 26 (8.1%) of the respondents were 25 years and less, while that of 104 (32.5%) respondents was greater than 25 years and ranged up to 35 years,. Eighty seven (27.2%) respondents were older than 35 years and up to 45 years of age, with 90 (28.1%) of others being older than 45 years and up to 55 years.

Only 13 (4.1%) respondents were aged 55 years and above. This indicates that majority of the respondents (191) were in the prime of their ages that ranged from 25–45 years. With regards to ranks, 16(5%) were recruit firemen/firewomen, 99 (30.9%) were firemen/firewomen, 46 (14.4%) were leading fire officers, 118 (36.9%) were within the ranks of station officer/group officer/assistant station officer/deputy group officer/sub officer/assistant group officer and the remaining 41 (12.8%) were Chief Fire officer/Deputy Chief Fire Officer/Assistant Chief Fire Officer/Divisional officers/Deputy divisional officers. This suggests most respondents fall within the category of fighting fires.

On the issue of number of years of working, 3 (0.9%) had worked for less than a year, 46 (14.4%) had worked for 1–3 years, 55 (17.2%) had worked for 4–6 years, 35 (10.9%) had worked for 7–9 years and 181 (56.6%) had worked for 10 years and above. The results indicate that majority of firefighters have more than 10 years of working experience. In terms of number of working hours, 3(0.9%) worked for less than 5 h, 21(6.6%) worked for 5–7 h, 97(30.3%) worked for 8–10 h, 18(5.6%) worked for 10–12 h, and 181(56.6%) worked for over 12 h. This suggests that most firefighters work for more than 12 h per day.

## 4.2 Factor Analysis of Firefighting Task Characteristics and WMSD

In order to identify factors that significantly represent the hidden characteristics of the firefighting tasks, and those that are predictive of firefighters' work-related musculoskeletal disorders (WMSD), factor analysis was conducted using the SPSS software. The results obtained, in terms of the Kaiser-Meyer-Olkin (KMO) and Bartlett's test statistics are shown in Table 1 below.

**Table 1.** KMO measure of sampling adequacy and Bartlett's test result for firefighting tasks characteristics and WMSD

| | KMO measure | Bartlett's test of sphericity | | |
|---|---|---|---|---|
| Indicator | | $\chi^2$ | df | Sig. |
| Task characteristics | 0.839 | 756.369 | 55 | 0.000 |
| WMSDs | 0.919 | 1684.877 | 36 | 0.000 |

As shown in Table 1 above, the estimated KMO value for task characteristics is 0.839, indicating that the correlation pattern for task characteristics indicators are good, as recommended by [15]. Again, the estimated chi-square ($\chi^2$) value from the Bartlett's test was $\chi^2 = 756.369$ ($p = 0.000$), which is highly significant ($p < 0.001$). The result from both the KMO and Bartlett's tests indicate that it is appropriate to factor analyse all the task characteristics indicators tested, using principal component analysis. The KMO value for WMSDs was 0.919, indicating that the correlation pattern for

WMSDs indicators are good, as recommended by [15]. Further, the estimated chi-square ($\chi^2$) value from the Bartlett's test was $\chi^2 = 1684.877$ ($p = 0.000$), which is highly significant ($p < 0.001$). The results from both the KMO and the Bartlett's tests show that it is appropriate to factor analyse all WMSDs indicators tested, using principal component analysis.

### 4.3 Principal Component Analysis of Firefighters' Task Characteristics

In identifying the factors perceived by the firefighters as representing the non-predictive characteristics of the firefighting tasks, component analysis was performed. The resulting rotated component (C) matrixes entailing the estimated factor loadings/ regression values (*R*) for the 11 tested factors determinant of the hidden characteristics of the firefighting tasks are shown in Table 2 below.

**Table 2.** Rotated component matrix with regression estimates for firefighting task characteristics indeces

| Indicators | *R* - values | | |
|---|---|---|---|
| | C 1 | C 2 | C 3 |
| Degree of uncertainty | 0.676 | −0.042 | −0.142 |
| Exposure to human loss | 0.775 | −0.126 | 0.005 |
| Interpersonal tension | 0.278 | 0.598 | −0.156 |
| Shift work | 0.277 | −0.369 | 0.585 |
| Overloading/under-loading | 0.242 | 0.417 | 0.634 |
| Traumatic accidents | 0.754 | 0.043 | −0.122 |
| Accountability for decisions taken under pressure | 0.606 | 0.247 | −0.104 |
| Terrible sensory experiences | 0.736 | 0.144 | −0.117 |
| Serious fires in which people are being trapped | 0.702 | −0.037 | −0.096 |
| Danger of injuries to and illness of firefighter | 0.546 | −0.315 | 0.325 |
| Slow response time | −0.183 | 0.706 | 0.264 |

As it is observable Table 2 above, the factors predictive of the firefighting tasks characteristics are oriented in three (3) components (C), out of which two components, that is, C1 (entailing 4 factors signifying traumatic encounters) and C2 (entailing one factor signifying slowness of response). For these factors to have predictive significance, their factor loadings must be equal to or above the 0.7 threshold recommended by [14].

The traumatic encounters that are hidden characteristics of the firefighting tasks are; (i) Exposure to human loss ($R = 0.775$), (ii) Traumatic accidents ($R = 0.754$), (iii) Terrible sensory experiences ($R = 0.736$), and (iv) Serious fires in which people are being trapped ($R = 0.702$). The slowness of response, which is also a hidden characteristics of the firefighting tasks has to do with Slow response time ($R = 0.706$). Thus the regression estimates for four (4) hidden factors associated with the firefighters' task that cause trauma (i.e. exposure to human loss, handling traumatic accidents, terrible sensory experiences, and encountering serious fires in which people are trapped) are all greater than [14]'s recommendation of 0.7, and as such measure the traumatic characteristics of the firefighters' task. Similarly, the regression estimate for one (1) hidden factor associated with the firefighters' task that informs the slowness of their response (i.e. slow response time) is also greater than [14]'s recommendation of 0.7 and as such measures the slow characteristic of the firefighters' task.

### 4.4 Principal Component Analysis of Firefighters' Work-Related Musculoskeletal Disorders

In identifying the factors perceived by the firefighters as predictive of work-related musculoskeletal disorders (WMSD), component analysis was performed. The rotated component matrix entailing the estimated factor loadings/regression values (*R*) for the 9 tested factors predictive of the firefighters WMSD are shown in Table 3 below.

**Table 3.** Rotated component matrix and factor loadings for WMSD

| Indicators | *R* - values |
|---|---|
| Neck | 0.746 |
| Shoulder | 0.805 |
| Elbow | 0.799 |
| Wrist/hands | 0.767 |
| Upper back | 0.748 |
| Lower back | 0.773 |
| One or both hips/thighs | 0.826 |
| One or both knees | 0.801 |
| Ankle | 0.722 |

As it is observable Table 3 above, the measured factors predictive of the firefighters' WMSD are oriented in only one component. For these factors to have predictive significance, their factor loadings must be equal to or above the 0.7 threshold recommended by [14]. The factors are; (i) Pain in the neck ($R = 0.746$), (ii) Pain in the shoulder ($R = 0.805$), (iii) Pain in the elbow ($R = 0.799$), (iv) Pain in wrist/hands ($R = 0.767$), (v) Pain in the upper back ($R = 0.748$), (vi) Pain in the lower back ($R = 0.773$), (vii) Pain in one or both hips/thighs ($R = 0.826$), (viii) Pain in one or both knees ($R = 0.801$) and (ix) Pain in the ankle ($R = 0.722$). Thus the regression estimates for all the nine (9) factors in the firefighters' task that lead to their development of WMSDs (i.e. Pain in the neck, Pain in the shoulder, Pain in the elbow, Pain in wrist/hands, Pain in the upper back, Pain in the lower back, Pain in one or both hips/thighs, Pain in one or both knees, and Pain in the ankle) are all greater than [14]'s recommendation of 0.7, and serve as predictive factors for WMSDs development in the firefighting task.

### 4.5 Analysis of Years Worked and Task Characteristics

In order to find out if the firefighters' work experiences influence the extent to which they are affected by the task characteristics factors identified from the factor analysis, a correlation analysis was conducted. The Pearson correlation coefficient ($\alpha$) estimates for the relationship are shown in Table 4 below. As it is observable from Table 4, there is a very significant and positive correlation ($\alpha = 0.156$, $p = 0.005$; $p < 0.05$) between the trauma caused by the exposure of firefighters to human loss and the number of years they have been working. This implies that the longer the worklife of a firefighter, the greater the traumatic encounters he/she will derive from his/her exposure to human loss during task performance. There is also a very significant and positive correlation ($\alpha = 0.215$, $p = 0.000$; $p < 0.01$) between the trauma caused by the firefighters handling of traumatic accidents and the number of years they have been working. This implies that the longer the worklife of a firefighter, the greater the traumatic encounters he/she will derive from his/her handling of traumatic accidents during task performance.

**Table 4.** Correlations estimates for task characteristic and firefighters' work experiences

| Indicators | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1. Exposure to human loss | – | | | | | |
| 2. Traumatic incidents | 0.501** | – | | | | |
| 3. Terrible sensory experiences | 0.475** | 0.507** | – | | | |
| 4. Serious fire with people trapped | 0.476** | 0.482** | 0.472** | – | | |
| 5. Slow response time | −0.138* | −0.104 | −0.053 | −0.153 | – | |
| 6. Years worked | 0.156** | 0.215** | 0.145** | 0.128* | −0.004 | – |

** very significant, $p \leq 0.01$ (2-tailed); * significant, $p \leq 0.05$ (2-tailed).

As it is also observable from Table 4 above, the correlation between the trauma caused by the terrible sensory experiences felt by firefighters and the number of years they have been working is positive and very significant ($\alpha = 0.415$, $p = 0.009$; $p < 0.01$). This implies that the longer the worklife of a firefighter, the greater the traumatic encounters he/she will derive from the terrible sensory experiences felt by him/her during task performance. A significant and positive correlation ($\alpha = 0.128$, $p = 0.022$; $p < 0.05$) exists between the trauma caused by firefighters' encounters with people entrapped by serious fires and the number of years they have been working. This implies that the longer the worklife of a firefighter, the greater the traumatic encounters he/she will derive from his/her encounters with people entrapped by serious fires during task performance. There is a negative, but insignificant correlation ($\alpha = -0.004$, $p = 0.937$; $p > 0.05$) between the slowness of firefighters response to task and the number of years they have been working. This implies that the longer the worklife of a firefighter, the lesser the tendency for him/her to be slow in responding to task.

The above analysis showed that all the four (4) hidden factors identified from the factor analysis that highlight the traumatic characteristics of the firefighters' task (i.e. exposure to human loss, handling traumatic accidents, terrible sensory experiences, and encountering serious fires in which people are trapped) correlated with the number of years the firefighters have worked.

### 4.6 Analysis of Years Worked and WMSD Development

In order to find out if the firefighters' work experiences influence the extent to which they are affected by the WMSDs identified from the factor analysis, a correlation analysis was conducted. The Pearson correlation coefficient ($\alpha$) estimates for the relationship are shown in Table 5 below. As it is observable from Table 5, there were insignificant correlations between all the nine (9) factors in the firefighters' task that lead to their development of WMSDs (i.e. Pain in the neck, Pain in the shoulder, Pain in the elbow, Pain in wrist/hands, Pain in the upper back, Pain in the lower back, Pain in one or both hips/thighs, Pain in one or both knees, and Pain in the ankle) and the number of years the firefighters have worked. Specifically, there is a negative and insignificant correlation ($\alpha = -0.090$, $p = 0.110$; $p > 0.05$) between the firefighters' WMSDs caused by pain in the neck and the number of years they have been working. This implies that a longer worklife of a firefighter will have no significant effect in reducing the neck pains associated with his/her task.

As it is also observable from Table 5 above, there is also a negative and insignificant correlation ($\alpha = -0.081$, $p = 0.147$; $p > 0.05$) between the firefighters' WMSDs caused by pain in the shoulder and the number of years they have been working. This implies that a longer worklife of a firefighter will have no significant effect in reducing the shoulder pains associated with his/her task. A negative and insignificant correlation ($\alpha = -0.033$, $p = 0.560$; $p > 0.05$) exist between the firefighters' WMSDs caused by pain in the elbow and the number of years they have been working. This implies that a longer worklife of a firefighter will have no significant effect in reducing the elbow pains associated with his/her task. Also, a negative and insignificant correlation ($\alpha = -0.090$, $p = 0.110$; $p > 0.05$) between the firefighters' WMSDs caused by pain in the wrist or hands and the number of years they have been working. This implies that a longer worklife of a firefighter will have no significant effect in reducing the wrist or hands pains associated with his/her task.

There is a positive and insignificant correlation ($\alpha = 0.046$, $p = 0.407$; $p > 0.05$) between the firefighters' WMSDs caused by pain in the upper back and the number of years they have been working. This implies that a longer worklife of a firefighter will have no significant effect in increasing the upper back pains associated with his/her task. Similarly, a positive and insignificant correlation ($\alpha = 0.063$, $p = 0.263$; $p > 0.05$) between the firefighters' WMSDs caused by pain in the lower back and the number of years they have been working. This implies that a longer worklife of a firefighter will have no significant effect in increasing the lower back pains associated with his/her task. A negative and insignificant correlation ($\alpha = -0.028$, $p = 0.617$; $p > 0.05$) exists between the firefighters' WMSDs caused by pain in one or both hips/thighs and the number of years they have been working. This implies that a longer worklife of a firefighter will have no significant effect in reducing the hips and/or thighs pains associated with his/her task.

There is also a negative and insignificant correlation ($\alpha = -0.022$, $p = 0.699$; $p > 0.05$) between the firefighters' WMSDs caused by pain in one or both knees and the

**Table 5.** Correlations estimates for firefighters' work experiences and WMSDs

| Indicators | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Neck | – | | | | | | | | | |
| 2. Shoulder | 0.688** | – | | | | | | | | |
| 3. Elbow | 0.602** | 0.639** | – | | | | | | | |
| 4. Wrist/hands | 0.490** | 0.653** | 0.612** | – | | | | | | |
| 5. Upper back | 0.440** | 0.521** | 0.551** | 0.488** | – | | | | | |
| 6. Lower back | 0.502** | 0.576** | 0.545** | 0.547** | 0.623** | – | | | | |
| 7. One/both hips/thighs | 0.535** | 0.557** | 0.596** | 0.557** | 0.577** | 0.594** | – | | | |
| 8. One/both knees | 0.500** | 0.523** | 0.556** | 0.547** | 0.545** | 0.578** | 0.699** | – | | |
| 9. Ankle | 0.469** | 0.457** | 0.470** | 0.467** | 0.501** | 0.435** | 0.640** | 0.641** | – | |
| 10. Years Worked | −0.090 | −0.081 | −0.033 | −0.003 | 0.046 | 0.063 | −0.028 | −0.022 | 0.030 | – |

** very significant, $p \leq 0.01$ (2-tailed); * significant, $p \leq 0.05$ (2-tailed).

number of years they have been working. This implies that a longer worklife of a firefighter will have no significant effect in reducing the knees pains associated with his/her task. There is also a positive and insignificant correlation ($\alpha = -0.030$, $p = 0.591$; $p > 0.05$) between the firefighters' WMSDs caused by pain in the ankle and the number of years they have been working. This implies that a longer worklife of a firefighter will have no significant effect in increasing the ankle pains associated with his/her task.

The implications of all these findings are that the manifestation of WMSD, as suggested by [2], is not associated to inadequate work control and relational conflict. As observed from this study, the firefighters have adequate control of the task by virtue of their work experiences, but were yet prone to varieties of WMSDs. This therefore, showed that the state of a firefighter's developed WMSD, such as work-related musculoskeletal complaints in the neck, shoulder or the upper back and lower back in a firefighting task is not influenced by work experience. Arguing from the perspectives of [7], the development of such WMSDs could be attributed to other firefighting task characteristics, such as the task's physical work demand (i.e. handling heavy materials, poor back position and repetitive activities), psychosocial demands and its hazardous physical fitness requirement.

## 5 Conclusion

This study has shown that firefighters in Ghana encounter traumatic situations in the conduct of their tasks. These traumatic encounters are informed by four hidden factors, which include exposure to human loss, handling traumatic accidents, terrible sensory experiences, and encountering serious fires in which people are trapped. Based on the analytical findings, it is concluded that in Ghana, the enormity of trauma faced by firefighters in the performance of their task increases as the number of years they spend in performing the firefighting task increases. Secondly, this study has established that the firefighters being prone to varieties of WMSDs is not associated to inadequate work control and relational conflict in the performance of the firefighting task, since the firefighters have adequate control of their tasks by virtue of their work experiences. In this regard therefore, it is also concluded that in Ghana, the level of WMSDs experienced by firefighters is not influenced by the number of years they have been working. It could rather be a result of other firefighting task characteristics, such as the task's physical work demand, psychosocial demands and its hazardous physical fitness requirement. It is therefore, important that policies are enacted to help alleviate the traumatic encounters and work-related musculoskeletal disorders experienced by firefighters towards the enhancement of their productivities. The findings provide useful practical insight on how firefighting task can be optimized in order to help alleviate the hidden aspects of the task characteristics and the WMSD firefighters encounter in the performances of their work.

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# Evaluation for Development of Construction Safety Work-Wear Under Severe Environmental Conditions

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**Abstract.** This study was to investigate the satisfaction of construction workers and their physical and physiological responses to work-wear in poor workplaces. A survey was conducted on the physical response to the worker's satisfaction with the construction worker's current construction safety clothing and the sense of warmth during work. The results are as follows. First, the workers felt that the body reaction during work, feels more heat above the bottom, and that the construction safety suits worn are easily torn or punctured with arms, elbows, etc. From the above results, we propose that ergonomic study of construction safety apparel considering the work posture and the risk of musculoskeletal disease is required for the construction safety work-wear to prevent the risk of workers in the construction site.

**Keywords:** Construction safety work-wear
Physiological and subjective comforts · Ergonomic design

## 1 Introduction

Clothing directly touches human body, between the human and external environment, helping the human body adjust or modify its physiological functions according to environment. Ultimately, clothing enhances the physical, physiological, and psychological comfort, and broadens the activity area of humans. Construction and civil-engineering industry have a negative impact on workers' work efficiency, health and safety accidents, especially when the construction industry is outdoors. Especially, in summer, there are so many workers who are neglected to wear work clothes because of the heat of outdoor worker, and inconvenience. In, NIOSH (1987), engineering measures such as improvement of work environment, installation of safety facilities, process improvement, and automation of facilities are priority measures to protect workers from disasters. However, due to the fact that the construction site is an outdoor work, it is difficult to prepare engineering measures in terms of reduction of sequence stress [1].

The purpose of this study was to investigate actual workers' satisfaction with the work clothes at the actual workplace, concrete material (ventilation degree, static


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electricity, wrinkle degree, fit), physical and physiological reaction during work, and the status of work clothes management.

# 2 Literature Review

## 2.1 Sensorial Comforts for Severe Environmental Conditions

The thermal dissatisfaction of human body can be classified into two categories; one is a general thermal discomfort that takes place when whole human body feels an over-excessive heat or cold, while the other is a local thermal discomfort that takes place when a part of human body feels an over-excessive heat or cold. The latter is caused by non-uniformity of the thermal environment such as vertical temperature difference and radiant temperature asymmetry. In terms of co-relation between thermal environment and comfort, comfort is determined by factors such as metabolic heat production, heat transfer to environment, physiological adjustment, and body temperature changes [2, 3] (Fig. 1).

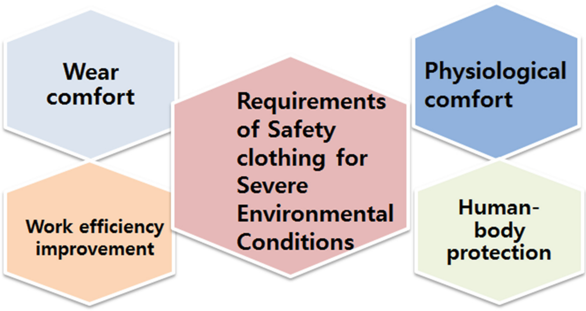


**Fig. 1.** Requirements of safety clothing for severe environmental conditions

Out of them, heat transmission is a fundamental thermal action in the human body-environment system, as mentioned above. It is characterized by two kinds of conditions; one is objective/common conditions such as air temperature, thermal radiation, air speed, humidity, etc., and the other is subjective/personal conditions including activity, clothing, etc.

In one previous construction field study, developing a prototype uniform will be the first stage in aiming to create a working uniform in the. At this study was conducted using a questionnaire in the construction field of Daegu city, and the data was gathered from 121 questionnaires. Findings were as follows: first, about the case of putting on and removing the uniform and if any areas of uniform caused discomfort, second, the areas of the uniform that caused problems were the waist, knee, shoulder, arm and neck regions, and third, the free range of movement of these regions were restricted and caused the person to feel cramped. The prototype that was developed offered more range of movement in the knee and crotch area, while not causing the uniform to be cramped too much during motion, and improved comfort by raising the waist line of back part, and by having the ability of the uniform to be tightened or loosened with zipper according to the persons preference. The upper area of the uniform was improved by dropping the shoulder seam line which enhanced comfort and also allowed a better fit for the elbow and wrist. The prototypes additional feature included a slit zipper in the sides of the trousers and a gusset in the under-arm area to improve breathability and sweat elimination [3].

Hence, sensorial comfort means the effect of fabric properties on human sense. Our sense working by a nervous system based upon neuron. The contact between the skin and the inner clothing layer determines the subjective perception of clothing comfort, especially at high skin humidity. Strong friction between skin and clothing results in greater displacement of the skin during body movements, and thus leads to a higher degree of discomfort [3, 5].

### 2.2 Ergonomic Design for Construction Safety Work-Wear

"Generally clothing comfort is defined as absence of perceived pain or discomfort". It is also defined as "Welfare, lack of pain and of nuisance" [4].

For steady exposure to cold and warm environments, thermal comfort and neutral temperature sensations lie in the range for physiological thermal neutrality (28°–30 °C), in which there is no physiological temperature regulatory effort. Discomfort correlates best with lowering average skin temperature toward cold environments and with increased sweating toward hot environments. In general, discomfort is associated with a change of average body temperature from 36.5 °C.

To develop an improved work clothing which is much safe, comfortable, mobility and convenient than what workers currently wear at construction site, the investigation had been conducted to evaluate current work, discomforts and damages related to the work clothing. The results of that study enable us to improve the work clothing, many parts such as material, pattern and design. To improve the amenity of heat, the surface of a material was used by 'Aerocool®' fiber which contains inside dryness function. In order to absorb perspiration on the back the armpits, mesh martial that is mixture of 'CooleverTM®' and 'MirawaveTM®' fiber was used to absorb perspiration in an effective manner. Developed sample work clothing evaluated an objective assessment and subjective assessment to compare to conventional work clothing, and assessment group consists of seven subject groups and nine expert groups to evaluate external appearance and adaptability to the movements. In all aspects of the test, the result of evaluation process of the sample work clothing received more positive assessment than the conventional work clothing [6, 7].

Another previous study was to develop a multi-functional fabrication technology suitable for the work environment of the workers who pass the European Union Safety Standard (EN) by collaborating with KST and HSTG. Developing user-oriented multi-purpose safety work-wear using multi-functional fabrics and developing marketable safety work-wear for domestic and foreign workers in order to develop optimized multi-purpose safety work-wear, studying the precedent cases, and needs were analyzed. The result of the study, they developed a multi-functional fabric suitable for the European Union Safety Standard (EN) which improves the safety function of the user.

It is a functional aspect considering activity, it secured expertise and practicality by establishing a marketing strategy for the domestic and overseas safety work-wear market by design diversification of work clothes considering color scheme, texture of material, line of clothing, detail and changed body condition [1].

As a result of the above researches, various kinds of safety work clothes used in the construction industry field have not only a basic guarantee for the safety environment but also the uniform design that does not take into consideration industrial use and functionality in the same condition (Fig. 2).

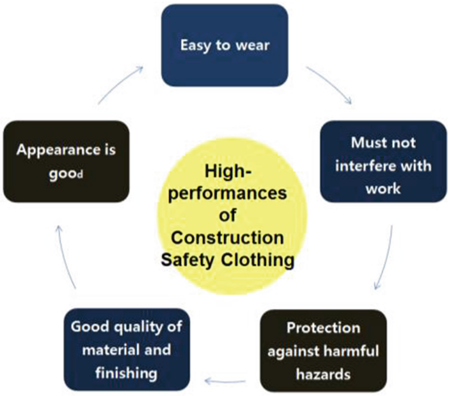


**Fig. 2.** High-performances of construction safety clothing

Therefore, the purpose of this study is to survey the items of construction safety work-wear worn by construction workers in the current construction work site. Based on the results of these surveys, it is suggested that the existing safety work-wear should be supplemented as much as possible and to propose various construction and safety work-wear items that can be used in various industries, jobs and disaster sites that require safety protection as well as multipurpose. It is expected that this will increase the wearing rate of safety work clothes in the field and it will lead to decrease of disasters and increase of social welfare.

## 3 Experimental Method and Procedure

The questionnaire survey of this study was conducted as follows. Visit the actual construction work site, ask for consent, and distribute questionnaires to current 113 workers. The contents of the questionnaires were divided into the following three items: (1) satisfaction with work clothes for work clothes worn by construction workers, (2) body reaction to heat during work, form, function, dimensional satisfaction. These questionnaires are compiled and analyzed using statistical analysis of SPSS 19.0 program (Fig. 3).

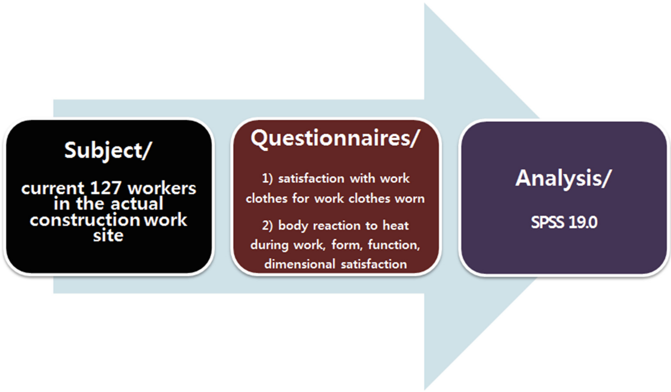


**Fig. 3.** Experimental method and procedure

# 4 Results and Discussion

## 4.1 Evaluation of Safety Clothing Comfort

Total of 150 subjects were randomly selected from 56 subjects aged 20–40 years old and 57 subjects aged between 40–60 years old. The age group between 20 and 40 years old was divided into group A and the group B between 40 and 60 years old.

According to the results of the survey on the satisfaction level of construction safety wear, it was found that the overall satisfaction level of work clothes and material satisfaction of group A and group B show similar results without age difference group difference. In the overall satisfaction survey on color, material, and form, overall satisfaction was higher than the average, and in group B, it was found to be slightly higher than group A. In other words, the basic appearance satisfaction indicates that the workers have no meaning and are satisfied with the current work clothes (Fig. 4).

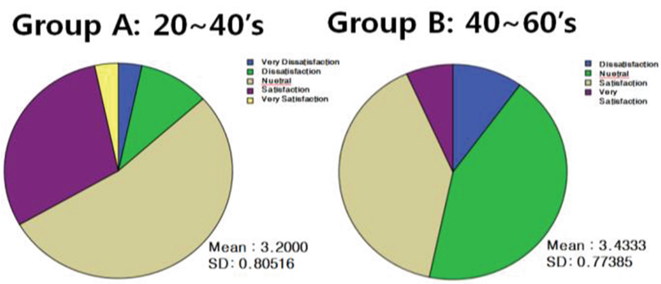


**Fig. 4.** Overall satisfaction with work-wear using 5-Likert scale

In the case of material satisfaction (Fig. 5), it is generally more than the average satisfaction. However, the dissatisfaction level shows that the dissatisfied dimension is higher than the other dimensions, especially in the response of "the dust sticks well," and "the sweat is not absorbed well". In other words, it can be seen that there is a lot of dust in the work clothes in construction/civil works where dust is generated a lot, and it can be seen that this phenomenon affects the work satisfaction. In addition, this results that sweat is not absorbed well shows that the work satisfaction of workers is inevitably lowered in construction/civil works where there is a lot of physical labor. It is an important evaluation subject to be referred to in the development of work clothes.

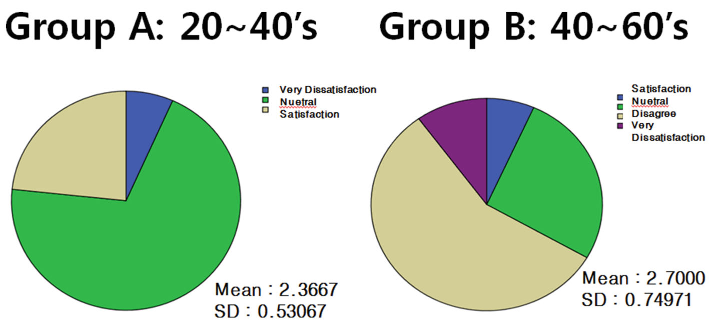


**Fig. 5.** Material satisfaction with work-wear

### 4.2 Evaluation of Subjective Physiological Comfort in Wearing Work-Wear

Overall, both group A and group B can feel more heat in the upper body, that is, above the chest, rather than the lower part of the body. It can be seen that the fever region of the human body is based on the fact that it is head, neck, and chest. Especially, in case of work clothes covering head, face and neck, it is data that shows that ventilation of work clothes should be an important development purpose (Table 1).

**Table 1.** The physiological comfort of each part of the body that feels hottest during work: Group A

| Each part of the body | Mean | Standard error | Standard deviation |
|---|---|---|---|
| Head, Face | 2.20 | 0.3335 | 1.8270 |
| Neck, Shoulder | 3.10 | 0.2414 | 1.3222 |
| Chest, Belly | 3.32 | 0.2612 | 1.4302 |
| Back Spine | 3.32 | 0.3095 | 1.6955 |
| Arm, Elbow, Wrist | 4.36 | 0.2372 | 1.2291 |
| Legs, Foot, Ankles | 5.04 | 0.2490 | 1.3604 |
| Whole Body | 6.86 | 0.1010 | 1.1704 |

Especially, we think that this phenomenon is more prominent in the construction/civil work field because there are a lot of work in the upper body rather than a lot of power or motion in the lower body. Prior to this questionnaire, previous researches on the development of work-wear at special sites showed that many of the respondents felt the heat in the upper part of the body (Table 2).

**Table 2.** The physiological comfort of each part of the body that feels hottest during work: Group B

| Each part of the body | Mean | Standard error | Standard deviation |
|---|---|---|---|
| Head, Face | 1.43 | 0.2070 | 1.1353 |
| Neck, Shoulder | 2.83 | 0.2994 | 1.6412 |
| Chest, Belly | 3.56 | 0.2473 | 1.3562 |
| Back Spine | 3.43 | 0.2475 | 1.3564 |
| Arm, Elbow, Wrist | 5.13 | 0.2072 | 1.1361 |
| Legs, Foot, Ankles | 5.40 | 0.2273 | 1.2482 |
| Whole Body | 6.20 | 0.2112 | 1.1561 |

## 5 Conclusion

The satisfaction level of construction safety work-wear that is currently worn is very unsatisfactory in response to “dust sticks” and “sweat is not absorbed well.” This means that dust has been accumulated on work clothes and is difficult to remove easily, it can be seen that this has a very uncomfortable effect on the work of the worker, and it is judged to cause a physical-physiological discomfort during work.

In addition, the subjective body - physiological responses in the construction work environment of extreme heat showed that both groups A and B felt more heat in the upper body than in the lower body. The results of this research can be interpreted that the construction safety work clothes currently worn only focus on safety, which means that it is weak in terms of material and design considering ergonomic, especially physiological part. The various work clothes that have been developed so far still focus on safety, and the ergonomic and physiological aspects are not properly reflected.

Therefore, the above results show that the construction safety work-wear of the present construction safety work clothes are improved in the quality of the material, the upper body movement, the ease of operation of the arms and elbows, the durability enhancement and the thermal comfort is suggested that it is desirable to develop.

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# Thermal Comfort Assessment of Metro Manila Development Authority (MMDA) Traffic Enforcers in Pasig City, Philippines

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**Abstract.** Heat can have varied impacts especially on workers who need to perform their duties for long hours under the heat of the sun. This paper evaluates the thermal comfort of traffic enforcers in Pasig City and determines its impacts on their work, safety, and health. Quantitative data on external factors such as air temperature, wind speed, UV index, and relative humidity, as well as qualitative information on internal factors such as the perceived level of physical activity and clothing comfortability were gathered and analyzed to determine their influence on the overall thermal comfort of the MMDA traffic enforcers. Interviews with traffic enforcers were conducted. The results showed that some of these factors do not favor thermal comfort. Some recommendations were given to help improve the traffic enforcers thermal comfort during the performance of their work.

**Keywords:** Thermal comfort assessment · Thermal comfort · Traffic enforcers
Workplace environment · Heat stress

## 1 Introduction

Metro Manila, one of the busiest cities in the Philippines, is considered as the hot spot of opportunities for people coming from the provinces and other places in the country. It is even said that Metro Manila is by far the most congested city in the Philippines. Yet, the city is known to offer many possibilities for a better future and attract many people to look for jobs in this ever-growing metropolis. However, this growth brings with it certain consequences that may slow down its development, such as the worsening traffic situation. Although Metro Manila is known for its unbearable traffic, one solution that the government had introduced to ease and improve its traffic condition is the establishment of the Metropolitan Manila Development Authority, or MMDA.

Although the functions and capability is overarching the whole development of Metro Manila, MMDA is more popularly known for its tasks of enforcing and implementing regulations and rules in relation to traffic and road improvements. Some of these traffic-related tasks include the control of traffic stop lights in busy


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intersections, enforcement of traffic rules and laws, flood control, road clearing operations and many others.

To implement these tasks, MMDA traffic enforcers have to usually endure long and grueling hours under the intense heat of the sun. This becomes even more demanding during rush hours when the city workers are about to begin or to end their working day. Merely standing by the road and performing your duties under the sun while donned in their uniform can be tiring and uncomfortable. In many cases, the lack of shade from trees and buildings expose them to longer periods of direct and intense heat of the sun. Cars and buses plying the busy roads also help warm the surrounding air through their hot exhaust pipe gases.

Such external work conditions can be very stressful for the traffic enforcers. Moreover, the traffic enforcers perform their work in full uniform which usually consists of 2 to 3 layers of clothing. The amount of heat arising from the road environment and from their layered uniform have an effect on the overall performance of the MMDA traffic enforcers. Although it can be said that traffic enforcers are sometimes provided with outposts where they can have a short refuge from the sun, and provided with mobile devices to assist them in their tasks, the general work conditions are still quite stressful and uncomfortable.

In general, the traffic enforcers assess their thermal comfort by means of the air temperature that they feel. In reality, there are at least six factors that contribute to their overall feeling of thermal comfort. These factors may be divided into two groups: environmental (external) factors and personal (internal) factors. The external factors include air temperature, wind speed, ultraviolet (UV) index and relative humidity, while the internal factors consist of clothing insulation and metabolic heat. Although these factors are independent of each other, they all contribute in varying degrees to the overall thermal comfort.

Studies show that exposure to excessively warm weather conditions or heat stress especially in urban areas can have detrimental effects not only on one's health but also on the safety behavior and productivity of workers [1–3]. In one study, it shows that manual workers from low-middle income countries in the tropics who are exposed to extreme heat in their workplaces may be at risk of heat stress [4].

In the past years, the MMDA had allowed its traffic enforcers and street sweepers to have a daily 30-min to one-hour afternoon break or the so-called "heat stroke break" during the summer months of March to May as a precautionary measure from heat-related illnesses such as heat cramps, heat exhaustion, heat rash and heat stroke, the latter being considered as a medical emergency [5–8].

Heat stroke is the most serious of the heat-related illnesses. A person who suffers from heat stroke is unable to control one's body temperature, i.e., with the rapid increase in the body temperature (41°C or higher within 10 to 15 min), the sweating mechanism fails, and the body is unable to cool itself naturally. Heat stroke can lead to death or permanent disability if emergency treatment is not provided. Heat exhaustion is a milder form of heat-related illness resulting from several days of exposure to high temperatures and inadequate hydration. Heat cramps are muscle pains or spasms in the abdomen or extremities usually as a result of too much sweating during strenuous activity. Aside from depletion of moisture, sweating lowers the salt level in the muscles causing painful cramps. Heat rash is a type of skin irritation resulting from excessive sweating during hot, humid weather [9, 10].

A very important precautionary measure to avoid heat-related illnesses due to exposure to extreme heat conditions in the workplace is hydration or fluid intake, preferably cold fluids. If the weather is hot, it is necessary to increase fluid intake, regardless of the activity level. In this situation, one need not wait to feel thirsty to replenish one's bodily fluids. During heavy exercise or high activity level in a hot environment, it is advisable to drink adequate non-alcoholic cool fluid every hour to maintain the color and volume of urine output [9, 11].

The suggested clothing material during warm weather conditions are cotton, linen, rayon and denim/chambray. Cotton is soft, lightweight, and breathable fabric. It is able to soak up sweat and allows heat to easily escape the body to keep it cool. Linen is another very light fabric. Its loosely woven fabric allows heat to escape from the body to keep it cool. It can absorb a lot of moisture and dry itself quickly. Rayon is a synthetic fabric blended from cotton, wood pulp, and other natural or synthetic fibers as a cheaper alternative to silk. Its thin fibers allow it to breathe well to keep the body cool. Finally, denim is made from very tightly woven cotton which makes it breathable and a good sweat absorbent. Chambray is an imitation of denim, but lighter in weight [12].

Thermal comfort refers to the perceived feeling on a person's body as a consequence of the interplay of various factors in one's environment. These factors may be divided into two types: external and internal factors [13]. The external factors include the air temperature ($^{o}$C), wind speed (km/hr), relative humidity (%), and UV index; the internal factors include clothing insulation and metabolic rate.

The UV index (UVI) set by the World Health Organization measures ultraviolet radiation from the sun using a scale from 0 to 11. UVI reading of 0 to 2 means low danger from the sun's UV rays for the average person; UVI reading of 3 to 5 means moderate risk of harm from unprotected sun exposure; UVI reading of 6 to 7 means high risk of harm from unprotected sun exposure and protection against skin and eye damage is needed; UVI reading of 8 to 10 means very high risk of harm from unprotected sun exposure and extra precautions are needed because unprotected skin and eyes will be damaged and can burn quickly; and UVI reading of 11 or more means extreme risk of harm from unprotected sun exposure and all precautions are needed because unprotected skin and eyes can burn in minutes [15, 16].

Metabolic rate is a measure of the amount of bodily heat produced per unit time due to bodily functions and activities done by a person [13]. Since it is not easy to measure this value in the field, the personal perception on the level of physical activity involved in one's work is used and will be referred to in this study as activity level.

Clothing insulation is both a potential cause of thermal discomfort as well as a means to control it depending on the conditions in the workplace. At times, workers have no other choice but to wear the required uniform even though it may not be totally suitable in the workplace. A periodic assessment of the current uniform and the evaluation of newer types of clothing material may help improve the thermal comfort of workers [13]. This factor will be referred to as clothing comfortability in this study.

## 2 Objectives and Significance of the Study

This study aimed to assess the thermal comfort of MMDA traffic enforcers in Pasig City, as they perform their duties in their workplaces. Also, this study aimed to determine the critical factors that can affect the overall thermal comfort of the traffic enforcers. The findings can be used to improve their working conditions from the point of view of thermal comfort. These will potentially provide MMDA traffic enforcers a more humane workplace and environment considering the amount of stress that they undergo when working for long working hours under the sun.

## 3 Research Methodology

The information and data used in this study were limited to the period covering November 19, 2017 to December 8, 2017 in Pasig City. Quantitative and qualitative information and data were collected in the field. The qualitative data were obtained from interviews with twenty Pasig City MMDA traffic enforcers during their daytime break period, i.e., sometime between 10:00 am to 2:00 pm. On the other hand, the quantitative data were collected with the use of a mobile application (AccuWeather) and information from the website www.timeanddate.com. The quantitative data include actual readings on the air temperature ($^{o}$C), wind speed (km/hr), ultraviolet index (UVI), and relative humidity (%) during the period of study. The actual readings from AccuWeather's patented RealFeel® Temperature during the same period of study were also collected as additional inputs in the analysis of the collected data since they integrate the effects of several other factors to provide an accurate measure of how representative the actual weather conditions really "feel" to an appropriately dressed person.

Information on the internal factors such as the perceived level of physical activity (or activity level) and clothing comfortability were obtained from actual personal interviews with MMDA traffic enforcers during their daytime break period. Additional information such as their age, length of years of service with MMDA, awareness of work health hazards, and hotness perception were also collected to support the data analysis.

An analysis of all collected data and information were conducted to determine their influence on the overall thermal comfort of the MMDA traffic enforcers. Based on the results of the analysis, recommendations to improve the traffic enforcers' thermal comfort were also presented.

## 4 Results and Discussion

The average age of the Pasig City MMDA traffic enforcers is 34.6 years old, while their average length of service with MMDA is 5.63 years. The following data and information on the different factors affecting their thermal comfort were also collected.

## 4.1 Air Temperature

Based on the AccuWeather readings, the average air temperature in Pasig City, Metro Manila during the period of November 19, 2017 to December 8, 2017 is 31.65 °C. Since it is higher than the average room temperature of 25 °C, the air temperature alone is not ergonomic and hence, does not favor the thermal comfort of the MMDA traffic enforcer (Fig. 1).

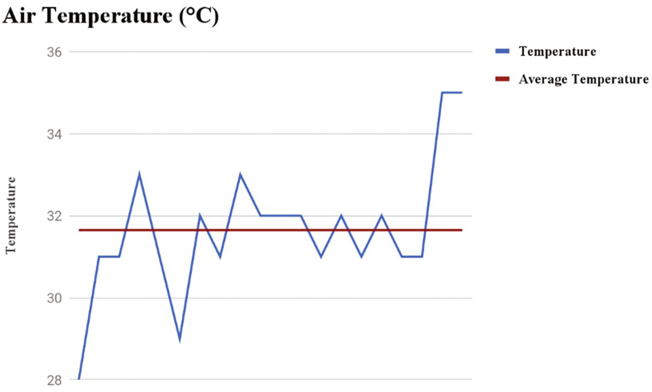


**Fig. 1.** Average air temperature (°C).

## 4.2 Wind Speed

Based on the AccuWeather readings, the average wind speed in Pasig City, Metro Manila during the period of November 19, 2017 to December 8, 2017 is 13.25 km per hour. Since it is relatively higher than the average annual wind speed of about 9.5 km per hour, we can say that the average air speed alone is ergonomic and favors the thermal comfort of the MMDA traffic enforcers [14, 18] (Fig. 2).

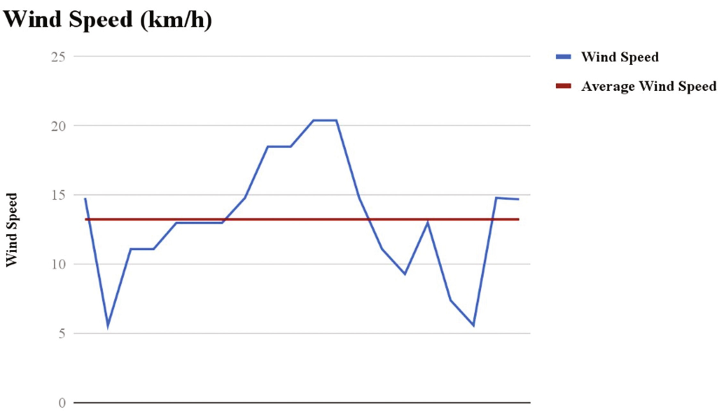


**Fig. 2.** Average wind speed (km/h).

### 4.3 UV Index

Based on the AccuWeather readings, the average UV Index in Pasig City, Metro Manila during the period of November 19, 2017 to December 8, 2017 is 4.45. Referring to the UV Index scale of the U.S. Environmental Protection Agency (EPA), it means that there is a moderate risk of harm if the person is unprotected from the UV light of the sun [16]. We can say that the average UV Index alone is not ergonomic and hence, does not favor the thermal comfort of the MMDA traffic enforcers (Fig. 3).

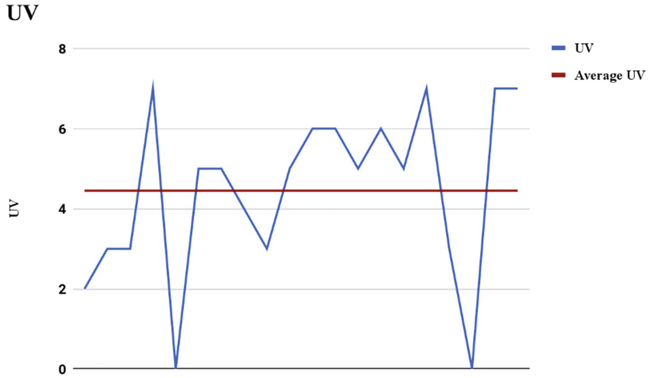


**Fig. 3.** Average UV index.

### 4.4 Relative Humidity

Based on the data obtained from www.timeanddate.com, the average relative humidity in Pasig, Metro Manila during the period of November 19, 2017 to December 8, 2017 is 63.65%. Although the value falls within the normal range of 40% to 70% for relative humidity, it still does not favor the thermal comfort of the MMDA traffic enforcers [13] (Fig. 4).

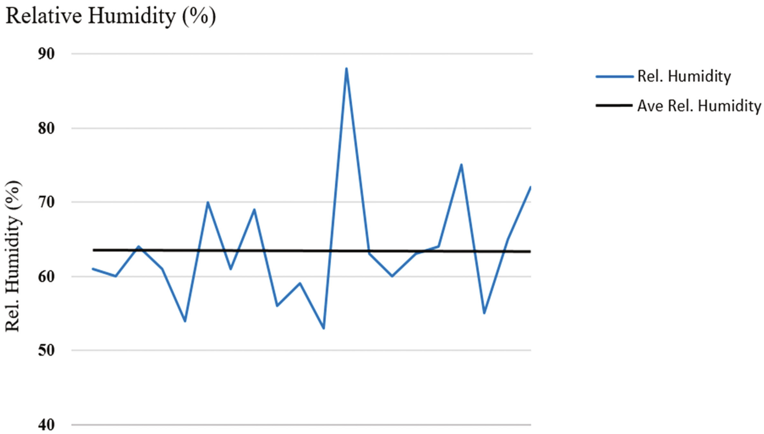


**Fig. 4.** Average relative humidity (%).

## 4.5 Activity Level

Based on the information gathered from interviews with the MMDA traffic enforcers, the average activity level rating during the period of November 19, 2017 to December 8, 2017 is 4.65. This means that the MMDA traffic enforcers have a relatively high level of perception on the physical activity involved in their daytime work shift. The allotted break time of each MMDA traffic enforcer is only about 30 min per day (Fig. 5).

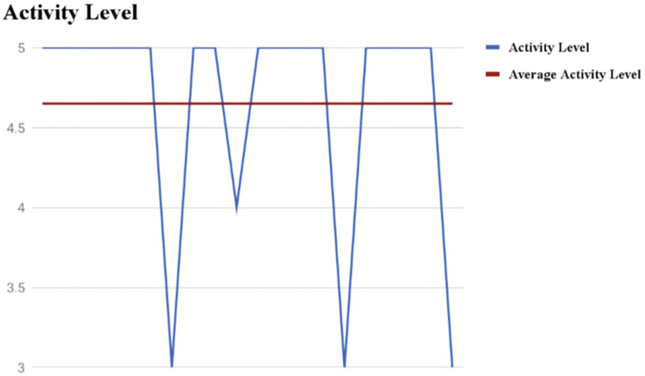


**Fig. 5.** Average activity level.

## 4.6 Clothing Comfortability

Based on the information gathered from interviews with the MMDA traffic enforcers, the average rating for clothing comfortability during the period of November 19, 2017 to December 8, 2017 is 3.3 in an arbitrary scale of 1 to 5, with 5 referring to high comfort. Although their uniform can help protect them from the scorching rays of the sun, the build-up of sweat on the skin and bodily heat due to physical activity and work environment still lead to a certain degree of thermal discomfort. Hence, the average clothing comfortability alone may be interpreted as not ergonomic [17] (Fig. 6).

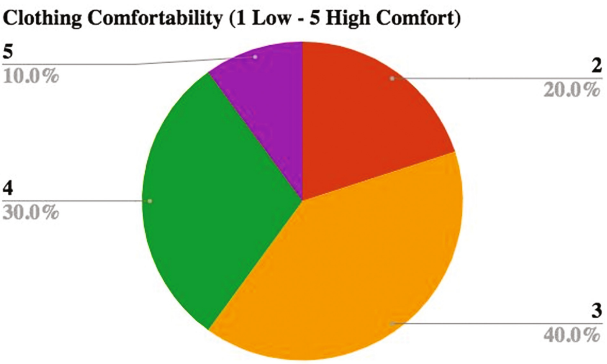


**Fig. 6.** Clothing comfortability.

### 4.7 Hotness Perception

Based on the information gathered from interviews with the MMDA traffic enforcers, the average rating for hotness perception during the period of November 19, 2017 to December 8, 2017 is 4.25 in an arbitrary scale of 1 to 5, with 5 referring to a really hot perception. The hotness perception is basically a personal perception of the MMDA traffic enforcers on the level of hotness of the day when they were interviewed. This study also shows that even if the period is still within the rainy season, the average hotness perception rating is still relatively high in Pasig City, Metro Manila (Fig. 7).

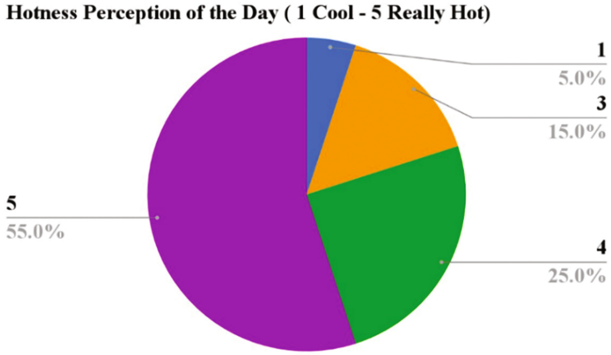


**Fig. 7.** Hotness perception of the day.

### 4.8 RealFeel® Temperature

Based on the AccuWeather readings, the average RealFeel® temperature in Pasig City, Metro Manila during the period of November 19, 2017 to December 8, 2017 is 36.71 °C. It was observed that the value was higher by about 5.0 °C over the average air temperature value of 31.65 °C. This indicates that the average RealFeel® temperature does not favor thermal comfort and correlates well with the general analysis for air temperature, UV index and relative humidity (Fig. 8).

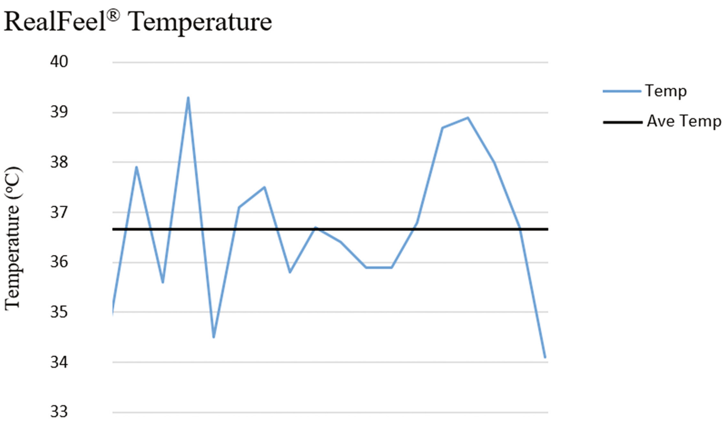


**Fig. 8.** RealFeel® temperature.

### 4.9 Awareness of Work Health Hazards

The MMDA traffic enforcers are allowed to have a daily 30-min to one-hour afternoon “heat stroke break” during the summer months of March to May as a precautionary measure from heat-related illnesses. However, only 17 out of 20 respondents were aware of this heat stroke break. The other 3 respondents were not aware of it because they were relatively new and still lack training and work experiences (Fig. 9).

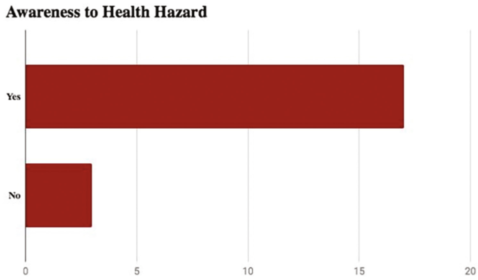


**Fig. 9.** Awareness to health hazard.

## 5 Conclusion and Recommendations

The critical factors that can affect the overall thermal comfort of MMDA traffic enforcers in Pasig City, Metro Manila during the period covering November 19, 2017 to December 8, 2017 can be divided into two types: (1) external factors which include air temperature, wind speed, UV index, relative humidity; and (2) internal factors which include activity level (or perceived level of physical activity) and clothing comfortability.

The analysis of the collected data of the four external factors showed that the average air temperature (31.65 °C), UV Index (4.45), and relative humidity (63.65%) do not favor thermal comfort. On the other hand, the average wind speed (13.25 km/hr) is higher than the average annual wind speed (9.5 km/hr) and hence, favors thermal comfort. Among the internal factors, both the average activity level rating (4.65) and the clothing comfortability (3.3) do not favor thermal comfort. The average RealFeel® temperature (36.71 °C) also shows that the combined effects of air temperature, wind speed, UV index and relative humidity do not favor thermal comfort.

The following provisions are recommended to improve the thermal comfort of the MMDA traffic enforcers: (1) cool water bottles for hydration; (2) sunscreen lotion for exposed skins; (3) sunglasses with UV filter; and (4) dry-fit arm coverings. Cotton fabric can be used as clothing material for their uniform in order to allow sweat and bodily heat to escape. Finally, traffic outposts for short breaks should be provided in strategic places where shaded areas are inadequate.

**Acknowledgments.** The authors would like to acknowledge the assistance of the twenty Pasig City MMDA traffic enforcers who preferred to remain anonymous for candidly sharing with us their personal observations on their work environments in order to make this research study possible.

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# Development and Assessment of Agricultural Safety Clothing Through Wear Test: Human Physiological and Subjective Comforts

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**Abstract.** The purpose of this study is suggesting several factors to consider when making or developing agricultural safety clothing to enhance farmers' health. This study is to suggest on development the newly-designed agricultural safety clothing for pesticide-proof and comfort functions of different materials of anti-pesticide protective clothing. In wearing tests, human physiological reaction and subjective comfort measured by Thermo-hygrometer from 5-parts such as forehead, chest, forearm, thigh, and lower leg before and after working. In the results of physiological and subjective comforts, agricultural safety clothing with water-oil repellent finished Sontara® was lower than agricultural safety clothing with PVC-coated nylon in human skin temperature, sweat quantity, inside-clothes temperature and humidity. The newly-designed agricultural safety clothing with water-oil repellent finished Sontara® were suggested all excellent in pesticide-proof effect and functionality and turned out to have higher comfort.

**Keywords:** Agricultural · Safety clothing
Pesticide-proof effect and functionality · Physiological and subjective comforts

## 1 Introduction

Some of agricultural safety clothing has been to meet requirements, and a few risk factors have been identified in farm-work by previous researches. By the way, farmers have improved their life conditions and raised their agricultural productivity so far.

Farmers are now pursuing an economic development and a scientific life style. So, they have increased the use of the more toxic pesticide to harvest more crops, which has caused various side effects. Because of that, insects have become resistant to pesticides [1].

It is known that the toxicity of pesticides becomes stronger and the concentration of pesticides becomes higher. Environmental pollution and poisoning problems have been raised on a large scale since nowadays. According to the report, 88.3% of pesticide


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users have experienced pesticide toxicity problems and 22.8% have serious health problems. It also means that it is inevitable to wear pesticide-proof clothing to protect the human body while using pesticides [1, 2].

This study focused on improving the safety and comfort of pesticide-proof clothing, comparing the differences in anti-pesticide between the newly developed 'water-oil repellent material,' Sontara® and other existing protective-clothing materials. Two types of clothing were made; water-oil repellent Sontara® was newly-developed, while the other was existing-typed one. This study compared them through wearing tests.

It is known that the toxicity of pesticides becomes stronger and the concentration becomes higher. Recently, environmental pollution and poisoning problems have been raised on a large scale. According to the report, 88.3% of pesticide users have experienced pesticide toxicity problems and 22.8% have serious health problems. It also means that it is inevitable to wear pesticides in order to protect the human body while using pesticides [1, 2].

This study focused on improving the comfort of pesticide-proof clothes, comparing the differences in anti-pesticide effect and function between the newly developed 'water-oil repellent material,' Sontara, and other existing protective-clothing materials. Two types of clothes were made; one was newly-developed, while the other was existing-typed one. This study compared them through wearing tests.

## 2 Literature Review

### 2.1 Pesticide-Proof Effect and Functionality for Agricultural Safety Clothing

Pesticides vary in their composition and function depending on the species. If insecticides penetrate insects and cause toxic effects in certain places, the impact of insecticides will occur, which is the most important function of pesticides. Not only does insecticide penetrate the body of insects easily through skin and shrubs, it also affects workers using insecticides. It is closely related [1, 4].

According to a recent study, the group of pesticide experts is developing not only the epidermal structure of insects, but also the research on chemical structure, the reduction of pesticide content and the pesticide penetration of the body, and the pesticide work clothes to enhance the comfort [1–3].

It is to use 'spun-laced, non-woven fiber, manufactured in water-oil-repellency method.' GIFAP (Groupement International Des Associations Nationales Fabricants De Products Agrochemiques) suggests a new clothing type, taking into account pesticide-proof effect and working activities [1].

Out of them, heat transmission is a fundamental thermal action in the human body-environment system, as mentioned above. It is characterized by two kinds of conditions; one is objective/common conditions such as air temperature, thermal radiation, air speed, humidity, etc., and the other is subjective/personal conditions including activity, clothing, etc.

Accordingly, here is a necessity of further studies on various conditions of clothes. In order to enhance comfort obtained by optimal heat transmission, and to protect human body from diverse thermal environments surrounding specific works, the influence of clothes needs to be regarded as the most important factor of subjective/ personal thermal environments [2, 4] (Fig. 1).

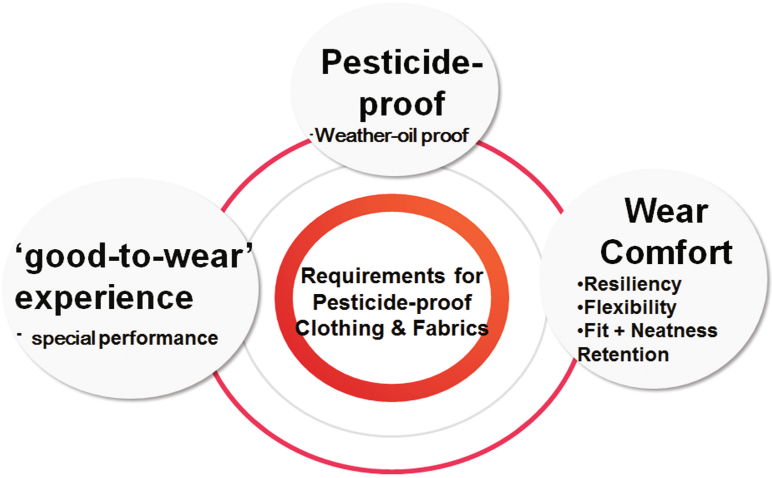



**Fig. 1.** Requirements of agricultural safety clothing and fabrics

These physical properties possibly make pesticide permeate into human body through many paths, and the pesticide permeation affects the human body with its toxic ingredients, staying inside the human body. In short, some ingredients of insecticides dissolve lipid layer of human skin tissue, and paralyze human nerves by poisoning, while rest ingredients are accumulated in the human body to cause other chronic and latent poisoning diseases.

## 2.2 Physiological and Subjective Comforts

Clothing comfort is one of the most important attributes of textile materials. Comfort cannot be reliably predicted by any single lab test of a fabric or by any series of different fabric tests. This is because comfort is inherently subjective; it is entirely a perception in the mind of the individual wearer and thus defies objective, quantified analysis. This perception differs 'person to person', 'day to day', and sometimes even moment to moment [8].

We feel discomfort whenever our perspirations are on in summer through the body & if the sweat drops are begins to deposit on our skin in order to failure of moisture regain of the garments. The rate at which water vapor moves through a fabric plays an important role in determining the comfort as it influences the human perception and the cool/warmth feeling [4, 6].

Another study is to explore the influence of the clothing ventilation in three body regions on the humidity of the local clothing microclimates under five work-shirts immediately after the onset of sweating in light exercise [5].

Farmers are seriously exposed to organic pesticides for very long periods of time, and farmers may have paralysis, including severe muscle aches in the lower body, loss of sensation at the distal end, paralysis, and even delayed polyneuropathy. In order to protect the body from these toxic pesticides and to maintain pleasant working conditions, you need the ideal type of pesticide application that needs to meet the requirements of good skin protection, comfort and durability. Pesticide applications should be made considering the effects of insecticides and pesticide application, and material and production method of cloth are important [5–7] (Fig. 2).

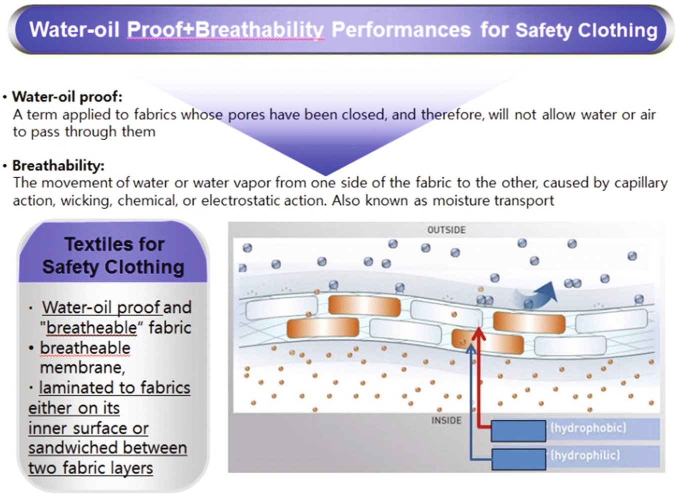



**Fig. 2.** Water-oil Proof + Breathability Performances for Safety Clothing

The purpose of this study is to suggest on development the newly-designed agricultural safety clothing for pesticide-proof and comfort functions of different materials of anti-pesticide protective clothing such as ‘PVC-coated nylon’ and ‘spun-laced non-woven water-oil repellent finished Sontara®’. Newly-designed agricultural safety clothing were assessed protective pesticide clothing though human wearing Lab.-test.

This study tested diverse cases to evaluate and compare objective/subjective comfort, in association with clothing materials, design types, and wearing methods. For the study, two protective clothes in different design types were made of water-oil repellent Sontara material; one was made in existing design type, while the other was made in a new design. Ultimately, this study pursued suggesting an ideal type of comfortable pesticide-proof clothes.

# 3 Experimental Method and Procedure

## 3.1 Specimen

The method of this study focused on testing insecticide interception and comfort sensation of the pesticide application of two kinds of textile materials; One is conventional PVC-coated nylon pesticide protective clothing and the other is newly-developed pesticide protective clothing using 'spun-laced Sontara®'.

According to a recent empirical study to test anti-pesticide-effect and comfort of farm-work clothes materials, 'spun-laced Sontara®' material was selected as the most comfortable material out of all the tested materials including 'spun-laced Sontara®'. 'spun-laced Sontara®' is a reinforced textile material manufactured by putting a water-pressure on short staples to make them a strong fibrous tissue. It also has a fine drape, good feeling, and almost infinite flexibility, which can give pesticide-proof clothing both properties of durability and comfort [1]. Details are described in Table 1.

**Table 1.** Specifications of pesticide protective fabrics (PVC-coated Nylon, 'spun-laced Sontara®' for agricultural safety fabrics)

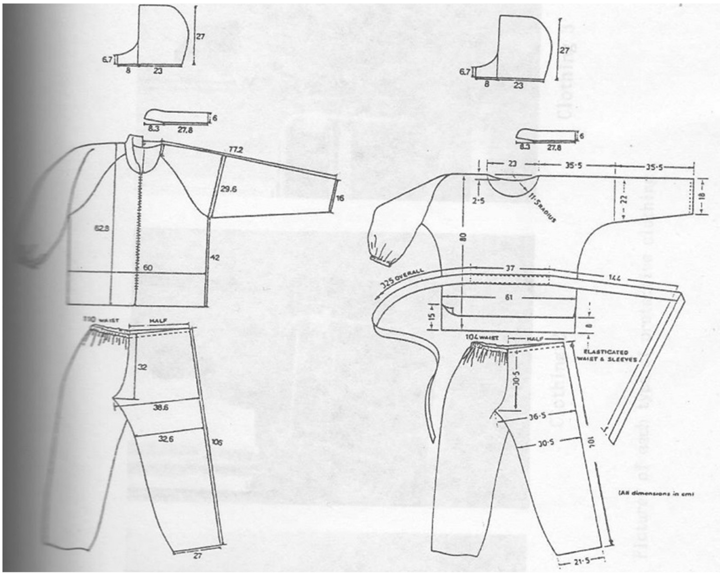
| Specifications | PVC-coated Nylon | 'spun-laced Sontara®' |
|---|---|---|
| Thickness (mm) | 0.97 | 0.78 |
| Weight ($gm^{-2}$) | 328 | 192 |
| Density (ends/picks, $cm^{-1}$) | 121/94 | 104/78 |

## 3.2 Evaluation on Human Physiological Reaction and Comfort of Protective Clothing

Two testing clothing adopted a conventional protective clothing for pesticide-spraying work, which one was designated by PVC-coated nylon pesticide protective clothing, and 'spun-laced Sontara®' (Water-oil repellent finished Sontara 808. Dupont Co.) was selected to make the newly-designed protective clothing.

The existing protective clothing had a nylon mesh lining to prevent the contact of skin and PVC-coated Nylon during sweating. However, Water-oil repellent finished 'spun-laced Sontara®' did not need inside-lining. The most significant difference from existing designs was the front slit of top. The newly-designed protective clothing (Fig. 3) was a T-shirt type without zipper, which prevents pesticide from permeating through seams.

The separation of top and bottom enlarges ventilation through the end area of top. It also increases comfort. A belt at waist can be tied to prevent the inflow of pesticide during spraying works. A convenient detachable is attached to the top to protect head and upper body from pesticide floating in the air. In short, the new protective clothing was made in consideration of pesticide-proof effect, comfort, usefulness, easy maintenance, and cost reduction.




Clothing 1 Clothing 2

**Fig. 3.** Patterns of two types of pesticide protective clothing, Clothing 1: conventional pesticide protective clothing using PVC-coated Nylon, Clothing 2: newly-designed pesticide protective clothing using Water-oil repellent finished 'spun-laced Sontara®'

## 3.3 Test Conditions

The conditions of testing room were adjusted according to the average climatic condition of June, July, and August in Korea (28 ± 2 °C, 70 ± 5% RH), with the still air condition of below 0.3 m/s. The quantity of motion and working time was set up according to previous studies, considering the amount and time of pesticide-spraying work. The quantity of motion was set up as 5.4 m, on a treadmill with a 4.8 km/h speed and 5% inclination angle. Working time was 75 min in total including 15 min pre-rest, 40 min working, and 20 min post-rest.

## 3.4 Measurement of Skin Temperature and Temperature of Inner Clothes

Skin temperatures were measured by Thermohygrometer (Model; X 712-1, Takara Thermister Instruments Co. Ltd.) from 5-parts such as forehead, chest, forearm, thigh, and lower leg. Additionally, the skin temperature of back was also checked up. Details of measured parts are shown in Fig. 5. The skin temperatures were calculated by following formula (Fig. 4).

$$\begin{aligned}\text{Average skin temperature }(^{\circ}\text{C}) = 10.3 - \text{forehead temp.} + 31.3 - \text{chest temp.} \\ + \ 19.3 - \text{arm temp.} + 19.7 - \text{thigh temp.} + 19.2 - \text{leg temp.}\} \times 1/100\end{aligned} \quad (1)$$

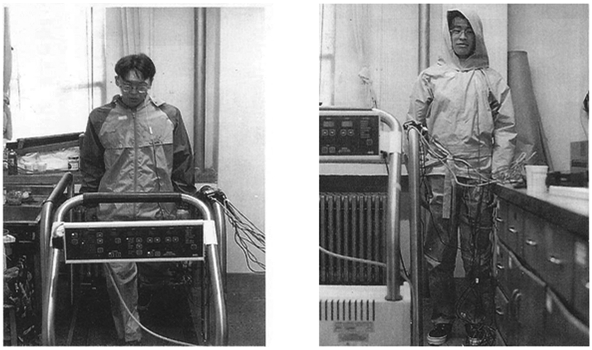
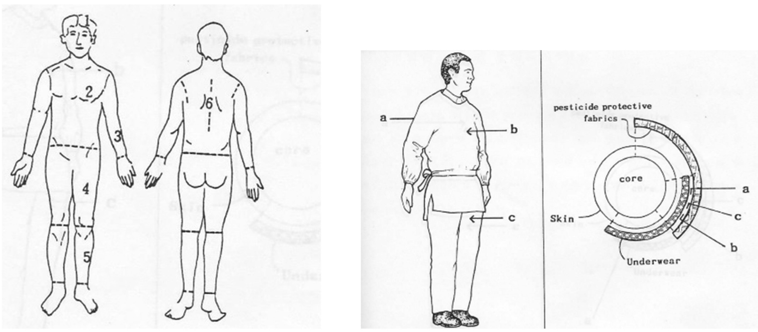


**Fig. 4.** The conditions of testing Lab.: quantity of motion as 5.4 m on the treadmill.

Temperatures were measured in the space between underwear and protective clothing at the area of chest and thigh, while humidity was measured at low leg and other 2 spaces; one was between chest skin and underwear, the other was between underwear and protective clothing. Detailed parts are shown in Fig. 5.




(a) (b)

**Fig. 5.** Measurement of skin temperature (a), Measurement of inner temperature between underwear and protective clothing (b) by Thermohygrometer (Model; X 712-1, Takara Thermister Instruments Co. Ltd.)

### 3.5 Measurement and Evaluation of Thermal Subjective Comfort

We checked up the subjective feeling including thermal comfort at 5-min intervals. Each scale is described in cool (1-point), neutral (2-point), slightly warm (3-point), warm (4-point), slightly hot (5-point), hot (6-point), very hot (7-point).

### 3.6 Method of Experimental Design and Statistics Process

Repeated tests were conducted on 6-subject of 2-type protective clothing, through randomized incomplete block design. Data analysis was processed by repeated measures ANOVA for repeated measurement results, using SPSS 19.

## 4 Results and Discussion

### 4.1 Comparison and Evaluation of Physiological Comfort

The mean skin temperature was figured by measuring temperatures at forehead, chest, arms, thighs, low legs at 1-min intervals. According to two kinds of protective clothing, Fig. 6 shows the change of skin temperatures varying with time. The skin temperature of Clothing 1 was higher than those of Clothing 2, while those of Clothing 1 and 2 have significant difference each other. ($P < 0.05$, t-value: 14.74). These results identify that protective clothing material and design are more influential to skin temperature. In the case of PVC-coated clothing, wearing underwear with high thermal storage and hygroscopicity is likely to lower average skin temperature.

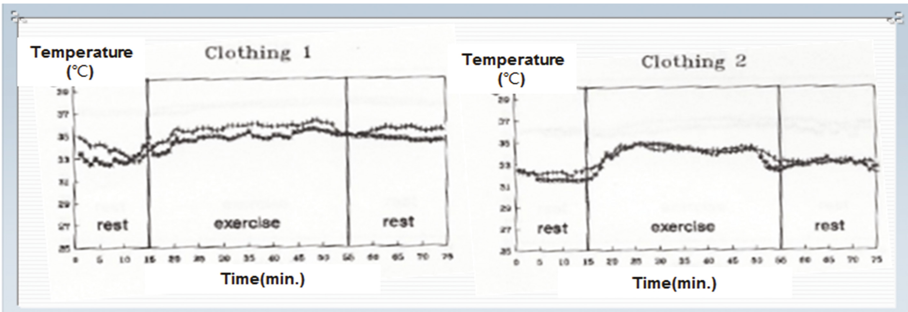



**Fig. 6.** The change of skin temperatures varying with time wearing Clothing 1, 2

Figure 7 shows the change of inner temperature between underwear and protective clothing temperatures varying with time wearing Clothing 1, 2. Comparing Clothing 1 and Clothing 2, the temperatures inside Clothing 2 of water-oil repellent finished Sontara were lower than PVC-coated clothing 1, with a figure of (t-value, 10.89). Comparing Clothing 1 and 2, there was slight difference in temperature changes. Above results show that protective clothing materials are most influential to the temperatures inside clothes, seeing water-oil repellent finished Sontara had a significantly low temperature.

### 4.2 Comparison and Evaluation of Subjective Thermal Comfort

Subjective thermal comfort was asked against all subjects at 5-min intervals, and the results are shown in Fig. 8. Seeing the results, there was a significant difference of

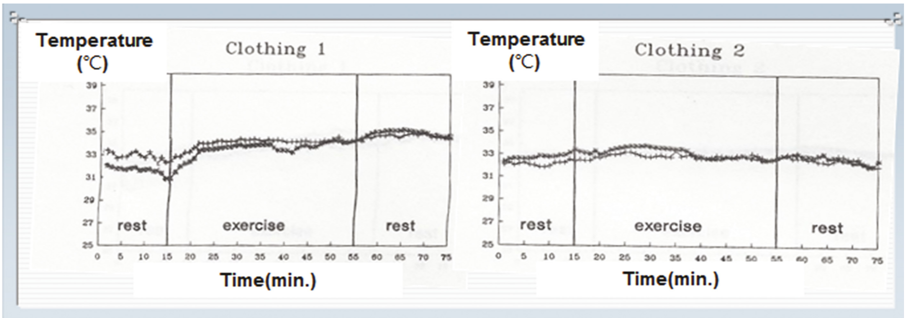



**Fig. 7.** The change of inner temperature between underwear and protective clothing temperatures varying with time wearing Clothing 1, 2

overall comfort between Clothing 1 and Clothing 2. Clothing 1 had a lower thermal comfort index by about 1 than Clothing 2, which means that the kinds of protective clothes are influential to increase thermal comfort. Comparing the thermal comfort, there was no significant difference (t-value, 12.92).

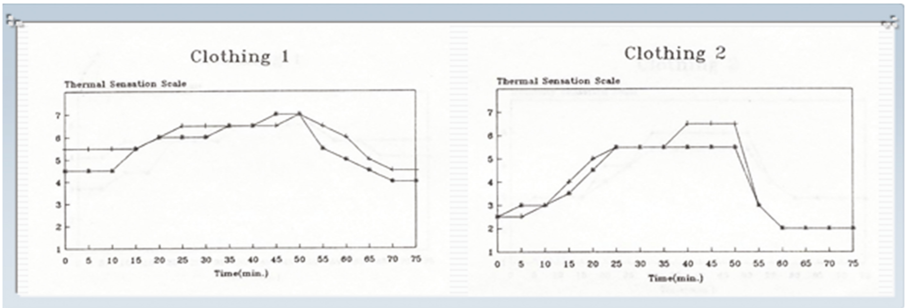



**Fig. 8.** The change of subjective thermal comfort varying with time wearing Clothing 1, 2

In other words, comparison of subjective thermal comfort according to materials and design shows that thermal comfort is well maintained and improved in water-oil repellent finished Sontara, during a certain period.

## 5 Conclusion

Human physiological reaction during exercise or work tends to raise temperatures/humidity inside clothes and skin temperatures as the metabolic volume increases and heat of human body retains in the human body-clothing system, instead of being transmitted to outside. On the contrary, agriculture safety clothing using PVC-coated nylon had a wet-coated layer in its lower lamella, as a textile of a high-density structure made of high yarn number nylon filaments. It had relatively less tiny pores than water-oil repellent finished, which caused a lower heat-water transmission property.

Accordingly, this test of functionality evaluation on the two materials and wearing test identified the different ability of clothes in transmitting heat-water to outside of the human body-protective clothes system.

In the results of physiological and subjective comforts, agricultural safety clothing with water-oil repellent finished Sontara® was lower human skin temperature, inside-clothes temperature, and higher subjective thermal comfort than conventional agricultural safety clothing with PVC-coated nylon. This means that agricultural safety clothing material was more influential to comfort than design. As shown above on the results, water-oil repellent finished Sontara® were all excellent in pesticide-proof effect and functionality, and turned out to have higher comfort.

This study showed that design was not so influential to comfort because materials were more influential to comfort of clothes. Nevertheless, further study will be needed over designs and accompanied protective equipment including gloves, masks, and so on, in order to enhance comfort more effectively.

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# Evaluation of Risk Factors of Upper Limb Musculoskeletal Disorders in a Meat Processing Company

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**Abstract.** The aim of this study was to evaluate the risks associated with repetitive movements of the upper limbs in different meat processing tasks of a pig slaughterhouse. The study was conducted in a Brazilian pig slaughterhouse, in which 200 workers were evaluated through the OCRA Checklist. There were 18 work tasks analyzed from the following sectors: cuts (8); ham (4); pepperoni (3); sausage (2) and salami (1). The average score of OCRA Checklist was 20.6 ± 5.8 (moderate risk). The scores for the right upper limb (20.4 ± 6.0 - moderate risk) did not differ ($p = 0.163$) from the left upper limb (20.6 ± 5.8 - moderate risk). Two work tasks were considered high risk (11%) and 16 were within a moderate risk (89%). These results suggest that pig processing tasks predispose workers to a greater probability of developing upper limb work-related musculoskeletal disorders (>21.5% probability for high risk and 10.8 to 21.5% for moderate risk).

**Keywords:** UL-WMSDs · Slaughterhouse · Risk assessment · Ergonomics OCRA

## 1 Introduction

Brazil is the fourth largest producer and exporter of pig meat in the world [1]. However, improvements in the working conditions in meatpacking industry have not grown at the same rate as production growth [2]. The ergonomics-related risk factors that could lead to the development of upper limb work-related musculoskeletal disorders (UL-WMSDs) in meat processing include: repetitive work [3–7]; artificially cold environments [5, 8–10]; use of manual tools, and consequently, the application of force in the tasks [5, 7, 11–13]; and the use of gloves [5, 14].

In a recent study among 645 Danish slaughterhouse workers there was a prevalence of pain in shoulders, hands/wrists and elbows of 60%, 52% and 40%, respectively [15]. Moreover, 38% of the workers reported work disability due to upper limb pain


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emphasizing the functional consequences of pain in shoulder, arm and hand on daily work. Tirloni et al. [16] also found that the majority of workers in a pig slaughterhouse felt bodily discomfort in at least one region (83.3%) where the most affected body regions were shoulders (47.2%) and arms (25.0%). According to Sundstrup et al. [17], chronic upper limb pain is associated with reduced neuromuscular function of the shoulder and hand along with impaired work ability, work disability and general health.

Workers in pig slaughterhouses have high rates of acute injuries and chronic diseases [18]. Most of the injuries reports of a pig processing plant (63%) occurred in the cold work-sites, and the main source of injury were tasks requiring the use of handheld tools [19]. Recent tool sharpening and equipment malfunction were associated with the highest rate ratio of laceration injury [20]. Moreover, hand-intensive work, including high-velocity and high-force, is a risk factor for musculoskeletal injuries in pig slaughterhouses [21]. Moore and Garg [22] presented additional epidemiological evidence that upper extremity musculotendinous disorders may be causally associated with work in pig slaughterhouses. The disorders included nonspecific hand/wrist pain, epicondylitis, carpal tunnel syndrome (CTS), trigger thumb, trigger finger, and De-Quervain's tenosynovitis.

Exposure to risk factors due to multiple repetitive tasks, regularly performed in the slaughterhouse setting has been observed, and requires a systematic approach to quantify the proportion of these risks. Thereof, the OCRA (Occupational Repetitive Actions) Checklist was developed to analyze the workers exposure to risk factors of developing upper limb work-related musculoskeletal disorders (UL-WMSDs) (frequency of technical actions, postures of the upper limbs, use of force, 'stereotypy' or lack of postural variation, recovery periods, and others, defined as "complementary") related to activities performed [23]. This method was based on a consensus document of a technical committee in musculoskeletal injuries of the International Ergonomics Association (IEA) [23]. Although there are several studies measuring the risk of developing UL-WMSDs among poultry slaughterhouse workers [6, 24–28], few studies have evaluated pig slaughterhouses workers [29–31]. These studies were limited to analyzing a small number of tasks in pig slaughterhouses [29, 31] or only meat processing tasks (sausages and similar products) [30].

Therefore, the purpose of this study was to evaluate the risks associated with repetitive movements of the upper limbs in different meat processing tasks in a pig slaughterhouse, using the OCRA Checklist.

## 2 Method

The local Ethics Committee in Research with Human Beings, in accordance with the Helsinki Declaration, approved the procedures of this study.

The study was conducted in a pig slaughterhouse with 2,000 workers employed, in which 4,500 pigs were slaughtered daily, divided into two work shifts. The OCRA Checklist (Table 1) [32] was used to assess the risk of 18 work tasks, which included 200 workers of the meat processing plant. These individuals were randomly selected to participate in the study. Videos of 10 task cycles performed by each worker were recorded, while carrying out their work tasks, and used for subsequent analysis.

**Table 1.** Score description of the OCRA Checklist, risk classification and respective incidence of UL-WMSDs [32].

| Color | Risk | Checklist score | Incidence of UL-WMSDs |
|---|---|---|---|
| Green | Acceptable | <7.5 | <5.26 |
| Yellow | Borderline or very low | 7.6–11.0 | 5.27–8.35 |
| Light red | Low | 11.1–14.0 | 8.36–10.75 |
| Dark red | Moderate | 14.1–22.5 | 10.76–21.51 |
| Purple | High | >22.5 | >21.51 |

For data presentation, descriptive statistics in terms of mean, standard deviation and percentage were utilized. In order to compare the risk between the sides of the workers' body, the Student t-test (SPSS 17.0) was used ($p \leq 0.05$).

## 3 Results and Discussion

A total of 18 work tasks were analyzed in the different sectors of the pig slaughterhouse: cuts (8); ham (4); pepperoni (3); sausage (2) and salami (1).

Each work shift totaled 8 h 48 min, including a lunch break (60 min), five rest breaks (12 min) and the time to change clothes/uniform (clock in and clock out). Therefore, the net repetitive work time was classified in the range between 421 and 480 min, which represents the multiplier factor "one" of the OCRA Checklist.

Given that the company adopts five rest breaks distributed throughout the work shift, to the "recovery" factor of the OCRA Checklist, a value of "two" (on a scale of zero to 10) was assigned for all tasks analyzed. In order to achieve the ideal score (zero) associated with the "recovery" factor (5:1 ratio work time to recovery time), it would be necessary to allocate at least two more breaks. Insufficient rest breaks for the recovery of fatigue caused by repetitive work in the industry can lead to muscle injuries [33]. In an experiment testing the inclusion of extra rest breaks in a meat-processing plant, Dababneh et al. [34] established that taking hourly rest breaks does not compromise production and are beneficial to the workers' well-being.

In relation to the other risk factors considered by the OCRA method (frequency of technical actions, force applied, posture and complementary factors), scores were assigned according to the characteristics of each task and the technique adopted by each worker.

The average of technical actions performed by workers was $57.3 \pm 12.3$ per minute (Table 2), representing seven points in the OCRA's scale (0 to 10 points scale). In another Brazilian pig slaughterhouse, Reis et al. [30] presented similar results, observing an average of $64.1 \pm 14.3$ actions per minute, which corresponds to nine points in the OCRA Checklist. In a pig head processing company, Pellegrini et al. [29] reported that the ergonomic analysis of work showed an elevated risk for disorders of the upper limbs due to the high frequency of technical actions (between 15 and 82.5) combined with awkward postures, use of force, complement factors and the lack of the necessary time for recovery.

**Table 2.** Risk assessment for repetitive movements of the upper limbs performed by the slaughterhouse workers, and the simulations for reducing this risk by reducing the working pace.

| Activities - department | Actual situation observed | | | | Simulations for minimizing the risk | | | |
|---|---|---|---|---|---|---|---|---|
| | Units/min | TA/min | OCRA | Risk | Units/min | TA/min | OCRA | Risk |
| Remove carcass fat with knife | 7.5 | 60.0 | 42.0 | H | * | * | * | * |
| Filling franks package | 15.0 | 75.0 | 23.0 | H | 6.0 | 30.0 | 11.0 | VL |
| Secondary packaging of sausage | 3.3 | 76.0 | 22.5 | M | 1.5 | 35.0 | 11.0 | VL |
| Trimming fat for ham processing | 1.6 | 76.0 | 22.0 | M | 0.75 | 36.0 | 11.0 | VL |
| Filling sausage package | 27.3 | 82.0 | 22.0 | M | 12.0 | 35.0 | 11.0 | VL |
| Pepperoni package inspecion | 2.4 | 50.0 | 22.0 | M | 1.5 | 30.0 | 11.0 | VL |
| Remove thigh fat | 9.2 | 65.0 | 20.0 | M | 5.7 | 40.0 | 11.0 | VL |
| Shoulder boning | 1.6 | 50.0 | 19.5 | M | 0.94 | 30.0 | 11.0 | VL |
| Shoulder boning (neck part) | 1.6 | 50.0 | 19.5 | M | 0.94 | 30.0 | 11.0 | VL |
| Leg deboning | 0.8 | 48.0 | 19.5 | M | 0.5 | 30.0 | 11.0 | VL |
| Ham cooking | 3.0 | 43.0 | 19.0 | M | 2.1 | 30.0 | 11.0 | VL |
| Trimming leg | 1.7 | 53.0 | 19.0 | M | 1.2 | 35.0 | 11.0 | VL |
| Remove jowl | 4.6 | 46.0 | 18.5 | M | 3.0 | 30.0 | 11.0 | VL |
| Leg partition for ham processing | 1.1 | 55.0 | 17.5 | M | 0.7 | 35.0 | 11.0 | VL |
| Belly fat trimming | 2.9 | 60.0 | 17.5 | M | 2.0 | 36.0 | 11.0 | VL |
| Trimming filet | 1.7 | 48.0 | 16.5 | M | 1.25 | 35.0 | 11.0 | VL |
| Sausage stuffing | 2.4 | 50.0 | 16.5 | M | 2.2 | 40.0 | 11.0 | VL |
| Packing sausage 4.5 kg | 15.0 | 45.0 | 15.0 | M | 12.0 | 35.0 | 11.0 | VL |
| Average | 5.7 | 57.3 | 20.6 | M | 3.2 | 33.6 | 11.0 | VL |
| Standard-deviation | 7.0 | 12.3 | 5.8 | | 3.7 | 3.5 | 0.0 | |

Risks: H-high; M-moderate; VL-very low; * It is necessary to restructure the activity due to the strength demands; TA-technical actions.

As suggested by Kilbon [33], the worker should not exceed 25–33 actions per minute, considering that frequencies above these values interrupt the physiological recovery mechanisms from operating efficiently, increasing the incidence of tendon injury.

Slaughtering and meat processing work tasks require high loading intensities and cyclic repetitive muscle actions of the upper limbs. Furthermore, limited time for recovery and temporary episodes of work disability, the prevalence of musculoskeletal pain in the hand, arm and shoulder is high among slaughterhouse workers [15]. Studies have shown that most of the poultry [8, 35] and pig [16] slaughterhouse workers felt bodily discomfort, being the shoulder region as the most affected [8, 16, 27, 35, 36].

The average score of OCRA Checklist for all tasks analyzed in the company was 20.6 ± 5.8 points (Table 2), which is considered as a moderate risk (Table 1). The scores for the right upper limb (20.4 ± 6.0 - moderate risk) did not differ (p = 0.163) from the left upper limb (20.6 ± 5.8 - moderate risk). Similar results (average 22.2 ± 7.7; right 22.2 ± 7.8; left 21.6 ± 8.1) were found in another pig slaughterhouse [30]. In addition, moderate risk was also observed in several other Italian [37] and Brazilian poultry slaughterhouses [6, 25, 26]. Occhipinti and Colombini [38] reported an OCRA Index of 23.8 (high risk) in pig slaughterhouse workers, with 86 workers been evaluated and 193 cases of WMSDs diagnosed (224.42%). However, only one task was evaluated in the study [38], while in the other studies the results represent an average of various tasks.

Considering the five risk categories proposed by the OCRA Checklist, two work tasks analyzed in the present study were considered as high risk (11%) and 16 were within a moderate risk (89%) (Table 2). Another study in a Brazilian pig slaughterhouse analyzed 22 work tasks, where most of them (16) presented moderate risk (73%), and six, high risk (27%) [30]. Among three work tasks analyzed by OCRA method in an Italian pig slaughterhouse, Botti et al. [31] found one task representing high risk and two of low risk.

A series of studies carried out in Brazilian slaughterhouses raised the hypothesis that there was a reduction in the number of high-risk tasks due to the implementation of the Standard Regulatory Norm 36 (NR-36) [39]. This standard establishes the minimum requirements for evaluation, control and monitoring risks in tasks performed at meat processing plants. Among the requirements of the NR-36 that directly influence the results of the OCRA Checklist, minimum duration of the psychophysiological recovery periods is established (20 min, 45 min or 60 min) [39]. Considering the duration of the shifts (up to 6 h, up to 7 h 20 min or 8 h 48 min, respectively) in the production sectors of the plant, this requirement should be adopted. The recovery periods should last at least 10 min and at most 20 min, and not be allocated in the first hour of work, contiguous with the meal interval or at the end of the last hour of the workday. By adopting these measures, there is a reduction of the time of exposure to repetitive tasks and/or muscular overload, reducing the score of the variable “recovery” of the OCRA Checklist. Thus, the hypothesis is evidenced by the disparity between the results of pre [25] and post NR-36 studies [6, 26, 28, 30]. Reis et al. [25] evaluated a Brazilian poultry slaughterhouse prior to implementation of the NR-36, and found greater exposure to repetitive activities (480 min), with a shorter duration for daily rest break (10 min).

Based on epidemiological data, the precursors of the OCRA method [32] developed hypotheses of disease prevalence expected in a particular occupational setting. Therefore, possible percentages were defined for each level of incidence of UL-WMSDs in the Checklist (Table 1). In meat deboning task, Colombini et al. [32] found an incidence of UL-WMSDs of 47.7% in workers of workstations classified with 28 points in the OCRA Checklist (high risk). Thus, it is possible to affirm that the workers analyzed in the present study who performed tasks of moderate risk have a 10.76 and 21.51% probability of developing UL-WMSDs, whereas in high-risk tasks the probability is >21.51%.

Pig slaughterhouse workers are exposed to ergonomic risk related to the physical load and physical environment [40]. Musculoskeletal problems caused by poorly organized work environments are of concern, as they lead to the development of occupational diseases with negative economic and social repercussions, both for companies and for government, and especially for families [41]. Therefore, an ergonomically appropriated work place is of fundamental importance for the for companies, due to the loss of employees, and for the government, which should provide payment of welfare benefits for treatment and rehabilitation [41]. Pellegrini et al. [29] recommend to consider some organizational factors for the prevention of UL-WMSDs in pig slaughterhouse workers: alternate tasks with the rotation of workers on more tasks; adopt a rational distribution of rest breaks (preferably hourly); use of knives that have the handle covered by adherent material and do not cause compression in the hands; sharpening the knives several times a day; provide information and training for workers on the proper use of knives and education on sharpening knives at the first signs of fatigue.

Given that highly repetitive movements of the upper limbs are characteristic of pig slaughterhouses [21, 29, 30, 42], and previous studies suggest decreasing the pace of work to prevent UL-WMSDs [6, 8, 25, 26, 28, 30], simulations of reduced working pace to achieve very low risk levels utilizing the OCRA Checklist were performed (Table 2). Through simulations, in 17 of the 18 tasks it was possible to decrease the risk of developing UL-WMSDs to very low levels, by reducing only the working pace ($-37.4 \pm 13.4\%$). In one of the activities (“remove carcass fat with knife”), it was not possible to achieve a very low risk level by reducing only the working pace, due to the high demand for strength required to perform the task. This type of simulation was also performed in a previous study, in which it was possible to reduce the risk of UL-WMSDs to very low levels, by reducing only the working pace ($-46.7 \pm 14.8\%$) for most of the pig slaughterhouse work tasks (19/22).

Faced with this evidence, there is an evident need to improve the working conditions in the meat-processing industry [43]. Additional preventive measures such as improvements in cold protective clothing, ergonomic interventions in repetitive work tasks [44], increasing the degree of mechanization [43], and reducing knife work [13] should also be considered to prevent WMSDs in pig slaughterhouse workers.

## 4 Conclusion

The majority of the work tasks performed by the employees were classified as moderate risk, and there was no difference for the risks observed between left and right upper limbs. The simulations of reducing the working pace showed the effectiveness of this organizational measure to reduce the risk of UL-WMSDs in most of the analyzed work tasks.

Thus, considering that there are many identical workstations in the production sectors of this industry, it is estimated that most of the workers were exposed to moderate risk, which provides two to four times greater chances of developing UL-WMSDs than the population that was not exposed.

More studies are needed to determine whether the present findings can be generalized to other pig slaughterhouses, given that the current study was limited to analyzing only those workers within a Brazilian slaughterhouse.

Finally, some organizational measures should be considered to reduce the risk of UL-WMSDs: reducing the working pace; adopting rest breaks well distributed throughout the workday (preferably hourly); adopting job rotation between tasks with different biomechanical requirements; increasing the number of employees; using sharp knives to reduce the effort required to perform cutting task; reducing the use of knife, and monitoring the risk level of work activities through objective tools such as the OCRA Checklist.

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# Safety and Risk Factor Assessment by Telecommunication Mast Riggers and Technicians in Nigeria

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**Abstract.** The telecommunication industry in Nigeria today is one of the largest growing industry in the nation, and acts as a high generating revenue for the economy. With the spread of mobile network coverage around the nation, there is the need for necessary improvements, to meet up with this growing demand. This increases the need for further construction and use of telecommunication masts from points to points all over the nation. This paper reviewed the various ergonomic and human safety factors which are considered by riggers and technicians whilst working at significant heights above ground level. The paper also reviewed various safety equipment used during the installation of telecommunication masts or radio mobile equipment on telecommunication mobile sites or base stations. A review of relevant literatures was conducted from journals and conference articles from databases including Emerald, Taylor and Francis online, Springer, Ebsco Host, Scopus, amongst others. Findings from the study revealed various safety methods adopted whilst working at significant heights during equipment installations. The study also revealed the various safety equipment used by both the riggers and technicians on telecommunication sites as well as their effects on safety. An important conclusion from this study is that the safety of riggers and technicians is paramount, hence, the need for safety precautions to be taken to avoid accidents. This study recommends that policies regarding the safety of riggers and technicians are to be reviewed and implemented. This includes safety checks and proper use of equipment to avoid risks caused by carelessness, over confidence and negligence.

**Keywords:** Telecommunication masts · Safety equipment · Risks
Riggers and technicians · Nigeria

## 1 Introduction

In Nigeria today, services like mobile tracking devices, internet calls, electronic payments are becoming increasingly rampant and has become a vital and indispensable tool for exchanging or transmitting information (Bello 2010). It is well known that the telecommunication industry in Nigeria today has become one of the largest growing industry. It also acts as a high revenue generating arm of the nation and contributes positively to the gross domestic product thereby creating job opportunities to millions of youths and professionals in the nation (Otubu 2012). As said by Bongo in 2015 the


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telecommunication industry is also a key area in which the level of competition is critical to the overall development of the industry as well as contributing to national well-being (Kovacs 2013). At the international telecommunications union (ITU) world summit in 2013, investors were encouraged to head to Nigeria, as the nation is a haven for technology business in the telecommunication industry (Osuagwu 2014). It has been highly noted that the Nigerian telecommunication industry is rated to be well over 25 billion dollars and well invested in the ICT information and communication technology sectorial growth which is at 30% for the past 3 years. A sectorial contribution to the gross domestic product GDP was 7.05% in 2012 and it stood at 8.05% and will continually grow due to it being favorable and of robust socio-economic impact to the nation (Osuagwu 2014). Mobile base stations and cellular telephones masts are an integral part of the infrastructure required for an effective telecommunication system. To have optimal network coverage most base stations are located in close proximity from point to point by target users to create a better and more efficient mobile network communicating system (Adebayo 2016). According to Harling et al. (2015), mobile telecommunication towers and mast are now the second most important engineering structure after bridges. Technological innovations for Long Term Evolution (LTE) mobile technology require further construction of mast which are versatile and easy to maintain. Their replacement is inexpensive are easily modularized as their life expectations can be reached without additional corrosion protection (Harling et al. 2015).

Factor of safety in a work place can be defined as the measure of reliability of a particular event and can be termed also as a constant value imposed by law, standard, contract and custom in which people must be forced to conform or adhere to for their own personal safety. This has been attributed under the telecommunication industry as the threshold to avoid going against stated work standards and policies ensuring safety of workers while working in the industry. Risks has been stated to be the combination of health hazard and exposure which can both be termed as acceptable and to whom it is acceptable to in relation to worker's health and safety in the telecommunication industry. To communicate risk, there is a need for employer compliance to liability prevention by keeping unsafe working conditions, poor ergonomic work conditions and organization of work and psychosocial strains (Slatin 2010).

## 2 Literature Review

Most often than not safety management systems in the workplace has been explored in relations with safety statistics such as rate of accidents and injuries at the work place or firm. Various studies have looked into this practice to achieve positive safety results of accident and injury protection via engaging of workers, technicians etc. in the industry (Wachter and Yorio 2014). Results from this study conducted showed that there was a significant negative relationship between the levels of safety focused worker engagement with accident rates, the study determined that safety management systems and worker engagement levels can be used individually to predict accident rates by strongly emphasizing on the human element when developing and implementing safety methods and procedures, the researcher observed and effected the do it yourself approach to uncover and correct organizational behavior as well as supervising safety acts to prevent it from happening, In this study an assignation was carried out by adopting the method used by (Rich et al. 2010) which comprised the safety manager on the field to evaluate worker engagement in the industry by creating the enthusiasm and interest in the safety program and also focus their attention on the safety procedures required on the job (Wachter and Yorio 2014).

Engaging employees has been argued as a strong motivation in the first line of safety and health in the industry, this uses the involvement of one on one principle by ensuring all employees are responsible for general safety in the workplace and industry as discovered upon adequate data collected gives a feeling of overall responsibility in the workplace (Raines 2011). In the year 2012 it was discovered that the health and safety committee (HSC) and health and safety organizations (HSO) have not gotten most companies safety performances, a study was conducted by the Danish ramazzini center using an industrial plant to test how the HSO can improve the company safety culture, results via this study in 2012, this showed a doubling of formal meetings which increased the resolution of most safety issues and in the study it was observed enforcement notice were issued by the authorities which aided seriousness in submission and adhering to safety performances in the first six months to two years of said research in Denmark (Nielsen 2014). In the year 2015 a study was further conducted on occupational study at the work place where injuries and diseases were concerned, the study surmised that due to developments in science and technology like protective equipment use, engineering controls, safer machinery and greater adherence to regulations and labor inspections by the appropriate authorities in the industry causing a decline in such cases, however the study presented that the system of health and safety management are not effective in the new industrial evolution to combat cases like work related disorders, (Kim et al. 2016) and inequality in the availability of occupational health services in the 3rd world countries. The study came up with the solution of instead of utilizing a safety cultural approach which dealt with the workplace alone a related approach called the prevention culture be created and adopted which addresses the societal effects or national level as well (Kim et al. 2016).

Another study was conducted on accident causes and prevention in 2015 via the school of health sciences in Australia, it was determined that the implication cost of accidents has grown globally in the workplace and industry possibly due to the development in safety management against level of technological advancement which has outpaced safety management in most nations causing serious challenges for policy makers and professionals involved in accident prevention and safety management, literals were reviewed and further research to look into this study was recommended (Pillay 2015). Health hazards and risk safety practices caused by poor safety practices in sites are considered as either chronic or acute, majorly hazards in telecommunication mast sites are either riggers falling from height and electric shocks to technicians or exposure to health via radiation, (PPE) personal protective equipment's (Vithrana et al. 2015) And awareness programs need be created regularly to combat lack of interest to safety by employers and technicians including awareness on possible risk factors and knowledge on how to reduce risk factors amongst riggers and technicians using compliance (Vitharana et al. 2015). In 2016 a study was conducted in Canada on the impact of psychological stress on the safety of technicians and riggers in the industry caused by safety climate which is used to improve safety performance in different regions and help technicians and workers manage stress (Chen et al. 2017), it was discovered that safety climate had effects and affected technicians both on safety outcomes on psychological stress and physical safety outcomes, the study hence promoted the monitoring of not just safety performance but also the assessment of technicians psychological wellbeing focusing on developing training programs on improving psychological health and especially post-trauma psychological health leading to improvements in the technician or workers performance in an industry (Chen et al. 2017).

## 3 Research Methodology

In Nigeria Today not much study has been conducted to effect the safety and risk factors by telecommunication mast riggers and technicians that work on mobile stations and towers in the country, this has led to accidents that resulted in deaths from falls whilst working at heights or electrical shocks from radio mobile equipment's due to the non-use of safety equipment's for personal protection or non-standard gloves for electrical works. Most often than not overconfidence and carelessness by said riggers and technicians resulted in such accidents and hazard on telecommunication mobile sites leading to either death or injuries that could have been avoided. EHS compliance has actually been stressed and reiterated by relevant organizations involved in the protection and safe guarding of riggers and technicians that work in the telecommunication industry but the compliance ratio by the riggers and technicians is still on an all-time low. This study has been carried out using literal reviews from advanced European and African countries with the aid of journals from science direct, international labor organizations, world health and safety organizations, Ebsco Host, Emerald insight, Taylor and Francis online, springer, online sources etc. This study would look into the ways safety assessment has been conducted, who is responsible for safety and policy regards monitoring of risk factors and assessment by the relevant bodies and authorities.

## 4 Safety Factors, Statements and Management

### 4.1 Safety Statements

This represents an organizations commitment to safety by stating how an employer in a telecommunication firm will ensure the safety of employees in that firm by providing the necessary resources to maintain and review safety and health standard policies, the safety statement will cover the selection and use of competent people via trainings and certification, equipment's and materials, the employer shall provide the equipment's and skill sets required to match job description.

In the telecommunication industry the following examples are required for tower mast riggers and technicians,

- Training for riggers to be certified in working at heights and safety
- Training for electrical technicians and installers on electrical safety and adherence certifications

- Provision of PPE which include coveralls, goggles, insulated gloves and well griped gloves for climbing, safety helmets, safety boots, reflective jackets, safety belts and fall arrestors etc.
- Provision of first aid kit and training in its use for first response to emergencies
- Ensure fire extinguishers and EHS compliance checklists are ticked as all on sites
- Mandatory presence of HSE certified officer to ensure compliance on sites and give motivational and pep talks on safety before and after work commences on site, he would also ensure adequate health and psychological evaluation of riggers and technicians before and after work, including ensuring they avoid overstress from fatigue and no rest while undergoing job.
- Constant training on health and safety by communications, seminars, conferences and the do it yourself approach by supervisors.

### 4.2 Safety Managements

There are three major needs for having a good safety management system in a telecommunication firm whilst having workers work on sites.

- Economic and financial implication: evidence has borne that by practical experience that an effective safety management operation in a telecommunication firm using technicians and riggers contribute to success in business growth, accidents and deaths by employees tend to have significant cost implications often hidden and underestimated.
- Legal implication: Nigeria as a country has laws and policies that involve safeguarding safety or workers in the telecommunication industry plus labor organizations whose sole interest is to ensure the welfare of employees and technicians, this requires that the employer be proactive in managing the safety and welfare responsibilities in a firm by dealing with them in a systematic way and also help comply with legal requirements to avoid litigations from accidents, injuries or deaths caused by negligence and a breach of safety factors whilst working on telecommunication sites and towers.
- Moral and ethical reasons: an active safety management in a telecommunication firm would prevent accidents and injuries or death which would as well avoid personal losses at the firm and as well as prevent traumatic occurrence as a result of accidents or death while working at height or electrical installations on a telecommunication mobile site.

### 4.3 Risk Factors and Assessment

Risk factors in a telecommunication firm should include a step to step point in being factored for avoiding risks at a mobile communication site or workplace.

- Use of safety and health policy
- Identify possible hazards
- Assess risks via risk assessment to cause harm at firm or site
- Decide precautions for the risks and measures to combat them
- Record your finding and keep constant reports and data

- Constantly review and update your data to meet new situations that can be caused by technological advancement
- Motivate employees in a telecommunication firm by declaring either bonuses or awards for record of no accidents or near miss, injuries or death at timely intervals
- Make safety and risk avoidance a responsibility for all in the firm.

## 5 Results and Discussions

From all the literal reviews conducted and undergone, the telecommunication industry in Nigeria as the rest of the world requires a close knit health and safety policy that would be monitored and all necessary sanctions adhered to by the relevant health and safety company certification policies like the telecommunication council, the ISO certification bodies and the health and safety committee in charge of telecommunication industry in Nigeria and ensure compliance of the firms who would also monitor the riggers and technicians working both at height in Nigeria as well as in radio equipment's and installations that require technicians and installers.

The telecommunication firms should not be made responsible alone for the safety and risk factors in the nation but should be a responsibility for all including government monitoring bodies, labor organizations and health & safety bodies as well as riggers and technicians.

## 6 Lessons Learned

From the reviewed literature and study conducted whilst digging into telecommunication reviews in Nigeria, safety and risk factors to telecommunication mast riggers and technicians in the industry will reduce immensely avoidable deaths and injuries including risks associated to non-performance or negligence of safety in the Nigerian telecommunication industry.

Hence by clearing the risks of litigation and payment of compensation or damages from the industry to families for accidents and deaths caused by non-compliance to safety. The profits in the industry will further increase leading to a more favorable increase in the percentage of the gross domestic product and revenue generated from one of the largest revenue generating arm of the Nigerian economy.

## 7 Recommendation and Conclusion

The telecommunication industry in general as observed while research was being conducted on literal reviews into this study has barely been touched in terms of research papers and journals, yet it is a relatively large industry not just in Nigeria but in Africa and the rest of the world.

Telecommunication health and safety has barely been touched as well as researches conducted to its fullest in this industry, hence I would recommend further study be conducted into this industry to match the present industrial revolution and time per technological advancements reached already in this industry.

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# Analysis of Accidents Involving Machines and Equipment Using the Human Factor Analysis and Classification System Method (HFACS)

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**Abstract.** Brazil is the forth nation in the world that registers more accidents during labor activities, behind only by China, India and Indonesia. The most causes of workers death and mutilations results from accidents involving machines and equipment. The main aim of this article is to discuss and analyze the causal factors that leads to the human error in the accidents involving machinery and equipment that happened in Brazil between 2009 and 2015 using HFACS, which provides the casual factors that will serve as basis to this study, and to contribute to reduce the number of accidents not just in Brazil, but in a worldwide level, and avoid the recurrence of accidents involving machinery and equipment as well. Several HFACS categories appeared frequently: Technological Environment (78,4%), Violations (76,1%), Perceptual Errors (65,6%), Inadequate Supervision (58,1%) and others.

**Keywords:** Human factors · Accident · Machine · Equipment

## 1 Introduction

Brazil is the forth nation in the world that registers more accidents during laboratorial activities, behind only by China, India and Indonesia. Since 2012, economy has suffered a U$ 6,8 billion impacts caused by people who requires leave of absence of work after suffering injuries during their activities. The most causes of workers death and mutilations results from accidents involving machines and equipment. Only between 2011 and 2013, an average of 12 workers were amputated per day because of accidents with machines and equipment in Brazil.

Due to this significant number, people were losing family members or having serious sequels due to work accidents caused by lack or inefficiency of safety in machines and equipment. Despite labor laws and regulatory standards, this fact is still very worrying, which shows that these are still not enough. Measuring losses through accidents involves a complex equation, since a portion of the losses are invisible (such as loss of life, change in the life and work activity of the accident, impacts on family life, and a decrease in the quality of life) which cannot be quantified [1]. However, these losses must and can be prevented. In this context, accident analysis is important


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way to help understand how they happen, identify the contributing factors that led to the accident and propose appropriate measures to prevent further accidents in the future [2]. Accident analysis should follow a method, as this is essential for understanding how the accident occurred [3]. Thus, many methods have been developed and described in the literature in the last decades, mainly motivated by the inability to establish methods that can be applied in all types of socio-technical systems and in different types of accidents.

The article has the objective of analyzing the causal factors of accidents involving machines and equipment in Brazil from 2009 to 2014, using the Analysis Using Human Factors and Classification System (HFACS) method.

### 1.1 The Human Factors Analysis and Classification System (HFACS)

The Human Factors Analysis and Classification System (HFACS) is a taxonomic incident coding system developed for the US Marine Corps aviation sector and for application by practitioners to aid in investigating and analyzing the role of human factors in accidents and incidents [4]. HFACS provides analysts with taxonomies of failure modes across the following four levels: unsafe acts; pre-conditions for unsafe acts; unsafe supervision; and organizational influences [5].

Additionally, the analysts based on the taxonomies presented by HFACS, which works backward from the immediate causal factors, classify the errors and associated causal factors involved an accident [2]. Therefore, the HFACS framework goes beyond the simple identification of what an operator did wrong to provide a clear understanding of the reasons why the error occurred in the first place. In this way, errors are viewed as consequences of system failures, and/or symptoms of deeper systemic problems; not simply the fault of the employee working at the “pointy end of the spear” [6]. Furthermore, the HFACS framework is capable of exploring the possible causes of accidents with different complexities. In recent years, the HFACS framework has been widely introduced into civil aviation and other domains to study human errors in accidents because of its high reliability [7].

The original HFACS framework [4] describes 19 causal categories. While useful as originally designed for aviation, the nomenclature and examples within some of the causal category proved incompatible within the min. Therefore, the original HFACS framework was modified and a new HFACS machine framework was developed. The first of four levels of the HFACS describe the *unsafe acts* committed by operators that led to the accident, classified into two categories of errors and violations. Level 2 factors, *preconditions for unsafe acts,* refers to both active and underlying latent conditions that contribute to the occurrence of unsafe acts. Preconditions for unsafe acts comprise three categories: conditions of operators, environmental factors, and personnel factors. The third level of failure within HFACS, *unsafe supervision,* considers those instances where supervision is either lacking or inappropriate. The final category of failure, *organizational influences,* addresses the fallible decisions made at board and management levels that influence operations at the lower system levels [8].

## 2 Method

### 2.1 Data Source

The accident reports used in this analysis were obtained from databases maintained by Ministry of Labor in the period from 2009 to 2014. The causal factors obtained were classified by industrial activities (for example, construction industry) and by immediate morbidity factor (immediate factor of cause of the accident, such as a machine). The causal factors related to accidents involving machines or equipment, independent of the field of activity, were selected for analysis, which resulted in 150 different causal factors. These 150 causal factors were ranked in descending order of the number of times (frequency) that contributed to the accidents occurring. Those factors that had frequency less than 10 were excluded years, were eliminated because they are of little relevance. Also excluded were causal factors with vague description (e.g., "other environmental factors"), which made it impossible to understand and categorize. There remained 96 causal factors for the analysis object of this study.

### 2.2 Coding Process

Four analysts coded each incident/accident case. The analysts had previously been trained together on the use of the analysis and categorization framework to ensure that they achieved a detailed and accurate understanding of it. This training consisted of seven half-day modules delivered by a human factor expert. The training syllabus included an introduction to the HFACS framework; explanation of the definitions of the four different levels of HFACS; and a further detailed description of the content of the nineteen individual HFACS categories. The presence or absence of each HFACS category was evaluated from the causal factors. Each HFACS category was counted a maximum of one time per case.

Each analyst did the categorization in the HFACS method independently. To verify the reliability of the categorization, the concordance index among the students was calculated. The agreement index used was calculated as proposed by [9]: (number of students who agreed to factor categorization)/(number of students who agreed on the categorization of factor + no of students who disagreed on the categorization of the factor). The concordance index ranges from 0 to 1 or may be displayed as a percentage. A concordance index of 70% was adopted as an acceptable minimum in this study, following the one proposed by [9, 10].

### 2.3 Statistical Analysis

Preliminary assessments of the incident characteristics and HFACS data were performed using frequency counts. The nature of the relations, if any, between each HFACS level with the level immediately above was conducted using the chi-square test. A value of 1 means that one variable perfectly predicts the other, whereas a value of 0 indicates that one variable in no way predicts the other. The lower level categories in the HFACS were designated as being dependent upon the categories at the immediately higher level in the framework, which is congruent with the framework's underlying theoretical assumptions. From a theoretical standpoint, lower levels in the HFACS cannot adversely affect higher levels. Higher levels in the HFACS are deemed to influence (cause) changes at the lower organizational levels, thus going beyond what may be deemed a simple test of co-occurrence between categories. Analyses were conducted using the software package SPSS.

# 3 Finds

## 3.1 Overall Results

When categorizing the 96 accident factors to the HFACS method, we obtained the data given in Table 1. In this categorization, there was 71% agreement among the analysts, which satisfies the rate of at least 70% adopted, according to [9, 10].

**Table 1.** Factors categorized in HFACS

| HFACS Category | Frequency | Percentage |
|---|---|---|
| *Level-1 Unsafe acts* | | |
| Decision errors | 0 | 0 |
| Skill-based errors | 42 | 4.4 |
| Perceptual errors | 687 | 65.6 |
| Routine violations | 798 | 76.1 |
| Exceptional violations | 0 | 0.00 |
| *Level-2 Preconditions for unsafe acts* | | |
| Physical environment | 282 | 26.9 |
| Technological environment | 882 | 78.4 |
| Adverse mental states | 129 | 12.3 |
| Adverse physiological states | 0 | 0.0 |
| Physical/mental states | 0 | 0.0 |
| Crew resource management | 64 | 6.1 |
| Personal readiness | 115 | 11.0 |
| *Level-3 Unsafe supervision* | | |
| Inadequate supervision | 609 | 58.1 |
| Planned inappropriate operations | 571 | 54.5 |
| Failed to correct problem known | 88 | 8.4 |
| Supervisory violations | 466 | 44.5 |
| *Level-4 Organizational influences* | | |
| Resource management | 37 | 3.5 |
| Organizational process | 476 | 45.4 |
| Organizational climate | 122 | 11.6 |

Most of the causal factors were encoded in active errors, preconditions for active errors and unsafe supervision. Not surprisingly, these were identified in more than three quarters of cases. Unsafe acts were identified in 90.5% of cases, preconditions for unsafe acts were associated with 90.3% of cases, while unsafe supervision was identified in 87.1% of cases. Organizational influences were identified in relatively few cases (56%) compared to the other levels.

The most frequent active errors were routine violations (76.1%) and perceptual errors (65.6%). Violations are related to non-compliance with machine handling rules, for example cleaning/regulating/lubricating of machine or equipment in moving. Regarding the perceptual errors, much of this mistake made by the operators is related to a lack of knowledge and training, for example, lack of knowledge about the functioning/state of equipment. Decision errors and exceptional violations were not identified in this study.

The preconditions for errors most commonly involved was the technological environment (78.4%), which normally involves machinery in poor conditions, for example, a system/protection device that is absent/deficient by design and system/machine/equipment poorly designed. The physical environment (26.9%) is related to the organization of space, cleaning and noise disturbances, for example, noise interference and difficulty in circulation. Adverse mental status was present in 12.3% of the accidents, which involved, for example, performance under psychic conditions, or inadequate cognitive and fatigue/waking state. No cases of adverse physical states and physical or mental limitations have been identified.

Supervision failures included inadequate supervision (58.1%), which is often related to oversight of personnel and resources, for example, absence/inadequate of supervision and lack of training. The inadequate planning of the task was present in 54.5% of the accidents, which involved, for example, lack or inadequacy of task risk analysis and poorly designed task. The violation of supervision (44.5%), in this study is related, mainly, to the lack of qualification of the team, for example Appointment of unskilled and inexperienced worker to occupy a job/perform unusual function. The failed to correction problem (8.4%) was identified in only one factor "postponement of neutralization/elimination known risk".

Finally, the organizational influences included the organizational process (45.6%), which had the most recurrent factors: non-existent or inadequate work procedures and lack of or inadequacy of the work permit system. The organizational climate (11.6%), which generally involved communication failures in the company and an increase in pressure for productivity. Resource management (3.5%) was present in the lack of personal protective equipment and poor personal management.

[4, 10] suggested that inadequate top-level decision making can negatively influence staff and practices at the supervisory level, which in turn affects the preconditions and therefore, the subsequent actions of front-line operators. This study provides statistical support for this hypothesis relationship.

Although most of these models emphasize the need to explore the socio-technical components of the system in order to identify the network of factors whose interaction resulted in the accident, most of the company's security professionals are restricted to evidence of non-existence or failures in protection barriers. An analysis that is interrupted at the first or second level doesn't search the true causes of these failures, which restricts the identification of the network of causal factors of the accident, with negative consequences for prevention. And with this, it contributes to the continuation of the simplistic, dichotomous conception about the causal factors of these accidents.

All types of errors within the HFACS taxonomy have been observed in the research reports. However, the analysts found it difficult to relate some causal factors to the categories of the HFACS method. This fact occurred because some factors were not self-explanatory and needed consultation in every report that we did not have. Thus, it is advised the access to all reports for a more reliable application.

The application of the method was valid because it showed the significant correlations that permeate an accident involving machines and equipment. This finding, in addition to the structure's ability to accommodate most of the contributing factors, suggests that the categories of error, although initially developed for aviation, are applicable to incidents and accidents involving machinery and equipment. Most importantly, the HFACS framework seems to be a useful tool for capturing all relevant data from factors that lead to human error. The failures were identified at all levels of structure, providing strong support for an approach to systems that contribute to accidents and the causal causality model of [11].

## 4 Conclusion

The machinery and equipment industry are the key sector in the process of industrialization and economic development of a country, supplying machinery and equipment that transform the conditions of production of agriculture and industry. However, despite all this development the measures for protection of the operator were not efficient.

The analysis provided an understanding, based on the principles of the HFACS method, of how actions and decisions at higher managerial levels influence and result in operator errors. The results show clearly defined, statistically described paths that relate errors at level 1 (operational level) with inadequacies at both immediately adjacent levels and upper in the organization. To significantly reduce the accident rate, these "paths to failure" related to these organizational and human factors should be addressed. This research draws a clear picture that supports the [11] model of active failures resulting from latent organizational conditions.

The results suggest that interventions at HFACS levels 1 and 2 would only have a limited effect on overall safety improvement. For example, shortcomings in the technological environment are associated with subsequent mistakes by perceptual errors (level 1). However, improving only the technological environment will very unlikely to have a major impact on safety unless supervisory processes (level 3) and organizational processes (level 4) are in place to provide such things as proper training, a maintenance program, good planning of the task and a well-defined security policy. These activities require commitment and organizational capability, which can only be offered at the highest levels of management. This study strongly suggests that greater gains in safety benefits could be achieved through segmentation actions in these areas. Subsequently, it's necessary to realize more studies about accidents with machines and equipment, to establish a similar pattern of results found in other countries and cultures.

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# Safety Behavior

# The REPAIRER Reporting System for Integrating Human Factors into SMS in Aviation Maintenance

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**Abstract.** Acknowledging the FAA's well-known PEAR model, and the influence of the dirty dozen in aviation maintenance, the authors examine a tracking and reporting system that fulfills FAA requirements for safety management systems in aviation maintenance organizations. Implications and suggestions for a robust safety management system which encompasses human factors and ORM, applicable to an aviation maintenance environment are presented, with the inclusion of specific risk hazards. The resulting safety reporting system proposed addresses both consistency and reliability challenges, unique to the aviation maintenance environment. Using the four pillars of safety as a foundation, the REPAIRER strategy procedures serves as the safety policy pillar, through the examination and rating of potential risk hazards, based on the dirty dozen. The resulting reporting system leverages aviation maintenance-specific factors to identify and correct for human errors, improving the reliability of maintenance procedures, enhancing safety practices, and ultimately creating a greater state of operational readiness.

**Keywords:** Aviation maintenance · Human factors
Operational risk management · Safety management system

## 1 Introduction

Human error can be traced to approximately 80% of major Federal Aviation Regulation (FAR) 121 Category aviation accidents in the United States. Of that 80%, up to 10% are caused by human error in aviation maintenance, which is accompanied with a 6.5 times greater chance for disaster [1]. As a result, the Federal Aviation Administration (FAA) is keen on reducing the percentage of accidents caused by human errors related to aviation maintenance. This motivation is further fueled by the projected growth of the aviation industry in the US over the next 25 years. With growth comes additional aircraft, and subsequently the maintenance that will be needed to keep them in the sky. With an increase in maintenance, comes a higher chance for human error within the aviation maintenance environment; while the percentage may stay the same, the pool from which that number is derived, is much larger. The FAA's current strategy to reduce the prevalence of human error in aviation maintenance for FAR 121 operations comes in the form of an internationally acclaimed safety system initiated over the past


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decade by the International Civil Aviation Organization (ICAO); Safety Management Systems (SMS). Although many elements of SMS have been used for decades, overall, it presents a model which identifies certain elements that are mandatory and essential for a successful safety program. These elements are shown in Fig. 1. [2] and represent the 4 supporting legs of the SMS table; Risk Management, Safety Assurance, Safety Policy and Safety Promotion. The SMS table top illustrates the fact that all elements must work together.

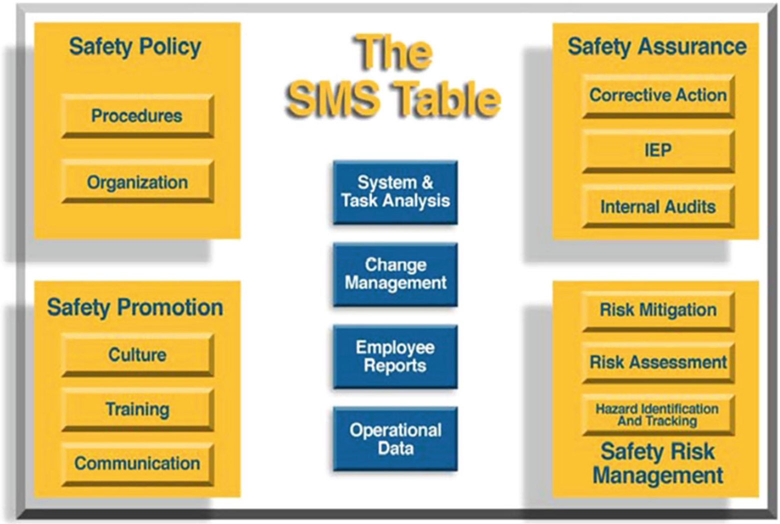


**Fig. 1.** The SMS Table [2]

**SMS Elements.** In Fig. 1, the top view of the SMS table can be clearly seen, with the basic requirements for each of the 4 table legs. The upper left corner highlights the important components of the Safety Policy leg via formal procedures, along with how the organization chooses to enforce such procedures. In aviation maintenance, a clear set of safety procedures would be required, along with identified organizational authorities to support the enforcement of safety responsibilities. The upper right corner features the Safety Assurance leg, which emphasizes the handling and tracking of hazards and corrective actions. This also includes having a reporting system to manage and track audits. For the Safety Assurance leg to be successful in an aviation maintenance environment, the anonymity of reporters would be essential. The lower left hand corner, Safety Promotion, represents how the maintenance organization will carry out the SMS system through the development of a safety culture, which in maintenance, would stem from open communication and training. The Risk Management leg in the lower right-hand corner illustrates the importance of risk management via the three required steps of; Hazard Identification, Risk Assessment and Risk Mitigation.

**The FAA Mandates SMS in All FAR 121 Operations by March, 2018.** Given the fact that the 4 SMS elements work so well together, the FAA has now mandated the use of SMS for all FAR 121 Operators in the United States by March, 2018. This includes FAR 121 maintenance operations that maintain those FAR 121 Operators' aircraft. The use of SMS by FAR 121 Operators can only enhance the safety, however, the overall effect on aviation maintenance operations will remain to be seen. Despite the success of SMS, there are potential issues that could hinder its implementation into aviation maintenance; culture, cost, and practical application. A shift in the safety culture poses significant challenges. The fast pace and unique stressors found in this environment make the implementation of any change difficult. Maintenance is a continuous process. Additionally, the inclusion of a new process will not come without the burden of training, design and implementation costs. The third obstacle would be to ensure all the legs of the SMS Table are carried out as intended. In large FAR 121 aviation maintenance organizations, the concern would be doing the four SMS table legs correctly and then ensuring they are being carried out on a day to day basis. For smaller FAR 121 maintenance operations, and eventually even smaller FAR 135 aviation maintenance operations, attempting to execute the 4 table legs of the SMS without the burden of excessive work, cost, and effort will be difficult. A solution to this issue would be to streamline the process and tailor the four SMS legs to fit the realistic needs of that aviation maintenance organization. The FAA is currently promoting this tailoring philosophy through their SMS training program as a way to address implementation issues. Tailoring the four legs would also allow aviation maintenance organizations to place additional emphasis on human factors, thus mitigating human error and reducing the prevalence of aviation maintenance related accidents.

**The SMS Program is Centered Around Risk Management Not Human Factors.** One problem with implementing SMS into aviation maintenance operations is the unavoidable risk of human error. Although the SMS is centered on a strong Risk Management Program, it is not the best tool when used independently to analyze and then address the specific human factors that contribute to human error. A closer look at Fig. 1. reveals that the most important leg of the SMS table is the 'Safety Risk Management' leg. As such, it is in the principles of modern risk management that the SMS program was founded on. Within this model is a well-tested, safety process that monitors and contributes to safety, as evidenced by its global use and endorsements by ICAO and the FAA. The Risk Management Process is clearly an effective approach to managing risk. It has proven itself successful over the past 40 years by NASA and the United States military aviation community. In the last 20 years, the entire United States Department of Defense has adopted it. The Risk Management Process consists of 5 important steps as follows: Identify the Hazard, Assess the Risk related to the Hazard, Create a Mitigation Strategy, Implement that Strategy and Assess and Evaluate the process to make changes of improvement.

**SMS and Risk Management.** At the heart of using the Risk Management Process is the simplified Risk Assessment Matrix. One of the biggest reasons for the success of the Risk Management Process is its ability to identify a hazard and take it through a successful mitigation process, which has been proven it its nearly 40 year track record. Even more important is the fact that within the process it has the ability to rate the hazard, through accurate probability, on its level of danger over time, through a standardized scale. It has become a tool for managers to critically analyze hazards, identify which of those are most critical and must be addressed immediately, and those that can be dealt with at a later time. The other advantage of the hazard rating system is that it can be used operationally, on the spot. As a hazard is identified, it can then be quickly analyzed through a standardized matrix, similar to the one used by the United States Marine Corps in Fig. 2 [3]. By using the Risk Assessment Matrix, any individual in an operational organization can quickly rate the severity of a hazard, the probability of it occurring, and then calculate the hazard's risk assessment. By having the risk level analyzed, it allows managers or other personnel to assess the severity of the risk and determine an appropriate course of action.

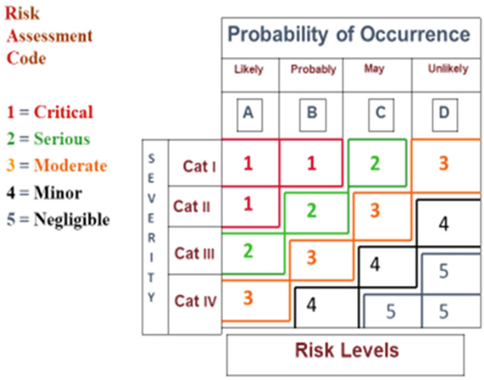


**Fig. 2.** Risk assessment management matrix [3]

**Human Factors to Analyze Human Error is also Needed in Maintenance.** Although the Risk Management process has proven effective at identifying and assessing hazards which pose risks, many aviation maintenance hazards are due to human factors, which ultimately result with errors in maintenance. Additionally, many of these errors are not found in isolation; they are multiple human factors, when linked together result with human error, ultimately working against safe maintenance practices. Numerous research studies have uncovered human error trends in aviation maintenance by examining years of accident investigation data related to aviation maintenance in FAR 121 Operations. According to Rankin [4], the breakdown of these accidents is 20% mechanical failure and 80% human error (to include: aircrew, air traffic control and maintenance personnel). Additionally, Graeber and Marx [5] indicate that human error has led to improper aviation maintenance, contributing to 12% of major aircraft accidents (for FAR 121 Operations) and 50% of propulsion system malfunctions that ultimately resulted in flight postponements and terminations. While 12% may not seem significant, for aviation maintenance operations, this percentage is alarming. The potential for human error in maintenance to directly contribute to an aviation accident, including loss of human life along and the destruction of an aircraft, is evident. Accidents such as these come with a tremendous price tag; a maintenance malpractice suit could easily bankrupt a major carrier. Commercial flight operations in the United States have been operating at the highest levels of safety in the past decade, however, a flurry aviation maintenance mistakes, or substantial increase in the demand for air travel, could quickly change that. According to Hobbs [6], human error in aircraft maintenance not only presents a dangerous hazard to flight safety, but it has the potential to generate significant financial costs related to flight postponements, terminations, alterations, and other schedule interruptions.

**Identifying the Human Factors that Contribute to Human Error.** The issue with human error in aviation maintenance is not that these dangers are not known or that the industry does not want to eradicate this danger from commercial flight. Instead, the problem is how to identify and control the myriad of human factors issues in maintenance, many of which tend to combine together, as if part of the procedure. When this occurs, the chain of errors which results can be disastrous. Aircrew and air traffic control research has helped drive major improvements in the flight process. Technological innovations have made considerable aviation safety improvements, resulting in a reduction of human error and a 40% reduction in aircrew related accidents between 1983 and 2002 [7]. Over the last 30 years, such successful processes like Advanced Crew Resource Management and technology improvements like Ground Proximity Warning System (GPWS), Terrain Collision Avoidance System (TCAS) and Onboard Weather Radar, have vastly reduced human error in the United States in the aircrew and controller environment. But what can be done to likewise reduce human error in maintenance?

**Understanding Human Error in Aviation Maintenance through Human Factors Research.** Looking closer at the research, human error in aviation maintenance tells of a complex story with no easy solutions. Critical evidence from research investigations performed in aviation maintenance found that 34% of regular maintenance tasks were performed incorrectly [8]. Further analysis shows that 38% of human error in aviation maintenance was related to aviation maintenance technical manuals that were used to perform maintenance procedures [9]. In the same study, the researchers were able to break the 38% procedural error from technical manuals down to: omitted information (48%), improper information (19%), difficulty interpreting data (19%), and inconsistent information (14%). The investigation also noted that 28% of the error resulted from the inability of aircraft maintainers to read, understand, or follow the technical manual appropriately. Graeber and Marx [10] noted that a significant number FAR 121 Operations accidents were caused by maintenance and concluded that these types of accidents were also categorized in causation by: omissions (56%), inadequate installations (30%), and incorrect parts (8%).

**Human Factors that Influence Human Error in Aviation Maintenance.** After reviewing much of the research on aviation maintenance-related accidents, it is clear that much of the human error is rooted in the conduct of maintenance itself; the technician either does the task correctly or incorrectly. This begs the question, why is this occurring? Marais and Robichaud [1] have found the environment surrounding maintenance procedures plays a crucial role in causing maintenance errors. Much of this is due to the fact that 90% of maintenance inspection procedures are visual, and often involve a critical sequence of procedures, which must be followed exactly. The investigation found that if aviation maintenance technicians (AMTs) were not provided the appropriate conditions (such as proper lighting), numerous defects in the maintenance process may be missed, resulting in human error and compromised safety. Other research completed by Transport Canada found similar environmental conditions, as well as other contributing factors, which could cause an aviation maintainer to err in their task. During the 1980's, Transport Canada did a great deal of research on human error in aviation maintenance, which ultimately resulted in the formation of the 'Dirty Dozen', the twelve most common contributing human factors that influence human error and contribute to aviation maintenance accidents.

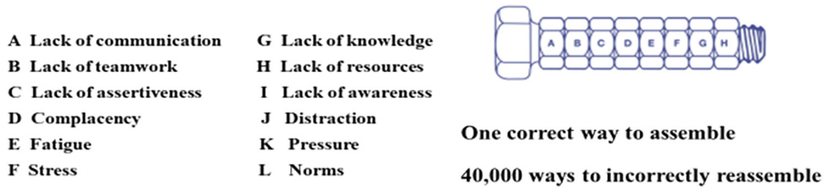


**Fig. 3.** The dirty dozen and 40,000 ways to make an aircraft maintenance error [11].

**Effects of Human Factors like the Dirty Dozen on Aviation Maintenance Human Error.** The illustration in Fig. 3 shows the Dirty Dozen next to a bolt with several nuts on it [11]. It represents an aviation maintenance procedure, making the point that there is only one way to procedurally take the bolts off the nut (one by one). Putting the nuts back on, however, could be done in 40,000 different ways. Each of the nuts could be associated with one of the Dirty Dozen. For example, the nuts should procedurally go back on the bolt in order from A-H, but due to lack of communication, nut A was set aside and nut B was placed on first. Due to lack of teamwork, as the maintainer was working alone, nut B was not placed perfectly to the top of the bolt. Due to lack of assertiveness the oncoming maintainer in the new shift placed nut C behind nut B even though he could see that nut B was possibly not perfectly flush, but was confident that with nut C tight behind it, there would be no problem. As this maintenance procedure continues through the completion of nut H, the human factors associated with the event are compounding, thus increasing the possibility of a human error, and potentially an aviation mishap. The point of the lesson is that any of the Dirty Dozen, along with many other human factors variables, can interfere with aviation maintenance personnel while working, causing any number of maintenance procedures to be completed incorrectly.

**The PEAR Method of Human Factors Analysis for Aviation Maintenance.** To help recognize the danger of potential human factors variables which can contribute to or cause dangerous levels of miscues in aviation maintenance, the FAA devised a maintenance human factors analysis method, in the form of an acronym called the PEAR method [12]. The "P" in the PEAR Model stands for people and all the possible human factors that can affect people, including physiological, psychological, and ergonomic factors that maintainers encounter in their daily tasks. The "E" in the PEAR Model stands for the environment that surrounds the maintainer. The environment includes elements such as temperature and humidity, the amount of light available, the air that is being breathed and noise. Other factors such as pressure to complete a task by a manager is also considered environmental, as is fatigue encountered during the night shift. The "A" in the PEAR model stands for the actions that the maintainer did or did not perform during the conduct of maintenance. Actions become important during the analysis phase given that they relate directly to procedural human error, which has been identified as the leading cause of maintenance aviation accidents. The last letter in the PEAR Model is "R", which stands for maintenance resources. Was proper maintenance equipment and/or tools utilized to complete the task? Most importantly, were the proper parts distributed for the assigned task? Each of the PEAR letters are important because they truly identify relevant human factors which can be linked to human error in maintenance. The issue, however, with the PEAR method, is that it does not optimally address human error. Should the PEAR be used after an accident or incident occurs or should it be used strongly in a prevention role as well? The new SMS system is based on a proactive and preventative safety stance. Perhaps now is the time to introduce a new model for human factors in maintenance using the SMS principles to proactively prevent human error in maintenance by including a form of the PEAR method within an SMS program?

**The REPAIRER Reporting System.** Such a model would seem difficult to design and achieve. However, if the foundation of the design is centered on streamlining and tailoring the SMS model for aviation maintenance purposes so that it can be used efficiently, a new model is feasible. By combining human factors and risk management to an SMS reporting system, both safety and efficiency can be achieved. Utilizing an existing acronym already familiar to maintenance personnel (PEAR), the REPAIRER reporting system is an appropriate place to begin [13].

**The First "R" is all about Rating and Reporting a Hazard.** The first "R" in the REPAIRER model stands for rating and reporting a hazard. In this first step, two critical elements of the SMS are immediately incorporated. A hazard is identified, rated and will be anonymously reported by anyone in the maintenance organization. The identification of a hazard and rating it are foundational SMS Risk Management steps, which can be found in the SMS Risk Management table leg. After the hazard is identified, utilizing a Risk Management Matrix can help managers to quickly assess how dangerous a potential hazard is by giving it a risk assessment value. Hazards with the highest risk assessment ratings should be given priority, as opposed to those with lower risk assessment ratings. Reporting the hazard is another SMS foundational step required under the Safety Assurance table leg. In essence, REPAIRER is first and foremost a reporting system to improve safety and gain opportunities for efficiency in a maintenance organization.

**The 'EPAIR' in REPAIRER Becomes the Human Factors Analysis of the Hazard.** Unlike other SMS reporting systems that simply identify and rate a hazard, REPAIRER requires human factors data to be reported, and is represented in the 'EPAIR' of the REPAIRER acronym. This is the opportunity for ideas found in the original PEAR method to be used in the SMS format, as a human factors analysis maintenance tool. The 'EPAIR' has now become a modified PEAR model within the

REPAIRER system to analyze potential human factors related to the hazard. The "E" stands for the environment that the hazard occurs in. Details of the environment need to be supplied by the person filling out the REPAIRER report. This includes a physical overview of the environment such as lighting and temperature, but also what was occurring within the organizational environment during the time of the hazard. The "P" stands for the people involved. This includes deficient qualifications and any training required to conduct the task. Additionally, any physical, physiological or psychological issues deemed relevant should be included in the report as well. The "A" in the REPAIRER method stands for the actions of the people involved. Because maintenance research points toward procedural problems, in terms of human error in causing maintenance accidents, it is important to identify what the people involved with the hazard did or did not do at this juncture. The "I" in the REPAIRER method stands for the investigation of the proper procedures associated with conducting the maintenance action, noting any shortfalls, as implied or found during the "A" step. This step is critical; it is imperative to know exactly how the incorrect maintenance action was performed, but also how it should have been done correctly. Additionally, there is a chance that the current procedure is either unsafe or inefficient, and therefore must be amended. The next letter in the REPAIRER model is the second "R" for the resources that were required to do the job. If the resources required to complete the maintenance task were inadequate in any way, they need to be reported here.

**Creating a Mitigation Strategy and Reevaluating it.** Once the Hazard has been identified, rated, and analyzed for potential human factors, it then becomes important to complete the next task; the recommended solution using the human factors analysis. With a recommendation in place, it must be continually reevaluated to ensure both safety and efficiency are achieved. Both are critical steps in completing the SMS requirement, given that the mitigation strategy falls under the Risk Management table leg. The reevaluation falls under the Safety Assurance leg. The second "E" in the REPAIRER model is associated with executing mitigation strategies for the identified hazard. At a minimum, the person or persons filling out the report need to make a recommendation. By doing so, the person reporting the hazard will have an incentive to do so, as they will feel part of the solution. The last letter of the REPAIRER model is the third "R" which stands for reevaluating the mitigation strategies after a period of time, to ensure they are working. Whether the mitigation strategy was created by the person generating the report or by others within the organization, it can never be taken for granted that the mitigation strategy is working in the maintenance environment. The final "R" of reevaluation requires some form of an audit or inspection to reassess the significance of the hazard, once the mitigation strategy is in place. If the mitigation strategy is working, no further action is needed. However, if the mitigation strategy needs to be changed or adjusted, this is the opportunity to do so. Once the strategy has been reevaluated, and is deemed completed, no further action is needed. The proper completion of the last "R" is paramount to concluding the REPAIRER process.

**Application.** With the REPAIRER Reporting System created, it is now essential to implement this system in an effort to determine the extent to which safety and efficiency in an aviation maintenance environment could be improved. First, the policy pillar of SMS would be addressed through the identification of the REPAIRER procedures. This would be supported via a departmental authority, such as the Quality Assurance Manager or the Director of Maintenance. Both of these positions provide the appropriate resources as well as authority measures to clearly identify safety policy procedures. Included in the policy would be methods for anonymous reporting. This is an essential component in the successful implementation of the REPAIRER reporting system; for doing so would allow employees at all levels in the organization to report a potential safety hazard, without risk of retribution. One way this could be accomplished would be via a mobile reporting app, many of which are confidential and anonymous; however, the REPAIRER system allows the freedom for organizational authorities to make such decisions as appropriate and fiscally feasible.

After the procedures are written, the SMS Promotion table leg would then need to be addressed. As with any SMS, in order for the policy leg to be supported, it needs adequate support from leadership. The end-state goal would be to create a culture of safety and open reporting, which is founded on the REPAIRER strategy. Given that the strategy is rooted in SMS policies and procedures, which most aviation maintenance organizations currently have in place, minimal training would be needed. After reviewing current safety policies, gaps could be identified between current procedures and the REPAIRER method. Once identified, short videos which explained the new, additional steps could be constructed. The videos would be 2–3 min in length and include employees from all levels of the organization. The videos could be accessed through mobile devices, which would have minimal impacts on workload. Each step could be completed separately, over the course of a week or two. At the end of the training period, a summary video would review the pertinent steps of the REPAIRER method, given again by someone in the organization that employees could relate to. However, this could not be completed without buy-in from leadership at every level in the organization. All managers and supervisors must relate the value created by the REPAIRER strategy to those that must enforce it on a daily basis. This could be done visually or virtually via white boards in the hangar or on the organization's website. In doing so, the technicians could see and track how their daily decisions impact overall safety, the number of accidents, and the fiscal repercussions that result.

Once these last two legs of the SMS table are in place, it would then be of utmost importance to test the REPAIRER Reporting System to determine the extent to which this system enhanced safety and efficiency, while maintaining fiscal constraints. An optimal organization for which the REPAIRER Reporting System to be tested would be small to medium sized aviation maintenance organizations which operated under FAA Part 121 authority.

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# Red or Blue Light? Which One Is Better? Is There a Right Answer?

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**Abstract.** As we all know, by now, light is much more important than we thought. Is our non-visual system that regulates our physiological and biological systems through our circadian rhythm. Spectral properties of light are crucial to our pineal and pituitary glands, the first is responsible for melatonin production, whereas the second one is in charge for adrenalin, noradrenalin, and stress hormones production. There is a link and coordination between pineal and pituitary glands. We must know that spectral qualities of natural is different from artificial light. The present paper aims to study the "do's and dont's" of a lighting design in an indoor space (workplace). To achieve such objective the research will be conducted throughout literature review. We expect to conclude that the right balance should be our major goal, and by doing so we are contributing for our health and wellbeing.

**Keywords:** Red light · Blue light · Pineal · Pituitary gland · Workplace

## 1 Introduction

Our lifetime, nowadays, is spend 90% indoors. Therefore, light, natural and artificial, have a greater impact on our visual and non-visual systems, however they have different characteristics, such as its intensity, colour temperature and spectral composition. In this article, the focus will be the spectral composition of light and how we are affected by it. For instance, red light stops our pituitary gland from producing stress hormones, and at same time, it promotes the pineal gland to produce melatonin.

Firstly, we will talk over the differences between natural and artificial light, especially because daylight has all spectrums, throughout the day, and the artificial light can only have a part of them. Next, we must understand the different needs of our visual and non-visual systems in order to comprehend how the several spectrums affect us. The eye and its ageing also play an important part, so we will talk about it too. After that, we will try to understand about how pineal and pituitary glands function and how they respond due to the light spectrum, namely the impact on oxidative stress and mitochondria. Then, at workplace, the objective is to know how we can counteract some of the adverse effects of light spectrum and how we can help ourselves to keep the balance in order to achieve a better health, wellbeing, and consequently, performance at work.


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### 1.1 Natural and Artificial Light

Earth's atmosphere absorbs and scatters much of the harmful ultraviolet (UV) radiation. One of the major differences of natural and artificial light is its spectrum. Where natural light (visible light) goes from 360 nm to 780 nm, UV range is 295–400 nm and, infrared radiation is over 780 nm (Fig. 1). [1] Different wavelengths influence our visual and non-visual systems in distinctive ways, and both are essential to keep our body and mind in balance. Artificial light and the different lighting systems do not cover all spectrum as natural light does. While daylight varies all over the day, that goes from red to blue (midday) and then to red again. Artificial lighting systems stays the same (spectrum) all day, and night, long.

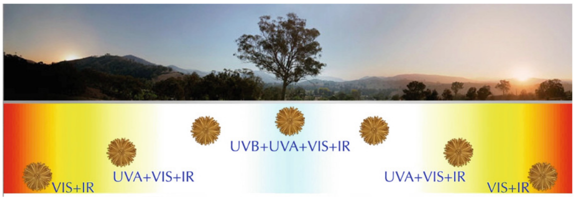


**Fig. 1.** Colours of daylight [2].

In the past, people lived under incandescent lamp at night. Currently, we spend most of our life under artificial light. [3] For decades, incandescent light have been used at home, while, nowadays, at offices we use fluorescent lamps. There are several differences between these two lighting systems, mainly their spectrum, incandescent is mostly red whereas fluorescent (and CFLs, Compact Fluorescents Lamps) is green or yellow. By the way, green spectrum (555 nm) is the best spectrum for our visual performance. [4] Furthermore, the light - emitting diodes (LED) are used today in almost every indoor space. [5] LEDs have a spectral emission in the blue light, around 470–480 nm. However, we should be preferred LEDs (<450 nm) because the blue light from 470–480 nm during a short to medium period (days to a few weeks) do not increase the risk of development of ocular pathologies [6].

### 1.2 Visual and Non-visual System

Consequently, we have to keep a balance between our visual and non-visual necessities. Here, we have to enlighten what the different spectrums of the electromagnetic radiation involve and how they influence our visual and non-visual systems in order to maintain our health and wellbeing. For instance, blue light boosts our non-visual system, but when the dose is too much it disrupts us, altering our circadian rhythm and everything that depends on it. Thus, computers, tablets, smartphone, televisions, which have LEDs can jeopardise our health and wellbeing, since its spectrum (blue) can overwhelm us. When we are exposed for long time in front of a computer, for example, we are augmenting our stress hormones, and simultaneously we are reducing our melatonin (darkness hormone) production. [1, 3, 7] The non-visual functions are located in the hypothalamic suprachiasmatic nuclei (SCN) that regulate and synchronize our biological functions, such as our circadian entrainment, pupillary light reflex, melatonin regulation, cognitive performance, mood, locomotor activity, memory, body temperature, among other functions. [6, 8, 9] It is the intrinsically photoreceptive melanopsin ganglion cells (ipRGCs), that are in the retina, that receive input from our visual photoreceptors (rods and cones) and, then mediates our circadian rhythms. The light in the retina, is then converted into neural signs and sent via the retinohypothalamic tract (RHT) to the SCN (our master clock). Of course, light have many characteristics that have impact on the circadian system like timing, intensity, duration, wavelength and temporal pattern. The different photoreceptors have distinctive peak sensitivities of the light stimulus. [3, 10] Rods operate at low (scotopic light), cones at high (photopic light), and ipRGC (non-visual) is most sensitive to blue light (480 nm) (Table 1). [4, 6] Moreover, the circadian system is not concerned about the distribution of light across the retina, since the angle is more effective when the light enters into the pupil on the lower retina, so the direction of light is another relevant factor. [4] Pupil constriction, the eye's natural defence against exposure to strong light, is wavelength-dependent (peaks at 480 nm). Therefore, we need blue light for our non-visual system (to produce cortisol, and serotonin), we need green/yellow light for our visual system, but we also need red light for our non-visual (melatonin production) balance as well. Moreover, the physiology by which ipRGCs control these functions have not been fully understood and, filtering out any of those light spectrums cannot be the answer for our problems. [3, 11, 12] As we can see, it is not easy to comprehend how this all works completely yet, because there is much more in stake than we could imagine some, not many, years ago.

**Table 1.** Photometric measures for circadian and neurophysiological light responses [11].

| Photoreceptor | Photopigment | Peak sensitivity |
|---|---|---|
| Short-wavelength (S) cones | S-cone photopsin (cyanolabe) | 420 nm |
| Medium-wavelength (M) cones | M-cone photopsin (chlorolabe) | 535 nm |
| Long-wavelength (L) cones | L-cone photopsin (erythrolabe) | 565 nm |
| IpRGC (intrinsic photosensitivity) | Melanopsin | 480 nm |
| Rods | Rhodopsin | 500 nm |

It appears to exist some kind of coordination between all photoreceptors (visual and non-visual), because in the absence of rod and cone function, the light responses are intervened by ipRGCs. Thus, rod and cones in the outer retina can be activated and drive non-visual system. Together, cones contribute to non-visual light system at the beginning of light exposure, but with increasing duration of light, their role diminishes, this happens because ipRGCs are a little bit sluggish, so cones act when ipRGCs are not fully prepared. As a result, non-visual light responses remain undamaged even when ipRGCs are dysfunctional and are only eliminated when rod-cone and ipRGCs are disrupted simultaneously. Even though, the role of cones remains debatable. [3, 13] Furthermore, for this all happens, we need to have a healthy eye.

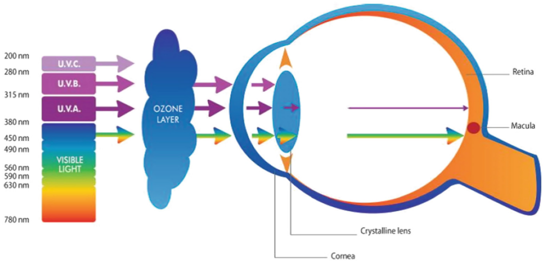


**Fig. 2.** Absorption and transmission of solar radiation in the eye [3].

The eye has some defence mechanism of its own, like the cornea that absorbs 100% of UV-C, almost 90% of UV-B (315–400 nm), and 60% of UV-A (280–315 nm) rays. The UV-A which passes through the cornea, are absorbed by the crystalline lens and only a small portion reaches the retina. However, the cornea and lens do not filter short high energy visible (HEV, 380–500 nm) wavelengths, which reach and are absorbed by the retina and retinal pigment epithelium (RPE). [5, 6, 8] (Fig. 2) Part of the downside comes with ageing, mostly due to the yellowing of the crystalline lens, and because of that the lens transmits less visible light. Early in life, blue is about 20% of the visible light received by the retina, dropping to 14% at 50 years of age and to 10% at 70 years. [1, 3, 7, 8] On the other hand, the yellowing lens protect the retina from blue light, since it blocks it. Interestingly, light history also has an impact, since persons who were more than 5 h a day of summer sun exposure in their teens and 30 s had a higher risk of developing retinal changes suggestive of early age-related maculopathy. For those that used some kind of protection (hat/sunglasses) the risk of early age-related macular degeneration (ARMD) decreased by nearly 50%., for instance. Unfortunately, the antioxidant mechanisms that protect the eye decreases around 40 s. [5] The visible light (400–780 nm) and a 320 nm fraction is transmitted through the vitreous body that reach the receptors of the retina. The macula is where retinal vision deteriorates faster since it is located directly in the focus of an envisioned light source. The antioxidative molecules within the macula (made up of carotenoids: luteus, Latin, means yellowish and gave the name lutea to the macula and zeaxanthin), filters out blue light before it reaches the cones rods, and RPE that protect the retina. Macular pigment molecules are free-radical scavengers; however it decreases with age and natural defenses and repair mechanisms become less effective and can cause oxidative damage. As for the choroid (which is controlled by the concentration of oxygen), damage can occur in the outer segments, which makes it prone to oxidative stress. Lipofuscin (the age pigment) is the chromophore involved in the retinal damage due to the exposure to blue light (where 400–440 nm might be more damaging, since is the most energetic of the visible spectrum which accumulates in the RPE leading to photoreceptors damage). RPE cells are not photoreceptive but are essential to the survival and regeneration of photoreceptors, since they provide nutrients, oxygen, and help maintaining its viability, [3] but they are very sensitive to photo oxidative stress (we will discuss about it later on).

Besides, ageing, not only in the eye, affects our circadian system and an inappropriate entrainment by light can cause a deterioration of sleep and a decrease life quality in the elderly (circadian disturbances, reduced pupil size and increased ocular lens absorption) which in turn, can lead to a decreased retinal illumination. Furthermore, ageing induces a decreased lens transmittance in the elderly in the blue light (400–480 nm). However, the lens density increases between the second and sixth decades of life, and that leads to a 45% and a 42% decrease in transmittance at peak melanopsin sensitivity (480 nm). Even though lens transmittance decreased for blue light, the melatonin suppression did not reduce, instead the peak of non-visual sensitivity shifted to 494 nm in the elderly (484 nm in the young). Therefore, the increased lens filtering does not necessarily lead to a decreased non-visual sensitivity to light on the circadian system and may involve other adaptive mechanisms and retinal plasticity that could serve as a compensative mechanism induced by photoreceptor loss. Ageing is associated with various molecular, cellular and neuronal changes and may affect the rhythmic information transmission by the SCN to other neural locations. Healthy ageing does not necessarily lead to altered sleep and circadian physiology [10].

## 1.3 Blue and Red Light

In order to understand better how red and blue light affect our visual and non-visual systems we will discuss the advantages and disadvantages of both. Exposure to blue light (400–490 nm) leads to photoreceptor death, which is a relevant fact since light has a cumulative effect, thus, some characteristics, namely duration of the exposure, time of day and, especially spectral output cannot be ignored. A higher rate of cell death occurs in lipofuscin fraction (chromophore A2E) in the outer segments. Although, we have some defence mechanisms like rhodopsin, which is located in photoreceptors outer segments (and can be induced by blue light). Fortunately, green light can regenerate the bleached rhodopsin completely, while blue light only regenerates 30%. Thus, we have to have in mind that the duration of exposure also, plays a major role in the damaging effect of light, whereas an intermittent light exposure (series of 5 min) may produce more damage than the same amount of light in single 5 min exposure. [1, 3, 6, 13] Fortunately, RPE cells appears to be concentrated in blue light between 415 nm–455 nm, which may protect the retina, conversely, in doing so reactive intermediate are formed (which can generate radicals), even though without affecting the igRGCs (465–495 nm). Both radical sources, the photoreceptor outer segment with their lipid membranes and the mitochondria can potentiate mutually. [3, 7] On the contrary, blue light can be very useful for treating seasonal affective disorder (SAD) with the use of a light box during the fall and winter months. In dentistry, for example, it can be used for tooth whitening using mainly the blue light and long UV (down to 370 nm), though it can reflect off dental structures and instruments, which can be inadvertently directed to one's eye. [5] For instance, LEDs are used to provide illumination in indoors environs, and although the light emitted appears white, the peak emission in the 400–490 nm and exposure to 470–490 nm (blue light, also) may damage less the eye than to 400–460 nm [6, 8, 9].

In spite of that, we also need to comprehend how the red-light spectrum affect our body and mind, since, for example, it stops the pituitary gland, and so non-visual system is not stimulated. Moreover, a smaller amount of bright light (blue light) in the evening and at nighttime is less probable to disrupt melatonin production. Melatonin, for instance, reduces the risk of breast, ovarian and prostate cancer. [9] The body is more susceptible to environmental stress when parasympathetic system is activated and in times of regeneration, but under the sympathetic more melatonin is released. Red or infrared region (NIR), is also present in natural light, incandescent or halogen lamps, have positive effects on regeneration processes in retinal pathologies, stroke, neuro-trauma, neurodegeneration, memory and mood disorder, pain and wound healing (Table 2) by counteracting the mitochondrial failure. However, there are mechanisms that can help us to counteract the damages of blue light, as low-level light therapy (LLLT), where photoneuromodulation of cytochrome oxidase activity is its main mechanism of action and its primary photoacceptor of light in the red to NIR. LLLT can enhance neural metabolism by regulating mitochondrial function, intraneuronal signaling systems. Moreover, LLLT can use light from lasers or LEDs in the red NIR (600–1100 nm) that modulates biological function or induce a therapeutic effect, known as photobiomodulation, or photoneuromodulation when nerve cells are the aim. The energy doses are too low to cause worries about heating and tissue damage but are high enough to modulate cell functions. While lasers provoke heat and can induce tissue damage, LEDs reduce the risk of thermal damage. Solar energy is multidirectional and non-coherent, while LLLT is monochromatic and allows a higher specificity and targeted molecular biomodulation. Photoacceptors are non-specialized molecules (not integral to light receptor organs) that can absorb light but are more abundant than photoreceptors and can be artificially introduced into living systems. LLLT is like of a chromophore, within a photoreceptor or photoacceptor molecule that can absorb some wavelengths and reflect others. There are two scenarios: several photoacceptors are responsible for this spectral pattern, or a single photoacceptor with absorption peaks at 420–450 nm and 760–830 nm. In the second, all bands match the absorption of the mitochondrial enzyme, and cytochrome oxidase is a crucial enzyme for cell bioenergetics mainly for nerve cells in the retina and brain. Early decreases in brain metabolic activity can be detected in people at risk of developing Alzheimer's disease (AD), due to reductions in cytochrome oxidase activity [12].

**Table 2.** Beneficial in vivo transcranial effects of low-level light therapy on the brain [12].

| Source | Wavelength | Relevance |
|---|---|---|
| Laser | 808 nm | Anoxic, Traumatic brain injuries; Embolic, Ischemic strokes |
| LED | 633, 870 nm | Traumatic brain injury (chronic) |
| Laser | 670 nm | Parkinson disease |
| Laser | 1072 nm | Mild cognitive impairment |
| LED | 810 nm | Depression, prefrontal functions |

Is not so easy to understand how blue and red affect us, is far more complex. For instance, both blue and red light affect cortisol levels at night. Cortisol appear to be controlled by blue and red lights at night, but the response characteristics are not the same. It is not known whether the photic input acutely modulating these biomarker levels is independent of the SCN or whether the SCN response to light is more complex. [14] The photic inputs for synthesis of melatonin by the pineal gland is only affected by blue light whereas cortisol production by the adrenal gland is modulated by both blue and red light. It seems that the sympathetic system has a spectral sensitivity to light broader than the pineal gland response. Nevertheless, a photic pathway to the endocrine and autonomic nervous systems exist other than that responsible for nocturnal melatonin suppression. Melanopsin has a peak sensitivity at 480 nm, but the ipRGC response is skewed towards 490 nm. To simulate sunlight, light bulbs emit most of the wavelengths present in sunlight (full spectrum, without the UV to reduce risk of skin cancer). The circadian system (melatonin pathway) is not the only light-sensitive pathway responsible for alertness at night, and other mechanisms may exist. Blue light in combination with daylight had the greatest positive impact on night-time (05:00 a m.) performance, while red light in combination with daytime darkness had the least positive impact. Light can be used to increase alertness ipRGCs, but are not the only mediator during the daytime, since they are not sensitive to red light [15].

### 1.4 Pineal and Pituitary Glands

It is important to perceive what, how and when blue and red light influence our visual and non-visual systems. There is a coordination between pineal and pituitary (Fig. 3) [16]. The pineal gland has the function to convey light/dark data to the body via night time secretions of melatonin. Melatonin is absorbed into the bloodstream, which is an ideal chemical messenger of time of day information to the body, produced at night under darkness, and appears to be only regulated by the SCN. [4] Circadian disruptions might be an essential role in the progress of health conditions such as cancer (breast, prostate, ovarian, colorectal, melanomas and non-Hodgkin's lymphomas), cardiovascular, gastrointestinal and digestive problems, premature ageing, diabetes, obesity, SAD, and cognitive impairment. [9] When the melatonin concentration is higher, the rate of cancer is lower. The red light stops the pituitary from producing stress hormones and promote melatonin production from pineal gland [17].

On the other hand, cortisol, is one of the steroid hormones produced by the adrenal cortex and participate in the body's homeostasis which increase the production of stress responses (pituitary hormones). [16] Cortisol follow a circadian rhythm more complex than melatonin and may not be linked with day and night but to be tied to the transition periods from dark to light and to a lesser extent, from light to dark. Cortisol levels usually raise in the morning, 30 to 60 min after awakening. The hormones synthesized by the adrenal gland across the 24-h day appear to be controlled by the hypothalamic-pituitary-adrenal (HPA) axis and by the autonomic nervous system through the adrenal medulla. Adrenocorticotropic hormone (ACTH) is released by the pituitary gland, (central part of the HPA axis), necessary for cortisol production and, under ACTH follow an equivalent circadian pattern as cortisol, though average ACTH levels vary with circadian time. Ablation of the SCN eradicates the ACTH circadian rhythm but not the production of corticosterone (both inhibits protein synthesis and degradation). This acute response to light at night occurs by the SCN, possibly through the autonomic nervous system (sympathetic system) innervating the adrenal medulla. The SCN seem to be tied to the HPA and the autonomic nervous systems as they affect glucocorticoid (control carbohydrate, protein, and fat metabolism and have anti-inflammatory activity) production. Although some details about the role of the SCN in modulating the circadian, endocrine, and autonomic nervous systems' responses remain unsolved, SCN might affect the responses from these systems [14].

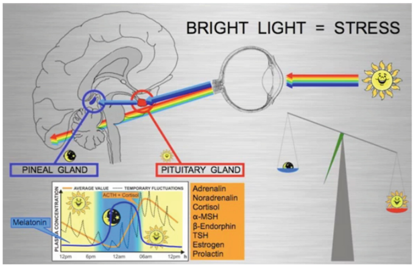


**Fig. 3.** Pituitary and pineal glands [16].

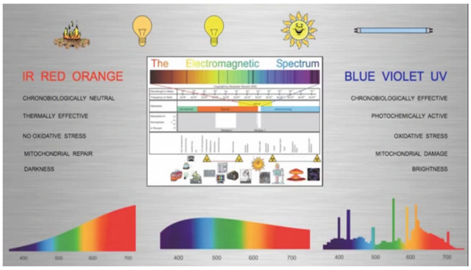


**Fig. 4.** Spectral opponency [16].

## 1.5 Oxidative Stress and Mitochondria

As we can see above (Fig. 4), red and blue light, also, affect our health through oxidative stress and mitochondrial, also. Moreover, ageing is linked with the growth of oxidative damage in several biomolecules, including DNA (deoxyribonucleic acid). Oxidative changes, and ROS, have been observed in diseases, such as cancer, atherosclerosis, diabetes, AD. However, they may be the response to the disease, not the cause. The DNA is constantly being damaged by endogenous and exogenous factors. DNA damage, both to nDNA (nuclear DNA) and mtDNA (mitochondrial DNA, its counterpart) usually prompts a DNA damage response (DDR) which is essential for the maintenance of genomic stability.

First, we will start to discuss about oxidative stress and why and how is related with light spectrum. In every breath we take, 20% is oxygen, which is essential in our lungs to our red blood cells, which deliver oxygen to every cell. Oxidation is the process where oxygen gives cells life by creating energy to support cell functions. The process of oxidation creates free radicals, such as UV light, air pollution or excessive alcohol/drug us, in our cells and in large amount can cause harm in the cells. While, the antioxidants, such as dark chocolate and nuts, tea and coffee or spices can help to regenerate them. Oxidative stress occurs when there is an imbalance in cells and has been implicated in health problems, that leads to cardiovascular diseases, joint disorders, chronic fatigue syndrome, rheumatoid arthritis, neurological diseases (AD, PD and amyotrophic lateral sclerosis), atherosclerosis, lung and kidney disorders, liver and pancreatic diseases, cancer, ageing, lupus, disease of the reproductive system. Moreover, in the eye: cataract, macular degeneration, diabetic retinopathy and retinitis pigmentosa. [3, 18, 19] Oxidative stress can induce expression of DNA repair enzymes such as DNA polymerase in RPE cells, and by doing so mitochondria are capable of repairing oxidative DNA damage to some level. Scarce repair could provoke a dysfunction in oxidative phosphorylation (a reversible change used to change enzyme activity), thus extending a cycle of ROS acceleration on mtDNA damage [17].

To cope with the oxidative stress, cells have developed a ubiquitous antioxidant defense system, which may be overwhelmed by pathological or environmental features so that a fraction of ROS may escape destruction and form the far more reactive hydroxyl radicals. An increase in ROS-elicited oxidative damage to DNA and other biomolecules may impair normal functions of tissue cells and lead to ageing and disease. A sophisticated enzymatic and non-enzymatic antioxidant defence system counteracts and controls ROS levels to maintain physiological homeostasis. The impairment caused by increased ROS is thought to result from random damage to proteins, lipids and DNA, and may be a stress signal that activates specific redoxsensitive signaling pathways, that once activated, may either damage or protect [19].

As for mitochondria, for example, it consumes 3–4 times more energy by photoreceptors than all other retinal neurons or cells in the central nervous system, so are more susceptible to blue light damage. Furthermore, mitochondria are predisposed to oxidative stress and when under stress or pre-damaged by genetic failures, radicals can spread out into the cell. Damage to mitochondrial DNA occurs we get older. Excessive oxidative stress can cause dysfunction in the RPE cells and, ultimately, cell death by apoptosis. Mitochondria may be important because ROS produced in their electron transport chain can injury cellular components. The mitochondrial genome exists in the form of closed double-stranded DNA molecules and may be targeted by exogenous DNA-damaging agents, including light exposure and ionizing radiations or chemical agents and by endogenous factor (mainly ROS). ROS, are not exclusively related to the ageing eye, they are formed inside the mitochondria, but can also be produced by exogenous harmful factors. If the amount of injury exceeds levels that can be repaired, complete depletion of mtDNA occurs. Reactive oxygen and nitrogen species produced during stress (just remember the effect of blue light over a long period of time) may impair vital biomolecules of the RPE cells. Ageing, light exposure, smoking, cardiovascular diseases, unhealthy diet and genes are all involved in the increased oxidative stress and accumulation of lipofuscin in RPE cells. [20] Cultures of primary retinal epithelial cells exposed to visible light (390–550 nm) for up to 6 h had a small loss of mitochondrial activity, the number of lesions diminished in the surviving cells, revealing DNA repair. Light exposure considerably damaged mitochondrial DNA at 3 h. The mechanism by which photosensitization leads to cellular dysfunction is unclear but may center on DNA damage. Significant DNA damage was observed both in mtDNA and nDNA. When kept in the dark (when melatonin, for example, is produced) nDNA did not damaged significantly. Still, mtDNA in RPE cells fed with lipofuscin and kept in darkness revealed a substantial decrease in lesion frequency at all-time. The susceptibility of mtDNA to mitochondria derived from ROS in response to blue light supports a role for visible irradiation in cellular dysfunction which can be be maximal in skin and eyes [17]. There is a brief increase in ROS produced in the mitochondria when they absorb the photons delivered during photobiomodulation (PBM). There must be other type of photoacceptor besides cytochrome c oxidase (CCO) that can produce beneficial effects is some biological scenarios. Wavelengths such as 980 nm, 1064 nm laser, and 1072 nm LED, and even broadband IR light have all been reported to carry out PBM type effects. [11] Reactive oxygen intermediate (ROI) and reactive nitrogen intermediate (RNI) are constantly produced under physiological condition and are essential in living organisms. Thus, ROI and RNI react with proteins, carbohydrates and lipids, resulting alteration in intracellular and intercellular homeostasis, leading to possible cell death and/or regeneration.

The most well studied mechanism of action of PBM centers around CCO, which is one of the mitochondrial respiratory chain, responsible for the decrease of oxygen to water using the electrons generated from glucose metabolism. These absorption peaks are mainly in the red (600–700 nm) and NIR (760–940 nm) spectral regions. When nitric oxide is dissociated, the mitochondrial membrane potential is augmented, more oxygen is consumed, more glucose is metabolized and more ATP (adenosine triphosphate, an chemical in the cells of living organisms that stores energy and releases it when it is necessary) is produced by the mitochondria. [11] PBM by light in the red to NIR (630–1000 nm) using low energy lasers or LED accelerates wound healing, increased collagen production and angiogenesis (the growth of blood vessels that occurs throughout life in both health and disease. Reducing or inhibiting angiogenesis can be therapeutic in cancer, ophthalmic conditions, rheumatoid arthritis, and other diseases), improve recovery from ischemic injury in the heart and decrease degeneration in the injured optic nerve. Effects of red to NIR result, partly, from intracellular signaling mechanisms triggered by the interaction of NIR light with the mitochondrial photoacceptor molecule CCO. NIR-LED PBM is an innovative and non-invasive therapeutic approach for the treatment of tissue injury and disease processes in which mitochondrial dysfunction. [21] Low energy photon irradiation by light in the far red to NIR (630–1000 nm) using low energy lasers or LED arrays has been found to modulate various biological processes in cell culture. The PBM by red NIR at the cellular level has been ascribed to the activation of mitochondrial respiratory chain components resulting in initiation of a signaling which promotes cellular proliferation and cytoprotecton (a process by which chemical compounds provide protection to cells). Moreover, 660–680 nm irradiation rises electron transfer in purified cytochrome oxidase to increase mitochondrial respiration and ATP synthesis in isolated mitochondria and to upregulate cytochrome oxidase activity in cultured neuronal cells. Therefore, PBM with red to NIR increases recovery pathways stimulating cellular viability and restoring cellular function following damage and it is an innovative and non-invasive therapeutic method for the treatment of tissue damage and disease where there is mitochondrial dysfunction. [21] We cannot continue to ignore those facts.

### 1.6 Workplace

The blue light (LEDs) present in our smartphones, tablets, and computer can decrease contrast leading to digital eyestrain, all present at our workplaces and promote fatigue, dry eyes, bad lighting can cause eyestrain, which include sore, irritated eyes and difficulty focusing. Anti-reflective lenses reduce glare and increase contrast and block blue light, yellow glasses, amber or gray distorts colour, and screen filters with yellow tinted lenses reduces the physiological critical light in the chronobiological band. While, CFLs have mainly green spectrum, which are the best option for our visual system. However, we need blue light (LEDs) for our non-visual system. Unfortunately, incandescent and halogen lamps have been discontinued and we need them for our non-visual balance. Moreover, people, in general, who require medications, such as birth control pills, tranquilizers and suffer from lupus or myalgic encephalomyelitis, should use UV protection due to the increased light sensitivity since they cannot bear “blue” light, CFL or other [1, 3, 5, 6, 8, 9].

### 1.7 Conclusions

The non-visual effects of light should be a concern in the design and operation of environments. [22] There are different views about if we know enough about the circadian system to design biologically-effective lighting systems. [15] Science and engineering rely on accurate measurement. IpRGC and their role in setting physiological and behavioral state, has revealed that current methods of light measurement are incomplete. [22] Additional studies on the safety of long-term exposure to low levels of blue light are needed and it is essential to consider the spectral output of LEDs to minimize the danger. [6] Brain disorders will become one of the most vital medical applications of light and with ageing together with ever lengthening life spans, that dementia, AD and Parkinson’s disease (PD) will become a global health problem and we have to learn how to deal with it intelligence. [11] Red light could help us to balance, or at least, minimize the adverse effects of blue light.

### 1.8 Discussion

In sum, LEDs used in LLLT are red and NIR (spectrum). So, if we cannot abuse of blue due to our eyes health and non-visual stability. Why don´t we create/adapt LEDs which can change it spectrum during the day? In that way, we should keep our visual and non-visual needs balanced. Yes, we don´t have many certainties, scientifically, but we already known that during the morning we need more blue light and at night red light is essential. At workplaces, it is already possible to change light intensity and colour temperature, but they only changes/alters our mood. It is light spectrum that activates, promotes, interrupt and stop our hormones production, thus, we need that lighting systems and sources change because if not our health, wellbeing and productivity are in jeopardy. The two spectrums, red and blue, especially, have good and bad sides. There is not a right answer, and what we really need is a right balance.

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# Development of Proactive Safety Behaviour Scale Within the Work Driving Context

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**Abstract.** This study explores an alternative approach to managing safety issues within the work driving setting by developing and piloting a measurement tool that examines proactive safety behaviours among work drivers. A systematic literature review was conducted to develop the construct and items for the survey, which is then assessed using an expert panel ($n$ = 5) and piloted with a sample of work drivers and supervisors involved in fleet-related activities ($n$ = 37). Principal component analysis produced six internally consistent factors that reflect: protection of other drivers and fixing issues, volunteerism/helping, noticing and reporting, safety voice, problem prevention and feedback inquiry. Investigating a proactive approach in managing risks while driving for work could provide a practical contribution to the field of work driving safety.

**Keywords:** Proactive safety behaviours · Safety management · Occupational safety · Work driving safety · Organisational behaviour · Traffic psychology · Road safety

## 1 Introduction

Road trauma has been identified as the leading cause of work fatality in Australia [1]. From 2002 to 2013, two-thirds of deaths in the Australian workforce involved a vehicle incident on public roads or worksites [1]. Other industrialised countries face similar issues. Data analysis conducted by the European Agency for Safety and Health at Work revealed that road trauma accounts for 29% of worker fatalities throughout Europe [2]. In the US, nearly a quarter of fatal work injuries occurred on the road in 2014 [3].

Given that road trauma is a common cause of work fatality in Australia and overseas, it is important for organisations and researchers to continually look for ways to improve employees' safety while driving for work. This research aims to provide an alternative approach to managing safety issues in the work driving setting by


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developing and piloting a measurement tool that intends to provide a series of lead indicators to work driving safety.

### 1.1 Background

Previous research has identified that most risk management approaches to work driving safety involve addressing safety issues after incidents have occurred [4, 5]. This approach is reactive and limited to the analysis of information post-incident, resulting in a superficial antidote to managing risks while driving for work [5]. In order to make meaningful improvements in work driving safety, it is important to focus beyond crash analysis, incident management and passive compliance with driving safety procedures. Organisations should strive to create a work environment where employees actively participate in the management of their safety, particularly when driving for work. In contrast to primarily focusing on crashes, driving-related injuries and traffic offences, organisations should promote and encourage "proactive safety behaviour" in the workplace to improve work driving safety.

Researchers within the occupational health and safety field developed the concept of proactive safety behaviours [6–8] using studies on contextual performance, organisational citizenship behaviours and work proactivity literature [9–11]. Essentially, these concepts suggest that there are certain work behaviours that may not be explicit in job descriptions or may not necessarily have a direct impact on the company's products or services, but these behaviours still contribute to the success of the organisation. For instance, firefighters must perform rescue operations (a necessary work task) but they may also pick up a shift when their co-workers are unwell (a behaviour that influences the broader work environment) [9]. Some researchers suggest that these contextual work behaviours are essential in the success and performance of organisations, especially when increased competition and economic challenges (e.g., downsizing) demand companies to perform better [9]. Team members' adaptability and willingness to exhibit extra effort contributes to the success of the organisation in the longer term.

Another source of research when investigating proactive safety behaviours is the work proactivity literature (e.g., [10, 11]). General proactive behaviours in the workplace are conceptualised as: self-stating, change-oriented and future-focused. These elements suggest that proactive behaviours are self-initiated rather than enforced [11]. Employees who exhibit high levels of proactive behaviours enact and drive change within the organisation. Being future-focused also suggests that proactive behaviours involve anticipating and thinking ahead, rather than reacting to the current situation.

### 1.2 Proactive Safety Behaviours

Within the traditional models of safety, accidents and injuries are often seen as a measure of occupational safety performance [12]. However, these measures are ineffective indicators of safety performance because accidents and injuries only reflect occurrences of failure [5]. These events are also relatively infrequent, and most times, the information gathered from these events is retrospective and sensitive [5].

Instead of focusing on these lagging indicators, other researchers have conceptualised safety performance in a different manner. Griffin and Neal proposed two components of safety performance: safety compliance and safety participation. Safety compliance refers to the compulsory behaviours that individuals must perform in order to meet the minimum requirements of safety in the workplace (e.g., wearing protective clothing and adhering to safety procedures) [7]. On the other hand, safety participation refers to behaviours that go beyond these minimal safety requirements. These behaviours may not directly contribute to the worker's personal safety, but instead assist in developing an environment that supports safety [7]. Safety participation are voluntary in nature and usually involve helping co-workers, promoting safety programs within the workplace, demonstrating initiative, and putting effort into improving safety in the workplace [7].

Research by Hofmann, Morgeson, and Gerras on safety citizenship behaviours expanded the construct of safety participation [14]. Using the dimensions studied within the organisational citizenship behaviour construct, Hofmann et al. (2003, p. 171) coined the term "safety citizenship behaviours" to describe the extra-role behaviours that employees carry out to improve the safety of their work environment. While safety participation is unidimensional in nature, Hofmann et al.'s research on safety citizenship behaviours provided a higher-order construct of these "extra-role" safety behaviours, which includes: helping, safety civic virtue, initiating safety-related change, voice, stewardship and whistle-blowing [14].

The concepts of safety participation and safety citizenship behaviours, along with the research on contextual performance, organisational citizenship behaviour and work proactivity underpins the construct of proactive safety behaviours. Proactive safety behaviour as a measure of safety performance is gaining more popularity within the general occupational and health safety research [6]. Curcuruto and Griffin argued that workers need to have a proactive role in safety promotion, and they must work together with their co-workers and managers in order to make meaningful improvements in workplace safety [6]. A way to have a proactive role in safety promotion is to engage in proactive safety behaviours, such as voicing concerns when safety issues arise, giving suggestions during meetings, correcting unsafe procedures and reporting unsafe and risky situations to management.

When applied in the work driving context, the concept of proactive safety behaviour refers to the positive actions that employees perform in order to prevent vehicle-related crashes and unsafe practices at work. These behaviours help create a work environment that emphasizes work driving safety as an important component of everyone's job. These behaviours are self-starting and change-oriented with the aim of improving current work driving safety practices.

### 1.3 Current Study

Employees should be empowered to participate in the decision-making processes that take place when conducting risk management for work driving safety. If workers are given the opportunity to participate in shaping the organisation's safety systems, workers can advise, suggest and request improvements and help develop strategies that prevent work driving crashes and injuries in a timely and cost-effective manner. Being proactive in safety has been associated with reduced safety incidents and injuries, better incident reporting attitudes and improved health outcomes (e.g., [6, 7, 15, 16]).

Research has also found that engaging in proactive safety behaviour is more effective at improving safety outcomes in the longer-term (measured by reduced accidents and workplace injuries) compared to merely complying with safety rules and regulations (e.g., [16–18]).

A major component of the current study is to understand the positive and proactive behaviours that work drivers and their supervisors perform in order to ensure employees' safety while driving for work. The study of proactive safety behaviours offers an alternative perspective on work driving safety management as it focuses on positive behaviours that work drivers could perform in order to ensure their safety while driving for work. This study is based on the perspective that instead of focusing on the absence of crashes and traffic offences as a sign of safety, organisations should be aiming to realign their strategies to promote ownership of safety and encourage positive proactive safety behaviour to maximise work driving safety benefits. Therefore, the aim of this research is to develop and pilot a new measurement tool for proactive safety behaviours within the work driving context.

## 2 Methodology

### 2.1 Systematic Literature Review and Expert Panel

The development of the measurement tool for proactive safety behaviours within the work driving setting followed the steps suggested by Hinkin [19]. According to Hinkin, scale development typically follows two approaches: deductive development and inductive development [19]. In the deductive approach, the theory informs the development of the scale (top-down). This approach requires a thorough and extensive understanding of the phenomenon being studied in order to inform the initial generation of the survey items [19]. The inductive scale development, on the other hand, does not follow a theoretical foundation and requires researchers to use qualitative approaches in order to generate items for the survey [19]. For the current research, the deductive approach was utilised.

A systematic literature review was conducted to inform the development of the theoretical construct and to assist in developing the items for the survey. Various databases were used to investigate relevant literature on safety citizenship, safety participation, extra-role safety behaviours and safety proactivity. Previous measures that were developed under these concepts were reviewed (e.g., [7, 8, 20]). The items from these measures were then adapted to suit the work driving context. The scaling method used for this survey was a 5-point Likert type scale to determine the likelihood that work drivers would perform these behaviours.

From the review, it was identified that proactive safety behaviours in the work driving context could involve six key behavioural indicators:

- *Problem prevention* – acting to prevent the re-occurrence of challenges and barriers to safety while driving for work.
- *Stewardship* – helping co-workers to ensure their safety while driving for work.
- *Voice* – speaking up when employees have work driving safety concerns.

- *Volunteerism* – volunteering to carry out activities that are not formally part of their job as well as helping and cooperating with others to ensure the safety of other employees while driving for work.
- *Change of organisational policies and procedures* – taking initiative to change the organisational policies and procedures with an aim to improve the safety of work drivers.
- *Feedback inquiry* – explicit verbal requests for feedback regarding the employees' safety behaviours while driving for work.

After developing the items for the survey, experts in fleet safety and occupational safety, as well as managers and supervisors of work drivers, were approached to take part in an expert panel. Five participants agreed to examine the survey in this capacity. Data was collected via email communication ($n$ = 2) and the online survey platform, Qualtrics ($n$ = 3). The items were checked for the clarity of wording (1 – not clear to 5 – very clear) and content (1 – low content validity to 5 – high content validity). Experts were also requested to provide comments on each item and a general comment regarding the dimensions. These comments were considered, and changes were applied to the existing items (e.g., minor changes in wording and sentence structure).

### 2.2 Pilot Study

To establish the validity and reliability of the newly developed survey of proactive safety behaviour within the work driving context, the questionnaire was piloted using two organisations that operate vehicle fleets. Data was collected online using the Qualtrics survey platform. The link to the survey was sent to the email of the organisation contact. Initially, 67 participants started the survey but only 37 fully completed the study. Two participants indicated that they are not eligible for the study, four participants stopped at the 3rd question and the remainder of the incomplete data ranged from 2% to 87% completion. It is likely that the length of the survey, which initially took approximately 30 min to complete, may have deterred the participants. The following results only report data from the completed surveys based on $N$ = 37 respondents.

## 3 Results

### 3.1 Participant Demographics and Work Driving Exposure

The majority of participants in the sample reported driving for work between 1 to 10 hours perweek (91.9%) and were driving up to 10,000 kilometres per year (86.5%). More than half (64.9%) of participants reported having held their driving licence for more than 20 years. The majority of participants in the sample reported driving for work between 1 to 10 h per week (91.9%) and was driving up to 10,000 kilometres per year (86.5%).

### 3.2 Data Analysis

A series of principal component analysis (PCA) with varimax rotation was conducted to determine the factor structure of the survey and to reduce the items. However, due to the small sample size, the initial results from the PCA was interpreted with caution. The items developed for volunteerism and the items developed for change of organisational policies and procedures seemed to be converging into a single factor structure. The research team decided to remove the items created for the change of organisational policies and procedure given that this factor may be more likely to act as a higher factor structure that encompasses the other factors. When these items were removed, the KMO test of sampling adequacy was .23 and a significant Bartlett's test, $\chi^2$ (561) = 1459.94, $p < .001$.

A second PCA with varimax rotation was conducted to assess the remaining items. Initially, 8 factors were extracted. However, items were deleted one by one (e.g., highly-correlated items). Items were retained if they have strong factor loadings, small cross-loadings and if the item provides a meaningful and useful contribution within the factor. The final factor analysis demonstrated 6 components with an Eigen value of >1. The KMO was .56, which is acceptable, and the Bartlett's test of sphericity was significant, $\chi^2$ (253) = 915.65, $p < .001$. As shown in Table 1, all extracted factors had reliability scores above Cronbach's $\alpha$ of 0.70, which is an acceptable measure for a scale's internal consistency [21]. Cumulatively, the overall factor structure accounted for 82.9% of the total variance.

**Table 1.** Results from the final principal components analysis with varimax rotation

| Factor label and items | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| *Factor 1 – Protection of other drivers and fixing issues (6 items)* | | | | | | |
| I go out of my way to look out for the safety of other drivers | .89 | | | | | |
| I take action to protect other drivers from risky situations | .86 | | | | | |
| I encourage new drivers to follow safe working procedures | .69 | | | .45 | | |
| If I see something unsafe, I go out of my way to take care of it | .69 | | .41 | | .40 | |
| I fix safety issues that relates to work driving even if it is not my responsibility | .67 | | | | .32 | -.38 |
| I inform other drivers that violations of safety procedures will have negative consequences | .60 | | .31 | .37 | | |
| *Factor 2 – Volunteerism/Helping (4 items)* | | | | | | |
| I volunteer to help other drivers with their work safety driving responsibilities | | .93 | | | | |
| I volunteer to help other drivers learn more about safe work driving practices | | .92 | | | | |

(*continued*)

**Table 1.** (*continued*)

| Factor label and items | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| I assist my co-workers to help them drive safely | | .85 | | | | |
| I volunteer to educate work driving safety procedures to new drivers | | .84 | | | | |
| *Factor 3 – Noticing and reporting (4 items)* | | | | | | |
| If I notice a defect in the vehicle I am driving, I take an appropriate action by notifying my supervisors or completing paperwork | | | .91 | | | |
| When I see a vehicle that needs maintenance, I inform my supervisors or the appropriate person about it | .31 | | .87 | | | |
| If I see my co-workers doing something risky while driving for work (e.g., using their mobile phone or speeding), I talk to them about the hazards of their risky behaviours | | | .73 | | .32 | |
| I would intervene if I see a co-worker doing something unsafe while driving for work | | | .64 | | .46 | |
| *Factor 4 – Safety Voice (3 items)* | | | | | | |
| I communicate my views about work driving safety issue, even if others would disagree | | .30 | | .90 | | |
| I speak up on work driving safety matters even if others might disagree | | | | .88 | | |
| I speak up about safety concerns during team meetings or toolbox talks | | .36 | | .80 | | |
| *Factor 5 – Problem Prevention (4 items)* | | | | | | |
| When driving for work, I plan extra journey time and breaks for bad weather, traffic congestion, etc | | | | | .82 | |
| I resolve problems in ways that reduce risks associated with driving for work | | | .38 | | .75 | |
| I implement solutions to solve safety issues that relate to driving for work | | | | | .70 | |
| When I see a potential work driving safety hazard, I do my best to fix it | .44 | | .42 | | .63 | |
| *Factor 6 – Feedback Inquiry (2 items)* | | | | | | |
| I actively seek feedback from my co-workers and passengers about my work driving | | | | | | .87 |
| I actively seek feedback from my supervisor about my work driving | | | | | | .83 |
| Percentage of variance explained after rotation (%) | 17.4% | 17.1% | 14.7% | 12.9% | 12.2% | 8.8% |
| Alpha reliability coefficient (α) | .90 | .96 | .89 | .96 | .80 | .81 |

# 4 Discussion

The current study developed and piloted a questionnaire to measure proactive safety behaviours among the work driving population. While research on general occupational health and safety is already focusing on proactive safety management, research and practice in work driving safety is lagging behind [5]. Therefore, this study aimed to apply the construct of proactive safety behaviours within the context of work driving safety.

When applied in the work driving context, the concept of proactive safety behaviour refers to actions that employees perform in order to prevent vehicle-related crashes and unsafe practices at work. These behaviours help create a work environment that emphasises work driving safety as an important job component. In the current study, the final principal component analysis demonstrated 6 factors, reflecting protection of other drivers and fixing issues, volunteerism/helping, noticing and reporting, safety voice, problem prevention and feedback inquiry. The results of the principal component analysis showed that, generally, most items remained within the hypothesised factors. For instance, the items for volunteerism/helping, voice and feedback inquiry were originally written for these factors. However, items written for the stewardship and problem prevention subscales were mixed. Examination of the factor structures showed that Factor 1 reflects protection of other work drivers and fixing issues, Factor 3 reflects noticing safety issues and reporting them whereas Factor 5 reflects general problem prevention. The change of organisational policies and procedures were removed from the principal component analysis as it was thought that it may indicate a higher-order factor.

## 4.1 Limitations and Future Studies

There were a number of challenges that were encountered during the pilot study, particularly in regard to recruitment of participants. While it is acknowledged that the survey was lengthy, it was necessary to initially retain all questions given that this pilot study was testing the stability and structure of a new measure. Future studies will use the results from the pilot study with fewer items. It is hoped that this streamlined, briefer version of the survey will encourage more individuals to participate in future studies based on this instrument.

## 4.2 Conclusion

The current project is motivated by the significant issue of work-related road crashes which result in fatalities and serious injuries. Furthermore, there is currently a lack of evidence regarding the identification of leading indicators for safety performance among the work driving population. The current project aims to make a practical contribution in the work driving safety field by developing a measurement tool that could examine these behaviours in the workplace and by investigating how organisations can engage their work drivers and management to be more proactive in managing risks while driving for work.

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# Analysis of the Influence Factors Affecting Campus Security Based on SEM Model

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**Abstract.** Conducting safety education lectures and distributing questionnaires to students, teachers and administrators are measures needed to improve the safety awareness of college students and promote safe behavior of students. This paper uses statistical data analysis software package SPSS17.0 to analyze and verify the collected data, using structural equation model (SEM) and confirmatory factor analysis. The paper investigate the factors influencing college students' safety awareness, reveals the influence of various factors and the present situation of students' safety consciousness. The results showed that the overall score index of safety awareness of students, teachers and administrators in a certain university is 75, therefore the overall level of students' safety consciousness is relatively good. Results of the study supports the implementation of safety environment and safety culture for colleges, in order to improve the safety management of college leaders.

**Keywords:** Safety consciousness · Questionnaire survey
Data statistical analysis (SEM) · Structural equation model · Factor analysis

## 1 Introduction

Security and development are eternal topics in human life, security development is an important guarantee for social and economic development. In recent years, China's education has developed rapidly, and the number of students in colleges and universities has increased year by year, and campus safety has become one of the leading and front-line teachers and their concerns. As a result, the country paid more attention to the human factor and the safety evaluation project was set up in the scientific and technological research project of the eighth Five-Year Plan in 90s [1]. With the Development of behavior Safety Management and behavior decision Theory, the research on the related problems of the complex system theory and the application of the Internet of things in the security management system [2], the Management Mechanism of Behavioral Safety is not only the guarantee of safe production in Enterprises, it is also an important foundation for the orderly living of teaching students in colleges and universities.


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The security consciousness of college students refers to the sum of the psychological process of cognition, emotion and will of students, things and environment in their academic life. In domestic research, Qian Liu, a Chinese scholar, concluded that safety science is the relationship between safety system and system safety, and explores the general rule of accident occurrence, prevention and control [3]. Through in-depth study, it is found that in most campus accidents, students have a weak sense of security. By analyzing the factors that affect campus safety and the applicability of grey relational theory in campus safety evaluation, Zu-xun Pei has obtained the characteristics of coupling between campus safety and grey system theory [4]. Li-xin Zhou and others stressed that the safety problem of colleges and universities are not only a problem of the school itself, but also a problem of the whole society, which needs the attention, support and maintenance of the whole society.

In the foreign research, Borgohain et al. [6] have reviewed all the security problems existing in the Internet of things and analyzed the possible safety and privacy problems faced by the end users in the Internet of things transmission process, and analyzed the Countermeasures for security defects. Hu et al. [7] in order to prevent the theft of campus events, the campus intelligent security solutions to campus security, based on in-depth analysis of networking technology is put forward on the school should realize the campus security system based on Internet of things as soon as possible, to provide a good learning environment for students learning life; Li et al. [8] put forward a campus safety framework based on geographic information system (GIS). It will organize all existing security facilities and human factors in a geographical model and use ArcGIS software as the two development platform to build spatial analysis module.

In view of this, in order to study the safety consciousness of college students in depth, the author sets out from the point of view of person, material and environment which may affect the safety consciousness of students, by compiling and distributing questionnaires on the factors affecting students' campus safety awareness and collecting data, and by structural equation model(SEM). Using quantitative and qualitative methods to analyze and study the safety consciousness of employees and its influencing factors, in order to enhance and strengthen the safety awareness of employees, prevent and control the occurrence of unsafe behavior of employees, ensure the safety of students' study and life [9].

## 2 Design of Investigation Scheme

### 2.1 Questionnaire Design

Using SEM model to analyze the influencing factors of College Students' safety consciousness from the aspects of people, objects and rings, and divide the influencing factors of safety consciousness into 4 latent variables: Student's self-quality, campus safety management team construction, campus environment and social environment. Among them, the students' self-accomplishment ($\eta_1$), campus environment ($\eta_2$) and campus safety management team construction ($\eta_3$) are the endogenous latent variables of the model, and the social environment ($\xi$) is the exogenous latent variable of the model. Based on this, 20 observation index variables that may affect employee safety awareness are designed, as shown in Table 1. The questionnaire adopted the Likert five subscale method. In terms of scale, 5 levels were set up: score 1 means nothing, score 2 indicates very low, score 3 indicates low, score 4 indicates high, score 5 indicates very high, see Table 2.

**Table 1.** Observation index variable table

| Latent variable | Symbol | Observation index variable |
|---|---|---|
| Students' own accomplishment | $A_1$ | Understanding of the hidden dangers of safety |
| | $A_2$ | Level of safety education |
| | $A_3$ | Understanding of the security regime |
| | $A_4$ | Emotional academic stress |
| | $A_5$ | Concern about group events |
| School environment | $A_6$ | Leaders' concern for violations |
| | $A_7$ | Leaders attach importance to Campus Safety |
| | $A_8$ | Campus safety culture atmosphere |
| | $A_9$ | Degree of perfection of campus facilities |
| | $A_{10}$ | Students' support for Campus Management |
| Social environment | $A_{11}$ | Cognitive level of Internet Fraud |
| | $A_{12}$ | Family members' concern for security |
| | $A_{13}$ | The attention of the personnel outside the School to the Security |
| | $A_{14}$ | Campus perimeter security |
| Construction of Campus Safety Management team | $A_{15}$ | Counselors' ideological education |
| | $A_{16}$ | Leadership control of major hazard sources |
| | $A_{17}$ | Frequency of safe learning in schools |
| | $A_{18}$ | Comprehensive level of fire protection facilities on campus |
| | $A_{19}$ | The perfection of School Safety rules and regulations |
| | $A_{20}$ | campus security quality |

## 2.2 Questionnaire Design

A total of 300 questionnaires were issued with a simple random sampling survey, of which 254 effective questionnaires were effective, with an effective rate of 84.7%. The number of students, teachers and managers was 222, 24, and 8, and its composition was shown in Fig. 1.

**Table 2.** Likert five component table

| Measurement scale | Nothing | Very low | Low | High | Very high |
|---|---|---|---|---|---|
| Value | 1 | 2 | 3 | 4 | 5 |

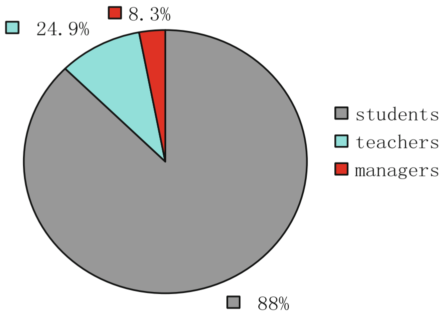


**Fig. 1.** Composition of the respondents

### 2.3 Data Reliability Test

In this paper, through statistical analysis software SPSS17.0, the reliability of all data in the questionnaire is tested, and the test results of Cronbach's reliability coefficient are shown in Table 3.

**Table 3.** The overall Cronbach's reliability coefficient analysis results

| Reliability statistics | |
|---|---|
| Cronbach's reliability coefficient | Number of items |
| 0.885 | 20 |

The overall Cronbach's reliability coefficient analysis results in Table 3, the overall Cronbach's reliability coefficient is 0.885 greater than 0.7, indicating that the overall reliability of the questionnaire is higher. The reliability of each latent variable in the questionnaire is tested and analyzed. The results are shown in Table 4.

**Table 4.** Cronbach's reliability coefficient analysis

| Latent variable | Number of measurable variables | Cronbach's reliability coefficient |
|---|---|---|
| Students' own accomplishment | 5 | 0.729 |
| School environment | 5 | 0.778 |
| Construction of Campus Safety Management Team | 6 | 0.829 |
| Social environment | 5 | 0.637 |

We can see from Table 4, the social environment factors of Cronbach's reliability coefficient is less than 0.7, reliability is not high, the reason is: (1) the external social environment in the process of complex factors, design the questionnaire topic is difficult to fully consider (2) in the course of the investigation, freshman to understand some of the design the problem may be ambiguous. The above reasons lead to the lack of credibility, but the reliability coefficients of these four latent variables are all greater than 0.5, indicating that the design measures are reasonable.

### 2.4 Data Validity Test

The validity of the data was tested by structural validity. The structure validity of the data is tested by using the fitting of the model of the confirmatory factor analysis. The applicability test of the factor analysis module in SPSS17.0 is used, and the results are shown in Table 5.

**Table 5.** Results of KMO and Bartlett's Test

| Inspection of KMO and Bartlett | | |
|---|---|---|
| Kaiser-Meyer-Olkin measure | | 0.882 |
| The sphericity test of Bartlett | Approximate chi-square | 1775.818 |
| | df | 190 |
| | sig | 0.000 |

The validity of the data was tested by structural validity. The structure validity of the data is tested by using the fitting of the model of the confirmatory factor analysis. The applicability test of the factor analysis module in SPSS17.0 is used, and the results are shown in Table 5.

## 3 SEM Modeling and Analysis

### 3.1 Construction of SEM Model

According to each latent variable and observation variable, the measurement equation and the initial model of structural equation are constructed, the structural equation is

$$\begin{bmatrix} \eta_1 \\ \eta_2 \\ \eta_3 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ \beta_{21} & 0 & \beta_{23} \\ \beta_{31} & 0 & 0 \end{bmatrix} \begin{bmatrix} \eta_1 \\ \eta_2 \\ \eta_3 \end{bmatrix} + \begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \gamma_3 \end{bmatrix} \xi + \begin{bmatrix} \zeta_1 \\ \zeta_2 \\ \zeta_3 \end{bmatrix} \quad (1)$$

Among them, $\zeta$ and $\eta$ are exogenous and endogenous latent variables of the observed variables x and y, respectively. The effect of $\beta_{23}$, $\beta_{21}$ and $\beta_{31}$ on endogenous latent variables, $\gamma_i (i = 1, 2, 3)$ indicates the effect of exogenous latent variables on endogenous latent variables, and $\zeta_i (i = 1, 2, 3)$ represents the error term of endogenous latent variables.

The measurement equation of endogenous latent variables is:

$$A = \Lambda_y \eta + \varepsilon \tag{2}$$

$\Lambda_y$ is composed of $\lambda_i (i = 1, 2, \ldots 12)$, which indicates the path coefficient between the endogenous latent variable and the endogenous observation variable, and $\varepsilon_i\ (i = 1, 2, \ldots 15)$ represents the error term of the endogenous observation variable.

The measurement equation of exogenous latent variables is:

$$\begin{bmatrix} A_{11} \\ A_{12} \\ A_{13} \\ A_{14} \end{bmatrix} = \begin{bmatrix} 1 \\ \alpha_1 \\ \alpha_2 \\ \alpha_3 \end{bmatrix} \xi + \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \\ \delta_4 \end{bmatrix} \tag{3}$$

$\alpha_1$, $\alpha_2$, and $\alpha_3$ respectively represent the path coefficients between exogenous and exogenous variables, and $\delta_1$, $\delta_2$, $\delta_3$, and d represent the error terms of external observation variables.

LISREL software is used to build the model. The method of maximum likelihood estimation is used to standardize the path coefficient. The result is Fig. 2.

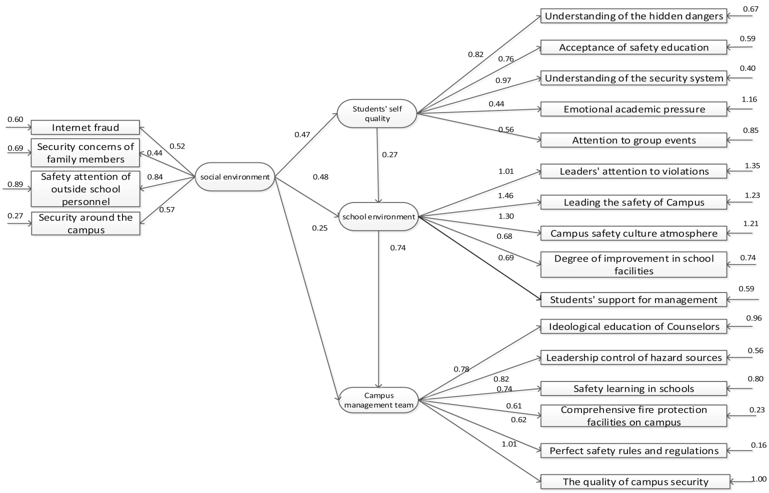


**Fig. 2.** Standard estimation for SEM path diagram

### 3.2 Global Fitting Evaluation of Initial SEM Model

$\chi^2$/df, RMSEA, CFI, NFI, IFI and other parameters were selected to test the fitting effect of the model. After the LISREL software operation, the SEM model can be used to estimate the parameters of the parameters of each goodness of fit index, as shown in Table 6.

**Table 6.** Initial SEM model fit index

| Index of goodness of fit | $\chi^2/df$ | RMSEA | CFI | GFI | IFI |
|---|---|---|---|---|---|
| Estimated value | 3.302 | 0.095 | 0.93 | 0.92 | 0.93 |
| Fitting standard | [2, 3] | $\leq 0.08$ | $\geq 0.9$ | $\geq 0.9$ | $\geq 0.9$ |

### 3.3 SEM Model Modification

The modified exponential method is used to modify the initial model. The path with larger MI value is selected to adjust and the theoretical analysis is combined with the practice to increase the corresponding free path. The modified model path is shown in Fig. 3.

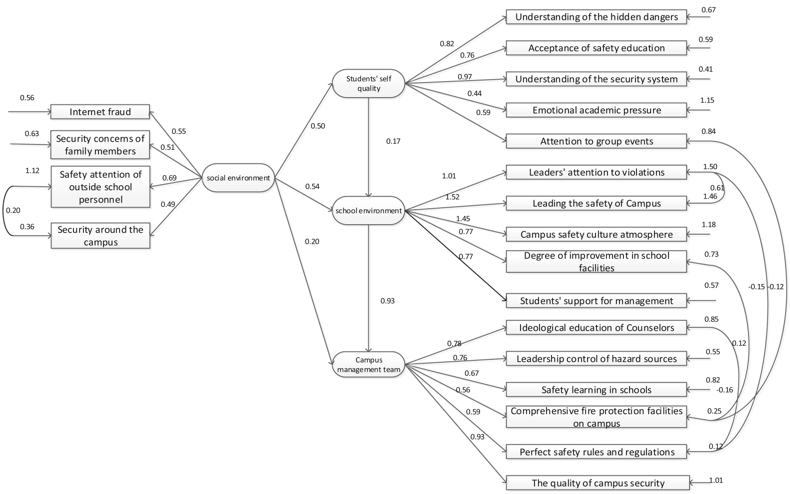


**Fig. 3.** Modified SEM path diagram

The parameter estimation of the modified SEM model is carried out, and the parameters of the parameters of its goodness of fit index are obtained (Table 7).

**Table 7.** Results of goodness of fitting index for revised SEM model

| Index of goodness of fit | $\chi^2/df$ | RMSEA | CFI | GFI | IFI |
|---|---|---|---|---|---|
| Estimated value | 3.302 | 2.533 | 0.078 | 0.96 | 0.95 |
| Fitting standard | [2, 3] | [2, 3] | $\leq 0.08$ | $\geq 0.9$ | $\geq 0.9$ |

### 3.4 Analysis of the Relationship Between Latent Variables

We can see from Fig. 3, the path coefficient between social environment factors and internal environment factors, the construction of campus safety management team factors, the quality of students factors were 0.54, 0.20 and 0.50, showed that the social environment factors and internal environment factors, the campus safety management team because there is a positive correlation between the son and the quality of students and social environment factors. The safety factor of atmosphere every 1% increase will directly make the campus environment factor, the construction of campus safety management team factors, the quality of students factor respectively increases 0.54%, 0.20% and 0.50%; the path coefficient between school environmental factor and the student own quality factor is 0.17, that student's literacy factor every 1% increase will directly make the campus environment factor 0.46%; the path coefficient between school environmental factors and the construction of campus safety management team factor is 0.93, that Each increase of 1% in the campus environmental factors will directly increase the construction factor of the campus safety management team by 0.93%.

## 4 Conclusion

By conducting lectures on safety education and issuing questionnaires for college students, teachers and leaders, the SEM structural equation model was used to explore and analyze the influencing factors of College Students' safety awareness.

(1) the overall score of students' safety awareness is 75, which indicates that the overall safety awareness of teachers and students in the university is good.
(2) The scores of the students' environmental factors are the highest, the second is the construction factor of the campus safety management team, and the scores of the students' self-quality factors are the lowest. Therefore, schools should increase investment in student safety education and safety culture, and create a safe, healthy and harmonious environment for teachers and students to learn and work.
(3) There is a certain correlation between every influence factor variable of College Students' safety consciousness, no matter which factor is affected, it will affect other factor coefficient and student's whole safety consciousness level. Therefore, it is an effective measure to improve the overall safety awareness of college students by maintaining the higher score coefficient of each factor variable.

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# Ergonomic Evaluation of a Manual Load in a Car Assembling Company

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**Abstract.** The work quality and the importance of maintaining a healthy relationship between men and their work environment encourages companies to refer to the term "ergonomics", which seeks to minimize risks of work accidents and achieve ideal working conditions. The research was done in a car assembly company. This company was chosen to analyze a process in which a fuel tank is taken from a rack and moved to the mounting band.

The purpose of the study is to verify the need to redesign the required manipulator for the transfer of the fuel tank inside the assembly line, because it is not functional to carry out the loading activity, therefore the work is done in a manual way, which under the conditions of safety and health at work is "accepted" for its realization according to the "MEXICAN OFFICIAL STANDARD (NOM-023-STPS-2012)", however when the process is submitted to other evaluation ergonomics methods it is shown that the activity is not suitable to be carried out by the operators under the current working conditions.

Analysis were done with ergonomics methods such as NIOSH function and Utah Estimation of Back Compressive Force (UBCF) to determine the maximum load and the static compression force of the cited task.

Besides, Statistical Control Process (SPC) showed the variation of the several components that are assembled during one shift. Due to the unfavorable result of the process, the possible harmful consequences in the human being were investigated, among them: physiological fatigue, muscle injuries, herniated discs, bone lesions, lumbar and ligament injuries.

As a solution to the findings and to prevent occupational hazards, it was proposed to modify the manipulator to avoid the effort at the time of the activity of lifting the fuel tank and at the same time making the transfer more easily to the production line.

**Keywords:** Statistical Process Control (SPC) · Ergonomic
National Institute for Occupational Safety and Health (NIOSH)
Risk of work · Redesign · UTAH


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# 1 Introduction

Ergonomics is a multidiscipline concerned with the adaptation of work to man. The health of working people in several industries and occupations is potentially at risk through workplace exposure to airborne chemical, biological agents, the lack of safety instruments and the poor performance of activities.

The evaluation of a job in organizations has become an indispensable activity in the search for continuous improvement and ergonomics at work, currently there are several methods that allow analyze the man's working conditions and determine conclusions for the activities that must be modified.

The car assembly company has decided to analyze a process in which a fuel tank is taken from a rack and moved to the mounting band, evaluating loads, movements and consequences in the health of man.

## 1.1 Statistical Process Control and Graphic X-R

The graphical control of processes (SPC, of the English statistical process control) alludes to the use of graphs of control, based on statistical techniques, what allows to have objective criteria taking as a base the data, to distinguish variations of a process and that is consider important. By collecting measurement data at different sites in the process, variations in the process can affect the quality of the final product or service, these can be detected and corrected, reducing waste and preventing problems can affect to the final customer. With its emphasis on early detection and prevention of problems, SPC has a clear advantage over quality methods such as inspection, which apply resources to detect and correct problems at the end of the product or service, when it is too late.

In addition to reducing waste, SPC can result in a reduction in the time needed to produce the product or service. This is partly because the probability of the final product having to be reworked is lower, but it also possible that when SPC is used, we identify the bottlenecks, potential problems of stop lines and other types of delays within the process. Reductions in the cycle time of the process related to improvements in profitability have made the SPC a valuable tool from the point of view of reducing costs and satisfying the final customer.

Appropriately applied, the control charts can:

- Be used by operators for continuous control of process
- Help the process work consistently and predictably
- Allow the process to achieve
  - High quality
  - Low unit cost
  - High effective ability
- Offer a common language to manage the performance of the process
- Distinguish special causes of variation from common ones, as a guide for local actions or actions on the system.
- higher productivity of the company
- Assurance of product quality
- Satisfactions to internal, external and final customers

### 1.2 Ergonomic

Ergonomics is the group of applied scientific knowledge for the work, systems, products and environments are adapted to the capabilities and physical and mental limitations of the person. Context of the Investigation.

The goal of ergonomics is to adapt the work to the capabilities and possibilities of the human being. All ergonomic work elements are designed considering who will use them. The same must happen with the organization of the company: it is necessary to design it according to the characteristics and needs of the people who integrate them.

Applied psychosociology starts from the fact that the needs of people are changing, as is the social and political organization itself. Therefore, organizations cannot be isolated centers and remain oblivious to these changes.

Nowadays, quality of work life is demanded. This concept is difficult to translate into words, but it can be defined as the set of work conditions that do not affect health and that also offer ways for personal development, it means, greater content in tasks, participation in the decisions, greater autonomy, possibility of personal development, etc.

The main objectives of ergonomics and applied psychology are the following:

- Identify, analyze and reduce occupational risks (ergonomic and psychosocial).
- Adapt the work position and working conditions to the operator's characteristics.
- Contribute to the evolution of work situations, not only from the angle of material conditions, but also in their socio-organizational aspects, so that work can be carried out by safeguarding health and safety, with maximum comfort, satisfaction and efficiency.
- Control the introduction of recent technologies in organizations and their adaptation to the capacities and aptitudes of the existing workforce.
- Establish ergonomic prescriptions for the acquisition of tools, tools and diverse materials.
- Increase motivation and satisfaction at work.

### 1.3 Method of NIOSH

In the manipulation of loads, human effort intervenes both directly and indirectly. The method of NIOSH consists of calculating the load lifting index (LI), which provides a relative estimate of the level of risk associated with a specific task, the NIOSH lifting equation is a tool used by occupational health and safety professionals to assess the manual material handling risks associated with lifting and lowering tasks in the workplace, the recommended weight limit (RWL) is the principal product of the revised NIOSH lifting equating. "The RWL is defined for a specific set of task conditions as the weight of the load that nearly all healthy workers could perform over a substantial period without an increased risk of developing lifting- related LBP" [1].

The RWL is define by the following equation: LC X HM X VM X DM X AM X FM X CM.

The LI is a term that provides a relative estimate of the level of physical stress associated with a manual lifting task.

$$\mathrm{LI} = \frac{Load\ Weight}{Recommended\ Weight\ Limit} = L/RWL \quad (1)$$

- Load constant: It's the constant load that the human manipulates during the process.
- Horizontal multiplier: Distance of the hands away from the mid-point between the ankles, in inches or centimeters, HM = (25/H) distance in centimeters [1].
- Vertical multiplier: Distance of the hands above the floor, in inches or centimeters, VM = (1−0.003/V-75/) height in centimeters [1].
- Distance multiplier: Absolute value of the difference between the vertical heights at the destination and origin of the lift, in inches or centimeters, DM = (0.82 + (4.5/D)) distance moved in centimeters [1].
- Asymmetric multiplier: Measure the degree to which the body is required to twist or turn during the lifting task. The asymmetric angle is the amount of trunk and shoulder rotation required by the lifting task, AM = (1−(0.0032A) A = The angle between the sagittal plane and the plane of asymmetry. [2].
- Coupling multiplier: Determine the classification of the quality of the coupling between the worker's hands and the object as good, fair, or poor, CM = 1.0, 0.95 or 0.90 [1].
- Frequency multiplier: Determine the appropriate lifting frequency of lifting tasks by using the average numbers of lifts per minute during an average 15-min sampling period, FM = 1−(F/Fmax) F = task frequency rate and Fmax = maximum frequency as obtained from a table.

The loads handling is a frequent task in industries, where factors such as the frequency of lifting and the load weight can affect the physical condition of workers, the appearance of fatigue and injuries can be perceived by the accumulation of small traumas. "The most frequent injuries are among others: contusions, cuts, wounds, fractures and above all musculoskeletal injuries" [3].

Organizations currently must ensure the safety and occupational health of employees, since maintaining an ergonomic work environment provides a series of benefits for both the company and the human being. The risk of injuries produced in organizations must be monitored and prevented, since according to "the ILO affirms that manual handling is one of the most frequent causes of occupational accidents with 20–25% of the total of those produced at present. "[3], the company has searched solutions that reduce human effort by implementing a load manipulator from the origin to the destination.

### 1.4 Low Back Compressive Force

Estimation of compressive force. This model evaluates the risk of low back injury and quantifies spinal loading that are causing a lot of problems in many industries particularly in industries where it is required to load heavy materials that exceed the limits [4]. This model analyzes this effect by estimating the load, body weight, torso angle, and the distance that the load is held out from the body. Term A is the compression caused by the moment of the upper body weight. Term B is the compression caused by the load moment. Term C is the direct compressive component of upper body weight and load [4]. Compressive force is developed directly by the load and body weight as the force component that is directed through the lower back and through the muscle force required to balance moments, "Utah" can be functional for the recommended evaluation of load in a job.

## 2 Materials and Methods

In the powertrain assembly company, ergonomics is a very important factor, in assembly lines due operators must have work stations that are safe and comfortable, in the case of the fuel tank assembly, there are different versions for the models that are handled, those that depend from the model of the version have a weight range from 14.5 kg to 16.5 kg.

In the station where the fuel tank is taken, there is a manipulators to take the fuel tank from its shelf, take it to the transporter and place it in its assembly position, this in order to facilitate the loading of the tank for the operator.

However, the design of the manipulator is not completely effective for the activity that does it, the force exerted by the pressure of the suction is not enough and sometimes the manipulator can become heavy, uncomfortable, insecure for the product and for the operator, so the device is not entirely functional, but with many opportunities for improvements.

For this type of cause, the device has many recurring failures and periods of maintenance too long, which sometimes causes the operator to have to use as an emergency strategy the manual load of the component and transport it until the final point of use.

As Fig. 1, the rack on which the fuel tank is transported has 3 positions on the shelf where the tanks are located, an individual study was carried out in each of the positions to make a sample of the possible impact in the operator.

Figure 2 shows the most severe condition and on which more attention must be paid since the angle of the column to which the operator is exposed to perform the activity is too excessive and putting the person at risk and that the operator may have a spinal or lower back injury due to the conditions under which he is performing his activities.


**Fig. 1.** Sample of the rack from which the tanks are transported and stored at the point of use.


**Fig. 2.** Operator taking the fuel tank in the lower position of the shelf

## 2.1 Analysis Development

Once the problem was detected, it was decided to carry out a statistical analysis to verify the permitted load range, based on the NIOSH index, and through of a series of data the recommended load weight was obtained which was used as an upper limit considering the current conditions of the process.

Statistical control graphs were made relating the load weight recommended (NIOSH value) against the weight of the different tanks handled by the operator during a work shift. A graph was made for each of the shelving positions. The graphs allowed concluding that the manual loading process is not correct, since the recommended load limit (NIOSH value) is below the weight of each tank (Fig. 3).

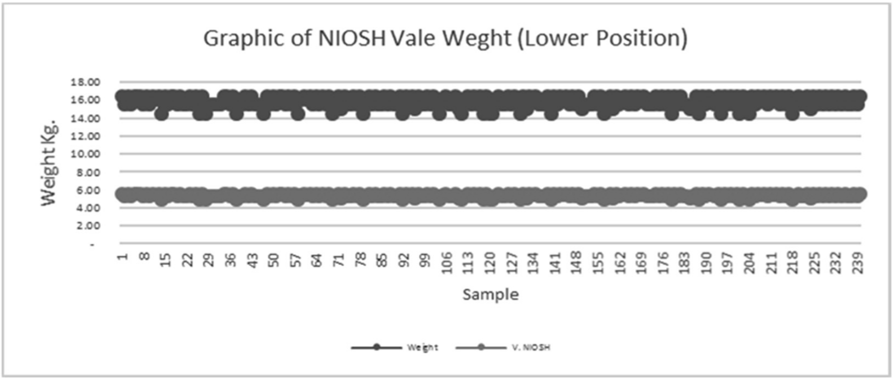


**Fig. 3.** Graph of samples, NIOSH VS value, and weight of fuel tanks.

The evaluation of the process was also considered through of the "Utah" estimation of force compression of the back "which evaluated the compression force exerted on the back when the spine is in an incorrect angle. The study was carried out for the 3 fixing positions of the gasoline tank, which allowed to determine the compression index and make a comparison of the recommended New-ton loads against the value of the obtained data (Tables 1 and 2).

**Table 1.** "Low Back Compression Force" data table for the top position of the rack where the tanks are located.

| Contributor | Computation | Value (N) |
|---|---|---|
| Back posture | | |
| A = 29 (BW) sin θ | 29 * (80) * (0.31) | 717 |
| Load moment | | |
| B = 190 (L*HB) | 190 * (15.8) * (0.20) | 602 |
| Direct compression | | |
| C = 7.5 [(BW)/2 + L] | 7.5 * {(80)/2 + (15.8)} | 316 |
| Estimated compressive force | | |
| Fc = A + B + C | Comparison value: 3100 N | 1634 |

**Table 2.** "Low Back Compression Force" data table for the bottom position of the rack where the tanks are located

| Contributor | Computation | Value (N) |
|---|---|---|
| Back posture | | |
| A = 29 (BW) sin θ | 29 * (80) * (0.31) | 1640 |
| Load moment | | |
| B = 190 (L*HB) | 190 * (15.8) * (0.20) | 1474 |
| Direct compression | | |
| C = 7.5 [(BW)/2 + L] | 7.5 * {(80)/2 + (15.8)} | 316 |
| Estimated compressive force | | |
| Fc = A + B + C | Comparison value: 3100 N | 3430 |

The process was reviewed under a technical guide for the evaluation and control of the risks associated with the handling of loads, where the indicated graph evaluates the risk associated with lifted weight and the frequency of the load.

The average weight of the load is 15.8 kg and the frequency of load lifting is 2 min, which by making the comparison it was observed that the activity is at the limit to be able to consider a moderate ergonomic risk.

As a summary of the studies previously considered, it was concluded that the activity under the current conditions has a moderate ergonomic risk and that an operator cannot be exposed to this activity for a long time.

## 3 Result

Based on the previous study, the improvement to the manipulator that is used to help the operator to eliminate the risk of developing any disease or injury due to manual loading is taken into consideration.

First, after making the improvement, a re-evaluation of the NIOSH value was performed, which represents our maximum recommended weight limit that under the new conditions the operator could charge.

As we see in Fig. 4 it represents the comparison of the new recommended load limit against the weight of the fuel tanks. In other words, the new recommended load weight limit is between 24 to 26 kg. While the weight of the fuel tanks is between 14.5 and 16.5 kg.

What we can understand is that now the recommended weight limit is much higher than the weight of the tanks, which allows the operator to perform this operation for a prolonged period of time but without putting it at risk of contracting any injury in the back.

In the same way that the allowed weight was verified with the NIOSH system, the verification of the compression in the lower back is made again, considering the new working conditions.

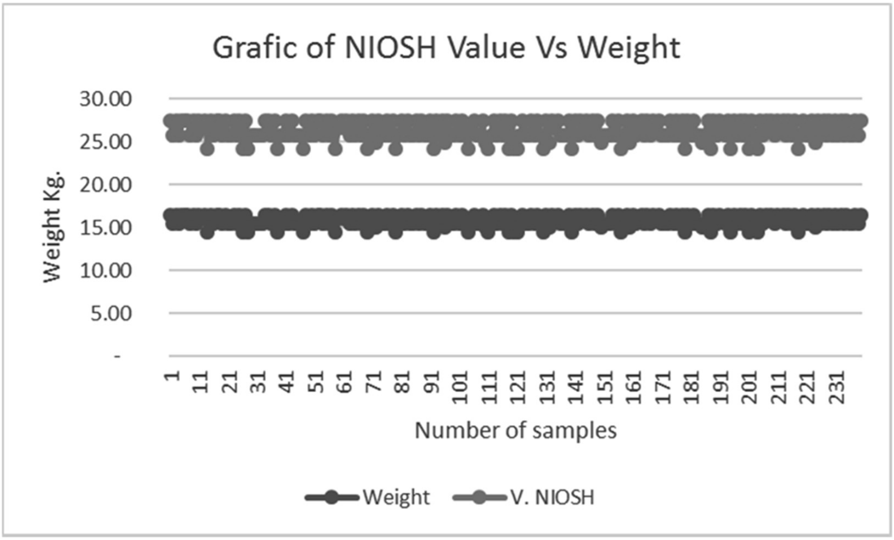


**Fig. 4.** Graph of samples taken to the improved process comparing NIOSH value vs Tank weight

**Table 3.** Data table "Low Back Compression Force" for the lower position of the shelf where the tanks are located, process improvement.

| Contributor | Computation | Value (N) |
|---|---|---|
| Back posture | | |
| A = 29 (BW) sin θ | 29 * (80) * (0.31) | 323 |
| Load moment | | |
| B = 190 (L*HB) | 190 * (15.8) * (0.20) | 301 |
| Direct compression | | |
| C = 7.5 [(BW)/2 + L] | 7.5 * {(80)/2 + (15.8)} | 316 |
| Estimated compressive force | | |
| Fc = A + B + C | Comparison value: 3100 N | 939 |

As seen in the Table 3, the change is too great to the conditions that were previously used, which confirms that the improvement to the assembly process was satisfactory.

With this result we can defined that the weigh for the Operator is low and he can use the device and the material without risk to have an injury.

## 4 Conclusions and Recommendations

As conclusions, we can define that ergonomics is a very important factor that should be considered in all areas of work of a company.

Since in spite safe conditions and compliance with regulations, we have to look for possible risks of injury within the work areas, since by preventing them we can avoid costs due to illnesses, disabilities and at the same time we create a safe working environment for workers where they feel safe in their work area and help to raise the productivity of a company.

Always an improvement in security is a benefit for the company and employees.

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# Occupational Exposure and Safety in High-Risk and Complex Environments

# Handing Over the Safety Baton in High-Risk Systems

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**Abstract.** Successful, round-the-clock operations in high-risk and complex organizations rely on the proper transfer of critical information through skilled team communication and a reliable system for handing over the operations to the next shift. Handovers, by nature, pose a risk to processes when information is lost or corrupted between the sender and the receiver. This paper reviews some of the large-scale accidents that have occurred in the past 25 years, whose investigations reveal a failure in handover as one of the underlying causes of the accident. The paper then discusses the results of a qualitative study on the handover activity at the Norwegian User Support and Operations Center's (N-USOC). The N-USOC has a control room for experiments on plant breeding in closed growth systems inside the International Space Station (ISS). This study provides an invaluable insight into the HO variability of a specific team in the use of two different control room consoles. Finally, the paper expounds on why there is a difference in the HO of two consoles by the same operators and why thorough planning is vital to efficient and safe operations.

**Keywords:** Human factors · Human-systems integration
Safety management · Control room · Handover · Shiftwork
Communication · Team · ETTO

## 1 Introduction

Experiments on board the International Space Station (ISS) are supported by operators working in control rooms around the world. These are teams dedicated to one experiment and one *payload* on board the ISS; handling everything related to hardware, telemetry, communications and the experiments themselves.

Such complex socio-technical systems, similar to drilling and production in oil platforms, hospitals, operations at a port or an air traffic control center, require round-the-clock operations and surveillance. In such systems, adverse effects of process changes may not be observed until succeeding shifts [1]. It is therefore critical to be aware of the status of the system in the previous shifts, the current status, and to be able to foresee future developments. The transfer of responsibility for operations and the


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transmission of information are key to maintaining safe operations. A successful handover (HO)[1] plays an important role in ensuring the fluidity of work processes and the safety of organizations dealing with shift work.

The paper begins with a brief presentation of some large-scale disasters connected to poor HO processes in the last 25 years. The results of a qualitative study on the HO activity at the Norwegian User Support and Operations Center's (N-USOC) are then presented in light of the factors identified. This study also provides an invaluable insight into the HO variability of a specific team in the use of two different control room consoles. The paper discusses the results of the HO study and why thoroughness in planning is essential to efficiently handing over operations in shift work.

We argue that a successful HO includes thoroughness in the design and preparation of the complex system aside from properly performing the HO activity itself. This thoroughness enables operators to form a share understanding of the system and efficiently HO the shift without compromising safety. Furthermore, thoroughness rewards operators with the opportunity to focus on the safety-critical information and filter out irrelevant details.

## 2 Background

**HO in High-Risk Systems.** In this study we have defined HO (also known as hand-off, sign-off, and change-off) as: the transfer of appropriate information from the outgoing individual/group to the incoming individual/group of the next shift to ensure continuity of operations. The three key elements in a shift HO consist of (1) preparation by outgoing shift, (2) communication or information exchange between the two shifts, and (3) cross-checking the information by the incoming shift [1, 5].

A majority of high-risk organizations are characterized by complexity, intractability, and tight coupling [6, 7]. HOs pose a risk to processes when information is lost or misunderstood between the sender and the receiver. Safety-critical information such as upsets in the system during the previous shift or potential problems in the succeeding shift may be lost due to various factors. This section provides several examples of shift HOs gone wrong.

Poor HO and inadequate logbook entries failed to inform the crew of existing process problems that led to the Esso gas plant fire and explosion in Longford in 1998 [8]. The Texas City refinery explosion was a result of overfilling a column containing raffinate that became an ignited vapor cloud. The logbook contained entries of varying quality and detail, providing little information on safety issues [9]. The overflow of 250 000 L of petroleum and subsequent fire and explosion in Buncefield in 2005 was due to several factors - pressure on the staff, poor procedures, technical problems, a flawed display screen design, and an inadequate time provided for an HO [10, 11]. In the blowout of a semi-submersible drilling rig in 2010, Deepwater Horizon, 11 offshore

[1] HO research has covered several high-risk industries such as nuclear power plants, air traffic control, railroad dispatch, space shuttle mission control centers, ambulance dispatch, and the health sector [2, 3].

workers were killed and the disaster turned out to be one of the largest offshore oil spills to date [12]. The HO process at the drilling rig required both incoming and outgoing personnel to review and sign the HO assurance form. However, the investigation revealed that three out of five HO forms were not fully completed and several critical decisions were made based on inadequate information [13]. The Bayer CropScience Pesticide Waste Tank Explosion in 2008 was due to a HO failure where process information and lab results pointing to excessive concentration of methomyl were not conveyed [14]. In New Zealand, the derailment of the metro passenger train 8219 Wellington in 2013 was caused by miscommunication and a shift change that was performed while maintenance activity on the braking system was being carried out [15]. The shift change resulted in the braking system maintenance not being completed prior to the derailment. In the health sector, an HO failure brought about one of the most publicized drug overdose cases as cancer patient Betsy Lehman died after received four times the recommended dose of a very potent anticancer drug despite several medical practitioners countersigning the medication order [16, 17].

HO failures or deficiencies may result in serious consequences to operators, material damage, or lawsuits, as seen from these examples. From accident investigations, a number of factors emerge. A degree of caution, however, should be taken. Reader and Connor [12] warn of the limited effects of measures and plans to improve safety based on accident reports alone. Firstly, the result of an investigation may be affected by the accident investigation method chosen and as they may only identify 'fragmentary information' with respect to the accident [18]. Secondly, the lessons from an investigation may become out-of-date due to 'accelerating technologies', thus resulting in failure to learn in due time [19]. Thirdly, accident investigations may pose a risk of the principle 'What you look for is what you find, what you find is what you fix [20]. Careful introduction of measures, such as changes in HO procedure, should take into consideration the interdependencies in the system [12, 21].

**High-Risk Systems and the ETTO Principle.** Hollnagel's [22] efficiency-thoroughness trade-off (ETTO) describes the variability of human performance in adapting to the current work context. Understanding the `how and why' in the variability of human actions are crucial to successful operations and in finding the root causes of an accident. The trade-off between thoroughness and efficiency is influenced by the regularity or stability of the system. Thus, the system characteristics determine the potential for performance optimization [22]. This implies that the thoroughness in the planning and design of a system affects the subsequential efficiency in performance.

**The N-USOC and ETTO.** As a member of the European Space Agency (ESA), N-USOC in Trondheim runs a number of experiments on the ISS [4]. The experimental setup in space is controlled on the ground at the N-USOC. The N-USOC is one of seven centers participating in the ISS program. There are two control room consoles at the N-USOC – the European Modular Cultivation System (EMCS) console and the Vessel Identification System (VIS) console. The EMCS is a console for running experiments which occur within a short but intense period. As the experiments are conducted on the ISS, it comes with a heavy price tag and involves the astronauts performing the procedures for the experiment. The meticulous planning therefore occurs in good time before the experiments begin and includes simulations at the

N-USOC and painstaking preparations for numerous contingency plans. The VIS console at the control room oversees the other payload in the ISS which monitors ship maritime traffic from space. The VIS console receives information broadcasted by the Automatic Identification System (AIS) regarding ship velocity, identity, and position and provides a means of investigating the potential for monitoring AIS-equipped ships from the ISS. The VIS console runs continuously throughout the year with minimal involvement of the astronauts. ETTO-wise, the VIS is considered a more predictable and highly stable system compared to the system characteristics of the EMCS.

## 3 Methods

This qualitative study employs two methods for gathering data: (1) through a questionnaire; and (2) an interview. The questionnaire was distributed to the control room operators who voluntarily answered the questions anonymously. There were five out of eight individuals that provided answers to the various questions in the questionnaire. Although not everyone answered the questionnaire, the preliminary results of the study provided an indication of the perceived quality of the HO process. The questionnaire included the operator's satisfaction with the current HO, information communicated, and channels of communication used, training methods, supporting tools, frequently occurring problems, and areas for improvement. After the questionnaire was analyzed, an in-depth interview followed. There were six out of eight control room operators who volunteered for the interview. Questions in the interview guide included their thoughts on the results of the questionnaire, examples (if any) on problems solved differently between shifts, length of time used for the HO, factors affecting length and detail of HO, threshold for asking help from other operators, miscommunication, delay of HO due to on-going activities, and critical information to hand over. The semi-structured interviews were conducted individually with a voice recorder after receiving consent from the participants. The interviews lasted between 15 to 25 min. A transcript of each interview was created and analyzed using HyperResearch.

## 4 Results

**Questionnaire.** In general, the operators were satisfied with their current HO. The operators were similar in their answers related to the information needed in the HO and the type of support tools available for the HO (console logs, displays, face-to-face communication, to-do list, the HO procedure, crew timeline and crew procedures, daily reports). The questionnaire, however, revealed uncertainties related to whether or not the incoming personnel understood everything the previous shift said and if the latter remembered to communicate all the crucial information. The operators have no standardized requirement for checking that the incoming shift has understood the information. Moreover, the level of detail and the quality of logging was reported to vary among the operators. The questionnaire was able to capture some of the possible operator challenges in the HO process such as the language barrier between a technician and a scientist, and high shift activity level (may result in lower logbook quality or unfinished entries). Although they were satisfied with the overall HO activities at the N-USOC, they were able to come up with suggestions for improving the HO. These include a printed checklist filled out by both parties, a plenum discussion, control questions, and technical training to improve the language barrier.

**Interview.** The HO activity employs at least two channels available for information transfer during the HO – verbal communication and the use of the logbook. The level of detail in the log entry, the amount of time used for HO, and the number of HO tools used slightly varies between operators. The documents available at the console contain lists of terms that are relevant to the particular experiment. The interview also indicated that there have been instances where the same problem was approached in differing ways, although the overarching approach is in agreement. The majority of the operators are experienced and familiar with the system. Scenarios and contingency plans are created as a group. Some of the information (commands executed during the shift) are sometimes communicated through the logbook and some pending activities are listed in the to-do-list or verbally. There is no requirement to provide feedback or ask control questions although some expressed that they do not leave unless they are certain that the incoming operator does not have any more questions.

HO is trained in-house and a multitude of simulations are performed within this period. Training length is dependent on individual progress and progress is thoroughly evaluated by the training supervisor together with an external member of the ESA prior to becoming an operator. Cognitive capabilities are evaluated through the training program which has several modules to complete and then evaluated before a trainee is allowed to handle the control room. The required cognitive functioning differs from shift to shift due to the variation in the activities. The occurrence of critical activities arises during the scheduled HO, although it is common practice to delay the HO in order to ensure that critical operations are not interrupted. There is only one operator per shift and the time provided for HO is one hour. The time provided for HO was evaluated by all the operators as adequate, however, the actual length varies in practice. Workload and events fluctuate between shifts, which in turn, affects the time used for HO. An operator with a technical understanding of the system is available 24/7 and is therefore not part of the shift rotation. The procedures for handing over the VIS and the EMCS are similar. EMCS, however, is more strictly complied with than the procedure for the VIS. There is no checklist to be used in facilitating the HO.

The HO between the night shift and the morning shift is sometimes kept to a minimum due to operators being tired and ready to go home. The punctuality of the team does not appear to be an issue. Incoming operators arrive on time, some slightly earlier than the HO schedule. The EMCS activity, including the HO, is characterized by compliance. There is evidence of complacency or practical drift when it comes to the HO of the VIS. The procedure exists but is not strictly followed.

The HO procedure was developed during a project and has not been regularly updated. The EMCS is a team priority and everyone is highly involved and take the role seriously. Both operators (incoming and outgoing) are responsible for the successful transfer of information, although there is an occasional problem with performing to-do lists especially when given verbally. Prior to the launching of an experiment, the team works on several What-If scenarios and develop contingency plans for them. The information during the HO is expected to fill in the incoming operator with the necessary information so that the external partners interact with a “single” operator.

The location (the control room) is an appropriate place for the HO as the systems need to be continuously monitored. Moreover, the control room is isolated from noise and physically separated from the daily office activities. The necessary HO tools are available at the console although, some information may be found in different places such as email or to-do list. The physical layout of the control room is satisfactory. The group is aware that not everything can be prepared for and are flexible and experienced in prioritizing activities correctly during such events. Internal and external technical support is available 24/7, in case of technical problems. However, there is a higher threshold for requesting support during the night shift.

## 5 Discussion

The results indicate a functional HO at the N-USOC. One of the reasons behind this would be the considerable amount of time, planning, and preparation required before the experiment begins. As the group members discuss the steps and develop a detailed procedure for the experiment, their mental model becomes a shared one. Through having a shared mental model, they are able to predict what the possible demands are for the next shift and the next three days, allowing them to foresee which information is necessary to hand over [23].

Communication between shifts seems to be working well within the group. As the HO is performed face to face, it is easier to read the gestures and facial expressions of the person one is handing the shift to. In addition, the members of the group also talk to each other on a daily basis, providing a lower threshold for asking questions or clarifications. Moreover, the daily interaction may also provide them with improved non-technical skills such as team decision making and situation awareness.

The experiments N-USOC run on the ISS require a great deal of funding. One of the consequences of an HO failure would be easily reflected in their financial status. Not only are the instruments used expensive, they also run the risk of not being able to land another contract due to a bad reputation. Another one would be experiment failure resulting in a long period of waiting for the next opportunity since there are many experiments the ISS needs to run in space. With such consequences, the activities in the N-USOC are coupled with high risks, which also explains why the team enters into a more serious “experiment mode”.

The control room operators at the N-USOC undergo intensive training for the activities before they are allowed to man the console. The intensive training allows for familiarization with the terms, the processes, and the most common problems and their appropriate solutions. Also, the opportunity to observe another HO is present, which allows the observer to correct their own mental model if they have observed a deviation from what they would expect to occur. It also provides an opportunity to ask questions and clarify misunderstandings during the training.

The HO is not a routine task for them as it occurs about 20 times per year. There are long periods in between experiments, which limits their experience with HOs, but can also be a positive condition when preventing practical drift [24]. The HO process is seldom performed, hence, it is less likely that corners are cut or for improper behavior to be slowly drifting from compliance to the procedures to a practical adaptation of the procedure with the purpose of saving time and effort [24].

Despite their successful HOs, the team must remain consistent in their HO performance and alert to unexpected situations and challenges. As the operators work eight-hour shifts, it is possible that they can get fatigued by the end of their shift when HO occurs. Another challenge could be the length of time the HO occurs in practice. While the incoming operator may be punctual, and the time allotted to the HO is adequate, the outgoing operator may be experiencing tiredness and would want to perform the HO as fast as possible. Rushing an HO runs the risk of inadvertently skipping critical details. Misunderstandings during the HO may be reduced through asking control questions, on the part of the outgoing operator and for the incoming operator, asking questions to clarify information or to challenge information is also critical. Hasty HOs can be limited by introducing a minimum time used for the HO before the outgoing shift is allowed to leave.

The HO process demands the use of working memory which has a limited capacity [25]. With so much information for the outgoing shift to remember to relay to the incoming operator, and for the receiving end to absorb all this information, there is a risk that one or even both parties forget some of the information during the HO. This risk is minimized by having several channels of communication. The outgoing operator has information in the logbook the incoming can check and a display monitor with information on several details. The operator also has a checklist for the HO to reduce the cognitive load.

Another challenge in the team's HO process would be the logbook entry. Several participants in the questionnaire remarked that there are individual differences in the manner operators fill out the logbook. Although they have a template, the entries may vary in the level of technicality and the evaluation of which color to use on the event. There might be a need for another plenum discussion to clarify the procedure for logbook entry. This discussion may offer insight on the level of detail the procedure needs to be adjusted to, in order to result in a more standardized format. Compliance of operators to procedure improves if the operators are involved in the development of the procedure, or in this case, the update. The operators are knowledgeable on the practical execution and first-hand experience on handing over the shift. Moreover, their involvement creates a sense of ownership, which then enables them to be more willing to comply with the procedure.

The variability in the HO such as the length of time used to handover the shift to the next operator, the amount of entry in the logbook, and the difference between the focus in handing over the EMCS from the VIS console may be explained using the ETTO principle. The EMCS console is given more focus since it has a lesser degree of regularity and involves a greater risk in comparison to the VIS console. This illustrates that while the procedures for these consoles are similar, the EMCS HO is performed more formally than the VIS HO.

The EMCS HOs are also variable since not all shifts are the same. An operator devotes more time to the HO of an 'eventful' shift than in a shift that has proceeded as expected and is designed mainly for retrieving AIS information. The thoroughness of the logbook entry may also be explained by the same principle. The amount of detail reflects how the operator has used more resources on attending to the events during the shift than on filling out the document. Although keeping a logbook with insufficient information is not ideal, this deficiency is compensated by the amount of verbal HO and length of time used. Furthermore, the lack of procedure for checking if the incoming operator understands the information is compensated by the intense preparation and knowledge of the experiment. As a result, the thoroughness prior to the experimental phase provides them with an understanding of differentiating less important details from essential information.

## 6 Conclusion

HO is a critical part of the N-USOC operations. The operators have available procedures, various tools to ease the cognitive load, and ample time to perform the HO. The physical environment has not been considered a problem and communication is considered satisfactory. Overall, the HO at the N-USOC has been regarded by the participants as well functioning and the operators are mostly satisfied with the way they perform this activity.

N-USOC's operator competence is achieved through individually-based training and selection of operators. Competence and knowledge of the system, together with thorough planning prior to the experiment, grant them the flexibility and efficiency in terms of handing over the safety baton.

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# Risk Related to the Application of Hydrogen Propulsion Technology in Cars

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**Abstract.** The introduction of hydrogen technologies in the automotive and energy industry requires research in all areas of its possible application including production of hydrogen, through its operation. All of these stages are burdened by the risk caused by interaction of hydrogen with the environment and technological subject. Security group risks represent significant risk of handling hydrogen due to the possibility of explosion. Based on the risk value, the safety level of the individual subsystems of hydrogen production and utilization process is subsequently assessed. Consequently, it is possible to assess the overall safety of the mobile system based on the final/resulting value of the risk. In case of improper handling, technical failure/incident or unexpected adverse event, there is a risk of hydrogen leak into the environment. With the wide range of explosive capacity of hydrogen-air mixture, it can represent a high risk of explosion with a relatively little energy initialization.

**Keywords:** Human factors · Hydrogen technologies · Automotive Risk · Explosion · Safety · Security

## 1 Introduction

Hydrogen technologies are the focus of interest in various industries. Their development and boom brings with them various limitations and possible threats that, if not identified in good time, can cause damage to property and endanger human lives. The security of any new technology available to the general public is even the highest priority for the whole society. To ensure maximum safety, it is necessary to know all possible limitations and risks arising from the use of the technology.

Automotive engineers are trying to incorporate hydrogen propulsion systems into bodyworks used for conventional internal combustion engines (except for prototypes and models developed for this type of drive). The advantage of this solution is a smaller number of unified parts and associated lower development, production and maintenance costs. Depending on spatial options, some design solutions do not interfere with the interior of a vehicle more than would be in the case of fossil fuel propulsion system. Others create limitations in the form of reduced luggage space. Some drive components


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remain unchanged from the classical internal combustion engine version Others are specific to the hydrogen propulsion system [1].

## 2 Risks Related to Operation of Vehicles with Hydrogen Propulsion System

Mobile devices are characterized by specific risks arising from their ability to change their positon depending on the need of the driver, passengers. This creates a potential threat not only for the car and its servicing (in this case, also for the passengers) as regards to the Safety category, but also for the area that is in the close proximity to the automobile. It is therefore necessary to take into account their possible threat to civil society in the design of hydrogen-powered vehicles – Security [1].

Car owners will demand the same benefits and practicality (such as downhill, fast fuelling, parking over/under-ground garages, reliability), as is the case with current cars. At the same time, the risk must be the same as or lower than for fossil fuel powered cars. Hydrogen propulsion engineers must take account of hydrogen risk factors already in the design phase of the vehicle as well as in the selection of used materials. It is necessary for the owner of a hydrogen-powered car to safely use its properties, without having to know and control hydrogen technology and fuel cell technology. However, there is a need to avoid unintentional accidents resulting from unawareness of the risk of hydrogen use during car driving, parking, repairs and recycling [1].

Vehicle accident represents an important area for identifying dangers as a part of risk management. In this case, uncontrolled leakage of hydrogen could result in a considerable material and financial damage or damage to human health and life. The high-pressure tanks of vehicles used in the current hydrogen cars reach the capacity of up to 8 kg of hydrogen compressed at a pressure of approximately 70 MPa. This pressure, together with high explosiveness and hydrogen flammability, poses an increased risk with the use of such technologies in trucks or buses since they require a larger impact area to be counted on in the event of hydrogen leakage [1].

As for leakage of hydrogen, several accident scenarios can be associated with leakage of this dangerous substance. Vehicles using hydrogen fuel cells will be parked in publicly accessible parking spaces including covered garages and homes. It is also necessary to assume the potential intentional misuse of negative properties of hydrogen by persons to destroy property and health. Repair and recycling of hydrogen powered cars will bring new specific problems and will also require a different approach in some procedures such as tank replacement, refuelling, and the post-accident repair. Unprofessional application of operating procedures, the use of unoriginal, inappropriate spare parts that do not meet the required material standard can be considered as significant threat [1].

### 2.1 Risks in Mobile Hydrogen Applications for Safety Area

Properties characteristic to hydrogen as a fuel of energy carrier define technical and operational measures to minimize the risks arising from hydrogen propulsion system operation:

1 – risk of burring, ignition, explosion
2 – risk of overpressure,
3 – low temperature risk
4 – risk due to hydrogen embrittlent,
5 – risk as a consequence of the effect of hydrogen on the human organism [1].

Flammability risk – represents the basic risk of the hydrogen system. For hydrogen, it is highly probable that it will leak due to its physical and chemical properties. The leakage is directly related to the formation of a combustible mixture and can lead to ignition and explosion. Its flame speed, which is higher than with fossil fuels, represents a significant factor [1].

The risk of overpressure - is conditioned by the fact that high-pressure values are applied in hydrogen storage. As a result, all components ensuring the implementation of storage technology are situated in the high-pressure area throughout their lifecycle, the result of which is hydrogen embrittlement [1].

Temperature risk - occurs when cooling hydrogen to liquid hydrogen (−253 °C). When cooling the surrounding materials, there are substantial changes in the solidity properties that could result in damage in the material structure [1].

Hydrogen embrittlement - is a property that occurs under specific conditions. The materials of high-pressure tanks or other devices can lose their structural resistance over long periods of time in contact with hydrogen. The factors that affect it can be classified as follows - type of material, hydrogen concentration, hydrogen pressure, temperature, mechanical stress, pressure change, grain diameter, microstructure and heat treatment history, moisture contained in hydrogen [1].

Effect of hydrogen on human body - direct contact with gaseous or liquid hydrogen can result in local anesthesia up to freezing. Burning hydrogen which creates a high temperature and a specific flame also represents a health risk. Hydrogen is not toxic, but there is a risk of choking, especially in confined spaces, such as inside the car body. It can be said that the possibility of hydrogen leakage outside the specified working environment represents the greatest risk. Explosive mixture is created, and it requires only minimal energy to initiate an explosion [1].

All of the above-mentioned risks also have an impact on Security because of hydrogen technology failure - especially when using this technology in the transport means, may involve a high number of people at risk. Cars can get virtually anywhere during their operation - and the increased risk will be mainly their movement in densely populated areas [1].

### 2.2 Risks in Mobile Hydrogen Technologies for Security Area

Improper servicing, recycling – due to the necessary availability of services and the expected use of the existing service centers for individual car brands, it is necessary to consider the service of hydrogen cars. Considering that several people may be present at the car service center when the staff is manipulating with the hydrogen system components, the risk of leakage and subsequent incident initiation is increased. Service centers are often located in places with a large number of uninterested persons around. It is also possible to characterize the risk involved in recycling of these cars after their lifecycle (Fig. 1).

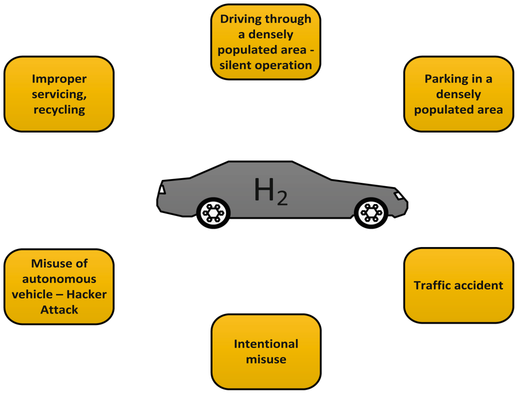


**Fig. 1.** Risks in mobile hydrogen technologies for security area

Driving through a densely populated area - silent operation - driving hydrogen cars in cities with the increased number of people around the car poses a danger. Since the hydrogen fuel cell produces very little noise during its operation and the electric power obtained from it drives the vehicle by electromotors that are also quiet, it can be assumed that with the spread of hydrogen cars the risk of pedestrian injuries will increase.

Parking in a densely populated area (city centers, residential areas, above/underground garages, shopping centers) - Hydrogen leakage may occur during parking, with the subsequent trigger of an explosion, which may endanger people in the vicinity. The explosion has the potential to subsequently trigger a domino effect – e.g. collapsing of a building, subsequent fire – they can endanger many more people around than those transported in the respective car.

Traffic accident - location of a motor car is an important factor in case of car accident. Leakage and subsequent initiation of hydrogen in an inappropriate environment (tunnel, ferry, car train) will have far more serious consequences than would be the case in open space traffic accident where hydrogen can dissolve rapidly into the atmosphere.

Intentional misuse - In case of intentional misuse, the dangers are comparable to those with internal combustion engines. It may result in the deliberate knocking down of persons, or the intentional damage to the car in order to endanger and damage the property or the health of the persons. With the upcoming autonomous cars, it is also worth considering the possible hacker attacks on vehicle control software for communication with the environment.

## 3 Numerical Calculation of Hydrogen-Air Mixture Explosion

To evaluate the thermodynamic parameters in the vicinity of the stoichiometric hydrogen/air mixture explosion, a numerical calculation pressure effects on the selected obstruction geometry was performed In order to demonstrate the devastating effects of a possible hydrogen explosion, numerical calculation was considered with a stoichiometric hydrogen/air mixture with a total volume of 0.5, 1, 3 and 10 $m^3$. The created model takes into account the ideal ball shape of the mixture with the following radius

$$r = \sqrt[3]{\frac{3 \cdot V}{4 \cdot \pi}} \text{ (m)} \tag{1}$$

In a three-dimensional geometry model, a hydrogen/air sphere-shaped mixture is located 1 m above the center of the coordinate system (above the floor level). To produce 1 $m^3$ of stoichiometric mixture, according to combustion statics, 0.296 $m^3$ of H2 and 0.704 $m^3$ of the air are required. If we assume a total hydrogen burning,the temperature of mixture will increase and it can be described by the following calorimetric equation

$$\Delta T = \frac{Q}{\sum_i (\rho_i \cdot V_i \cdot c_{vi})} \text{ (K)} \tag{2}$$

where ΔT is the mixture temperature increase at hydrogen combustion (K), Q - the amount of heat released (J), ρi - the density of the i-th component of the mixture after incineration ($kg \cdot m^{-3}$), Vi - gas after combustion ($m^3$), cvi - thermal capacity at constant volume of the i-th component of the gas mixture after combustion ($J \cdot kg^{-1} \cdot K^{-1}$). With perfect hydrogen combustion, we can assume a mixture of nitrogen and water vapor at which the temperature of the gas mixture is increased by 2107 K which at the original temperature before the explosion of 293 K represents the final temperature of 2400 K [2]. If we assume idealized isochoric combustion of hydrogen in the entire volume, the pressure of the mixture will increase according to Charles's relationship

$$p_2 = \frac{T_2}{T_1} \cdot p_1 = 830 \text{ kPa (Pa)} \tag{3}$$

Where p2 is the absolute pressure in the volume of the mixture after hydrogen combustion (Pa), T1 - the temperature at the start of the combustion (K), T2 - the temperature after the hydrogen combustion (K), p1 - the atmospheric pressure (Pa).

### 3.1 Description of Simulation and Definition of Unambiguous Conditions

The explosion simulation runs from the time when the pressure was increased to 830 kPa and the temperature to 2400 K without the calculation of the chemical reactions occurring during the combustion of hydrogen. To evaluate the pressure and torque effects of the explosion on the surrounding environment, stationary obstacles with a width of 2 m, a height of 2 m and a thickness of 0.5 m were created.

No deformation of obstacles is considered in the calculation. The obstacles are located at 2.5, 5 and 10 m from the center of the explosion according to Fig. 2 so that the frontal surface normal passes through the center of the explosion.

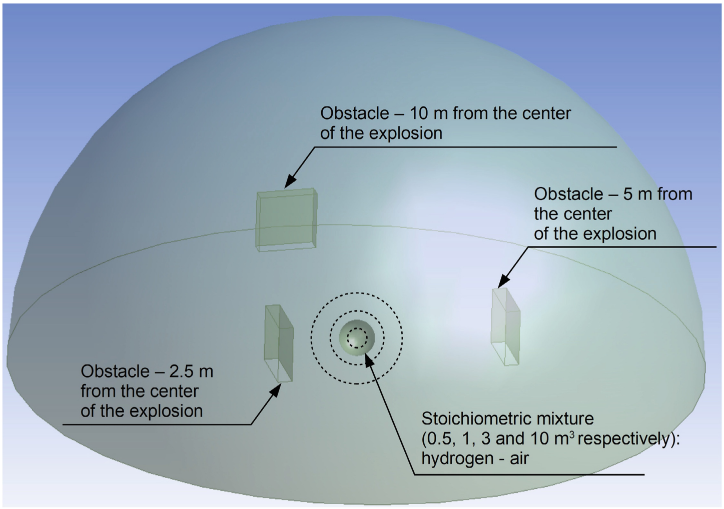


**Fig. 2.** Location of the source of the explosion and obstacles in the domain space

To determine the spread of the pressure waves, an area of the surrounding environment was created as a 25 mm radius space with a 12 m radius subdomain inside which has a compact network to obtain more detailed results (Fig. 3).

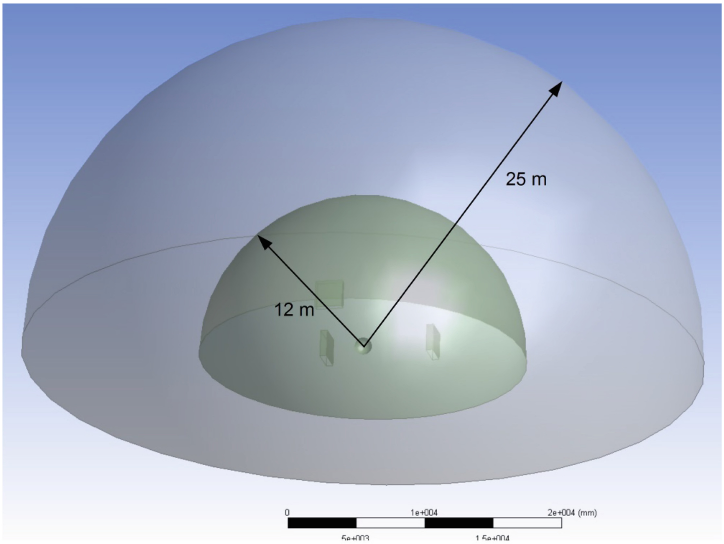


**Fig. 3.** Division of the computing domain into the subareas

During the simulation, only the fluid medium itself was solved while the obstacles were created by removing the material from the internal domain. After creating the geometry, the domains were discretized to the final number of elements, creating a computing network (Fig. 4). In the ANSYS CFX program in which the simulation was created for this purpose the "Mesh" tool serves.

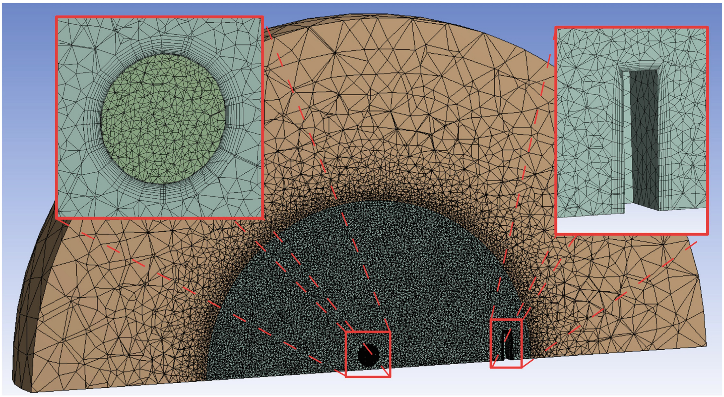

**Fig. 4.** View of an unstructured computational network with a detailed view of the network of hydrogen mixture and obstacle surrounding

An unstructured tetrahedron network was used for all domains. For the inner sphere representing the stoichiometric mixture, the average size of the element was set to 90 mm, the inner rounded space was 230 mm in size and the 25 m outer space had a size left at a system preset value. In the vicinity of the internal sphere where the rapid expansion of the gas with considerable gradients will occur, the network is densified to a distance of 200 mm, with the network at the surface containing 10 layers with a relative increase in thickness 1.2, due to the assumption of significant pressure gradients around the obstacles. The thickness of six layers was 200 mm with an increase in layer thickness 1.2. The network contains a total of 2.8 to 3.36 mil. elements depending on the volume of the stoichiometric mixture.

Simulation involves a compressible fluid the flow of which is solved using a turbulent k-omega model (with respect to velocities with Ma > 0.3). The simulation uses the "Total energy" heat transfer model. This is the transport of enthalpy and includes kinetic energy effects. Material of domains is the air with physical properties dependent on temperature. The initial conditions for the stoichiometric mixture are given at a temperature of 2400 K and an absolute pressure of 830 kPa (according to Eqs. 2 and 3). For the surrounding environment, an initial pressure of 101325 Pa and a temperature of 293.15 K is defined. The calculation is performed as a time dependent on a total time of 40 ms and a time step of 0.05 ms. The number of iterations per time step was set to 15, with an accuracy of $5 \cdot 10^{-5}$. The domains contain one boundary condition for fluid output at a radius of 25 m. The remaining exterior surfaces are set as a "smooth wall" without exchanging the heat to the surroundings.

## 4 Evaluation of Results of Numerical Calculation

The result of numerical solutions is to obtain pressure effects on obstacles located at 2.5, 5 and 10 m from the center of the explosion, at the stoichiometric volume of the hydrogen/air mixture of 0.5, 1, 3 and 10 $m^3$. From the effects described, an approximation can be made using multiple regressions between the investigated magnitude, the stoichiometric volume and the distance from the center of the explosion. In Fig. 4,

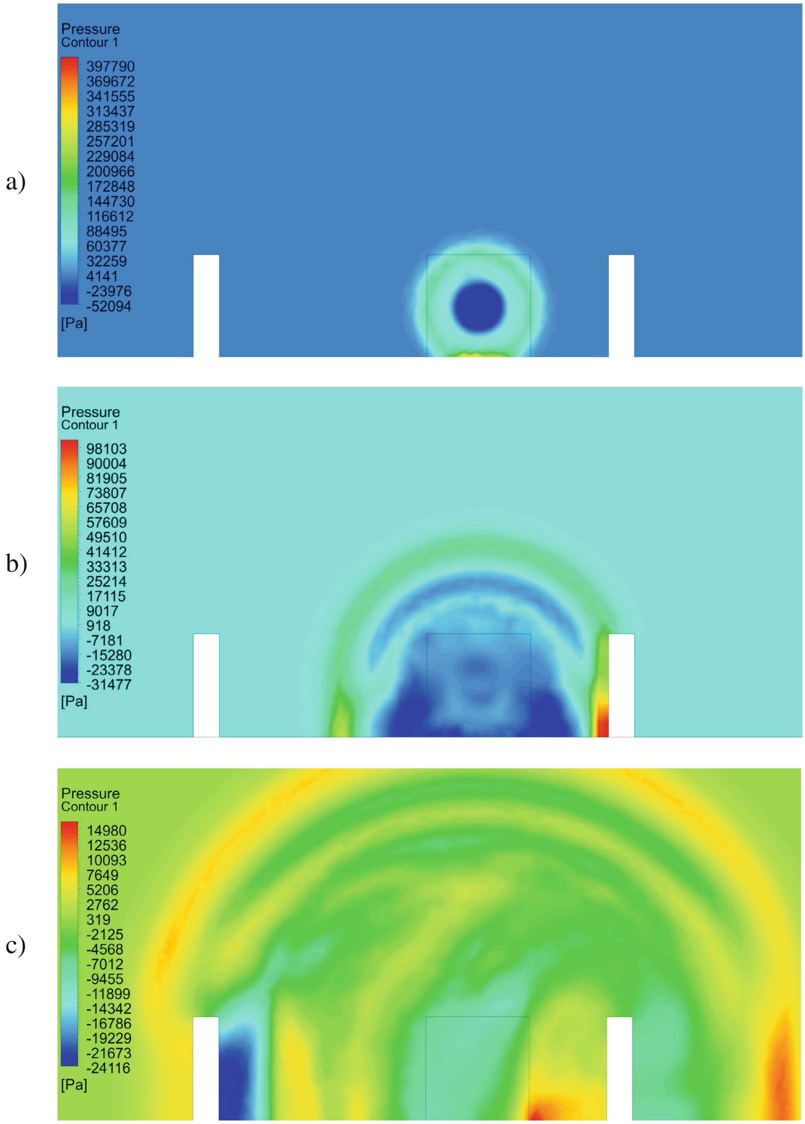


**Fig. 5.** View of isobaric areas in the YZ plane passing through the center of obstacles distant from the explosion centre 2.5 and 5 m for a mixture volume of 1 $m^3$ at time (a) 1, (b) 5, (c) 15 ms

isobaric areas in the YZ plane passing through the center of obstacles distant from the center of the explosion 2.5 and 5 m with a volume of 1 $m^3$ at a time from 1 to 15 ms are shown.

From Fig. 5, it is evident that after the pressure wave passage through an obstacle there is a sudden change of the pressure to the vacuum on the face areas of the obstacles intensifying so the devastating effects of the explosion. In Fig. 6 shows the average relative static pressure on the obstacle fronts in relation to time with a volume of 0.5 $m^3$.

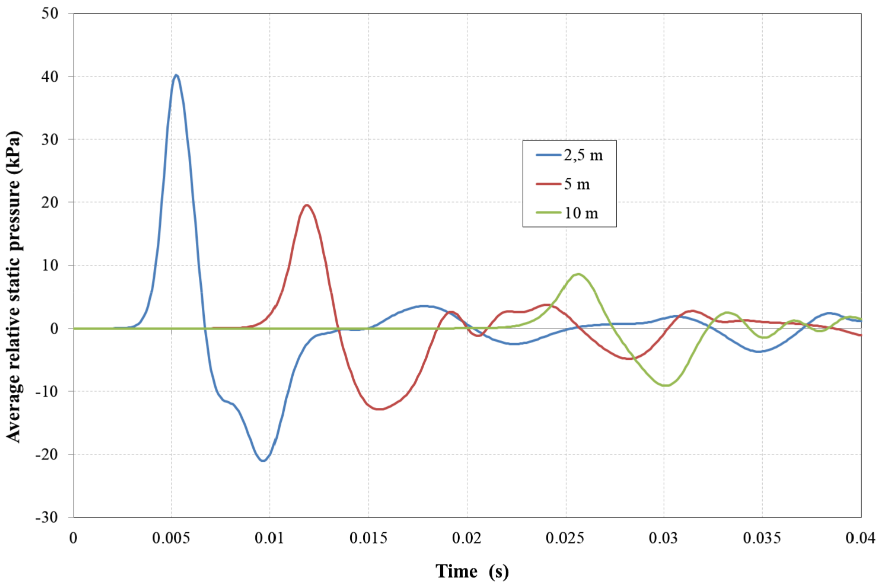


**Fig. 6.** Course of the average relative static pressure on the face areas of the obstacles in relation to time with the volume of 0.5 $m^3$

The dependence between the absolute value of the first amplitude of the pressure from the distance for the volume of the mixture of 0.5 $m^3$ can be described by the power dependence by regression analysis using the smallest squares method

$$|p_{\max}| = 69.45 \cdot l^{-0.896} \text{ (kPa)} \tag{4}$$

where $l$ is a distance of the face area of the obstacle from the centre of explosion (m).

For comparison, Figs. 7 and 8 show the average relative static pressure on the face areas of the obstacle at the volume of 1 and 10 $m^3$. It is clear from the courses that by increasing the volume of the stoichiometric hydrogen/air mixture the first amplitude of relative static pressure on the face area of the obstacle also increases while maintaining the same distance from the centre of the explosion.

Using a multidimensional regression, a comprehensive description of the average relative static pressure dependence on the face areas of the obstacles was obtained from the obstacle distance from the centre of the explosion and the amount of stoichiometric

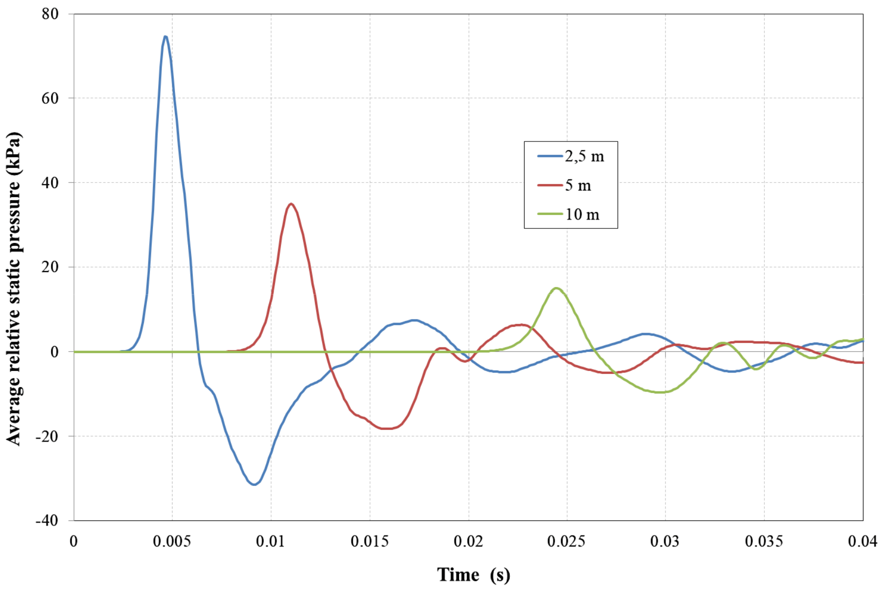


**Fig. 7.** Course of the average relative static pressure on the face area of the obstacles in relation to the time at the volume of the mixture of 1 $m^3$

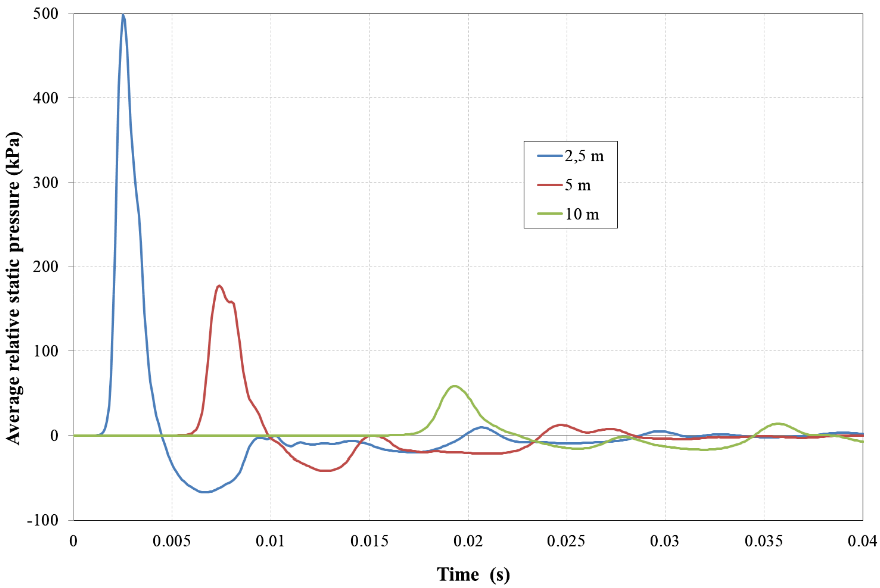


**Fig. 8.** Course of the average relative static pressure on the face area of the obstacles in relation to the time at the volume of the mixture of 10 $m^3$

mixture. For comparison, there is mentioned a power and non-linear dependence beeing valid for the volume of the stoichiometric mixture in the range of 0.5 to 10 $m^3$ and for the obstacle distance in the range of 2.5 to 10 m.

$$p = 263.91 \cdot V^{0.7345} \cdot l^{-1,2976}\ (\text{kPa}) \tag{5}$$

$$p = 3,4751 + 1,9744 \cdot l - 0,1832 \cdot l^2 + 252,62 \cdot l^{-1,432} \cdot V - 5,2928 \cdot l^{-1,135} \cdot V^2\ (\text{kPa}) \tag{6}$$

When computing the first static relative pressure amplitude according to the relationship (5) using linear regression, uncertainties are achieved up to 23% when compared to the results of the numerical calculation. The non-linear regression described by the relationship (6) indicates more acceptable results with an inaccuracy of up to 10.5%. The graphical representation of the first static relative pressure amplitude calculated by relation (6) is shown in Fig. 9

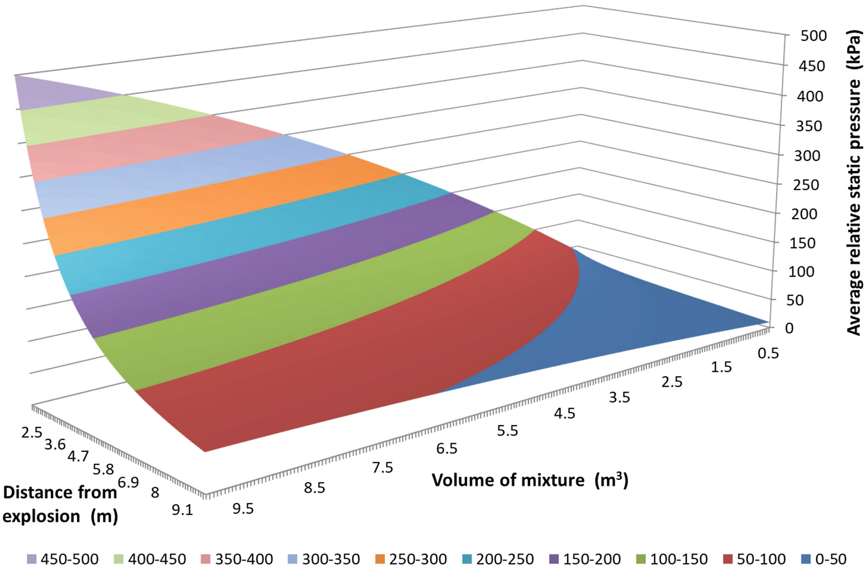


**Fig. 9.** Graphical representation of the first static relative pressure amplitude calculated by using non-linear regression

For comparing the numerical calculation with the non-linear regression equations, a complementary comparison simulation with a stoichiometric mixture volume of 6 $m^3$ and an obstacle distance from the 7 m explosion centre was created. Under these conditions, the first amplitude of static relative pressure reached 74.2 kPa. The value calculated using the relation (6) using non-linear regression is 78.8 kPa. The variance between the numerical and analytical calculation resulting from the multidimensional regression is 6.2%.

## 5 Summary/Conclusion

The paper deals with the risks arising from the operation of hydrogen systems in mobile applications. The risks themselves can be divided into Safety - Machine Safety and Security - Civilian Security. With a help of risk analysis, it can be concluded that the main risk of such technologies is undoubtedly the possibility of explosion. Subsequently, a simulation was created that points to the consequences of such an explosion under different conditions. By analyzing the numerical calculation of the explosion of the stoichiometric hydrogen/air mixture in a predetermined volume range of the mixture and the obstacle distance from the center of the explosion, mathematical dependencies using non-linear regression were compiled. While observing the defined uncertainty, the described relationships allow simply to determine the pressure on the face areas.

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# Younger Generation Safety: Hearing Loss and Academic Performance Degradation Among College Student Headphone Users

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**Abstract.** The potential for hearing loss among younger generations is escalating every year, as well as government expenses on hearing loss. Likewise, the use of headphones has been thought to degrade a college student's academic performance. Hearing loss is defined as a hearing impairment of one or both ears, partial or complete, that results from one's lifestyle, exposure and employment. This issue among the younger generation requires immediate attention. In light of this, this study was conducted in order to survey the listening habits and lifestyle of typical college students who use headphones for at least 5 days a week. Also it investigated possible safety issues and academic performance impacts associated with the use of the device. Two hundred and eighty (N = 280) both undergraduate and graduate students were surveyed, 39% were female (N = 110) and 61% male (N = 170). Eighty-four percent of the respondents were identified as a perpetual users of headphones on daily basis (N = 236), 34% were female (N = 80) and 66% male (N = 156). Results revealed that 44% of the respondents who use headphones on daily basis did not believe that headphone usage can in any-way affect their hearing. Thirty percent of the respondents affirmed that they use headphones because other teenagers use it, while 25% confirmed to be experiencing a ringing sound in their ears after using headphones. About 33% reported to be experiencing loss of sleep at night. Seventy-nine percent of the respondents use their headphones for more than 1 h daily at a volume above 60%. A majority of the respondents use ear-bud headphones. Approximately, 23% answered yes to the question on possible effects on academic performance and 27% of the 23% respondents affirmed to have noticed negative impact on their academic performance since they have started using headphones. Only 189 participants responded to the additional open-ended questions. Of the 189 respondents, 35% reported that headphone listening volume should be as low as 40%, while 14% agreed that headphones should not be used while reading or listening to lecture in a class. Only 13% reported that headphones should be used occasionally and 10% agreed that they should be used during physical activities and not during cognitive activities, which might result in multitasking. Findings from this study show concerns regarding the use of headphones as a possible cause of onset of hearing loss, reduced environmental awareness, and potential academic degradation among some college student users. In addition, the findings could propel a laboratory


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evaluation of college student headphones users on the extent to which headphones usage can contribute to early hearing loss.

**Keywords:** Auditory · Multitasking · Hearing · Headphone
Acoustic exposure · Tinnitus

## 1 Introduction

Headphones have been around for decades, but it was not until 1958 that the first pair of stereo headphones was developed and made available for use by people other than telephone and radio operators [1]. In 1979, with the success of the Walkman, the use of headphones grew substantially. Since then, headphones have been further developed to accommodate the needs of the market, which has resulted in a variety of headphone styles with different performance levels and at various prices. As a result, the market for headphones has become rather sizeable. It is very common these days to see individuals using headphones throughout their day activities. Many use headphones to listen to music on their phone or watch movies on their computer. However, as useful as this device may be in terms of allowing the user to listen uninterrupted, it does pose its own safety risks such as damaging hearing or degrading students' academic performances. And since the target population for headphones is Generations Y and Z, these are the individuals who will be most impacted by these possible hazards. In addition, many individuals within this demographic are or will be attending college, where they are even more likely to use headphones. Certainly, they will often need to study or do homework, concerning which some believe that headphones will allow them to eliminate many of the distractions they will encounter. In 2014, [2]'s study found that the use of headphones is one of the most popular day-to-day activities among the college students.

Recently, health care experts, audiologists, parents and governments have been concerned about different noise sources causing hearing loss in adolescents and young adults [3]. In the report by [4], it was stated that "Headphones and earphones appear to be the most damaging to human hearing. Since noise-induced hearing loss is a result of intensity (loudness) and duration of exposure, these devices may be capable of inducing a permanent bilateral sensorineural hearing loss, especially, if they are used at a volume setting of four or above for extended periods." Several studies have also reported that long-term use of earphones could result in hearing loss [5–7]. As reported in [8], The World Health Organization (WHO) confirmed that more than 5.3% (360 million people) of the world's population suffers from hearing loss. Hearing loss has not been fully traced to the use of headphones but there are a lot of ongoing researches in this area of study. The potential for hearing loss from headphones may be due to the manner in which headphones function, over the ear, in ear, and on ear [1]. No doubt, Thompson's statement might be true, but how many of the Gen Y and Z understand or know the level at which the volume should be or will adhere to the appropriate volume recommended by the manufacturers? In 2009, [9], study on the use of personal listening devices (PLDs) revealed that 71.4% of respondents in their study used a volume level of 60% or higher without knowing. Notwithstanding, the 60% volume level of different types of headphones do not produce the same level of intensity. In 2007, [7], study revealed that out of 1687 students who participated in their study, the frequent earphones users were 4 times more likely to listen to high-volume music than infrequent users and 48.0% confirmed that their earphones is always set in high volume. In 2004, [10], study findings revealed that output levels varied across earphone style, with insert types of earphones producing the greatest output relative to supra-aural and circumaural styles.

Dr. Foy [11] of the American Osteopathic Association reports in his recent publication that the rate of hearing loss in teens is 30% higher than it was in the in the 1990s, before headphones became incredibly common. While researchers have not concluded that headphones usage was the direct cause of this sudden increase in hearing loss, it is believed to play an active role in hearing loss, as individuals growingly turn to headphones when they feel the need to take control of their audio-environment. This technology is growing rapidly and the younger generation buys into the use of headphones without knowing the health issues associated.

In 2013, Fasanya [12], conducted his dissertation on quantitative analysis of acceptable noise level (ANL) for air conduction listening. In his study, university students served as participants. Amazingly, 10% of the students had their hearing threshold shifted and they were disqualified from continue with the study. Based on his investigation, some of the participants affirmed to be perpetual users of headphones on a regular basis. Ever since 2013, this has been a concern for the [12] to research on the extent at which headphones use among college students is contributing to their early age hearing threshold shift and other potential impacts it may contribute toward college students academic performances. Hoover and Krishnamurti [13] study revealed that about one-third of their survey respondents reported being distracted while wearing an MP3 player. Then, if this is the case, it will be important to investigate the academic performances of perpetual headphones users among college students.

According to [14], many headphones users have expressed concern regarding the possible contributions of headphones to noise induced hearing loss. Online report on Trends and Health website [15] in 2014 on health effects associated with the use of headphones and earphones revealed that users are liable to develop tinnitus through constant use of headphones. The authors justified her findings by saying that inserting the headphones will eliminate passage of air and indirectly allow the middle ear to build up wax faster. Therefore, it will be important to investigate the impacts of headphones use on the users' ears, particularly college students. The main goal of this study is to add to the existing knowledge on hearing loss from the excessive use of headphones among college students. In the light of this, the following objectives will be accomplished:

### 1.1 Study Objectives

1. Identify number of hours per day a potential student headphones user uses the device
2. Identify per students population, how many students use headphone on a daily basis.

3. Identify among the students' headphones perpetual users, how many understand the potential impacts associated with over use of headphone devices.
4. Survey student headphones users to determine the impact of the headphones usage on their hearing and academic performances based on their perception.

## 2 Materials and Method

### 2.1 Participants

The study population included both undergraduate and graduate college students at a public university in Northwest Indiana. In total, 280 students were surveyed, 84% (N = 236) of the surveyed students were headphones perpetual users on daily basis. Of the 236 respondents, 34% were female (N = 80) and 66% male (N = 156). Respondents were recruited through one-on-one contact and flyers posted around the campus. The research protocol was approved by the University IRB. Respondents were grouped into four age group categories (18–25), (26–32), (33–40), and (41+). Respondents' ethnicities are Caucasians, Black or African Americans, Native Americans or American Indians, and Hispanics or Latinos with the predominant ethnicity being Caucasians and Hispanics.

### 2.2 Questionnaire

The questionnaire was created on the basis of issues raised in previous studies on the use of headphones/earphones among younger generations. A 25-item questionnaire was created to explore more on the effects of headphones on college students. Overall headphones using habits were assessed by asking question on the primary use of the headphones. The period a user use the headphones on daily basis was also asked, which ranged from 1–7 days and hours per day from half hour to 5 h per day. The effects of the headphones usage was assessed on the basis of 12 items on yes/no questions. The volume control question was based on percentage (20%, 40%, 60%, 80% and 100%), kind of headphones/earphones used (Earbud-style, On-Ear and Over-Ear headphones). The questionnaire also includes an open-ended question on participants' suggestion/advice on headphones use. The questionnaire included items on the participant's gender, age, and educational level and field of study, and ethnicity.

### 2.3 Procedure

To be included as a participant, every respondent was required to be a frequent headphones user and a college student between 19 and 45 years of age. Advertisement on campus was done with study flyers posted on public notice boards for one month before the commencement of the survey distribution. Surveys were distributed to participants on one-on-one basis around the two campuses operated by the university. Survey completion took individual respondents 10–15 min. Any students approached who did not meet the inclusion criteria (age above 45 years, and not a student on the campus) were not allowed to complete the survey but (non-headphones users) were listed among the contacted students for the study. Non headphones users were counted among the surveyed students, because their demographic information was collected such as age, gender and field of study. It took approximately four months to complete the survey analyzed in this study. Three days, for two hours daily were dedicated for the data collection per week excluding holidays.

## 3 Data Analysis and Results

Data collection lasted for approximately one semester. Data where compiled using Microsoft Excel version 2010©. The study includes 28% Caucasian, 20% of Black or African-American, 28% Hispanic, 17% Asian, and 5% of other. Table 1 shows respondents demographic information. Fifty-nine percent of the respondents fall between the age of 18 and 25 years old. This category of people is referring to as Gen Z aka “jet generation”.

Table 1.

| Demographic information | | Population | F | M |
|---|---|---|---|---|
| Ethnicity | Caucasian | 67 | 19 | 48 |
| | Hispanic/Latino | 67 | 25 | 42 |
| | Black or African-American | 48 | 20 | 28 |
| | Native American | 1 | 0 | 1 |
| | Asian | 41 | 16 | 25 |
| | Other | 12 | 0 | 12 |
| Age | 18–25 | 140 | 66 | 131 |
| | 26–32 | 69 | 8 | 19 |
| | 33–40 | 24 | 4 | 5 |
| | 41+ | 3 | 2 | 1 |

The ages of the respondents were also categorized into three different generations: Gen X, Y, and Z. Figure 1 shows the growth trend in the three generations as they involve in the use of headphones. It shows in the graphical representation that headphones use depends on the generation. Respondents that fell within Gen Z use headphones more than those in Gen Y and more than those in Gen X. Of the 280 surveys distributed, only about 16% identified themselves as non-user of headphones. Out of the 16% (N = 44), about 76% (N = 33) respondents’ ages fall in age category 3, which is identified as Gen X and 23% (N = 10) ages fall in age-category 2, while only one of the non-user of headphone fall in age-category 1, Gen Z. Gen X non-users of headphones is about 75% higher than Gen Z non-users and approximately 53% higher than Gen Y non-users.

All Yes/No questions were coded (0 or 1) depending on what the respondents selected. Roughly half of the respondents reported not believe that headphones use in any form can affect their hearing. Thirty-six percent of the respondents reported using headphones for more than 2 h daily. Of the 36%, 44% reported having their volume

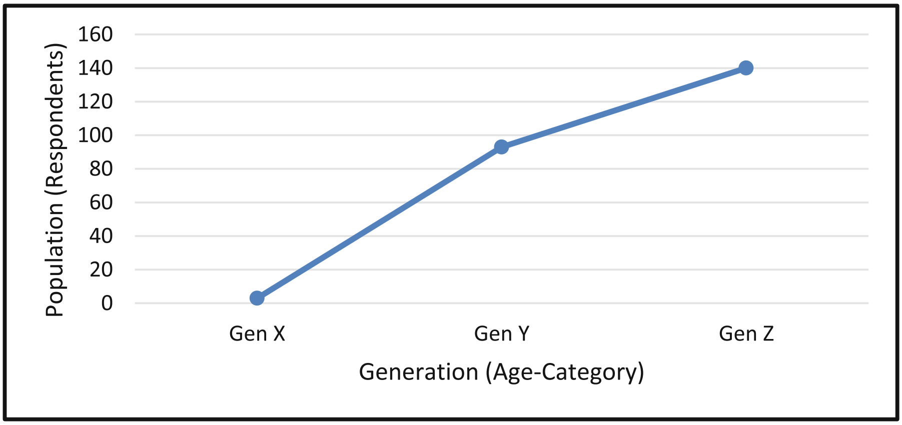


**Fig. 1.** Graphical representation of respondents' headphones users according to their age-category

level above 60% recommended by the manufacturers. Seventy percent of the respondents reported using earbuds type of headphones. Twenty-three percent of the respondents affirmed to notice negative shift in their academic performances since they have started using the headphones. The volume level at which respondents reported using headphones while studying is shown in Fig. 2.

Figure 2 indicates that forty-six percent of the respondents use headphones while performing other cognitive demanding activities such as reading scientific books, doing homeworks, writing report papers, working on projects, etc. Thirty-eight percent of the respondents reported to have noticed loss of sleep (insomnia) at night ever since they have started using headphones, while 24% reported ringing sound (Tinnitus) in their ears after using headphones. In terms of safety, only 39% believe that overuse of headphones can result in hearing threshold shift. As a matter of fact, about 12% of the

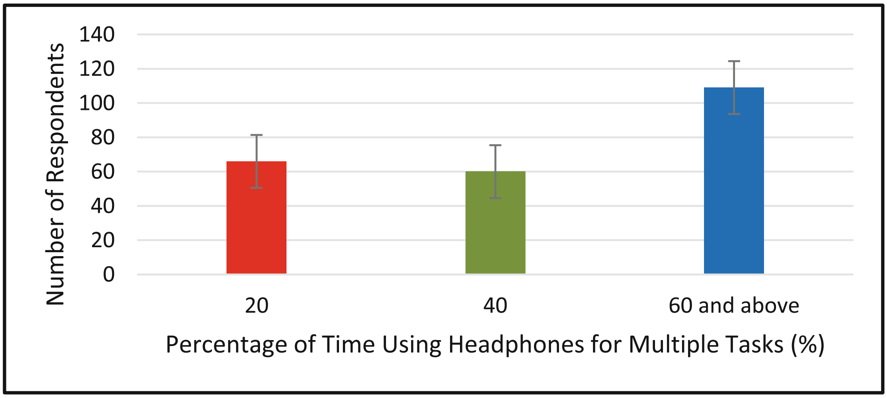


**Fig. 2.** Graphical representative of the respondents who use headphones while studying.

respondents reported not feeling comfortable without using headphones at all in one day. Incredibly, only 19% of the respondents affirmed having been advised by their parent, friend or instructor to stop using headphones on a regular basis. Only 189 of the surveyed population responded to the additional open-ended questions. Of the 189 respondents, 35% reported that headphones listening volume should be as low as 40%, while 14% agreed that headphones should not be used while reading or listening to lecture in a class. Only 13% reported that headphones should be used occasionally and 10% agreed that they should be used during physical activities only and not during cognitive tasks, which might result in multitasking.

## 4 Discussion

This study illustrates the negative impacts of headphones use among college students. Overall, results demonstrate that in the use of headphones, college students are much more likely to be distracted when at the same time performing some of their homework or doing school related activities that demand their full attention. As revealed from this study, this behavior had negatively contributed to decline in college academic performances of some of the college students surveyed, particularly, perpetual user of headphones. Although, this study did not reveal that using headphones only is correlated with the decline noticed in the academic performances of the college students, but using the headphones while full attention is required for another school work; such as assignment and studying for test. It is understood from this study that combined use of headphones and performing school works result in multiple tasks for the users. This has created resource sharing for listening to the signal from the headphones and paying attention to the school work in part of the brain for attention. Therefore, users tend to perform poor in one task. Forty-six percent of the respondents use headphones while carrying out other cognitive activities such as reading, doing homework, writing papers, and working on projects, etc. 23% confirmed to notice decline in their academic performances.

The findings further confirmed that using headphones among college students led to ringing sound in their ears (Tinnitus). This could be absolutely right, as 70% of the respondents affirmed using earbuds in their day-to-day activities. The report of [14] established the fact that inserting earbud headphones will eliminate passage of air and indirectly allow the middle ear to build up wax faster easily. Although, no laboratory (audiometry) test was conducted on the respondents for this study, the study only report the response feedbacks from the questionnaires distributed to the students. McNeill et al. [16] findings also supported the possibility that using headphones causing tinnitus. About forty-four percent reported having their volume level above 60% recommended volume level by the manufacturers, this is possible because of the headphones style respondents identified as the most commonly used one is earbud. According to [17], increase in the environment noise level, increases earbud headphones users susceptibility to background noise, therefore, users tend to increase the level of the music/signal to overcome the background noise. Indirectly, this might result is an increased sound pressure level at the eardrum. Findings from [18] study, confirmed the nonchalant behavior demonstrated by younger generation in volume setting as participants who participated in their survey reported high or very high volume settings and demonstrated low awareness towards loud music listening consequences.

The likelihood that the percentage of college students using headphones will increase is very high as there might be no role model to educate the next generation on the negative impact of addicted use of headphones. Since the larger percentage of the headphones perpetual users fall in Gen Z, this indicates that generation has influenced the way people involved in the habit of using headphones on their day-to-day activities. Additionally, this study reveal that only 13% of the respondents believe that headphones should be used occasionally, while only 19% confidently confirmed that they have been once corrected by their parents to avoid over use of the headphones. Therefore, parental monitoring is lacking and this could create a significant impact on the increase of the college students indulging in the habit in the near future.

Regardless of the usage characteristics, frequent users will have much higher frequency of the risk associated with headphones use than did infrequent users. This could be because, the headphones serve as a source of distraction, or attempts to overuse it, ignorance of unsafe volume levels as stipulated by the manufacturers, etc. The findings from this study aligned with the Dr. Foy of the American Osteopathic Association who reported in his article that hearing loss in teens is 30% higher than it was in the in the 1990s, before headphones became incredibly common. As this study revealed that 38% of the respondents reported noticing loss of sleep (Insomnia) at night since they had started using headphones. Loss of sleep at night is an onset of hearing loss. Numerous published articles on the use of headphones by college students revealed the potential for hearing loss at different volume levels depending upon usage [16, 19]. As a safety concern only 39% of the respondents believed that overuse of headphones can result in a hearing threshold shift.

## 5 Conclusion

The extent of hearing damage caused by headphones and Personal Listening Device (PLD) use is an unresolved issue. Numerous studies have reported that headphones and PLD users have significantly higher hearing thresholds compared with non-users [20–22]. The findings from this study suggests that perpetual user of headphones (male and female) will in one way or another suffer from the negative impacts of the habit. Given the high prevalence of the negative impacts of the behaviors (headphone usage) and the low prevalence of protective behaviors, the findings from this study suggest that the levels at which college students engage in these behaviors justify the development and implementation of strategies for prevention and intervention. It also suggests the need for more research in this area.

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# Application of Statistical Process Control to Guarantee the Safety in the Operation of a Sterilization Chamber with Ethylene Oxide Gas

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**Abstract.** The objective of this article is to apply Statistical Process Control (SPC) to guarantee the safety in the operation of a sterilization chamber with ethylene oxide gas in thermo-sensitive material. One of the most used in Mexico; but at the same time, one of the most unfavorable methods due to the risks it presents to exposed workers. Environmental and personal measurements were carried out to control the exposure limits. Once the data was collected, SPC tools such as variable control charts (X bar-R chart) were applied to verify that the process was under statistical control. The results of the environmental and personal measurements of the sterilization process carried out by the manufacturer of surgical and healing material showed the process is within the permitted exposure limits. Recommendations are extended in relation to the use of personal protection equipment and working environment conditions, to fulfill with the requirements of national regulatory frameworks.

**Keywords:** Statistical process control (SPC) · Sterilization · Ethylene oxide
TLV-TWA (PEL) or Permissible exposure limit
TLV-STEL or Limit in short periods of exposure

## 1 Introduction

### 1.1 Statistical Process Control and Graphics XR

Statistical process control, is the branch of quality that involves the collection, analysis and interpretation of data, establishment of quality, comparison of performance, check detours, all that for its use in improvement activities and quality control of products, services and diagnosis of defects [1]. This analysis is done through graphs or control charts; this is a graph used to observe and analyze statistical data variability and performance of a process over time [2].

There are several types of control charts, for this specific case will be using XR control charts or media vs. range graphics; this are graphs for variables that apply to


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mass processes, wherein periodically a sample or subgroup is obtained, this are measured, and the mean X and the R range is calculated to be recorded in the graphs [2]. Its objective will be to monitor process stability over time, so that we can identify and correct instabilities in a process.

### 1.2 Overview Ethylene Oxide Gas

Ethylene oxide is a gas, which at room temperature is a colorless gas with a sweet odor. Among its properties listed in Table 1; it can be mixed with water, alcohol and most organic solvents and is soluble in acetone. Ethylene oxide is flammable and explosive, incomplete combustion releases carbon monoxide [3].

**Table 1.** Physical and chemical properties of ethylene oxide [4].

| Property | Value |
|---|---|
| Odor threshold | 257 a 690 ppm |
| Flashpoint | −4 °F (−20 °C) |
| Auto-ignition temperature | 804 °F (429 °C) |
| Vapor density | 1.5 (air = 1) |
| Vapor pressure | 1095 mm Hg at 68 °F (20 °C) |
| Relative density | 0.87 (water = 1) |
| Water solubility | Miscible |
| Boiling point | 51 °F (11 °C) |
| Freezing point | −170 °F (−112 °C) |
| Ionization potential | 10.56 eV |
| Molecular weight | 44.06 |

### 1.3 Applications of Ethylene Oxide

Ethylene oxide is a synthetic chemical used mainly to produce ethylene glycol. A small amount (less than 1%) is intended to control insects in certain agricultural products, and a very small amount is used to sterilize medical equipment and supplies heat-sensitive, surgical instruments and other objects that meet biological tissues [5].

### 1.4 Sterilization Using Ethylene Oxide

The sterilization process shown in Table 2 is aimed at the total destruction of pathogenic or non-pathogenic microorganisms contained in an area or inanimate object.

This method applies to any substance or element that must come into contact with the human organism and it´s likely to contain pathogenic microorganisms. As one of the most used methods for the thermosensitive material, the advantages and disadvantages of its use must be taken into consideration, shown in Table 3. For the sterilization process, ethylene oxide can be used in the following ways [6]:

**Table 2.** Phases of the sterilization cycle.

| Phase | Description |
|---|---|
| 1. Conditioning load | It begins with a vacuum for the extraction of the air from the chamber, in order that the sterilizing agent reaches all the areas of the load |
| 2. Exposure to gas | By injecting the gas until reaching the cycle pressure. The concentration is maintained during the actual sterilization time |
| 3. Gas extraction | Degassing of the chamber occurs with successive voids |
| 4. Aeration | They are the air renewals of the chamber to eliminate the residual products of the sterilized material. At the end, the pressures are equalized so that the sterilizer door can be opened |

1. Pure 100%. The concentration of the gas in the chamber for the sterilization process is approximately 800 mg/l.
2. Mixed with diluent gases that reduce the effects, this mixture is cheaper and does not present any problem in its use. Works in cameras with positive pressure and at a concentration of 600–650 mg/l.

**Sterilization Process.** The sterilization process developed and validated for the company Quirmex S.A. of C.V. by the engineer Iván Soto Sanchez certified as a leading auditor in OHSMS/OHSAS 18001: 2007 [6].

**Table 3.** Advantages and disadvantages of sterilization with ethylene oxide

| Advantage | Limitations |
|---|---|
| • Thermo-sensitive material | • Very long cycles |
| • Does not require special containers | • Highly toxic to humans |
| • Allows material with all types of lumens | • Necessary to eliminate waste |
| • Effective | • Requires exclusive installations |
| • Does not deteriorate sharp material | • Flammable, explosive |
| • Compatible with most material | • Carcinogenic and mutagenic |
| • Appropriate monitoring | • Necessary waste monitoring |

### 1.5 Exposition

Sterilization with ethylene oxide is a very effective method for the elimination of microorganisms, however, it presents risks for personnel who are involved and/or exposed frequently or for a long time to this gas.

Breathing low levels of ethylene oxide for months or years has caused irritation of the eyes, skin and respiratory tract, and affected the nervous system. Exposures to higher levels for shorter periods have caused similar effects, although more severe [5].

The New Jersey Department of Health establishes the following health risks in its fact sheet on hazardous substances [4]:

### Acute effects on health[1]

- Contact can cause irritation and burns to the skin and eyes.
- Contact with undiluted liquid can cause freezing.
- Exposure to ethylene oxide can irritate the nose and throat.
- Inhalation can irritate the lung, causing a cough or shortness of breath.
- Exposure can cause headache, nausea, vomiting, dizziness, fasciculations and seizures.

### Chronic effects on health[2]

- Risk of cancer. Ethylene oxide is a human CARCINOGEN. There are indications that it causes leukemia in humans and has been shown to cause cancer of the blood, stomach, lung and other cancers in animals.

### Risks to reproductive health

- Ethylene oxide can be a TERATOGEN in humans.
- There are limited indications that causes spontaneous abortions.
- Ethylene oxide may cause damage to the developing fetus.
- Ethylene oxide may cause damage to the testicles.

### Other effects

- Ethylene oxide may cause an allergy to the skin.
- Ethylene oxide can irritate the lung.
- High or repeated exposure could cause nerve damage, causing weakness, tingling and poor coordination in the arms and legs.
- Ethylene oxide could cause liver and kidney damage.

## 1.6 Standards Related to the Use of Ethylene Oxide

Employee exposure to ethylene oxide should be limited to one part per million (ppm) as a weighted average in relation to the time of 8 h and 5 ppm on average for a time of 15 min (excursion limit) [7].

There are international standards for the use of ethylene oxide, these seek to establish measures that lead to ensure the safety of workers who use this gas. Table 4 shows the exposure limits established by some international institutions.

As a specification, international legislation (OSHA Regulations 06/04/88) establishes the maximum exposure level for 8 h (TWA/PEL) at 1 ppm and the maximum exposure level for short periods of time (STEL) at 5 ppm [9].

According to the Official Mexican Standard NOM-010-STPS-2014; it is considered as dangerous chemical substances: Those that due to their physical and/or chemical properties when being handled, transported, stored or processed, present the possibility of explosiveness, flammability, combustibility, reactivity, corrosivity, radioactivity,

[1] Acute (short-term) health effects can occur immediately or shortly after exposure to ethylene oxide.

[2] Chronic (long-term) health effects may occur sometime after exposure to ethylene oxide and may last for months or years.

**Table 4.** International regulations for exposure to ethylene oxide.

| Regulatory institution | Exposure values |
|---|---|
| Occupational Safety and Health Administration (OSHA) | 1 ppm, TWA 8 h; excursion 15 min, 5 ppm |
| National Institute of Occupational Safety and Health (NIOSH) | <0.1 ppm, TWA 10 h; 5 ppm, upper limit 10 min |
| Association Advancing Occupational and Environmental Health (ACGIH) | 1 ppm, TWA 8 h |
| Immediately dangerous to life or health air concentration values (IDLH values) | 800 ppm |

toxicity or irritability risks., and that when entering the organism through the respiratory, cutaneous or digestive routes, they can provoke exposed workers intoxication, burns or organic lesions, depending on the level, concentration of the substance and time of exposure [8]. Table 5 shows the indicated exposure limits for ethylene oxide.

**Table 5.** Limit values for exposure to polluting chemical substances in the work environment in accordance with NOM-010-STPS-2014

| No. | Substance | Alteration/effect on health | No. Cas | Connotation | TLV | |
|---|---|---|---|---|---|---|
| | | | | | TWA | STEL |
| 595 | Ethylene Oxide | Cancer, central nervous system damage | 75-21-8 | A2 | 1 ppm | — |

**Connotations, abbreviations and notes.** A2 Suspected carcinogen in humans. TLV or Exposure limit value: which is the reference concentration of a chemical agent contaminant of the workplace in the air, which can be weighted in time, short time or peak. TWA or Time-weighted average exposure limit value and STEL or Short-term exposure limit value.

## 2 Context of the Investigation

This study was carried out in the company Quirmex S.A. of C.V.; manufacturer of medical material for hospitals, sterile and non-sterile; such as gauze in all its presentations, elastic bandages, absorbent cotton, surgical uniforms, etc.

Approximately 18 months ago Quirmex decided to start the project of construction of a sterilization chamber to save costs and not outsource the sterilization process of all its products. This leads to the company facing a series of risks for the employees involved in the process; It is for this reason that security audits were implemented for this area.

## 3 Material and Method

The objective of this research is to evaluate the capacity of the process; based on the result reinforce the correct use and care that must be taken when using the ethylene oxide sterilization method by the workers exposed to it during their work activity.

The main sources of contamination in the work environment are during the sterilization cycle, at the end of the cycle, at the moment of door opening, during the discharge and in the losses that may occur in the equipment and hoses joints. It is also common to register ETO in ventilation rooms where the material is stored with forced ventilation in such a way that it releases the residues of ethylene oxide that were absorbed.

For the investigation, the analysis of the data is divided into two parts.

1. First, the measurements of the work environment are analyzed during the 8 h of the sterilization cycle (TWA/PEL), when the material is inside the chamber.
2. Secondly, the measurements obtained in the process of the end of the cycle during the opening of the door (STEL) exposures during 15 min are analyzed.
3. The measurements (with portable and fixed detector) of the environmental concentrations of ethylene oxide were taken during complete cycles for one month. Five cycles per week were performed for 4 weeks.
4. After obtaining all the data are recorded in Excel spreadsheets, the Minitab will be used for the realization of control charts, histograms and Cp calculations for each of the above situations to verify if they are within the limits allowed for specification and if the process is under statistical control.

## 4 Results

With a maximum exposure concentration (Fig. 1) averaging 0.37 ppm and an average exposure of 0.23 ppm during an 8-h day; the process is under statistical control; the maximum level of exposure for 8 h (TWA/PEL) at 1 ppm is below the upper limit allowed and is also below the recommended limit ensuring the health of the exposed workers (Table 6).

With an index (Fig. 2) $1 \leq \text{Cp} \leq 1.33$ it is concluded that the process is suitable for the job, but strict control is required if the Cp index approaches 1 (Table 7).

With a maximum concentration of exposure (Fig. 3) in short periods of 0.95 ppm and an average exposure of 0.59 ppm at the time of opening doors, where the maximum exposure peaks should be; the process is under statistical control; the maximum level of exposure for short periods of time (STEL) at 5 ppm is below the upper limit allowed, ensuring the health of exposed workers.

With an index (Fig. 4) $\text{Cp} > 2$ it is concluded that the process is more than adequate for the job.

**Table 6.** Measurements taken per hour (H) of ethylene oxide concentrations for maximum exposure level for 8 h (TWA/PEL). During sterilization process inside chamber.

| | Concentration of Ethylene Oxide (Per hour) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Hour | $H_1$ | $H_2$ | $H_3$ | $H_4$ | $H_5$ | $H_6$ | $H_7$ | $H_8$ |
| Days | 1 | 0.04 | 0.38 | 0.34 | 0.35 | 0.15 | 0.34 | 0.44 | 0.17 |
| | 2 | 0.02 | 0.48 | 0.07 | 0.23 | 0.35 | 0.13 | 0.37 | 0.02 |
| | 3 | 0.16 | 0.18 | 0.26 | 0.37 | 0.33 | 0.06 | 0.22 | 0.30 |
| | 4 | 0.02 | 0.36 | 0.17 | 0.22 | 0.01 | 0.34 | 0.05 | 0.26 |
| | 5 | 0.48 | 0.19 | 0.40 | 0.39 | 0.28 | 0.21 | 0.05 | 0.35 |
| | 6 | 0.22 | 0.08 | 0.39 | 0.31 | 0.08 | 0.27 | 0.12 | 0.32 |
| | 7 | 0.40 | 0.47 | 0.14 | 0.20 | 0.15 | 0.44 | 0.25 | 0.42 |
| | 8 | 0.24 | 0.22 | 0.34 | 0.07 | 0.39 | 0.24 | 0.06 | 0.17 |
| | 9 | 0.23 | 0.36 | 0.43 | 0.40 | 0.25 | 0.12 | 0.12 | 0.22 |
| | 10 | 0.23 | 0.48 | 0.44 | 0.28 | 0.29 | 0.23 | 0.07 | 0.40 |
| | 11 | 0.42 | 0.26 | 0.01 | 0.18 | 0.18 | 0.11 | 0.29 | 0.43 |
| | 12 | 0.48 | 0.01 | 0.46 | 0.33 | 0.34 | 0.21 | 0.02 | 0.36 |
| | 13 | 0.11 | 0.23 | 0.26 | 0.33 | 0.42 | 0.20 | 0.26 | 0.17 |
| | 14 | 0.44 | 0.03 | 0.03 | 0.05 | 0.12 | 0.08 | 0.11 | 0.07 |
| | 15 | 0.48 | 0.19 | 0.40 | 0.39 | 0.28 | 0.21 | 0.05 | 0.35 |
| | 16 | 0.18 | 0.18 | 0.14 | 0.43 | 0.27 | 0.29 | 0.08 | 0.31 |
| | 17 | 0.42 | 0.26 | 0.01 | 0.43 | 0.10 | 0.07 | 0.26 | 0.42 |
| | 18 | 0.02 | 0.27 | 0.15 | 0.15 | 0.12 | 0.40 | 0.16 | 0.19 |
| | 19 | 0.27 | 0.08 | 0.10 | 0.04 | 0.38 | 0.04 | 0.12 | 0.04 |
| | 20 | 0.21 | 0.28 | 0.25 | 0.05 | 0.31 | 0.25 | 0.06 | 0.02 |

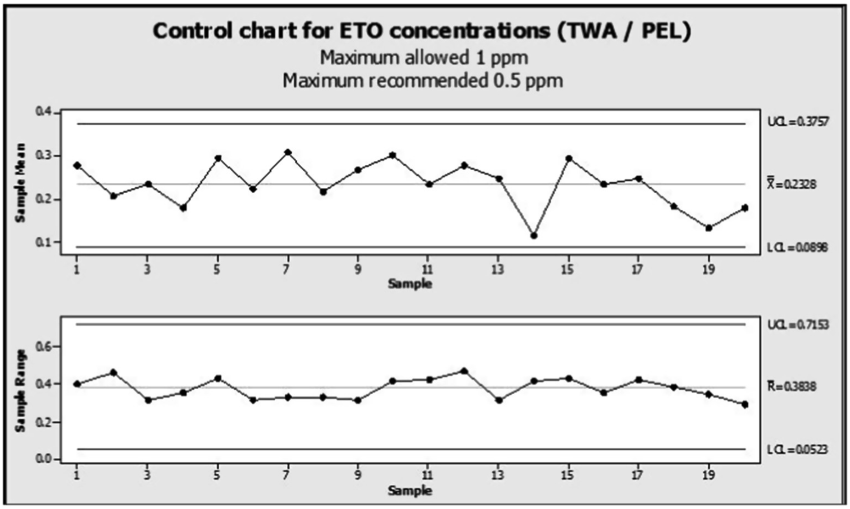


**Fig. 1.** Control chart X bar - R for maximum exposure level for 8 h (TWA/PEL). During sterilization process inside chamber.

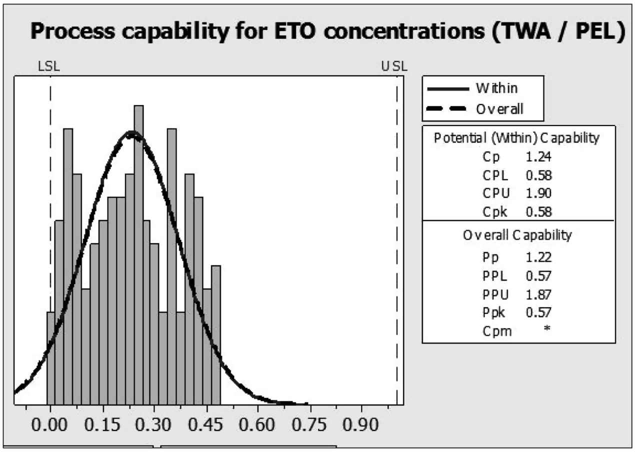


**Fig. 2.** Process capacity analysis for maximum exposure level for 8 h (TWA/PEL). During sterilization process inside chamber.

**Table 7.** Measurements taken per hour of ethylene oxide concentrations for maximum exposure level for (STEL). During door opening.

| | Concentration of Ethylene Oxide (Per hour) | | | | | |
|---|---|---|---|---|---|---|
| | Hour | $H_1$ | $H_2$ | $H_3$ | $H_4$ | H5 |
| Days | 1 | 0.69 | 0.60 | 0.68 | 0.35 | 0.99 |
| | 2 | 0.80 | 0.94 | 0.85 | 0.41 | 0.55 |
| | 3 | 0.94 | 0.49 | 0.52 | 0.96 | 0.81 |
| | 4 | 0.77 | 0.02 | 0.48 | 0.06 | 0.95 |
| | 5 | 0.85 | 0.47 | 0.80 | 0.50 | 0.99 |
| | 6 | 0.63 | 0.29 | 0.57 | 0.89 | 0.71 |
| | 7 | 0.86 | 0.10 | 0.38 | 0.40 | 0.75 |
| | 8 | 0.25 | 0.95 | 0.44 | 0.57 | 0.59 |
| | 9 | 0.76 | 0.59 | 0.49 | 0.87 | 0.49 |
| | 10 | 0.52 | 0.62 | 0.82 | 0.50 | 0.79 |
| | 11 | 0.92 | 0.85 | 0.78 | 0.17 | 0.69 |
| | 12 | 0.89 | 0.54 | 0.75 | 0.65 | 0.79 |
| | 13 | 0.22 | 0.90 | 0.69 | 0.79 | 0.40 |
| | 14 | 0.28 | 0.09 | 0.20 | 0.33 | 0.36 |
| | 15 | 0.26 | 0.03 | 0.90 | 0.99 | 0.37 |
| | 16 | 0.51 | 0.97 | 0.42 | 0.20 | 0.29 |
| | 17 | 0.19 | 0.82 | 0.92 | 0.89 | 0.73 |
| | 18 | 0.28 | 0.30 | 0.70 | 0.78 | 0.14 |
| | 19 | 0.71 | 0.81 | 0.45 | 0.97 | 0.66 |
| | 20 | 0.99 | 0.22 | 0.73 | 0.58 | 0.59 |

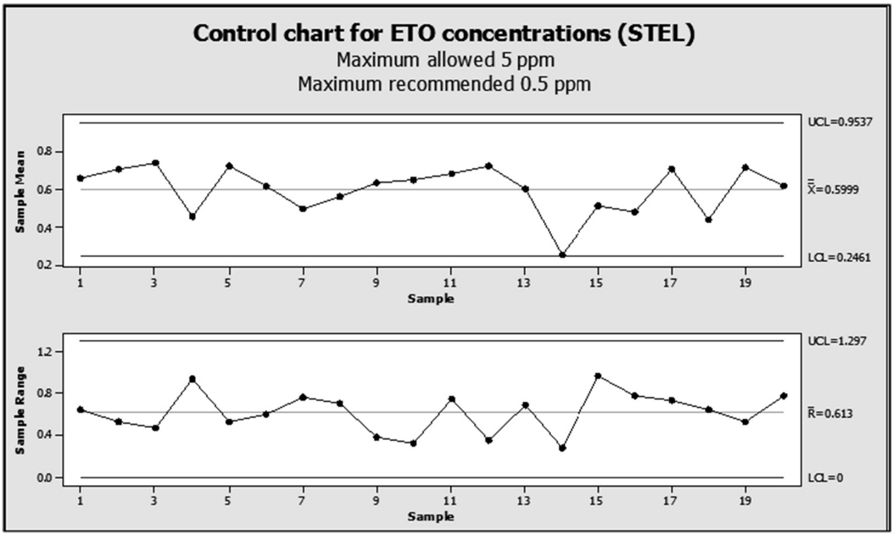


**Fig. 3.** Control chart X bar - R for maximum exposure level for (STEL). During door opening.

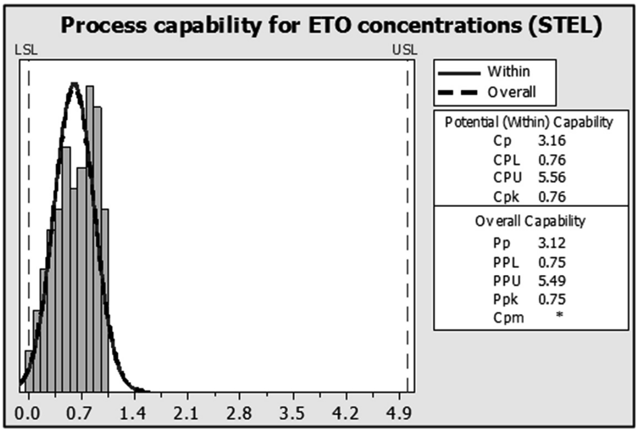


**Fig. 4.** Process capacity analysis for maximum exposure level for (STEL). During door opening.

## 5 Conclusions and Recommendations

The authors verify during the development of this article; as, through the application of Statistical Process Control (SCP), it is possible to guarantee the safety in the operation of a sterilization chamber with ethylene oxide gas in thermosensitive material used in hospitals and health centers.

The results of the study showed that both for the work environment during the 8 h of the sterilization cycle (TWA/PEL) when the material is inside the chamber, and for the process of the end of the cycle during the opening of the door (STEL) exhibitions for 15 min.; the processes are under statistical control and have an adequate capacity index for the work.

The following recommendations are made (only for guidance) to work practices related to exposure to ethylene oxide:

– Label the process containers.
– Provide employees with information and training on risks.
– Control airborne concentrations of chemicals.
– Use engineering controls if concentrations exceed the recommended exposure levels.
– Provide eyewash and emergency showers.
– Wash or shower if the skin comes into contact with a hazardous material.
– Always wash at the end of the work shift.
– If clothing is contaminated, remove contaminated clothing and put on clean clothes.
– Do not take contaminated clothing home.
– Receive special training to wash contaminated clothing.
– Do not eat, smoke or drink in places where chemical substances are handled, processed or stored.
– Before entering a confined space where ethylene oxide may be present, check that there is no explosive concentration and/or greater than that permitted.

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# Safety and Prevention in Construction/Mining Sector

# Role of Psychological Contract to Influence Safety Behaviour at Construction Sites

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**Abstract.** Viewing safety through the lens of the 'Psychological Contract' and considering the influence of supervisor on construction site, this research proposes a 'Psychological Contract of Safety' (PCS) which is based on the mutual obligations to safety between supervisor and workers, predicts safety behaviour at a construction site. In order to test this hypothesis, data were collected from a mega-construction project in Sydney, Australia. The empirical data indicates that there is a strong influence of the PCS on the safety behaviour of individual workers. Using Structural Equation Modelling this research tested a survey instrument that can be used in other construction settings to examine the strength of the mutual relationship between supervisors and workers and its influence on safety behaviour.

**Keywords:** Construction safety management · Psychological contract Safety behaviour · Workers perception

## 1 Introduction

The construction sector employs about 7% of the world's workforce, but is responsible for 30–40% of fatalities [1]. Despite technological developments and the implementation of robust safety management systems, the industry's chronic level of fatalities, serious injury and ill-health appear difficult to change [2]. This has led researchers and practitioners to focus on organizational and social factors to induce positive change to the industry's poor safety performance [3]. In this regard one line of inquiry has focussed on the role first-level supervisors play in translating senior management commitment to safety into safety values and practices in workgroups [4]. A second, related area that has received little attention is the influence that organizationally-based social exchanges between workers and supervisors have on safety [5]. Blau [6], while discussing social exchange theory, argued that when one party acted in ways that provided benefits to a second party, an implied obligation was generated for future reciprocity.


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This 'psychological contract' which is assumed as a consequent of social exchange theory [6], can be introduced to capture the momentum between supervisors and workers to explore their relationships in terms of safety. Advancing this line of thinking further, Psychological contracts of safety (PCS) can be conceptualized as the beliefs of individuals about reciprocal safety obligations inferred from implicit or explicit promises [7–9]. This research project argues that PCS could provide the cognitive basis for the development of workers safety behaviour arising from supervisor's safety behaviour, which ultimately affects the safety behaviour on the construction sites. Hence, this research project examines how the PCS (between supervisor and worker) influences workers' safety behaviour in a construction site.

## 2 Safety Behaviour

According to Heinrich and Granniss [10], roughly 88% of all accidents are caused by unsafe acts of people. Salminen and Tallberg [11] found out that 84–94% of all occupational accidents derived from the unsafe behaviour of people after they analysed occupational fatalities from years 1985–1990 and serious accidents from years 1988–1989 in Finland. Fleming and Lardner [12] also revealed that 80–90% of all workplace accidents and incidents are attributed to unsafe behaviours. Unsafe behaviour has been widely proven to be the major cause of accidents [13]. Failure to use the protective gear provided in the workplace accounts for approximately 40% of work accidents, and this statistic has not changed for more than 20 years despite continuing efforts [14]. A cost–benefits analysis suggests that safety precautions often entail a modest but immediate cost in terms of slower pace, extra effort, or personal discomfort. If the likelihood of injury is underestimated (a result of underestimation of rare events), the expected utility of unsafe behaviour exceeds that of safe behaviour. The attractiveness of unsafe behaviour is reinforced by the tendency to assign short-term results greater weight when one is choosing among action alternatives [15].

### 2.1 Components of Safety Behaviour

Safety compliance and safety participations are two kinds of safety behaviours. Safety compliance behaviour (SCB) refers to activities employees need to do in order to maintain workplace safety [16]. When employees do not obey the procedures and rules, their behaviours are labelled "unsafe activities" or "violations". Thus, unsafe activities and safety compliance behaviours are two ends of one dimension. Safety participation behaviour (SPB) refers to voluntary safety behaviours [16]. Safety compliance behaviour (SCB) would be part of work role, whereas SPB can extend beyond formal role.

## 3 Influence of Supervisor in Construction

Choudhry and Fang [17] argue that workers feel comfortable with supervisors who care for their safety. Langford et al. [18] indicated that the more relationship-oriented supervisors were, the more likely it was that operatives would perform safely.

Sully [22] argued that to better understand the relationship between safety behaviour and an individual employee, it was important to understand the dynamics underlying the relationship between employees and their organization. In a construction setting, the supervisor has been suggested to be the most influential agent representing the organization. In addition, they have been shown to develop high levels of physical and psychological closeness with their direct subordinates through bonds that begin to develop during their supervision of employees' day-to-day tasks. These bonds noticeably affect employees' perceptions of their psychological contracts [19]. In light of this the literature has treated supervisors as key agents representing the interests of organizations with respect to the psychological contract between employees and organizations (e.g., Conway and Briner [20], Robinson and Morrison [21]). Sully [22] proposed the psychological contract as means of exploring this relationship, arguing that safety was already based on reciprocity involving a duty of care on the part of the employer and a reciprocal obligation to uphold safety standards on the part of the employee.

## 4 Psychological Contract of Safety

In searching for balance in modern employment relationships, one of the greatest challenges is to match the needs of organizations and employees Freese et al. [23]. The 'psychological contract', which is assumed as a consequent of social exchange theory [6], can be introduced to capture the momentum between supervisors and workers to explore their relationships in terms of safety. Employees form expectations about workplace safety that lead them to believe that certain actions will be reciprocated. These expectations constitute a psychological contract when employees believe that perceived employer safety obligations and perceived employee safety obligations are contingent on each other [24]. Noteworthy to this context, in a series of studies, Walker [7, 24, 25] developed and tested psychological contract of safety scale in Australian health sector and identified safety climate, safety behaviour and safety outcomes (number of accident and injury) are significantly related with the level of fulfilment or breach of psychological contract of safety.

## 5 Research Aim and Hypothesis

The present study aims to better understand the mechanism by which supervisor safety behaviour affects worker's safety behaviour at construction sites. While the importance of supervisors to worker safety behaviour has been well-established, the specific behaviours most likely to support subordinate safety performance are less clear [26]. This research paper recognizes this research gap and proposes psychological contract of safety develops from supervisor-workers relationship, influences workers' safety behaviour. Using structural equation modeling (see Fig. 1), this paper develops and tests an integrative model of psychological contract of safety and safety behaviour in construction for the first time.

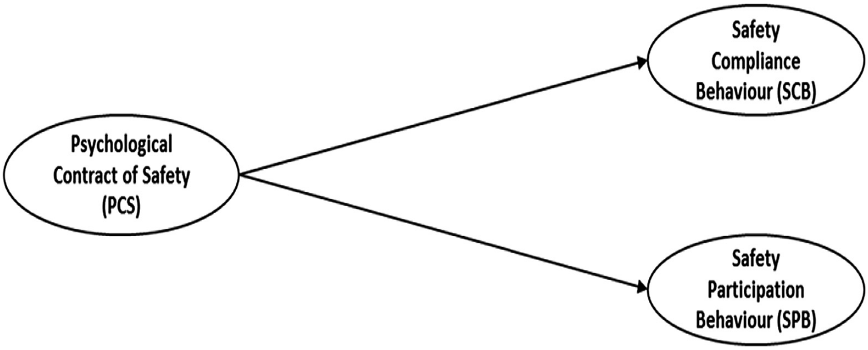


**Fig. 1.** Theoretical model

Based on a review of the literature, the following hypotheses were formulated:

H1: Psychological contract of safety (PCS) predicts and positively influences worker's safety compliance behaviour (SCB).
H2: Psychological contract of safety (PCS) predicts and positively influences worker's safety participation behaviour (SPB).

# 6 Methodology

## 6.1 Sample and Procedure

Data were collected from a mega-construction project of New South Wales, Australia that represented an $AU3.7 billion investment. The construction operation, which includes 8 rail stations/construction sites, started in 2015 and is expected to be finished by 2019. For this research project, construction sites were selected considering their progress against the research timeline. A total of five surveys were conducted at five construction sites from February 2017 to July 2017. The surveys were administered using the 'Viewpoint' automated response system with 'clickers' hand-held devices. Survey questions were projected on to a screen one by one and read out by a facilitator [27]. A total of 352 participants completed the surveys. All the participants were construction workers.

## 6.2 Survey Instrument

The survey consists of four parts: (1) psychological contract of safety (PCS), (2) safety compliance behaviour (SCB), (3) safety participation behaviour (SPB), and (4) demographic information. All the items except demographic information questionnaire were rated on five-point Likert scales ranging from '1 = Strongly Disagree' to '5 = Strongly Agree'. The survey scales were subjected to reliability analysis. Cronbach's α, as a measure of internal consistency reliability, is 0.928 for the whole questionnaire. PCS was measured using the scale previously developed by Walker [24] for the Australian health sector [24, 25] and adopted to the construction industry. The α value for a PCS was 0.923. Individual safety behaviour in this study was measured by the safety behaviour scale developed by Neal and Griffin [28] which included three items for SCB and three items for SPB. The α value for worker's safety compliance behaviour safety was 0.854 whereas participation behaviour was 0.847.

### 6.3 Demographic Information

Information about individual attributes includes gender, age, and work experience (in a number of years) were collected as part of demographic information Table 1.

**Table 1.** Profile of respondents

| | Frequency | (%) |
|---|---|---|
| Gender | | |
| 1. Male | 296 | 91.93 |
| 2. Female | 22 | 6.83 |
| Age | | |
| 1. Less than 20 | 10 | 3.10 |
| 2. 21–30 | 124 | 38.51 |
| 3. 31–40 | 94 | 29.19 |
| 4. 41–50 | 42 | 13.04 |
| 5. 51–60 | 31 | 9.62 |
| 6. Older than 60 | 9 | 2.79 |
| Work experience | | |
| 1. Less than 1 year | 18 | 5.59 |
| 2. 1–5 years | 44 | 13.66 |
| 3. 6–10 years | 53 | 16.46 |
| 4. 11–15 years | 121 | 37.58 |
| 5. 16–20 years | 35 | 10.87 |
| 6. More than 20 years | 40 | 12.42 |

## 7 Data Analysis

### 7.1 Treatment of Data

In order to ensure the quality of data collected before starting data analysis, all the completed questionnaires (N = 352) were checked against systematic response patterns and more than 5% missing items [24, 29]. Through this data screening process, 30 out of 352 completed questionnaires were dropped from data set. The pattern of missing data was found to be random and less than 5%. The Expectation Maximization (EM) [25] method was used to replace missing data using SPSS Missing Value Analysis.

### 7.2 Statistical Analysis

The computer program AMOS (version 24) was employed to conduct Confirmatory Factor Analysis (CFA) and evaluate the overall fit of the model tested, using maximum likelihood (MLE) estimation. SEM is a comprehensive statistical method for testing hypotheses about relations among observed and latent variables [30]. We adopted SEM because it enables the researchers to examine a series of dependence relationships simultaneously [31], which is particularly useful in testing the theoretical model proposed in this study.

### 7.3 Fit Indexes

There are three model fit categories namely Absolute Fit (Chi-Square, RMSEA and GFI), Incremental Fit (AGFI, CFI, TLI, NFI), and Parsimonious Fit (Chisq/df) [32]. Hair et al. [31] and Holmes-Smith et al. [33] recommend the use of at least one fitness index from each category of model fit. According to Hu and Bentler [34] recommended combinations of measures for good to excellent model fit are - Chi-square/df should be between 1 and 3, CFI should be greater than 0.90, SRMR should not be greater than 0.10 and RMSEA should not be greater than 0.08. The authors used Chi-square/df, CFI, SRMR and RMSEA as measures of model fit.

## 8 Results

### 8.1 Descriptive Statistics

Correlations among all the scales are reported in Table 2 below. All variables were significantly correlated ($p < 0.01$). However, none of the correlation values exceeds the threshold value of 0.9, which suggests that the multicollinearity problem does not exist between the items [31].

**Table 2.** Descriptive statistics and correlations among variables

| Scale | M | SD | PCS | SCB | SPB |
|---|---|---|---|---|---|
| PCS | 3.7 | 1.06 | 1 | .476** | .514** |
| SCB | 4.17 | 0.81 | .476** | 1 | .618** |
| SPB | 3.64 | 1.13 | .514** | .618** | 1 |

PCS: Psychological contract of safety, SCB: Safety compliance behaviour, SPB: Safety participation behaviour
**Correlation is significant at the 0.01 level (2-tailed).

### 8.2 Testing the Measurement Model

In order to test the measurement model, a confirmatory factor analysis was conducted using AMOS v24.0 with the covariance matrix and ML estimation. The result of the model, including three factors with a total of eighteen indicators, showed acceptable fit (Chi-square/df = 2.20, CFI = 0.95, RMSEA = 0.06 and SRMR 0.045). As shown in Table 3, all loadings relating indicators to latent factors were statistically significant ($p < .001$). Item 1 (counsel employees who break rules) of the psychological contract of safety (PCS) was dropped in the confirmatory factor analysis because of low factor loading (below 0.6) [35–37]. Then, the convergent and discriminant validity of factors were tested. The average variance extracted (AVE) for each construct is given in Table 4 and measures the amount of variance due to the underlying factor of interest in relation to the amount of variance attributed to measurement error. All values were well above the minimum value of 0.5 suggested by Fornell and Larcker [38]. Additionally, the square root of the AVE was also greater than the largest correlation between the construct and another construct (the variance shared between two constructs), which implied significant discriminant validity [39]. As shown in Table 4, all the three factors of this study do not have convergent and discriminant validity and reliability issues.

**Table 3.** Factor loading of items

| | | Factor loadings |
|---|---|---|
| | My employer meets their obligation to… | |
| PCS 2 | Involve employees in safety decision making | 0.75 |
| PCS 3 | Listen to employee safety concerns | 0.7 |
| PCS 4 | Inform employees about the outcome of safety meetings | 0.71 |
| PCS5 | Carry out safety incident investigations to prevent accidents happening again | 0.72 |
| PCS 6 | Set a good example for safety behaviour | 0.72 |
| PCS 7 | Ensure that safety documentation details safety procedures | 0.78 |
| PCS 8 | Conduct regular safety training with all employees | 0.74 |
| PCS 9 | Keep work equipment functioning properly | 0.75 |
| PCS 10 | Supply proper work equipment | 0.65 |
| PCS 11 | Provide training in the safe use of equipment | 0.66 |
| PCS 12 | Maintain a safe workplace | 0.71 |
| SCB 1 | I use the correct safety procedures for carrying out my job | 0.75 |
| SCB 2 | I ensure the highest levels of safety when I carry out my job | 0.86 |
| SCB 3 | I use all the necessary safety equipment to do my job | 0.84 |
| SPB 1 | I promote the safety program within the organisation | 0.83 |
| SPB 2 | I put in extra effort to improve the safety of the workplace | 0.87 |
| SPB 3 | I voluntarily carry out activities that help to improve work place safety | 0.73 |

### 8.3 Structural Model Assessment

The SEM analysis performed to test the proposed model (shown in Fig. 1) revealed an acceptable fit (Chi-square/df = 2.9, CFI = 0.93, RMSEA = 0.07 and SRMR 0.08). Figure 2 shows the hypotheses testing results. Solid lines with estimated standardized

**Table 4.** The convergent and discriminant validity of factors.

| Factor | CR | AVE | MSV | MaxR (H) | PCS | SCB | SPB |
|---|---|---|---|---|---|---|---|
| PCS | 0.923 | 0.502 | 0.333 | 0.926 | 0.708 | | |
| SCB | 0.858 | 0.669 | 0.519 | 0.867 | 0.53 | 0.818 | |
| SPB | 0.851 | 0.657 | 0.519 | 0.864 | 0.577 | 0.721 | 0.81 |

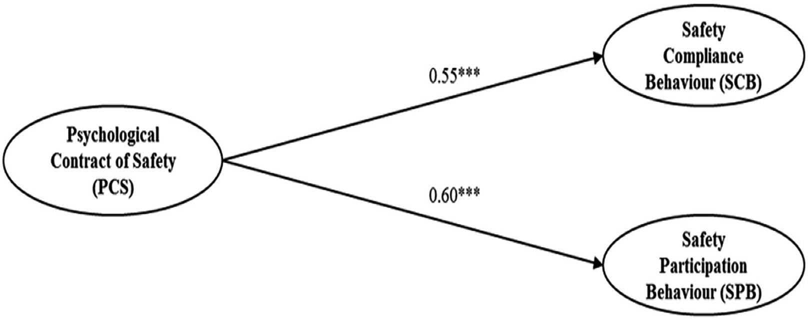


**Fig. 2.** Hypothesis testing

effect coefficients (β) represent significant links which passed the hypotheses tests, while dotted lines represent nonsignificant links (three asterisks mean $p < 0.001$).

Hypothesis 1 proposed that PCS predicts and positively influences worker's SCB. The results from this study suggest that the effects of PCS on worker's SCB (standardized $\beta = 0.55$, $p < .001$) was significant and positively related. Thus the hypothesis 1 is fully supported.

Hypothesis 2 proposed that PCS predicts and positively influences workers SPB. Again, our research suggests that the effects of PCS on worker's SPB (standardized $\beta = 0.60$, $p < .001$) was significant and positively related. Thus the hypothesis 2 is fully supported.

## 9 Discussion

This study aimed to understand how workers safety behaviour is shaped in construction by the supervisor behaviour using the PCS. Through the investigation of the strength of mutual obligations, influences of psychological contract on safety behaviour components were tested. Perceived level of fulfilment of the psychological contract was significantly and positively related to both participation and compliance safety behaviour of workers. In addition, the higher the level of fulfilment of mutual obligations, the higher the compliance and participation behaviours are reported. It is also evident that the influence of psychological contract on participation behaviour is moderately higher than on compliance behaviour.

In case of fulfilment of obligations, 'counsel employees who break rules', 'proving safe work equipment' and 'training on how to use work equipment' showed a lower level of agreement in this study. A higher level of PCS score could lead to a better consequence of workers safety expectations. Through this type of cross-checking organizations can identify which safety obligations are not fully met from workers' perspectives and how these fulfilled or unfulfilled obligations affecting workers' safety behaviour. The underlying meaning of supervisor behaviour in comparison with the level of fulfilment of mutual obligations can reveal how safety is managed at a construction site and the interpretations can help us to understand how top-level safety priority is translated in a construction yard. The findings of this research also emphasize the significance of PCS in construction safety management. The importance lies in the fact that PCS successfully predicts both types of safety behaviour. This finding recognizes psychological contract as an antecedent of workers safety behaviour where the level of fulfilment or breach of psychological contract will have a profound effect on workers safety behaviour. Safety participation and compliance behaviours are established variables in safety research which lead to safety outcomes (accidents and injuries). Hence, influencing and predicting safety behaviour components significantly means psychological contract may have an impact on number of accidents and injuries occurred due to workers' unsafe behaviour. Thus, developing and fulfilling a higher level of psychological contract can produce a greater level of safe behaviour and lower number of accidents.

## 10 Implication of Construction Safety Management

The findings have important implications for safety management in construction research, particularly reducing unsafe behaviours on site. This is the first research to explain how PCS influences safety behaviour in construction sites. In terms of promoting safety behaviour by the individual worker, an affirmative psychological contract can play a significant role as well as influence them to comply with safety activities. Applying psychological contract theory to construction safety provides a new direction for construction safety research where supervisors play the most important role in managing safety. It also extends previous research investigating social exchange constructs in a safety context to increase our understanding of what might impact safety behaviour of workers at a construction site. Using the validated scale of PCS, construction supervisors are expected to influence behaviour of workers more positively. In addition, after identifying the low level of fulfilment of PCS, top level managers can provide training to supervisor to improve their particular safety behaviours which affect worker's safety behaviour.

## 11 Conclusions

This research paper highlights and proposes significant features of psychological contract of safety for improving safety in construction sites. The research gap identified the lack of explanations of how supervisor behaviour affects workers safety behaviour. This gap has been addressed by introducing psychological contract of safety (PCS) while anticipating the influence of supervisor in a construction site. When supervisor plays the most significant role to shape workers behaviour in construction, a reality check could be done through psychological contract investigation which reveals the level of fulfilment of mutual obligations and its impact on workers safety behaviour. Using the structural equation modeling (SEM), this research establishes and validates the concept of psychological contract safety in construction safety research and enlightens how this concept could be used to improve safety perception and safety behaviour at construction sites.

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# Poka-Yokes as Occupational Preventive Measures in Construction Safety. A Review

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**Abstract.** Poka-yoke systems (from the Japanese "mistake-proofing") are defined within the construction sector as a group within specific tools available to implement the principles of Lean Construction. These principles are a way of designing construction projects in such a way that waste of materials, time and effort are minimized in order to generate the maximum possible value for the final customer. Objective: The aim of current research is to perform an analysis of the state of the art about publications dealing with Lean construction, poka-yokes, and preventive measures in the construction sector. Methodology: Main scholar databases were accessed by entering keywords related to the scope of the research. Results: In general, the impact of Lean technologies in the construction sector, including poka-yokes methodologies, has been investigated in some previous research. The main challenges that present the implementation of this type of techniques in a sector such as construction have been identified: the change in the work culture of the organizations, the lack of knowledge about the Lean techniques, or the costs and complexity of the implementation of the techniques. Some authors consider the Lean tools effective in increasing the safety conditions of workers and reduce the accident rate in construction sites, but other authors do not believe that there is empirical evidence to justify a significant improvement in the conditions of work. Conclusions: In order to increase the effectiveness of the poka-yoke in the form of Personal Protective Equipment (PPE), it is necessary to know more about the human failures present in incidents and accidents. Similarly, the design and implementation of poka-yokes in construction activities is difficult because many activities are based on the taking of previous decisions, which generate a dynamic planning in which the conditions of risks and defects are in continuous change. Additionally, some examples of poka-yoke device in construction sector were proposed by the authors at the end of the results section.

**Keywords:** Poka-yoke · Lean construction · Occupational safety
Personal protection equipment


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# 1 Introduction

Poka-yoke systems (from the Japanese "mistake-proofing") are defined within the construction sector as a group within specific tools available to implement the principles of Lean Construction. These principles are a way of designing construction projects in such a way that waste of materials, time and effort are minimized in order to generate the maximum possible value for the final customer.

The aim of current research is to perform an analysis of the state of the art about publications dealing with Lean construction, poka-yokes, and preventive measures in the construction sector.

# 2 Methodology

Main scholar databases were used by entering keywords related to the scope of the research; Web of Science (WOS), Science Direct, Springer Link, Scielo, Google Scholar, and Mendeley (Figs. 1, 2, 3, 5 and Table 1).

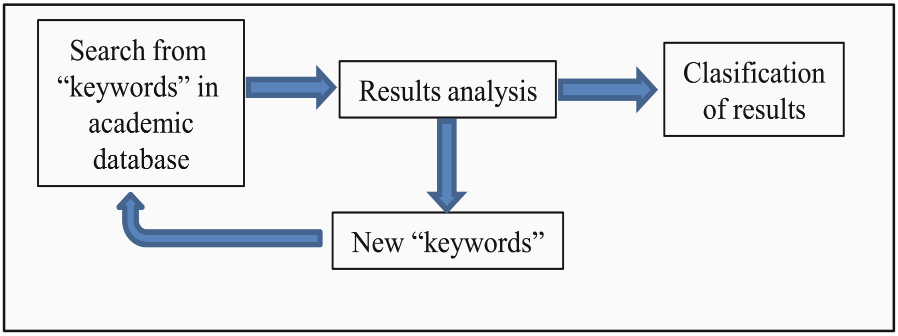


**Fig. 1.** Description of search methodology and "keywords" feedback.

Finally, some practical examples of possible poka-yoke systems in construction sites related with formwork activities were included.

# 3 Results

## 3.1 Lean Construction

Lean Construction systems are Project Management Methods based on Lean Manufacturing. Lean Construction try to minimize waste, time and efforts with the aim to obtain the maximum possible value for the final customer [1]. Other authors [2] defined this concept as "a holistic facility design and delivery philosophy with an overarching aim of maximizing value to all stakeholders through systematic, synergistic, and continuous improvements in the contractual arrangements, the product design, the construction process design and methods selection, the supply chain, and the workflow reliability of site operations".

Principles from Lean Methodologies in construction considers Construction Safety as an improvement in productivity and cost reduction. Different tools have been developed in order to implement Lean principles [2]. Poka-yoke systems is one of the most remarkable tools.

### 3.2 Poka-Yoke in Construction

Poka-yoke concept was defined by Shingo [3]. In essence fails and mistakes at workplace can be avoid easily and with low cost, applying tools as visual inspections, personal protection equipment and machinery with warning systems.

In general, impact of Lean technologies, that includes poka-yokes, have been studied previously [4]. In countries like United Kingdom, introduction of the Lean Construction concept is low after two decades of the formal definition [5]. Similarly, challenges linked to the implementation of Lean strategies in construction sector as costs, know-how, organizational culture, or complexity have been identified [6].

Effectiveness of Lean Construction tools is discussed in literature. Some authors considered that they improve occupational safety conditions in construction workplaces [7–9]. Other authors [9] did not found evidences in order to justify a significant improvement in the working conditions after the implementation of Lean tools.

Authors as Saurin [7], identified opportunities about the improvement of Occupational Safety levels using Lean Construction principles. His research is focused on the use of visual signs used in production systems (indicators, displays, kanbans,..) with the objective to identify safety boundaries in the development of the tasks. However, warning Poka-yokes as signs are not 100% effective, their robustness is mostly low since signs depend on how they are interpreted [10]. According to Saurin, [7], safeguards and personal protective equipment (PPE) can be considered as safety poka-yokes, because they usually protect workers from a wide range of hazards and absorb several possible errors. The main difference with quality poka-yokes, is that safeguards and PPE poka-yokes normally have a wider set of functions than the ones designed for quality control.

### 3.3 Design of Poka-Yoke

In order to improve the effectiveness of PPE as Poka-yoke systems is necessary a better knowledge about human fails in construction site for a better design of the systems. There is a lack of information in this field [7]. Frequently, improvements are based only in mistake-proofing of contractors during the construction phase of the project. Although some studies obtained results about poka-yokes attributes, only one research was found about a theoretical framework methodology for assessing poka-yokes [11].

Other authors [12, 13] preferred the use of surveys for assessing the use of Lean practices, but they are little use when companies are try to assess their particular lean practices.

Framework developed by Saurin et al. [11], can be summarized in the following three stages.

(1) Defining Poka-yokes attributes
(2) Defining evidence and source of evidence to assess the existence of each attribute
(3) Developing a scoring system to express the results of the assessment.

Additionally, Saurin [11] proposed future research needs linked to the framework proposed as reliability assessment, and the ability of predict effectiveness in terms productivity, accident rates or customer satisfaction.

### 3.4 Example of Poka-Yoke in Construction Site Related with Formwork Activities

In this section, two proposals of poka yoke systems in construction sites are shown and described.

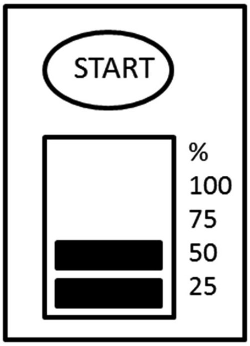


**Fig. 2.** Example of display to control maturation process.

**Control of Concrete maturation process - Warning display**
In addition to manual recordings about the time necessary to complete the concrete maturation process into the formworks, this display will show the worker if the time of maturation have expired and it is possible to remove formworks safely.

After the concrete pouring, the display will be set at zero level, and attached to the formwork structure. Once the time of maturation finish, the display will show a 100% level. The display tries to avoid any misunderstanding or mistake in the manual recordings, with a second source of information.

**Control of dangerous zones - RFID access**
Other example of a poka yoke warning system is the use of RFID in order to avoid the entering of a worker in dangerous working zone. Many times, some working places are not especially dangerous, but they become in dangerous zone because of the performance of some particular tasks. The idea is to create an easy system to detect the entrance of non-authorized worker during the dangerous tasks. The system is composed by an RFID label attached to the worker (R), a RFID detector in the entrance of the dangerous zone (A), and a visual warning alarm after the RFID detector (B). Then, if some worker is not aware of the risk of the zone, and try to enter in a dangerous workplace, the worker will be alerted by the RFID detection system.

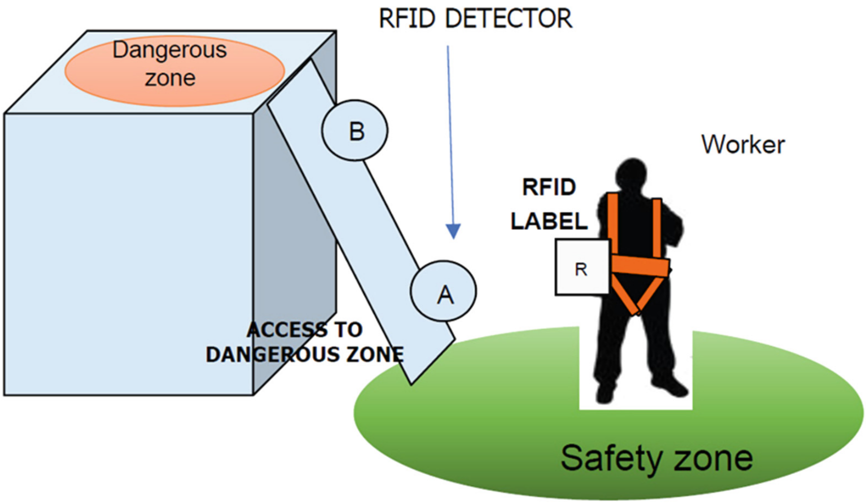


**Fig. 3.** Description of system to control the access in dangerous zone.

**Dynamics information panels**

Signs in construction sites many times are not effective because they are static and their information is not updated frequently. A warning poka-yoke solution is proposed in the Fig. 4. Dynamic information panels places in working sites were advices or warning messages are necessary could improve the safety levels of the workers. The display will show updated safety information according to the real evolution of the tasks. If any worker detect any relevant information, the safety manager in the construction site will updated the information display with worker feedback using the remote control.

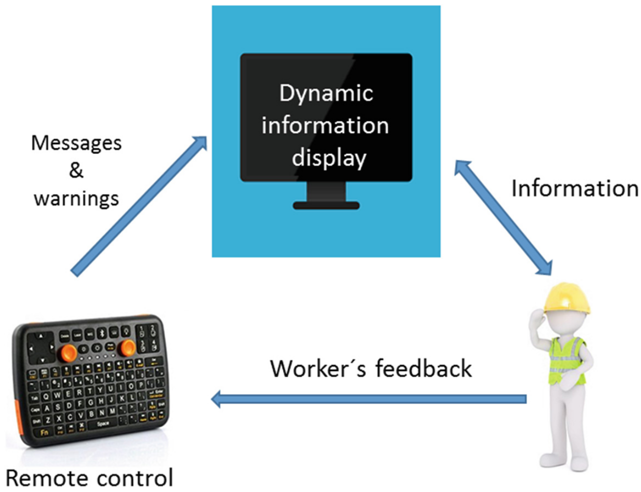


**Fig. 4.** Description of dynamic information panel.

**Reflective safety railing in construction sites**
One of the most important preventive measures in construction sites is the installation of the safety railing in order to prevent falls from height. They mark off the floors limit and they avoid the fall in case of the worker lose his vertical stability. For a better visual marking of the limit, reflective rails will be easily recognized by workers, and they show the distances and real sizes with more details.

**Fig. 5.** Example of safety railing in a construction site.

**Table 1.** Poka-yoke classification by Shigeo Shingo

| Category | Sub-category | Example |
|---|---|---|
| Adjustment functions | Control<br>Warning | Blocking<br>Light, sound alarm |
| Fixed functions | Contact | Sizes |
| | Fixed value | Movements |
| | Motion Stop | Steps fails |

## 4 Conclusions

Although poka-yoke systems are widely extended in many sectors, especially in manufacturing, there is a lack of academic researches focused in this topic. Effectiveness of Lean construction tools is discussed in literature, but it is not a consensus about the positive impact of them into the occupational safety levels in construction. Personal protection equipment and safeguards were considered the most remarkable poka-yoke devices related with Occupational Safety. The importance of a better knowledge of human fails, and how they can be removed from the construction site was highlighted as an essential future research in order to improve the design of the future poka-yoke systems.

Similarly, the design and implementation of poka-yokes in construction activities is difficult because many activities are based on the taking of previous decisions, which generate a dynamic planning in which the conditions of risks and defects are in continuous change. Reliability and prediction of the effectiveness of the Poka-yokes, should be investigated in future studies.

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# Contractor's Health and Safety Practices Model

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**Abstract.** Small and medium-sized (SME) contractors' form the bulk of contractors in the in Ghanaian construction industry. SME's contractors' health and safety issues have been a major problem to the construction industry. The laid down rules for health and safety (H&S) have been neglected, which has resulted into accidents on sites. Health and safety practices model of contractors in Ghana is presented. A six factor theoretical model developed from literature was used to develop the H&S model and safety practices of the Ghanaian contractors'. Exploratory factor analysis (EFA) was conducted on the selected variables to ascertain their suitability for confirmatory factor analysis (CFA). Three factors were retained from the six factor theoretical model during the CFA. Different factors for the model were obtained by combining some of the factors. Eight factors were obtained for the current model; with two factors having five variables and five factors have four variables each respectively. One factor has three variables.

**Keywords:** Compliance · Construction industry · Ghana
Health and safety · Model

## 1 Introduction

The theoretical Health and Safety (H&S) compliance model is based on literature and the views obtained from experts'. Mustapha, Aigbavboa and Thwala [1] in their study of Occupational Health and Safety (OHS) challenges in the Ghanaian construction industry recommended for a proactive measures to deal with OHS issues. They emphasized on effective OHS management to reduce accident. This indicates the need for the development of the H&S compliance model to assist in the elevation of the existing OHS challenges. Annan, Addai and Tulashie [2] posited that the challenges were due to the existence of some fragments of OHS legal requirements under jurisdictions of different agencies. Therefore, the need for the structuring of the OHS policies in Ghana and all government officials must be involved and committed.


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Shibani, Saidani and Alhajeri [3] asserted that poor performance of construction H&S in developing countries are due to lack of stringent measures in safety and construction laws. The World Health Organization (WHO) [4] indicated that hundreds of millions of people throughout the world are working in conditions that breed ill health and or are unsafe.

The unsafe acts will lead to accident and accident cases occur due to different actors coupled with different responsibilities [5]. Windapo [6] emphatically stated that accidents in will always occur on construction sites due to the contractors cost saving mindset. Windapo [7, 8] noted that building contractors in South Africa do not comply fully with H&S regulations. The existence of Occupational Health and Safety (OHS) challenges in Ghana has been pointed out by several researchers [2, 9, 10]. However, Kheni, Dainty and Gibb [10] were able to identify inadequate government support for regulatory institutions and lack of skilled human resources. While H&S training deficiency, inability to assess danger and workers reluctant attitudes towards H&S were identified by [9] as some of the challenges. The concept of OHS was conceived in the Ghanaian construction industry before the introduction of two major edicts [2]. The existence of some fragments of OHS legal requirements under jurisdictions of different agencies in Ghana has led to the OHS challenges in Ghana [2]. Moreover, the existence of several regulatory bodies in Ghana have also compounded the OHS challenges [2]. Such as 1. Mining and Minerals Regulations 1970 LI 665; 2. The Workman's Compensation Law 1987; 3. The Ghana Health Services and Teaching Hospital Act 526 (1999); 4. The Ghana Labor Act 2003 (Act 651); 5. The Radiation Protection Instrument LI 1559 of 1993; 6. The Environmental Protection Agency Act 1994 (Act 490); 7. The National Road Safety Commission Act 1999 (Act 567). However, the OHS activities depend solely on the Factories, Offices, and Shops Act 1970 (Act 328) and the Mining Regulations 1970 LI 665 which have limited scope considering the number of industrial activities.

The structural component of the theoretical model was based on the fundamental factors and constructs associated with all the previous models in previous research, the present model or conceptual framework model looks at the safe environment (SE), safe acts of worker (SAW), safe work condition (SWC) and reaction of worker to safe condition (RWSC). The identified gaps are Government support (GS) and contractor's organizational culture (COC) which will in turn predict the construction industry Health and Safety (H&S) compliance. The structural component of the model are: SE, SAW, SWC, RWSC, GS and COC. The measurement component of the hypothesized model comprises of the following health and safety compliance factors: SE = 8 measurement variables; SAW = 17 measurement variables; SWC = 18 measurement variables; RWSC = 8 measurement variables; GS = 5 measurement variables; COC = 11 measurement variables and HSC = 7 measurement manifest variables.

The theoretical underpinning of this priori is derived from the works of Heinrich and Accident Root Causes Tracing Model (ARCTM).Most of the important rules of Accident Root Causes Tracing Model (ARCTM) was derived from the efforts of Heinrich, Peterson, Bird, Ferrell and Peterson [12–14]. The conceptualized model is the notion that compliance of H&S is related to the evaluation of many variables. Such as SE, SAW, SWC, RWSC, GS and COC. It is difficult to discuss the principal variable without reference to variables of government support and contractor's organizational culture and inclusion of the other exogenous variables. The evaluation will depend on the compliance assessment of several indicator variables under each of the exogenous variables. In this paper, the objective evaluation of H&S compliance will be assessed by measuring the actual condition of the construction industry that is an exogenous variable in the model as shown in Fig. 1.

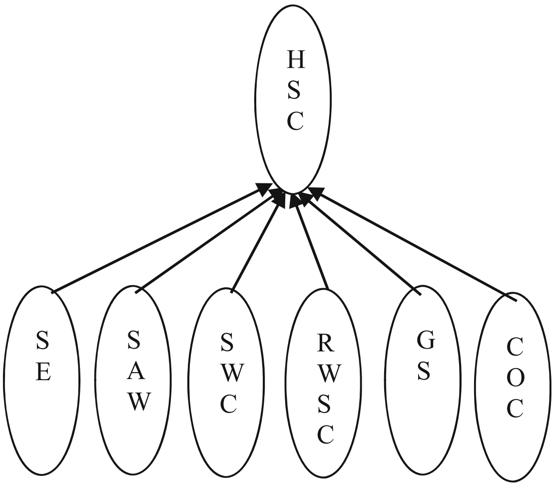


**Fig. 1.** Conceptual health and safety (H&S) compliance model (Model 1.0)

## 2 Selection of Variables for Health and Safety Compliance

The section provides detail information on how the theoretical model or the six factor model was achieved. The Health and Safety (H&S) compliance study models for the assessment of H&S compliance was made up of objective and subjective attributes. The Domino Theory by Heinrich and that of Adams had similar concept, but the elements were different [14]. Weaver had similar concepts of elements or factors as Henrich's [14]. Petersen's model developed in the 1971 had different concept with the Domino Theory which had influence on many researchers during Heinrich time. It is believed that the contributing factors, causes, and sub-causes are the main culprits in an accident scenario as inspired by the model [15]. Behavior model, human factor model, and Ferrel theory relate to human error theory [14, 16–18].

Most of these theories address the human (worker) as the main problem that makes an accident happen [15]. Abdelhamid and Everett [15] indicated that there is every tendency of humans to make error under various conditions and situations, but finally, the blame will fall on human most often (unsafe). Many important rules of Accident Root Causes Tracing Model (ARCTM) have been derived from the effort of Heinrich, Petersen, Bird, Ferrell and Petersen. ARCTM insist on specific issues such as worker training, worker attitude and management procedure problems should be recognized and modified to avoid reoccurrence of accident. Research conducted by [15] in identifying root causes of construction accidents concluded that the application of ARCTM should serve as a complement to accident investigation process and should be able to give solutions to accident occurrence and preventive measures in the construction industry.

The three constructs proposed by ARCTM to the two construct from Heinrich are supported and adopted in the current paper. This study considers the H&S compliance bundle in a typical construction industry to contain SE with 8 variables; SAW with 16 variables; SWC with 18 variables; RWSC with 8 variables. Almost all the H&S compliance studies have these constructs conceptualized on frequent basis. However, the current study brings into focus GS with 5 variables and COC with 11 variables each. The two additional constructs are the identified gaps in the literature and were found to be peculiar to Ghana.

## 2.1 Safe Environment (SE)

Employers have a legal obligation to provide a safe work environment and employees have a right to a safe work environment since a healthy workplace is a safe workplace. Steps must be taken by an employer to ensure the safety of all his employees while at work [19]. The National Occupational Health and Safety Policy of South Africa [20] indicated that safe work creates no obstacles to being competitive and successful. Health and safety in the workplace is about preventing work-related injury and disease, and designing an environment that promotes well-being for everyone at work [21]. The employer can achieve safe working environment through the provision of safe and healthy work environment, safe equipment and safe storage and transportation of dangerous substances. The recklessness and undesirable traits leading to accident can be prevented.

## 2.2 Safe Acts of Workers (SAW)

Mat Zin & Ismail [22] opined that ignorant behaviour and attitude of employers and employees contribute to rise of issue on behavioural safety non - compliance to requirements of Occupational Safety and Health Act (OSHA) 1994". "Safety behaviour describes the behaviour that support safety practices and activities such as providing safety training and safety compliance explains the core activities that need to be carried by employees according to occupational, safety and health requirements to prevent workplace accidents" as indicated by [22]. "Most of the accident causation theories addressed the human (worker) as the main problem that makes an accident happen such as permanent characteristic of human, the combination of extreme environment and overload of human capability and conditions that make human tends to make mistake" [15]. Safety behaviour or acts can be achieved through the following processes: working with safety devices such as personal protective equipment, use of equipment that are in good condition, follow the correct work procedure at any time work is to be carried out, employees should have good knowledge level of work and they should also obey work procedures whenever they are carrying out any activity.

### 2.3 Safe Work Condition (SWC)

Heinrich et al. [14] posited that "the carelessness or fault of a person is the negative features of a person's personality". Although, these unwanted characteristics might be acquired but, can be corrected. Errors and technical failures as a result of unsafe acts or mechanical or physical conditions can also be corrected to prevent accident occurring, by performing safe acts and under safe conditions [11, 18]. Abdelhamid and Everett [15] opined that "accident prevention is an integral programme, a series of coordinated activities, directed to the control of unsafe personal performance and unsafe mechanical conditions, and based on certain knowledge, attitudes, and abilities". It is therefore, mandatory to provide employees with safe work condition to enable them abide by H&S regulations and perform well at their respective work places.

### 2.4 Reaction of Worker to Safe Condition (RWSC)

Accident Root Causes Tracing Model (ARCTM) derived most of its important rules from the efforts of Heinrich, Peterson, Bird, Ferrell and Peterson [11–13]. ARCTM indicates that the unsafe condition which contribute to the occurrence of accident due to the employees' inability to identify the existence of the unsafe condition before the activity is carried out can be prevented if these actions are performed under safe condition. Reaction of the employee to safe conditions depends on the fact that the employee conducts his activity within a safe environment [13, 15]. However, to be at a safe side in conducting any activity, it is advisable that the employee should identify a safe condition for his activity [11, 13, 18].

### 2.5 Model Specification and Justification

The theoretical conceptual model for this paper was built on the work of Heinrich and Accident Root Causes Tracing Model (ARCTM) which was also built on the previous accident models. Five elements were stated in both Heinrich and Adams and have similar concept, but the elements were different [14]. The role of management in accident prevention was also emphasized in a broader sense taking into consideration the root of unsafe acts or conditions. Moreover, management organizational structure should reflect the relationship between the causes and effects of incidents and accidents which directly involves management [14].

ARCTM conceptualized that unsafe condition, reaction of worker to unsafe condition and unsafe acts of worker lead to accident. The non-compliance level of H&S in the construction industry are related to the environment, unsafe acts, unsafe condition, reaction of worker to unsafe condition and unsafe acts of worker. Both Heinrich and ARCTM emphasized on unsafe acts and unsafe condition as the main causes of accident in the construction industry. The two basic components of the model are: safe acts and safe condition. Based on the fundamental underpinning of two models, and the incorporated theoretical perspectives, which has been adopted in other similar studies, they are therefore useful for conceptualizing the current paper as a variety of H&S studies and H&S compliance being conceptualized within the broad theoretical framework. Therefore, the conceptual framework for this paper is primarily based on the approach used by Heinrich and Accident Root Causes Tracing Model (ARCTM).

## 3 Methodology

The methodology section gives a detail of the methodology used to arrive at the holistic Health and Safety (H&S) compliance for the Ghanaian construction industry. The theoretical or the six factor model was developed based on information from literature review and Delphi survey results. Both qualitative and quantitative methods of data collection were employed in the study. A Delphi survey was conducted for the qualitative aspect of the study and a field survey was used for the quantitative aspect. A Delphi study is a group decision mechanism requiring qualified experts who have a deep understanding of the issues at hand [23]. Each expert was required to meet at least five (5) of the following minimum criteria: 1. Residency; 2. knowledge; 3. Experience; 4. Employment; 5. influence and recognition; 6. Authorship; 7. Research; 8. Teaching; 9. Membership; 10. Willingness. The selected experts for the paper represented a wide variety of backgrounds and guarantee a wide base of knowledge [24]. The recommendations of [24] were adopted for the current study. The adoption of five of these criteria was considered more stringent than the recommended number of at least two criteria by [25, 26]. Nine experts (academics and construction professionals) from the major cities of Ghana were involved in the Delphi survey. The number of experts was considered adequate based on literature recommendations from scholars who have previously employed the technique. Experts were asked to rate the impact of other factors in predicting Health and Safety (H&S) compliance model features as shown in Tables 1, 2, 3, 4, 5 and 6. Data obtained were analyzed using Microsoft Excel spread sheet. The conceptual variables for Health and Safety (H&S) compliance model features were obtained from the Delphi survey.

A face-to-face method of questionnaire administration was adopted for the quantitative aspect of the study. Data gathered via a questionnaire survey as shown in Table 8 were analyzed using Structural Equation Modeling (SEM) software 20. The SEM was used to evaluate the reliability, discriminant validity and convergent validity of the instrument [27–29]. PAF Oblimin was used as an extraction method for the elements. A sample data of (558) were taken through random sampling before carrying out the exploratory factor analysis (EFA). Finally, a total of 269 samples were obtained for the EFA [30]. Structural Equation Modeling (SEM) process was undertaken as EFA for analysis of the theoretical conceptual model elements. The SEM software was used to assess the factor structure of the constructs of the theoretical model or the six factor model in Fig. 1 (Model 1.0). The sample size of 558 obtained for the current study is considered as large [31].This falls within the acceptable value for SEM to be conducted [31]. An appropriate sample size was emphasized by [26] to depend on observed variables. The variable ratio to sample size for the current study is 8.44:1. The theoretical conceptual model elements was analyzed using EFA. PAF Oblimin was used to determine the unidimensionality of the elements. Bartlett's Test of Sphericity and the Kaiser-Meyer- Olklin (KMO) was also used to measure the accuracy of the sample [27, 28].

# 4 Findings from Delphi Survey

## 4.1 Safe Environment

Table 1 provides the main attributes of Health and Safety (H&S) compliance. A Delphi survey was conducted to determine the various attributes that are required for the safety of employees within the work environmental. Seven (7) attributes out of eight (8) were considered by the experts to have high influence on the attributes that determine H&S compliance. None of the eight attributes had an IQD cut-off (IQD $\leq$ 1) score set to achieve consensus. These had high impact (HI -7-8) on Health and Safety (H&S) compliance. One (1) attribute (Safe transportation of building materials) had medium impact (MI-5-6) on H&S compliance (Table 1). The seven (7) attributes had god consensus, with the exception of one (1) which had weak consensus.

**Table 1.** Safe environment

| Safe environment | Median | Mean | SD | IQD $\leq$ 1 |
|---|---|---|---|---|
| Safe transportation of equipment | 7 | 6.83 | 1.57 | 1.08 |
| Safe and healthy work environment | 8 | 8 | 1.07 | 1.25 |
| Safe storage of equipment | 8 | 7.71 | 1.03 | 1.25 |
| Safe transportation of formwork and false-work | 7 | 6.14 | 1.55 | 1.25 |
| Safe transportation of building materials | 6 | 6.29 | 1.39 | 1.5 |
| Safe storage of formwork and false-work | 7 | 6.57 | 1.68 | 2.07 |
| Provision of warning systems | 8 | 7.57 | 1.5 | 2.25 |
| Safe storage of building materials | 8 | 7.29 | 1.75 | 3.25 |

SD = standard deviation; IQD = Interquartile deviation

## 4.2 Safe Act of Workers

Table 2 provides the first sub-attributes of Health and Safety (H&S) compliance. A Delphi survey was conducted to determine which of the sixteen (16) variables of safe acts of workers features have influence on H&S compliance of workers. Only three attributes (Ensure equipment/tools are in good condition before usage, ensure the use of personal protective equipment (PPE) and ensure proper positioning of tasks) out of the sixteen (16) identified attributes were considered by the experts to have reached consensus with IQD cut-off (IQD $\leq$ 1) score set to achieve consensus (Table 2). Fourteen (14) attributes were considered to have reached consensus when the median was used to achieve consensus. Two (2) attributes (Avoid annoyance and horseplay at the workplace and avoid annoyance and horseplay at the workplace) failed to reach consensus (Table 2). Four (4) attributes had strong consensus, while ten (10) had good consensus and the remaining two (2) attributes had weak consensus in deterring H&S compliance.

**Table 2.** Safe act of workers

| Safe act of workers | Median | Mean | SD | IQD $\leq$ 1 |
|---|---|---|---|---|
| Ensure the use of personal protective equipment (PPE) | 9 | 9 | 0.93 | 0.25 |
| Ensure equipment/tools are in good condition before usage | 9 | 8.14 | 1.36 | 1 |
| Ensure proper positioning of tasks | 7 | 7.29 | 1.38 | 1 |
| Ensure proper stacking of objects/materials in safe locations | 8 | 7.57 | 1.4 | 1.07 |
| Do not remove safety guards from the workplace or equipment | 8 | 7.87 | 1.25 | 1.25 |
| Use correct proper lifting, handling or moving of objects | 8 | 7.86 | 1.36 | 1.36 |
| Inspect workplace before commencing any activity | 9 | 7.86 | 1.73 | 1.36 |
| Do not throw or accidentally drop objects from high levels | 7 | 7.43 | 1.51 | 1.5 |
| Avoid annoyance and horseplay at the workplace | 6 | 6.57 | 1.84 | 1.5 |
| Work in good physical conditions | 8 | 8.29 | 1.5 | 2 |
| Tidy up workplace at the end of any activity | 7 | 6.5 | 1.71 | 2 |
| Concentrate on the task at hand | 7 | 7 | 2 | 2 |
| Use appropriate tools/equipment | 8 | 7.57 | 1.5 | 2.25 |
| Do not work under the influence of alcohol and other drugs | 8 | 8.14 | 1.46 | 2.25 |
| Do not smoke in flammable materials store | 9 | 8.43 | 1.68 | 2.5 |
| Do not service equipment that is in operation | 6 | 6.14 | 2.61 | 2.5 |

SD = standard deviation; IQD = Interquartile deviation

### 4.3 Safe Working Conditions

Table 3 provides the second sub-attributes of Health and Safety (H&S) compliance. A Delphi survey was conducted to determine which of the eighteen (18) variables of safe working conditions features have influence on H&S compliance of workers. Only six (6) attributes out of the eighteen (18) identified attributes were considered by the experts to have reached consensus with IQD cut-off (IQD $\leq$ 1) score set to achieve consensus (Table 3). However, sixteen (16) of the attributes reached consensus under the median score. Salary and payment of Social Security and National Insurance Trust (SSNIT) did not reach consensus under the median score to determine H&S compliance. Three (3) of the attributed had very high impact (VHI: 9-10). Eight (8) other attributes had high impact (HI: 7-8.99). The reaming four (4) attributes had medium impact (MI: 5-6.99) on Health and Safety compliance.

**Table 3.** Safe working conditions

| Safe working conditions | Median | Mean | SD | IQD $\leq$ 1 |
|---|---|---|---|---|
| Provision of training | 9 | 9.26 | 0.45 | 0.46 |
| Safe movement around workplace | 8 | 7.86 | 0.69 | 0.5 |
| Availability of facilities within a reasonable distance from the work area | 6 | 6 | 1 | 0.5 |
| Provision of incentives to workers | 7 | 6.8 | 0.75 | 0.8 |
| Good inspection program | 9 | 9 | 0.82 | 1 |
| Provision of sufficient lighting system for enclosed areas | 7 | 7.57 | 1.18 | 1 |
| Facilities must be available for both day and night workers | 7 | 7 | 1.41 | 1 |
| Provide Safety regulations of equipment | 9 | 8.5 | 1.12 | 1.25 |
| Good company safety policies | 8 | 8.71 | 0.88 | 1.25 |
| Good salary | 6 | 6.43 | 1.59 | 1.5 |
| Payment of Social Security and National Insurance Trust (SSNIT) | 5 | 5.43 | 1.18 | 1.5 |
| Provision of guidance on the recommended illumination level for various types of task | 8 | 7.43 | 1.13 | 1.5 |
| Workers should be given proper ventilation | 7 | 6.57 | 1.9 | 1.5 |
| Provision of break periods for workers to access the facilities | 8 | 7.14 | 1.95 | 2.5 |
| Provision of change room for workers | 6 | 6.14 | 1.57 | 2.5 |
| Facilities must be available for both day and night workers | 6 | 6.17 | 1.72 | 2.75 |
| Provision of facilities that are clean, safe and accessible to all workers | 8 | 7.43 | 1.81 | 3 |
| Provision of adequate facilities (toilet, drinking water, washing and canteen) | 8 | 7.43 | 2.07 | 3.5 |

SD = standard deviation; IQD = Interquartile deviation

## 4.4 Reaction of Workers to Safe Conditions

Table 4 provides the third sub-attributes of Health and Safety (H&S) compliance. A Delphi survey was conducted to determine which of the eight (8) variables of reaction of workers to safe conditions features have influence on H&S compliance of workers. Only three (3) attributes out of the eight (8) attributes identified under the sub-attributes were considered by the experts to have reached consensus with IQD cut-off (IQD $\leq$ 1) score set to achieve consensus. All the seven (7) attributes reached consensus under the median score, with exception of one (1) attributes (adhere to regular use of provided change room). The seven (7) attributes had high impact (HI: 7-8.99). One (1) attribute had medium impact (MI: 5-6.99). Seven (7) attributes had good consensus and one had weak consensus.

**Table 4.** Reaction of workers to safe conditions

| Reaction of workers to safe conditions | Median | Mean | SD | IQD $\leq$ 1 |
|---|---|---|---|---|
| Put to proper use of the available facilities (toilet, drinking water, washing and canteen) | 7 | 6.71 | 1.39 | 0.46 |
| Follow safety regulations | 8 | 7.74 | 1.92 | 0.93 |
| Adhere to company safety policies | 8 | 7.43 | 1.92 | 0.93 |
| Adhere to guidance on recommended illumination level for various tasks | 7 | 7 | 1.51 | 1.25 |
| Adhere to warning signs and notices | 8 | 7.43 | 1.59 | 1.25 |
| Attend safety training program | 8 | 7.57 | 1.99 | 1.57 |
| Adhere to regular use of provided change room | 6 | 5.86 | 1.64 | 1.61 |
| Attend safety education program | 8 | 7.43 | 2.32 | 1.68 |

SD = standard deviation; IQD = Interquartile deviation

## 4.5 Government Support

Table 5 provides the fourth sub-attributes of Health and Safety (H&S) compliance. A Delphi survey was conducted to determine which of the five (5) variables of government support features have influence on H&S compliance of workers. Three (3) attributes were considered by the experts to have reached consensus with IQD cut-off (IQD $\leq$ 1) score set to achieve consensus. All the five (5) sub-attributes were considered by the experts to have reached consensus under the median and had high impact (HI: 7-8.99). All the five (5) attributes had good consensus.

**Table 5.** Government support

| Government support | Median | Mean | SD | IQD $\leq$ 1 |
|---|---|---|---|---|
| Formulate H&S policy for construction activities | 8 | 7.71 | 0.7 | 1 |
| Implementation of H&S policy by government representatives | 7 | 7.57 | 1.18 | 1 |
| Monitoring of H&S policy implementation by the government representatives | 8 | 7.71 | 1.16 | 1 |
| Provision of H&S policy update by government representatives | 8 | 7.86 | 1.12 | 2 |
| Provision of Health and Safety (H&S) training by government representatives | 7 | 7.57 | 1.59 | 3 |

SD = standard deviation; IQD = Interquartile deviation

### 4.6 Contractors Organizational Culture

Table 6 provides the fifth sub-attributes of Health and Safety (H&S) compliance. A Delphi survey was conducted to determine which of the eleven (11) variables of Contractors Organizational Culture features have influence on H&S compliance of workers. Only one (1) attribute (Communication of H&S information to workers) out of the eleven (11) attributes was considered by the experts to have reached consensus with IQD cut-off (IQD $\leq$ 1) score set to achieve consensus. Four (4) of the attributes were considered by the experts to have very high impact (VHI: 9-10) under the median score. The remaining seven (7) attributes were considered by the experts to have high impact (HI: 7-8.99) on Health and Safety compliance.

**Table 6.** Contractors organizational culture

| Contractors organizational culture | Median | Mean | SD | IQD $\leq$ 1 |
|---|---|---|---|---|
| Communication of H&S information to workers | 9 | 8.57 | 1.05 | 0.82 |
| H&S inspection | 8 | 7.71 | 1.48 | 1.25 |
| Training of Workers on Health and Safety (H&S) | 9 | 8.43 | 1.05 | 1.25 |
| Company H&S policy | 8 | 7.67 | 1.11 | 1.5 |
| Update on H&S information to workers | 8 | 8 | 1.31 | 2 |
| Involve workers in H&S program | 9 | 8 | 1.2 | 2 |
| Provision of Signs/Notices on sites | 7 | 7.71 | 1.58 | 2 |
| Provision of personal protective equipment (PPE) | 9 | 8 | 1.51 | 2.25 |
| H&S staffing | 7 | 7 | 1.69 | 2.25 |
| Management commitment in H&S | 8 | 7.57 | 1.84 | 2.25 |
| Appropriateness of site for erection of residential building | 8 | 7.71 | 1.58 | 3 |

SD = standard deviation; IQD = Interquartile deviation

## 5 Findings and Discussion of Results

The findings section provide detail information on how the holistic H&S compliance model was achieved. At the end of the EFA on the theoretical H&S compliance model. Fourteen factors were realized, but two factors have less than three variables. The factors with two elements or variables were removed from the rest of the factors. The holistic H&S conceptual model comprised of twelve latent constructs (Fig. 2). Four of the theoretical H&S latent constructs names were retained with their measuring indicators. The retained H&S latent constructs or factors are safe act of workers (SAW), government support (GS), safe environment (SE) and contractors organizational culture (COC). Eight new elements or leading indicators names were used that is safety of materials and equipment (SME), safety precautions (SP), safety adherence (SA), safety training (ST), facility usage (FU), safe work condition (SWC), workers welfare (WW), and safety regulations (SR). The eight new latent constructs or factors were combination of elements from one latent construct or the other. As indicated earlier, the combination of the new latent constructs or factors was based on the EFA conducted on the theoretical factors of H&S compliance model Fig. 1 (Model 1.0). Kline [31] indicated that when the construct has few items or indicator variables, less than three, the model will not be over identified for testing, using SEM. The recommended number of items per element was three as shown in Table 8, to enable robust SEM testing [31] (Table 7).

**Table 7.** Cut-off values

| | |
|---|---|
| Item-total correlation | 0.30 |
| Cronbach alpha | 0.70 |
| Kaiser-Meyer-Olklin (KMO) | $\geq 0.70$ ($p < 0.05$) |
| Bartlett's Test of Sphericity | $p < 0.05$ |
| Factor loading | 0.40 |

Table 8 shows that there were five items each measuring safety of SME and GS. Four items each were measuring SP, AS, ST, FU, SWC, WW, SAW and SE. Only three items were measuring SR and six items were measuring COC. All the variables have factor loadings greater than 0.40, with the exception of AS and FU. Four variables (AS, FU, SWC and COC) have negative values which indicate that they cross load over another. Therefore, these factors are not suitable for inclusion in the model as shown in Fig. 2.

The corrected item-total correlation was greater than the suggested cut-off value of 0.30. This implies that the items were good measures of the element. The Cronbach alpha also was greater than the cut-off value of 0.70 as pointed out by [32] to be accepted as an internal reliability. The Kaiser-Meyer-Olkin (KMO) of 0.886 with Bartlett's Test of Sphericity of $p < 0.000$ were obtained. These results are in agreement with the recommended KMO cut-off value of 0.70 and Bartlett's Test of Sphericity of $p < 0.05$ [32].

**Table 8.** Items measuring each of the variables

| Variable | Question | Factor loading | Corrected item total correlation | Cronbach level after deletion |
|---|---|---|---|---|
| SME 1 | Safe storage of formworks and false work | 0.895 | 0.681 | 0.878 |
| SME 2 | Safe transportation of formworks and false work | 0.853 | 0.718 | 0.874 |
| SME 3 | Safe transportation of materials | 0.726 | 0.713 | 0.874 |
| SME 4 | Do not throw or accidentally drop objects from high levels | 0.531 | 0.549 | 0.881 |
| SME 5 | Ensure proper positioning of tasks | 0.509 | 0.557 | 0.881 |
| SP 1 | Do not smoke in flammable materials store | 0.886 | 0.536 | 0.881 |
| SP 2 | Do not work under the influence of alcohol and other drugs | 0.732 | 0.473 | 0.883 |

(*continued*)

**Table 8.** (*continued*)

| Variable | Question | Factor loading | Corrected item total correlation | Cronbach level after deletion |
|---|---|---|---|---|
| SP 3 | Ensure equipment/tools are in good condition before usage | 0.517 | 0.490 | 0.883 |
| SP 4 | Use appropriate tools/equipment | 0.426 | 0.522 | 0.882 |
| AS 1 | Adhere to warning signs and notices | −0.768 | 0.662 | 0.817 |
| AS 2 | Follow safety regulations | −0.724 | 0.619 | 0.823 |
| AS 3 | Adhere to guidance on recommended illumination level for various tasks | −0.610 | 0.556 | 0.830 |
| AS 4 | Adhere to company safety policies | −0.506 | 0.604 | 0.824 |
| ST 1 | Attend safety education program | 0.758 | 0.609 | 0.823 |
| ST 2 | Attend safety training program | 0.686 | 0.651 | 0.817 |
| ST 3 | Provision of training | 0.423 | 0.590 | 0.921 |
| ST 4 | Good inspection program | 0.396 | 0.687 | 0.918 |
| FU 1 | Adhere to regular use of provided change room | −0.691 | 0.486 | 0.840 |
| FU 2 | Put to proper use of the available facilities (toilet, drinking water, washing, and canteen) | −0.635 | 0.489 | 0.838 |
| FU 3 | Provision of safe means of facilities all the time | −0.446 | 0.651 | 0.919 |
| FU 4 | Provision of change room for workers | −0.416 | 0.627 | 0.878 |
| SWC 1 | Provision of sufficient lighting system for enclosed areas | 0.566 | 0.502 | 0.923 |
| SWC 2 | Safe movement around workplace | 0.394 | 0.495 | 0.923 |
| SWC 3 | Involve workers in H&S program | −0.332 | 0.640 | 0.897 |
| WW 1 | Provision of break periods for workers to access the facilities | 0.506 | 0.584 | 0.921 |
| WW 2 | Provision of facilities that are clean, safe and accessible to all workers | 0.453 | 0.730 | 0.918 |
| WW 3 | Provision adequate facilities (toilet, drinking water, washing, and canteen) | 0.434 | 0.714 | 0.918 |
| WW 4 | Provision of change room for workers | 0.409 | 0.645 | 0.919 |
| SR 1 | Provide Safety regulations of equipment | 0.592 | 0.531 | 0.922 |
| SR 2 | Provision of Signs/Notices on sites | 0.488 | 0.561 | 0.901 |
| SR 3 | Provision of personal protective equipment (PPE) | 0.414 | 0.598 | 0.899 |
| SAW 7 | Use proper means of lifting, handling or moving of objects | 0.594 | 0.683 | 0.876 |
| SAW 10 | Ensure the use of personal protective equipment (PPE) | 0.577 | 0.527 | 0.881 |

(*continued*)

**Table 8.** (*continued*)

| Variable | Question | Factor loading | Corrected item total correlation | Cronbach level after deletion |
|---|---|---|---|---|
| SAW 8 | Ensure proper stacking of objects/materials in safe locations | 0.521 | 0.580 | 0.880 |
| SAW 9 | Avoid annoyance and horseplay at the workplace | 0.426 | 0.561 | 0.880 |
| GS 3 | Monitoring of H&S policy implementation by the government representatives | 0.960 | 0.865 | 0.896 |
| GS 4 | Provision of H&S policy update by government representatives | 0.903 | 0.853 | 0.898 |
| GS 2 | Implementation of H&S policy by government representatives | 0.889 | 0.825 | 0.904 |
| GS 5 | Provision of H&S training by government representatives | 0.877 | 0.820 | 0.905 |
| GS 1 | Formulate H&S policy of construction | 0.692 | 0.660 | 0.934 |
| SE 2 | Safe storage of equipment | 0.606 | 0.613 | 0.884 |
| SE 3 | Safe storage of materials | 0.515 | 0.735 | 0.874 |
| SE 7 | Safe transportation of equipment | 0.373 | 0.687 | 0.877 |
| SE 1 | Safe and healthy work environment | 0.337 | 0.667 | 0.0879 |
| COC 9 | Assessment of hazard identification and risk | −0.665 | 0.645 | 0.896 |
| COC 8 | Management commitment in H&S | −0.605 | 0.703 | 0.893 |
| COC 11 | Update on H&S information to workers | −0.541 | 0.643 | 0.896 |
| COC 10 | Communication of H&S information to workers | −0.529 | 0.656 | 0.896 |
| COC 7 | Company H&S Policy | −0.484 | 0.702 | 0.893 |
| COC 6 | Health and safety inspection | −0.464 | 0.702 | 0.893 |

## 6 Conceptual Health and Safety Compliance Model

This section gives detail information on the number of latent constructs or variables for each of the factors for the conceptual H&S compliance model. An Exploratory Factor Analysis (EFA) was conducted on the theoretical model or the six factor model (Fig. 1) to arrive at the eight factor model as shown in Fig. 2. The measurement components for the conceptual health and safety compliance model as shown in Fig. 2 is made up of Safety of Materials and Equipment (SME) and Government Support (GS) with five latent constructs or variables each. While Safety Precautions (SP), Safety Training (ST), Workers Welfare (WW), Safe Acts of Workers (SAW) and Safe Environment (SE) have four latent constructs or variables each. Only Safety Regulation (SR) has three latent constructs or variables.

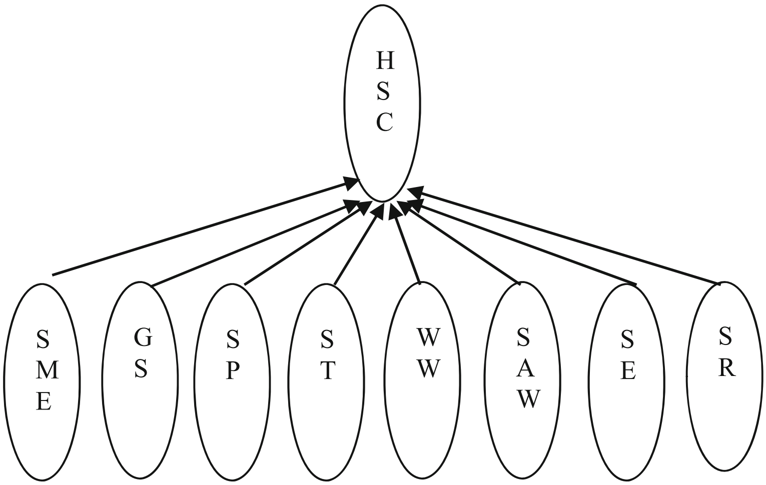


**Fig. 2.** Conceptual health and safety (H&S) compliance model (Model 2.0)

## 7 Conclusion and Recommendation

This paper explains the conceptualization of Health and Safety compliance model based on theoretical model or six factor model for the SMEs contractors in Ghana. The derived ten factor model will serve as H&S compliance model for the SMEs contractors' in Ghana. The application of the proposed ten factor model will assist in minimizing accidents on site, which will result in improved H&S compliance of SMEs contractors. The factor model should be applied in the H&S compliance programme by stakeholders and institutions responsible in planning process to enhance the quality of H&S practices among SMEs contractors. The factors that reveal SMEs contractors' preferences about H&S compliance should also be part of the planning input.

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# Measuring Resilient Safety Culture of Construction Projects

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**Abstract.** Resilient safety culture is characterised by continuous improvements of safety performance and the capability of creating foresight, recognising and anticipating the changing shape of safety risks in the complex sociotechnical systems. This study aims to conceptualise resilient safety culture of construction projects by integrating resilience engineering principles into the concept of safety culture. A correlation research design was adopted to achieve the research objectives and hypotheses. Data were collected using questionnaires with 78 completed building projects. The structural equation modelling technique was used to analyse the data collected. The results of this study (1) confirmed 24 measurable questions to assess resilient safety culture; (2) supported the hypothesized significant positive relationship between resilient safety culture and safety performance. The findings of this study imply that resilient safety culture can be used as a predictor of safety performance. It also provides a frame of practices to assess organisations' capability of safety management in the construction environment.

**Keywords:** Construction · Resilience · Safety culture · Safety management Safety performance

## 1 Introduction

In recent years, the increasingly inherent complexity in technology, work tasks and organizational structures of construction projects has led to the changing and unforeseen shape of safety risks and poses challenges for traditional safety management approaches [1, 2]. Resilience engineering approach has been recognised as a potential solution to the lack of effectiveness of traditional approaches in responding to the changing and unforeseen safety risks associated with the increasingly complex nature of sociotechnical systems [3].

To address the limitation of safety culture in responding to the changing and unforeseen shape of safety risks, researchers [4, 5] have discussed the notion of resilient safety culture and its application to the construction industry. In a recent publication, Trinh, Feng and Jin [5] defined resilient safety culture as an organisation's psychological/cognitive, behavioural, and managerial/contextual capabilities to "anticipate, monitor, respond and learn" in order to manage safety risks and create and ultra-safe organisation.


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Although the previous research has made significant contributions in introducing resilience into workplace health and safety and developing the concept of resilient safety culture, it seems that no empirical research has been conducted to examine the dimensions of resilient safety culture, which has been recognised as a multidimensional concept [5]. Against this background, this research aims to conceptualise resilient safety culture by integrating resilience engineering principles into the concept of safety culture in the context of the construction industry. The specific objectives are: (1) to identify the dimensions of resilient safety culture; and (2) to investigate the impacts of resilient safety culture and its dimensions on safety performance of construction projects.

## 2 Theoretical Foundation

### 2.1 Safety Culture Theory

Safety culture is often acknowledged as a subset of organisational culture, where the beliefs and values refer specifically to matters of health and safety [6]. A review of safety culture theory recognised psychological/cognitive, managerial/contextual, and behavioural factors as three dimensions for measuring safety culture. For examples, MD Cooper [7] also developed a reciprocal model of safety culture which contains three elements, namely internal psychological factors (how people feel), safety-related behaviours (what people do) and objective situational features (what the organisation has). This provide a framework that could be used for measuring and examining the reciprocal interactions between psychological, behavioural and managerial safety-related factors for safety performance improvement in different settings.

### 2.2 Resilience Engineering Theory

A review of resilience engineering theory indicated the three dimensions of organisational resilience, which include: (1) cognitive resilience, (2) behavioural resilience, and (3) contextual resilience [8–10]. In addition, the fundamental idea behind resilience engineering is that, in a world of limited resources, irreducible unpredictability, and multiple conflicting goals, an organisation must continually manage safety risks and create safety via resilience process including anticipating (knowing what to expect), monitoring (knowing what to look for), responding (knowing what to do), and learning (knowing what can happened) [3, 11]. Shirali et al. (2015, p. 20) summarised four capabilities representing the resilient systems as follows:

- Anticipating (knowing what to expect), that is, "how to anticipate more developments, threats, and opportunities in the future, such as the potential changes, disturbances, pressures, and their consequences".
- Monitoring (knowing what to look for), that is, "how to monitor something that is a threat or can become a threat in the near future. Monitoring must include both what happens in the environment and what happens in the system itself, i.e., system performance".

- Responding (knowing what to do), that is, "how to respond to the regular and irregular disruptions and disturbances through implementing a full and a ready set of responses or through adjusting normal functions".
- Learning (knowing what has happened), that is, "how to take lessons from experiences, in particular how to learn useful lessons from the experiences of success and failure".

### 2.3 Hypotheses

A comparison of the safety culture dimensions and organisational resilience dimensions reveals a similar factor structure of both concepts (i.e. psychological/cognitive, behavioural, and managerial/contextual). In addition, resilience engineering theory enhances the concept of organisational safety culture by offering organisations with four processes (i.e. anticipating, monitoring, responding, and learning) for safety management. It is therefore inferred that the concept of resilient safety culture can be measured and examined under the same framework (i.e. psychological/cognitive, behavioural, and managerial/contextual). Therefore, the following hypotheses are set out:

H1 – Resilient safety culture is measured by psychological resilience, behavioural resilience, and managerial resilience.
H 2 – Resilient safety culture has positive impact on safety performance.

## 3 Research Methodology

### 3.1 Data Collection Instrument

According to the hypotheses suggested in this study, the two major variables include and safety performance and resilient safety culture.

– Safety performance: To measure safety performance, the formula for calculating Recordable Incident Rate (IR) is given below:

OSHA Recordable Incident Rate [12]:

$$IR = \frac{\text{Number of OSHA recordable cases} \times 200000}{\text{Number of employee labor hours worked}}$$

In the formula, the 200000 employee hours worked reflects a 100-person crew working 40 h per week for 50 weeks.

– Resilient safety culture: In this study, the level of resilient safety culture is determined based on three factors: (1) psychological resilience, (2) managerial resilience, and (3) behavioural resilience. Under the conditions that are disruptive, uncertain, surprising, and have the potential to jeopardise the organization's long-term survival, cognitive resilience is an organizational capability that enables an organisation to notice shifts, interpret unfamiliar situations, analyse options, and figure out how to respond; behavioural resilience comprises the established behaviours and routines that enable an organisation to learn more about a situation, implement new routines, and fully use its resources; and contextual resilience is the combination of interpersonal connections, resource stocks, and supply lines that provides the foundation for quick actions [13, 14]. Each of those factors is evaluated using the measurable scales, which are actual safety practices implemented on construction sites reflecting all four resilience capabilities.

### 3.2 Sample and Data Collection

A questionnaire survey was selected. The questionnaire was consequently revised and finalised based on the experts' feedback. The research objective suggests a project's contractor as the unit of analysis. The building construction projects in Vietnam were chosen. For each randomly selected project, a project manager was contacted via telephone or email to request their participation in this research. The questionnaire was consequently revised and finalised based on the experts' feedback.

The questionnaire included 4 parts. The first part consists of questions about the general characteristics of the construction project. The second part requires respondents to provide information about safety performance of the project, as measured by Recordable Incident Rate. The third part consists of questions relating to safety practices to measure resilient safety culture. Based on the actual safety practices which were implemented in their completed construction projects, respondents were required to indicate the level of their agreement on a five-point Likert scale (between 1 = "Strongly disagree" and 5 = "Strongly agree") for each of statements found in this part. The fourth part collects the "types of project positions" whom the respondents consulted with when they were completing the questionnaire (e.g., site manager, site safety manager, site supervisor, site safety officer).

115 project managers of 438 contacted building projects participated in this study representing a response rate of 26.2%. The information of 78 completed building projects was input into a database after excluding invalid questionnaires and outliers.

### 3.3 Data Analysis Methods

Structural equation modelling (SEM) has been used for data analysis in this study. Confirmation factor analysis was used to confirm the reliability and fitness of the factor structure of resilient safety culture (i.e. psychological, behavioural and managerial resilience). In addition, the statistical analysis of SEM was to validate (1) the causal relationship between resilient safety culture and its dimensions and safety performance. There are two stages of SEM model including measurement model and structural model.

# 4 Results

## 4.1 Validity and Reliability Analysis

Indicators with very low loadings (below 0.4) were eliminated from the constructs, as suggested by JF Hair, GTM Hult, C Ringle and M Sarstedt [15]. The 24 measurement items of resilient safety culture and their respective loading include: Beh10 (0.659), Beh12 (0.646), Beh13 (0.545), Beh3 (0.71), Beh6 (0.597), Beh7 (0.6), Beh9 (0.643), Man1 (0.78), Man11 (0.709), Man13 (0.775), Man2 (0.793), Man4 (0.786), Man6 (0.81), Man7 (0.801), Man9 (0.723), Psy10 (0.739), Psy11 (0.683), Psy2 (0.714), Psy3 (0.695), Psy4 (0.762), Psy5 (0.818), Psy6 (0.683), Psy7 (0.765), and Psy9 (0.591). The results show that all the loadings are above 0.4, showing that the indicator reliability was acceptable. In addition, the results show that the calculated Cronbach's alpha and composite reliability scores of resilient safety culture are 0.957 and 0.961, respectively; and average variance extracted (AVE) score of resilient safety culture is 0.509. Thus, the measurement items are appropriate for assessing resilient safety culture. In addition, the results of discriminant validity indicate that discriminant validity is satisfactory and dimensions of resilient safety culture are different from each other.

## 4.2 Structural Model Analysis

The relationship between resilient safety culture and safety performance was investigated by SEM. The three dimensions of resilient safety culture (e.g. psychological resilience, behavioural resilience, managerial resilience) are the latent variables in the SEM model, whereas the measurement items of each latent variable were derived from validity and reliability analysis in Sect. 4.1. The result shows the paths from resilient safety culture to behavioural resilience, managerial resilience and psychological resilience are 0.824, 0.943 and 0.902, respectively, and are all significant ($p < 0.01$). Resilient safety culture has a significant negative correlation with Recordable Incident Rate ($\beta = -0.364$, $\text{t - value} = 3.572,\ \text{p} < 0.01$). Therefore, H1 and H2 are confirmed.

# 5 Discussions and Conclusions

This paper presented a testing and validation of the factor structure of resilient safety culture, which is characterised by continuous improvements of safety performance and the capability of creating foresight, recognising and anticipating the changing shape of safety risks in the construction environment. This responds to the need expressed in the safety literature by developing an instrument to evaluate resilient safety culture, which has been recognised as a multidimensional concept [5]. The confirmation factor analysis provides an empirical support to the proposed factor structure of resilient safety culture. The results indicated that its measurement items refer to the employees' perceptions of safety (Psy10, Psy11, Psy2, Psy3, Psy4, Psy5, Psy6, Psy7, Psy9), the behavioural safety of projects' site management and supervisors (Beh10, Beh12, Beh13, Beh3, Beh6, Beh7, Beh9), and safety system implemented by projects' contractor (Man1, Man11, Man13, Man2, Man4, Man6, Man7, Man9) in a building project. It was found that, psychological resilience can be measured through employees' perceptions of safety practices, managerial resilience can be measured through a safety system implemented by projects' contractor, and behavioural resilience can be measured through behavioural safety of projects' site management and supervisors. The measurable scales of the three dimensions of resilient safety culture indicated that, in order to achieve consistently high safety performance, safety practices could address not only project hazards and its safety risks, but also the unexpected (i.e. human errors and unpredictable hazardous situations). Therefore, a safety system implemented by projects' contractor, behavioural safety of projects' site management and supervisors, and employees' perception of safety could be three different aspects for assessing organisations' capabilities to manage safety risks and creating an ultra-safe organisation. In addition, the results confirmed that resilient safety culture is significant negatively related to Recordable Incident Rate of construction projects. Based on this finding, it is implied that the assessment of resilient safety culture could provide a reliable prediction of safety performance of construction projects.

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# Framework for Small and Medium-Sized Contractors Growth

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**Abstract.** Small and medium sized enterprise (SME) contractors form the bedrock of economic growth in all countries. This study presents a framework for the selection of projects towards the growth of SME contractors in the Cape Coast Metropolis of Ghana. Sixty questionnaires were administered among the SME contractors and forty-seven questionnaires were returned, representing 78.3%. Findings from the study showed that project selection should be done in careful manner for SME's, resources should not be tied up in less significant activities and the SME management should take decisions that are feasible for the growth and expansion of the company. It was concluded that the development of the final framework work will serve as a guide in predicting the growth of SME contractors in within the study area.

**Keywords:** Construct · Ghana · Growth · Resources · SME contractors Variables

## 1 Introduction

Small and medium sized enterprise (SME) contractors are found lagging to reach their optimum size (growth period of five years) as indicated by Mathonsi et al. [20] and Thwala et al. [10], due to bankruptcy rate of businesses in the construction industry. Aigbavboa et al. [2] and Abu Bakar et al. [1] were of the view that this difficulty has contributed to the slow growth of SME contractors. However, Akorsu et al. [3] and Guanghua et al. [15] have indicated that limited capital of firm has contributed to their slow growth of SME contractors. Amoah et al. [5] posited that the registration and classification of contractors in Ghana is mandatory for government projects only. However, the classification of a business at the time of registration depends on the resource holding capacity of the business. Moreover, the resource holding capacity (human, financial, equipment resources of the enterprise) of contractors are considered under businesses in the construction industry classification. Aniekwu [7] cited change


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of government as one of the major problems in the slow growth of SME contractors'. There is also delay in payments of projects executed by contractors has taken most the limited resources [22] and this has also contributed to their slow growth. This delay in payment may be associated with government sponsored projects which has political influence and adversely hinders SME contractors' growth [4, 14].

A firm 's growth can be measured in terms of its capital investment, value of assets, market capitalization, economic value-added elements or outputs (sales, revenues, profit). Each of the measures illustrates some feature of growth and each is subject to limitations as a growth indicator [1]. However, [11, 15] argued that business locations have an influence on the growth of a firm [11, 15] since most of the projects are often cited at rural or urban areas. Theory suggests that for a business to overcome market challenges and grow to achieve outstanding performance, it must aim at efficiency, profitability and good financial management [18]. There is also limited research on small-medium sized (SME) contractors' growth in Cape Coast. The retard in progress of Cape Coast Metroplis has been attributed to the slow growth of SME contractors. The paper aims to present a framework that will determine the constructs for project selection towards SME contractors' growth in Cape Coast. The apaper addressed small and medium-sized enterprise contractors in Cape Coast and their growth.

## 2 Literature

### 2.1 Small and Medium Sized Enterprise Contractors in Growth

The concept of "development" is a notion of improvement. What is to be improved, at what scale of improvement, who or what the improvement is meant for, where to improve, and how to improve? "Development theories usually consider how and why levels of "development" and may vary between locations as pointed out by [23]. Therefore, "development" as posited by [23] refers to specific, intentional interventions to achieve improvement or progress. Knowledge of market within any business environment is required for the success of a company. Therefore, relationship of business with potential and existing clients and customers should be mandatory for SME contractors' growth. [17] argued that a company should have knowledge of its market's changing needs and opportunities, how it will identify and reach out to new customers and clients, the quality of its products or services, its productivity, its marketing and advertising, and skills possessed by its management. Mao [17] posited that the success of any company depends on the entire organization, since growth depends on an organization in its entirety. This includes the structures, policies, procedures, systems, activities, how authority is exercised, how decisions are made, coordination, integration, and communication. The factors to be considered for growth of a company are the market, products or services, oganization as a whole, the people in the business and the finances to run it successfully [17]. Growth is defined in terms of the value addition, quality of product, increase in production output, share of market, employee size, goodwill of customers, geographical spread etc. [12, 19]. In the construction industry the financial classification is often used as a measure of growth of business [5]. Insah [13] indicated that for a business to overcome market challenges and grow to achieve outstanding performance, then it must aim at efficiency, profitability and good financial management.

### 2.2 Small and Medium Sized Enterprise Contractors in Cape Coast

Small and medium sized enterprise (SME) contractors' in Cape Coast and throughout Ghana are often established by one individual and doubles as the manager with very limited formal education as indicated by [21] and takes all key decisions. Damoah [9] argued that skills and capabilities, resource base, employee size, risk tolerant level, technological edge have a direct influence on growth and performance of SME contractors in Cape Coast. The slow growth of SME contractors in Cape Coast has been attributed to different factors. He quickly pointed out some of the factors as follows: lack of government support, unprofessional conduct of consultants, delayed payment for work done, high staff turnover, low educational level of contractor and poor management which impede SME contractors' growth. Damoah [9] further argued that ownership structure is an influencing factor to on the asset base of a firm. Moreover, location of operation, direction and governance mechanism of the firm are very competitive, and these drive the weak and poor firms away from the market.

## 3 Methodology

This section discusses the methods used for data collection. Both snowball sampling techniques were used in the administration of the questionnaires to the employees of small and medium sized enterprise (SME) contractors in Cape Coast. Firstly, few contractors within the reach of the researcher were identified. Other contractors were identified on consultation. Directions and actual locations were provided by the few contractors within reach which led to the locations of all the SME contractors used for the study. The target sample size were the site managers, in the absence of the site manager, the site engineers, architects, surveyors or foremen were used as the representatives, were they served as overseers of the projects.

## 4 Findings

The table above shows that 42 respondents representing 89% were males whiles 5 respondents representing 11% were females. It can be asserted that the construction industry still remains a male dominant area in the Cape Coast Metropolis.

**Table 1.** Gender

| | Frequency | Percent (%) |
|---|---|---|
| Male | 42 | 89.4 |
| Female | 5 | 10.6 |
| **Total** | **47** | **100.0** |

Source: Field Data, 2017.

Also, in analyzing the age of respondents which ranged from 20–25, 26–30, 31–35, 36–40 and 41–45. It was reported that a greater percentage of respondents fell within the range of 31–35 years with a percentage of 38.3 of the total sample size, whiles 36–40 years respondents were less than 10 percent. Result from the table indicates that most of the respondents were in their youthful age group of 20–35 years (Table 2).

**Table 2.** Age group

| | Frequency | Percent |
|---|---|---|
| 20–25 yrs | 5 | 10.6 |
| 26–30 yers | 15 | 31.9 |
| 31–35 yrs | 18 | 38.3 |
| 36–40 yrs | 4 | 8.5 |
| 41–45 | 5 | 10.6 |
| **Total** | **47** | **100.0** |

Source: Field Data, 2017.

### 4.1 Qualification of Respondents

The Table 3 below indicates the educational qualification of the respondents, 38.3% respectively possessed national diploma or certificate and bachelor's degree, whiles less than 25% were holders of post graduate and senior school certificates. This shows that more than 85% of the respondents had the required knowledge and skills, since they were duly trained.

**Table 3.** Highest qualification

| | Frequency | Percentage |
|---|---|---|
| Senior school certificate | 6 | 12.8 |
| National diploma or certificate | 18 | 38.3 |
| Bachelor's degree | 18 | 38.3 |
| Post-graduate | 5 | 10.6 |
| **Total** | **47** | **100.0** |

Source: Field Data, 2017.

### 4.2 Years in Firm

38.3% of respondents have worked in their firms for 2–5 years, whiles 31.9% have worked for 6–10 years, also, less than 20% have been working from 16 years to above 31 years. This indicates that the firms have experienced personnel in their organizations (Table 4).

**Table 4.** Year in firm

| | Frequency | Percentage |
|---|---|---|
| 2–5 yrs | 18 | 38.3 |
| 6–10 yrs | 15 | 31.9 |
| 11–15 yrs | 6 | 12.8 |
| 16–20 yrs | 4 | 8.5 |
| 21–25 yrs | 1 | 2.1 |
| 26–30 yrs | 1 | 2.1 |
| 31 yrs and above | 2 | 4.3 |
| **Total** | **47** | **100.0** |

Source: Field Data, 2017.

## 4.3 Respondents Status in Firm

From the Table 5 below, 14.9% were Site Engineers and Foremen respectively, whiles Architects and Surveyors also stood at 21.2% respondents. Again, 36.2% of the respondents were site managers, from the Table below, this shows that adequate data were collected as those who provided them were directly involved with activities at the construction sites.

**Table 5.** Position in firm

| | | Frequency | Percentage |
|---|---|---|---|
| | Foreman | 7 | 14.9 |
| | Site engineer | 7 | 14.9 |
| | Architect | 5 | 10.6 |
| | Site manager | 17 | 36.2 |
| | Surveyor | 5 | 10.6 |
| | Store manager | 2 | 4.3 |
| | **Total** | **43** | **91.5** |
| Missing | System | 4 | 8.5 |
| **Total** | | **47** | **100.0** |

Source: Field Data, 2017.

## 4.4 Number of Years Firm Has Been in Existence

Analyzing the years that firms have been in existence from the Table 6 below, over 50% have been in existence for more than 15 years, whereas 10–14 years and 5–9 years were 21.3 and 17% respectively. It shows that these firms have gained enough experience with the challenges associated with executing project throughout the cause of their existence.

**Table 6.** Years of Firm

| | | Frequency | Percentage |
|---|---|---|---|
| | 5–9 yrs | 8 | 17.0 |
| | 10–14 yrs | 10 | 21.3 |
| | 15–20 yrs | 15 | 31.9 |
| | 21–30 yrs | 6 | 12.8 |
| | 31 yrs and above | 6 | 12.8 |
| | **Total** | **45** | **95.7** |
| Missing | System | 2 | 4.3 |
| **Total** | | **47** | **100.0** |

Source: Field Data, 2017.

## 4.5 Construction Project Being Executed Currently

55.3% of the respondents worked in firms who were executing public liability project, 29.8% for private firm's project whereas 14.9% were undertaken sole proprietorship project, as it is indicated on the Table 7 below.

**Table 7.** Type of construction project currently working on

| | Frequency | Percentage |
|---|---|---|
| Private firm | 14 | 29.8 |
| Public liability | 26 | 55.3 |
| Sole proprietorship | 7 | 14.9 |
| **Total** | **47** | **100.0** |

Source: Field Data, 2017.

However, from the study as shown on the Table 8 above, 80.9% of the respondents worked with firms executing building construction project, whiles 14.9% were executing civil engineering works, 4.3% also worked in firms undertaken both building construction and civil engineering projects. The implication is that most of the respondents were working in firms executing building construction works, and mostly public liability projects.

**Table 8.** Construction project worked on by firm

| | Frequency | Percentage |
|---|---|---|
| Building construction | 38 | 80.9 |
| Civil engineering | 7 | 14.9 |
| Other | 2 | 4.3 |
| **Total** | **47** | **100.0** |

Source: Field Data, 2017.

## 4.6 Classification of Firms

With respects to classification from the Table 9 above, firms with D1/K1 and D2/K2 were 31.9 and 36.2% respectively, whiles D3/K3 represented 17% and D4/K4 10.6%. This indicates that, the respective firms had the necessary organizational capacity to enable them tender and execute the projects.

**Table 9.** Firm's Classification

| | | Frequency | Percentage |
|---|---|---|---|
| | D1/K1 | 15 | 31.9 |
| | D2/K2 | 17 | 36.2 |
| | D3/K3 | 8 | 17.0 |
| | D4/K4 | 5 | 10.6 |
| | **Total** | **45** | **95.7** |
| Missing | System | 2 | 4.3 |
| **Total** | | **47** | **100.0** |

Source: Field Data, 2017.

## 4.7 Client of the Project

From the Table 10 below, 66% of the respondents worked in firms that executed public project whereas 12.8 and 10.6% worked on project from parastatal organizations and property developers respectively. Also, 4.3% others worked on a hospital and a university project. The firms of the respondents mostly executed public project whiles less than 30% constructed project from other clients, this indicates that, the government and its agencies were the major employers of the firms in the construction industry.

**Table 10.** Which client owns the Project?

| | | Frequency | Percentage |
|---|---|---|---|
| | Property developer | 5 | 10.6 |
| | Parastatal organization | 6 | 12.8 |
| | Public | 31 | 66.0 |
| | Other | 2 | 4.3 |
| | **Total** | **44** | **93.6** |
| Missing | System | 3 | 6.4 |
| **Total** | | **47** | **100.0** |

Source: Field Data, 2017

The Table above shows the variables that influence the growth of SME contractors'. 2% of the respondents disagreed whiles 34% strongly agreed and 64% also agreed that project selection should be in careful manner, with a respondent's mean of 4.30. Furthermore, 34% of the respondents strongly agreed and 51% agreed that sufficient attention should be given to selected projects, to satisfy the players in the industry, whiles 9% of the respondents disagreed and 4% strongly disagreed. Moreover, 2% of the respondents had no opinion and disagreed respectively to effective use of money on end-of-the-year activities, whereas 2% also strongly disagreed with a mean of 2.93 and 95% of the respondents agreed. 51% of the respondents strongly agreed and 48% agreed that team members should be able to determine their work load whiles 2% strongly disagreed and disagreed respectively, with a respondent's mean of 4.40. Additionally, 36% of the respondents agreed, whiles 57% strongly agreed that effective use of resources on projects will enable the growth of SME contractors' whiles 2% disagreed, strongly disagreed and had no opinion respectively.

On whether project selected for execution should satisfy short-term demand, a mean of 4.43 was obtained, 2% of the respondents strongly disagreed, 4% had no opinion whiles 40% agreed and 53% strongly disagreed. However, 47% of the respondents agreed whereas 43% strongly agreed that SME contractors should not engage in long-term work that is not profitable, as those with no opinion and strongly disagreed were 4% respectively. Also, 6% of the respondents disagreed that they should prevent company managers from causing resource problems whiles 40% agreed, 47% strongly agreed and 4% had no opinion. Additionally, 53% and 40% of the respondents agreed and strongly agreed respectively that SME contractors should take a decision that is feasible whiles 2% disagreed, with a mean of 4.38. Also, 53% of the respondents agreed and 43% strongly agreed respectively that resources should not be tied up in less significant activities with a mean of 4.39, whiles 2% disagreed (Table 11).

**Table 11.** Factors that influence growth of SME contractors'

| Variables for growth of SME contractors' | | Mean | Std. deviation | Ranking |
|---|---|---|---|---|
| GT1 | Project selection should be in careful manner | 4.30 | 0.587 | 1st |
| GT2 | Resources should not be tied up in less significant activities | 4.39 | 0.614 | 2nd |
| GT3 | Should take a decision that is feasible | 4.38 | 0.614 | 2nd |
| GT4 | Effective use of money on end-of-the-year activities | 4.37 | 0.645 | 4th |
| GT5 | Should not engage in long-term work that is not profitable | 4.30 | 0.756 | 5th |
| GT6 | Project selected for execution should satisfy short-term demand | 4.43 | 0.773 | 6th |
| GT7 | Effective use of resources on projects | 4.45 | 0.829 | 7th |
| GT8 | Team members should be able to determine their work load | 4.40 | 0.798 | 8th |
| GT9 | Should prevent company managers from causing resource problems | 4.30 | 0.840 | 9th |
| GT10 | Sufficient attention should be given to selected projects, to satisfy the players in the industry | 4.04 | 1.053 | 10th |

Source: Field Data, 2017.

The Framework in Fig. 1 depicts what was obtained from literature and used for the fieldwork.


**Fig. 1.** Small and medium-sized contractors growth

### 4.8 Discussion of Results

This section discusses the findings of the research. Majority of the respondents were male and the majority the category of their ages falls between 26 to 30 years and 31 to 35 years. Most of the employees had Bachelors' degree and National Diploma certificates. Most all the responds indicated that their firms have been in existence between 2 and 5 years and 6 to 10 years. Site managers happened to be responsible for day to day activities of their firms. Private liabilities have dominated the number of building construction projects awarded in the town, followed by private firms, with few civil engineering works. The contractors executing the projects fall within the D1/K1 and the D2/K2. Careful manner of project selection was ranked high among the ten variables from literature. This is followed by feasible decision on type of projects, allocation of resources to significant activities and effective use of money on end-of-the-year activities to minimize waste of resources which should be channeled to useful activities.

## 5 Conclusion and Recommendations

Five variables have been identified, as shown in Table 1 to be the most appropriate and effective for the growth of SME contractors in Cape Coast Metropolis. The framework will serve as a guide in predicting the growth of SME contractors in Cape Coast Metropolis. Further research should be conducted to determine the strength of each variable in the framework in order to improve on it.

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# Analyzing the Impact of Group Norms on Workers' Safety Behaviors in a Construction Team

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**Abstract.** The construction industry is universally accepted as one of the most dangerous industries. Workers' unsafe act is one of the main causes of construction accidents. And group norms are widely regarded as important roles in regulating safety behaviors. According to the social identity theory, research on group norms of construction teams seems to be more important. Group norms can be divided into injunctive and descriptive norms. However, there are limited studies how injunctive and descriptive norms influence workers' safety behaviors and the mechanism in construction teams. This study aims to build and test a mediation model about how workers' safety behaviors are affected by these norms. The empirical data were collected from different construction sites and analyzed by the Structural Equation Modeling (SEM) technique. Results reveal that injunctive and descriptive norms have both a direct and an indirect influence on workers' safety behaviors. And safety attitude serves as the mediating factor. This study supports a better understanding on how safety behaviors are affected by group norms from the perspective of sociological classification in construction teams.

**Keywords:** Construction team · Group norms · Injunctive norms Descriptive norms · Safety behaviors · Safety attitudes

## 1 Introduction

The construction industry is acknowledged as one of the most dangerous industries for its high rate of fatal injuries. In spite of many technologies and practices that have been developed and taken to improve safety in construction, accidents and injuries still happen from time to time [1–3]. In China, for instance, there were 3523 construction accidents and 3806 fatalities in 2016 [4].

Accident investigations have revealed that 80–90% of accidents in construction are caused by workers' unsafe behaviors [5, 6]. Such alarming numbers have captured many researchers' attention on how to reduce construction workers' unsafe behaviors. Among all the influencing factors of safety behaviors, group norms are widely regarded


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as important roles in regulating workers' safety behaviors [7]. What's more, construction workers usually work in a team and thereby share the same identity of the workgroup [8]. They usually feel closer to their teams than to organizations in physical distance as well as psychological distance [9]. According to the social identity theory [10], research on group norms in construction teams is of great importance.

Group norms can be divided into injunctive norms (what is commonly done) and descriptive norms (what is commonly approved or disapproved of) from a sociological perspective [11]. It has been proved that the two dimensions can serve as predictors of individual behaviors [11, 12]. Descriptive and injunctive norms are proximal factors related to groups [13]. Some researchers emphasized that distinguishing between injunctive norms and descriptive norms could improve the predictive utility of norms [14]. However, there are limited studies on the influence of injunctive norms and descriptive norms on workers' safety behaviors and their influencing mechanism in construction teams. To fill this gap, this study aims to build and test a mediation model about how workers' safety behaviors are affected by these norms.

## 2 Literature Review

The group norm is defined as an individual's perception of a description and prescription of group members' behaviors [15, 16]. A number of researchers have demonstrated that group norms have effects on an individual's behavior in his or her group (e.g., [17]). With respect to safety behaviors, many studies have specifically supported empirical evidence of group norms on safety behaviors [13, 18].

The effect of group norms on individual behaviors has captured the attention of many researchers because group norms play a critical role in understanding individual's attitude and behavior [19]. In addition, group norm is a powerful way by which workers perform specific behaviors, especially when workers have difficulty in judging the appropriateness of the behavior in uncertain contexts [7]. Certainty is related to the confidence with how to behave in a specific situation [20]. Relying on the evaluations of others (e.g., group norms) can provide increased confidence. If workers perceive reference group members as performing safely, they are also more likely to be motivated to enhance their own safety performance [13].

Some researches has demonstrated the influence of group norms on construction workers' safety behaviors [8, 18], but they didn't take different types of norms into consideration. As mentioned earlier, group norms can be divided into descriptive norms and injunctive norms. In addition, the predictive ability of norms on behavior can be improved by distinguishing the two types of norms [14, 21].

Injunctive norms are associated with the motivation that is derived from the perceived benefits and the perceived losses of the group [22]. For example, construction workers may perform unsafe behaviors because they are told to "work quickly in order to finish the job rather than safely" by their coworkers or foremen in the team. Descriptive norms are predictive indicators of individual workers' behavior (e.g., [11]). In practice, construction workers' safety behavior would be greatly influenced if they are provided with opportunities to observe coworkers' behavior in a given situation.

In many domains, some researchers found descriptive and injunctive norms had direct and indirect effect on safety behaviors, and safety attitude served as the mediation [3, 13, 23]. In construction, there are limited researches about the influencing mechanism between group norms and safety behaviors. However, it has been proved that construction workers' safety attitudes were significantly influenced by group norms [18]. Attitudes refer to "individual's total positive or negative evaluations of the behavior" [17]. Attitudes are related to an individual's safety behavior at the social-cognitive level. In addition, workers' attitudes with respect to safety are proximal antecedents of safety behavior at the individual level [13]. Generally speaking, positive attitudes regarding safety can promote a greater motivation to perform safe behaviors (e.g., the use of personal protective tools like helmet can prevent injuries). A number of researches have theoretically and empirically supported the important role of safety attitudes in the predictions of safety behaviors (e.g., [24]).

From the above, this study is aiming to build and test the influencing model between injunctive norms, descriptive norms, safety attitudes and safety behaviors in construction teams. Based on the notions and related researches, the hypothetical model is depicted graphically in Fig. 1. And the following 5 hypotheses are proposed:

Hypothesis 1: Descriptive norms are positively associated with workers' safety behaviors in construction teams.
Hypothesis 2: Injunctive norms are positively associated with workers' safety behaviors in construction teams.
Hypothesis 3: Descriptive norms are positively associated with workers' safety attitudes in construction teams.
Hypothesis 4: Injunctive norms are positively associated with workers' safety attitudes in construction teams.
Hypothesis 5: Safety attitudes are positively associated with workers' safety behaviors in construction teams.

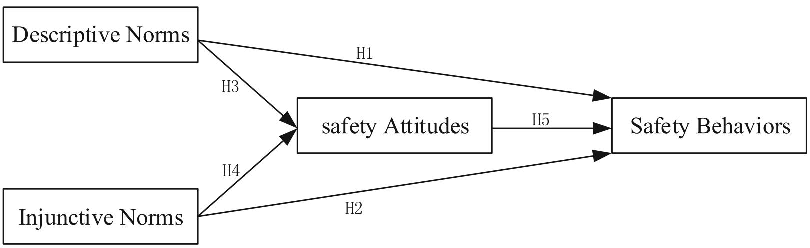


**Fig. 1.** Hypothesized meditational model to predict safety behaviors

## 3 Method

### 3.1 Participants

For data collection, three construction sites in Chongqing, China, were approached. A questionnaire was designed to quantificationally measure the variables presented in the previous section. A total of 247 workers at site participated in this research survey, 165 valid responses were returned. Questionnaires were completed anonymously, and the survey team members collected the questionnaire immediately once completed to ensure the confidentiality. Approximately 22–25 min in total were taken to finish the survey.

### 3.2 Measures

**Injunctive Norms and Descriptive Norms**
Refer to the questionnaire of Fugas et al. [13], 8-item scales were used to assess descriptive and injunctive norms. The participants were required to response these items using a 5-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree). And other variables were evaluated with a 5-point Likert scale as well. Injunctive norms were measured by four items. An example was" My foremen in the team always not only demand us to work safely, but also explain why we should work safely". And four items were adopted to assess injunctive norms. An example was "My co-workers think that personal protective equipment should be used, even if it is uncomfortable".

**Safety Attitude**
A3-item scale was adopted to measure safety attitudes by considering the previous survey [25]. An example of these items was "In my job, using necessary safety equipment is beneficial to safety".

**Safety Behavior**
A3-item scale from Neal and Griffin [26] was used to measure safety behaviors. An example was "I always use necessary safety equipment when I am doing my job."

## 4 Results and Discussion

A two-step Structural Equation Modeling (SEM) was used to analyze the empirical data [27]. The computer program AMOS 24.0 with maximum likelihood estimation (MLE) was adopted to get path estimates, and to measure the overall fit of the structural model. This study chose different types of indexes of overall fit, including Chi-square/Degrees of Freedom (Chi-square/df; <3.00), Goodness of Fit Index (GFI > .90), Comparative Fit Index (CFI > .90), Root Mean Residual (RMR < .10) and Root Mean Square Error of Approximation (RMSEA < .10).

### 4.1 Confirmatory Factor Analysis

Confirmatory factor analysis (CFA) was adopted to measure the validity and reliability of the four constructs presented above. There are several ways to measure the reliability of designated constructs, and the internal consistency method serves as the most commonly method in several researches. Results showed that all factor loadings were ranging between .77 and .83, which were statistically adequate. The composite reliability is measured as the coefficient in the internal consistency. As displayed in Table 1, the composite reliability values range from .77 to .83, which were larger than .60 suggested by Fornell and Larcker [28]. Average variance extracted is regarding to convergence validity. Average variance extracted for all factors range from .52 to .55, which were above .50 suggested by Fornell and Larcker [28]. These results showed that all the measurement items reached the requirements for both internal reliability and convergent validity.

**Table 1.** Descriptive statistics, internal consistency and reliability

| Variables | M | SD | Composite reliability | Average variance extracted |
|---|---|---|---|---|
| Descriptive norms | 4.30 | .53 | .81 | .52 |
| Injunctive norms | 4.39 | .62 | .83 | .55 |
| Safety attitudes | 4.25 | .66 | .77 | .53 |
| Safety behaviors | 4.21 | .78 | .79 | .55 |

## 4.2 Structural Equation Modeling

The estimated model was showed in Fig. 2 including the standardized path coefficients. The fit indices of the structural model were displayed as follows: Chi-square/df = 1.18, GFI = .91, CFI = .98, RMR = .04, and RMSEA = .04. These fit indices all fulfill their requirements respectively, which indicated that the hypothesized model was acceptable.

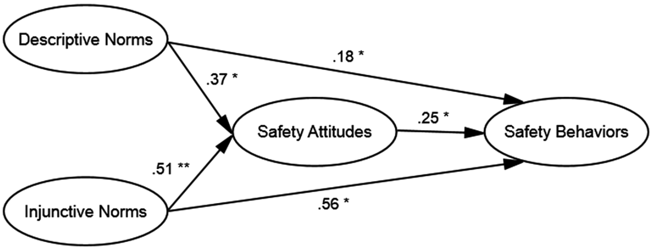


**Fig. 2.** Path model showing direct and mediated pathways to safety behaviors. Note: **p < .01, *p < .05.

This analysis showed that both descriptive norms and injunctive norms were significantly and positively related to workers' safety behaviors. Descriptive norms had direct effect on workers' safety behaviors ($\beta = 0.18$, $p < .05$). Thus, the hypothesis1 was supported. In addition, injunctive norms were also found to have a direct influence on workers' safety behaviors ($\beta = 0.56$, $p < .05$) in construction teams, which supported the hypothesis 2. In this sense, injunctive norms had a stronger influence on workers' safety behaviors than descriptive norms. What's more, descriptive norms and injunctive norms were confirmed that they had an indirect effect on safety behaviors in which safety attitude served as the mediator. Safety attitudes ($\beta = 0.37$, $p < .05$) partially mediated the relationships among descriptive norms and workers' safety behaviors in construction teams. Therefore, the hypothesis 3 was supported. In addition, Safety attitudes ($\beta = 0.51$, $p < .01$) also partially mediated the relationships among injunctive norms and workers' safety behaviors in construction teams, which supported the hypothesis 4. In this respect, injunctive were also more related to workers' safety attitudes than descriptive norms. This study also found that safety attitudes ($\beta = 0.25$, $p < .05$) had important and positive effects on safety behaviors. Therefore, the hypothesis 5 was supported.

## 5 Conclusion

This study aimed to develop and test a mediation model how injunctive norms and descriptive norms affect workers' safety behaviors in construction teams. This research revealed that injunctive norms and descriptive norms not only have a direct influence on workers' safety behaviors, but also have an indirect effect on workers' safety behaviors in construction teams. During the indirect process, safety attitude serves as the mediating factor, which lays a theoretical foundation for understanding how group norms influence workers' safety behaviors in construction teams. In practice, the results can provide a valuable reference for decision makers.

Although this study provides a better understanding of how injunctive norms and descriptive norms affect workers' safety behaviors, several limitations also exist in this study. First, this study did not consider different sources of injunctive and descriptive norms. Second in the present study, three construction sites where the questionnaire survey was conducted were all located in Chongqing, China. The finding of this study may not be typical to apply to different cities or countries. Hence, additional research is required to take these limitations into consideration.

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# Influential Factors of Unsafe Acts of Contractors in Cape Coast Metropolis

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**Abstract.** Human factor has been identified as the most prevailing and contributing factor to high rate of accidents in the construction industry. Inappropriate operation and misappropriate use of equipment among employees have also been identified as the major roots causes. The paper identifies acts that lead to accident among contractors' on construction sites in Cape Coast Metropolis. Data were collected through administrating of questionnaires, and analysed using descriptive statistics and ranking. Findings show that 85% of the respondents had the required knowledge and skills to prevent accidents on construction and likewise towards unsafe acts practices on site. Further findings show that the most outstanding acts that lead to accidents among contractors within the metropolis are: working without presence of a supervisor/authority on the job, with a standard deviation of 1.053, followed by working under the influence of alcohol and other substances, with standard deviation of 0.900 and smoking, creating naked flame or sparks in areas where flammable materials are stored, with a standard deviation of 0.894. The least among the ranking of the acts that lead to accidents are leaving nails or other sharp objects from timber, with a standard deviation of 0.503 and unsafe acts is the most significant factor in the cause of site accident, with a standard deviation of 0.587. The outcome of the research findings will assist safety personnel in the application of appropriate mitigation measures that will minimize unsafe acts of employees within a working environment.

**Keywords:** Accident · Attitude of employees · Construction industry Working environment

## 1 Introduction

There have been high rates of occurrences of accidents on annual basis, in the construction industry [15, 17] This incidence has placed the construction as the most dangerous industry in the world. Kim et al. [8] concurred with the outcome of [15, 17] results. Hong et al. [5] posited that high frequency and high death rate in construction


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industry has been attributed to falls from height. This incidence occupies 60% of total accidents in Chinese construction industry. Human factors also has been identified to contribute to most of this type of accident [5]. In another instance, [13] and [4] examined the behaviour of unsafe acts of workers within different environments and concluded that worker's individuals' risk assessment, contextual factors, and social factors influence the internal processes (decision-making and perception). However, [10] was of the view that values, beliefs and perceptions of risk of workers also influence their behavior and increase the occurrences of accidents in the construction industry. Shin et al. [16] in his study indicated that safe working attitudes affect employee behavior. In another study, by Khosravi et al. [7] showed that the attitude and motivation have sufficient evidence to influence the occurrence of unsafe behavior and accidents. Berek et al. [3] opined that worker's knowledge affected unsafe action by means of perceived benefit, and safety attitude. Berek et al. [3] further indicated that worker's perceived risk has direct influence on the unsafe acts of workers. Huang et al. [6] opined that there are different levels at which workers perceive risks in the construction industry. Khosravi et al. [7] indicated that individual factors have some influence on unsafe behaviour and accidents in the construction industry. Different researchers, Liao et al. [11] and Kines [9] have different views on how communication has influence on unsafe acts of contractors. Liliweri [12] opined that the processes through which a change in attitude of an employee occurs, is through communication. Liliweri [12] further indicated that "one of the goals of communication is to influence the attitude of a worker, which ranging from changes in thoughts, views, opinions, and feelings, even to behavioral change." Kines [9] concur with the view of [12] and indicated that a high frequency in communication will have an impact on worker attitudinal change of a worker and this observed bahaviour will contribute to unsafe acts of workers. Liao et al. [11] on the other hand, asserted that good communication among workers will increase the safety awareness of workers and decrease the unsafe acts among them, within any work environment. Berek et al. [3] in their study of internal factors that influence unsafe acts on construction workers concluded that workers' knowledge on the type of job do affect their unsafe action, by means of perceived benefit and safety attitude. They further indicated that worker's perceived risk also can affect worker's unsafe action directly. The only solution to these issues is through effective communication between sub-contractors and the workers. The paper addressed influential factors of unsafe acts of contractors in Cape Coast Metropolis. It explored literature on unsafe conditions and unsafe acts of workers on construction sites and concluded with communication as a means of accident reduction in the construction industry.

## 2 Literature Review

Hamid et al. [2] in their study of causes of accidents in the construction industry, identified the following: workers' negligence, failure of workers to obey work procedures, work at high elevation, operating equipment without safety devices, poor site management, harsh work operation, low knowledge and skill level of workers, failure to use personal protective equipment and poor worker's attitude about safety. However, Ragab [14] opined that accidents are caused by unsafe acts or unsafe conditions.

Unsafe conditions have been identified to fall under the following: People who do not think before they up any task, those who do not follow instructions, or not putting their training into practice.

i. Unsafe manual handling, loading, stacking and storing of materials.
ii. Overloading of platforms, scaffolds, hoists, plant, etc.
iii. Incorrect use and abuse of plant and equipment.
iv. Use of faulty equipment and "homemade" repairs.
v. Illegal adaptions and illegal removal of guards/barriers.
vi. Failure to use PPE and ignoring safety signs/warning devices

They further indicated that accident can also result in loss of earnings, incapacity for the job, inability to support family, etc. Due to these accidents, employers face financial and time costs in compensation, loss of working time, lost management time during investigations, possible fines, etc. devices [14]. The costs of accidents include pain, suffering, ongoing disability, and potential fatalities.

## 2.1 Unsafe Conditions and Unsafe Acts

Unsafe acts and unsafe conditions have been categorized as follows:

### 2.1.1 Unsafe Conditions

Every activity has certain inherent potential for accidents. Unless the care is taken the accidents are bound to happen. In an unsafe condition, a lot to unforeseen can happen. Such as: working at elevated places, improper earthling, working on lines without taking proper safety precautions, unguarded floor openings, and excavations, exposed live wires, improper illumination, constrained location, unsafe design and construction such as poor scaffolding, structures, platforms, working on transmission lines and emergency works leading to hurried working devices [14].

Steps should be taken in order to avoid accidents. Such as: defined procedures and using recommended safety gadgets and adhering to the safety instructions. In spite of adhering to safe instructions, accidents may occur due to reasons that cannot be avoided and lack of control by the operator. Such accidents are said to be due to unsafe conditions [14].

### 2.1.2 Unsafe Acts

Unsafe acts are due to the fault of the persons engaged in the work. These occur as a result of the following: not adhering to safety rules, not using proper safety gadgets devices, energizing an electric line without ensuring that all the persons working on it have reported back, working without taking proper line clear, replacing fuses or closing breakers without knowing the reason for keeping it open, opening and closing of switches without authority or warning, failure to place warning signs or signals where they are needed, throwing materials or tools at another worker, riding on running boards or other unsafe places of vehicles, jumping from vehicles and platforms, unnecessary haste in working, operating hoists and trucks without proper communication, making safety devices inoperative, using unsafe equipment, wrong tools for the job or using hands instead of right tools, over confidence like working on live electrical equipment that could be conveniently de-energized, taking unsafe position or posture too close to openings and lifting in an unstable position, distracting, teasing, joking, quarreling, annoying and failure to use recommended safety protective equipment or devices [14].

To prevent any unsafe acts on construction sites, there is the need to institute preventive measures. Such as the following: laid down working rules should be observed, required safety gadgets should be used and employees should be attentive and concentrate on their work devices [14].

### 2.2 Communication as a Means of Accident Reduction

Effective communication among employees is very paramount towards safety on construction sites. When communication among employees is cut, it contributes to series of accidents on sites. Abbott [1] posited that effective safety communications between management and supervisors to workers and visitors will help to reduce the hazards that have been found to be responsible for injuries, serious accidents and fatalities. Abbott [1] further emphasized that the main causes of severe accidents that have resulted in major injuries and fatalities are slips and trips, being struck by objects, and transport-related accidents. Employers and workers should work in partnership to communicate safety information by reporting problems to the appropriate supervisors. Therefore, the need to endorse safety communications in all training, instruction and supervision for all workers on the site in order to ensure that the site rules are understood and carried out [1]. Ultimately, an adequate enforcement procedure for all site rules must be communicated to all site workers and visitors, and put into practice, in order to improve health and safety.

## 3 Results and Discussions

**Demographic Information**

### 3.1 Gender of Respondents

The Table 1 above shows that 42 respondents representing 89% were males whiles 5 respondents representing 11% were females. It can be asserted that the construction industry still remains a male dominant area in the Cape Coast Metropolis.

**Table 1.** Gender

| | Frequency | Percentage |
|---|---|---|
| Male | 42 | 89.4 |
| Female | 5 | 10.6 |
| Total | 47 | 100.0 |

Source: Field Data, 2017.

## 3.2 Age of Respondents

Also, in analyzing the age of respondents which ranged from 20–25, 26–30, 31–35, 36–40 and 41–45. It was reported that a greater percentage of respondents fell within the range of 31–35 years with a percentage of 38.3 of the total sample size, whiles 36–40 years respondents were less than 10%. Result from the table indicates that most of the respondents were in their youthful age group of 20–35 years (Table 2).

**Table 2.** Age group

| | Frequency | Percent |
|---|---|---|
| 20–25 yrs | 5 | 10.6 |
| 26–30 yrs | 15 | 31.9 |
| 31–35 yrs | 18 | 38.3 |
| 36–40 yrs | 4 | 8.5 |
| 41–45 | 5 | 10.6 |
| Total | 47 | 100.0 |

Source: Field Data, 2017.

## 3.3 Qualification of Respondents

The Table 3 below indicates the educational qualification of the respondents, 38.3% respectively possessed national diploma or certificate and bachelor's degree, whiles less than 25% were holders of post graduate and senior school certificates. This shows that more than 85% of the respondents had the required knowledge and skills, since they were duly trained.

**Table 3.** Highest qualification

| | Frequency | Percentage |
|---|---|---|
| Senior school certificate | 6 | 12.8 |
| National diploma or certificate | 18 | 38.3 |
| Bachelor's degree | 18 | 38.3 |
| Post-graduate | 5 | 10.6 |
| Total | 47 | 100.0 |

Source: Field Data, 2017.

## 3.4 Years in Firm

38.3% of respondents have worked in their firms for 2–5 years, whiles 31.9% have worked for 6–10 years, also, less than 20% have been working from 16 years to above 31 years. This indicates that the firms have experienced personnel in their organizations (Table 4).

**Table 4.** Year in firm

| | Frequency | Percentage |
|---|---|---|
| 2–5 yrs | 18 | 38.3 |
| 6–10 yrs | 15 | 31.9 |
| 11–15 yrs | 6 | 12.8 |
| 16–20 yrs | 4 | 8.5 |
| 21–25 yrs | 1 | 2.1 |
| 26–30 yrs | 1 | 2.1 |
| 31 yrs and above | 2 | 4.3 |
| Total | 47 | 100.0 |

Source: Field Data, 2017.

### 3.5 Respondents Status in Firm

From the Table 5 above, 14.9% were Site Engineers and Foremen respectively, whiles Architects and Surveyors also stood at 21.2% respondents. Again, 36.2% of the respondents were site managers, from the Table above, this shows that adequate data were collected as those who provided them were directly involved with activities at the construction sites.

**Table 5.** Position in firm

| | | Frequency | Percentage |
|---|---|---|---|
| | Foreman | 7 | 14.9 |
| | Site Engineer | 7 | 14.9 |
| | Architect | 5 | 10.6 |
| | Site Manager | 17 | 36.2 |
| | Surveyor | 5 | 10.6 |
| | Store Manager | 2 | 4.3 |
| | Total | 43 | 91.5 |
| Missing | System | 4 | 8.5 |
| Total | | 47 | 100.0 |

Source: Field Data, 2017.

### 3.6 Number of Years Firm Has Been in Existence

Analyzing the years that firms have been in existence from the Table 6 below, over 50% have been in existence for more than 15 years, whereas 10–14 years and 5–9 years were 21.3 and 17% respectively. It shows that these firms have gained enough experience with the challenges associated with executing project throughout the cause of their existence.

**Table 6.** Years of firm

| | | Frequency | Percentage |
|---|---|---|---|
| | 5–9 yrs | 8 | 17.0 |
| | 10–14 yrs | 10 | 21.3 |
| | 15–20 yrs | 15 | 31.9 |
| | 21–30 yrs | 6 | 12.8 |
| | 31 yrs and above | 6 | 12.8 |
| | Total | 45 | 95.7 |
| Missing | System | 2 | 4.3 |
| Total | | 47 | 100.0 |

Source: Field Data, 2017.

### 3.7 Construction Project Being Executed Currently

55.3% of the respondents worked in firms who were executing public liability project, 29.8% for private firm's project whereas 14.9% were undertaken sole proprietorship project, as it is indicated on the Table 7 below.

**Table 7.** Type of construction project currently working on

| | Frequency | Percentage |
|---|---|---|
| Private firm | 14 | 29.8 |
| Public liability | 26 | 55.3 |
| Sole proprietorship | 7 | 14.9 |
| Total | 47 | 100.0 |

Source: Field Data, 2017.

However, from the study as shown on the Table 8 above, 80.9% of the respondents worked with firms executing building construction project, whiles 14.9% were executing civil engineering works, 4.3% also worked in firms undertaken both building construction and civil engineering projects. The implication is that most of the respondents were working in firms executing building construction works, and mostly public liability projects.

**Table 8.** Construction project currently worked on by firm

| | Frequency | Percentage |
|---|---|---|
| Building Construction | 38 | 80.9 |
| Civil Engineering | 7 | 14.9 |
| Other | 2 | 4.3 |
| Total | 47 | 100.0 |

Source: Field Data, 2017.

### 3.8 Classification of Firms

With respects to classification from the Table 9 above, firms with D1/K1 and D2/K2 were 31.9 and 36.2% respectively, whiles D3/K3 represented 17% and D4/K4 10.6%. This indicates that, the respective firms had the necessary organizational capacity to enable them tender and execute the projects.

**Table 9.** Firm's classification

| | | Frequency | Percentage |
|---|---|---|---|
| | D1/K1 | 15 | 31.9 |
| | D2/K2 | 17 | 36.2 |
| | D3/K3 | 8 | 17.0 |
| | D4/K4 | 5 | 10.6 |
| | Total | 45 | 95.7 |
| Missing | System | 2 | 4.3 |
| Total | | 47 | 100.0 |

Source: Field Data, 2017.

### 3.9 Client of the Project

From the Table 10 below, 66% of the respondents worked in firms that executed public project whereas 12.8 and 10.6% worked on project from parastatal organizations and property developers respectively. Also, 4.3% others worked on a hospital and a university project. The firms of the respondents mostly executed public project whiles less than 30% constructed project from other clients, this indicates that, the government and its agencies were the major employers of the firms in the construction industry.

**Table 10.** Which client owns the project

| | | Frequency | Percentage |
|---|---|---|---|
| | Property developer | 5 | 10.6 |
| | Parastatal organization | 6 | 12.8 |
| | Public | 31 | 66.0 |
| | Other | 2 | 4.3 |
| | Total | 44 | 93.6 |
| Missing | System | 3 | 6.4 |
| Total | | 47 | 100.0 |

Source: Field Data, 2017.

The Table 11 above shows the factors that contribute to unsafe acts of workers in the construction industry. 2% of the respondents disagreed whiles 34% strongly agreed and 64% also agreed that unsafe act is the most significant factor in the cause of site accident, with a respondent's mean of 4.30. On working without authority on the job, 9% of the respondents disagreed, 4% strongly disagreed whiles 34% strongly agreed and 51% agreed. Moreover, 2% of the respondents had no opinion and disagreed respectively to working at improper speeds, exceeding the prescribed speed limit as an act that lead to accidents, whereas 2% also strongly disagreed with a mean of 2.93 and 95% of the respondents agreed. 51% of the respondents strongly agreed and 48% agreed that incorrect use of tools and equipment and machinery causes accidents whiles 2% strongly disagreed and disagreed respectively, with a respondent's mean of 4.40. Additionally, 36% of the respondents agreed, whiles 57% strongly agreed that climbing or standing on rebar instead of using ladder lead to accident, also, 2% disagreed, strongly disagreed and had no opinion respectively.

**Table 11.** Acts that lead to accidents in Cape Coast Metropolis

| Unsafe acts of workers | N | Min. | Max. | Mean | Std. Deviation | Ranking |
|---|---|---|---|---|---|---|
| Unsafe act is the most significant factor in the cause of site accident | 47 | 2 | 5 | 4.30 | 0.587 | 21st |
| Working without authority on the job | 46 | 1 | 5 | 4.04 | 1.053 | 1st |
| Working at improper speeds, exceeding the prescribed speed limit | 46 | 2 | 5 | 4.37 | 0.645 | 17th |
| Incorrect use of tools and equipment and machinery can also cause accidents | 47 | 1 | 5 | 4.40 | 0.798 | 8th |
| Climbing or standing on rebar instead of using ladder | 47 | 1 | 5 | 4.45 | 0.829 | 7th |
| Improper placing and stacking of objects and materials in dangerous location | 47 | 1 | 5 | 4.43 | 0.773 | 10th |
| Improper lifting, handling, or moving of objects | 46 | 2 | 5 | 4.30 | 0.756 | 12th |
| Lifting of heavy objects manually without proper force-saver equipment | 46 | 2 | 5 | 4.30 | 0.840 | 5th |
| Failure to warn or secure members out of danger | 45 | 2 | 5 | 4.38 | 0.614 | 19th |
| Workers paying less attention to warning | 46 | 2 | 5 | 4.39 | 0.614 | 19th |
| Using defective equipment and tools to work | 45 | 2 | 5 | 4.44 | 0.755 | 13th |
| Annoyance and horseplay in the workplace | 45 | 2 | 5 | 4.27 | 0.780 | 9th |

(*continued*)

**Table 11.** (*continued*)

| Unsafe acts of workers | N | Min. | Max. | Mean | Std. Deviation | Ranking |
|---|---|---|---|---|---|---|
| Ignoring to wear personal protective equipment (PPE) | 45 | 2 | 5 | 4.44 | 0.659 | 16th |
| Working in poor physical conditions | 45 | 2 | 5 | 4.49 | 0.661 | 15th |
| Leaving nails or other sharp objects from timber | 45 | 4 | 5 | 4.44 | 0.503 | 22nd |
| Throwing or accidentally dropping objects from high level | 45 | 2 | 5 | 4.47 | 0.757 | 11th |
| Working with lack of concentration | 43 | 2 | 5 | 4.42 | 0.626 | 18th |
| Working under the influence of alcohol and other drugs | 45 | 1 | 5 | 4.31 | 0.900 | 2nd |
| Improper positioning of task | 45 | 2 | 5 | 4.22 | 0.850 | 4th |
| Improper posture of tasks | 45 | 2 | 5 | 4.27 | 0.837 | 6th |
| Servicing equipment which is in operation | 44 | 1 | 5 | 4.39 | 0.754 | 14th |
| Smoking, creating naked flame or sparks in areas where flammable materials are stored | 45 | 1 | 5 | 4.53 | 0.894 | 3rd |

Source: Field data (2017)

On the issue of improper placing and stacking of objects and materials in dangerous location, a mean of 4.43 was obtained, with 2% of the respondents strongly disagreed, 4% had no opinion whiles 40% agreed and 53% strongly disagreed. However, on improper lifting, handling, or moving of objects, 47% of the respondents agreed whereas 43% strongly agreed that it is an act that causes accident, as those with no opinion and strongly disagreed were 4% respectively. Also, 6% of the respondents disagreed that lifting of heavy objects manually without proper force-saver equipment lead to accident at the construction site whiles 40% agreed, 47% strongly agreed and 4% had no opinion.

Moreover, 53% and 40% of the respondents agreed and strongly agreed respectively that failure to warn or secure members out of danger is an act that causes accident whiles 2% disagreed, with a mean of 4.38. Also, workers paying less attention to warning had a mean of 4.39, as 53% of the respondents agreed and 43% strongly agreed, whiles 2% disagreed. In using defective equipment and tools to work, 4% disagreed that it leads to accident at the site but 36% agreed, 53% strongly agreed, and 2% had no opinion, whiles on annoyance and horseplay in the workplace 38% agreed, 42% strongly agreed and 2% disagreed whiles 13% hand no opinion. Furthermore, 43% agreed that ignoring to wear personal protective equipment (PPE) was an act that lead to accident, as 49% of the respondents strongly agreed, whiles 2% strongly disagreed and had no opinion respectively, with the case for working in poor physical conditions, 53% and 38% strongly agreed and agreed respectively, just as 2% disagreed and had no opinion respectively.

Also, on leaving nails or other sharp objects from timber, 53% respondents agreed whiles 43% strongly agreed it lead to construction site accident, however, 55% strongly agreed and 34% agreed that throwing or accidentally dropping objects from high level causes site accident, whiles 4% and 2% disagreed and had no opinion respectively, with regards to working with lack of concentration, 47% also agreed and 43% strongly agreed it was an act that lead to accident but 2% strongly disagreed. With a mean of 4.31, working under the influence of alcohol and other drugs was agreed to lead to construction site accident by 40% by the respondents, 47% strongly agreed, 4% disagreed whiles 2% strongly disagreed and had no opinion respectively.

Moreover, 49% agreed and 38% strongly agreed that improper positioning of task leads to accident whereas 9% disagreed, however, improper posture of tasks was also agreed and strongly agreed by 43% of the respondents respectively to lead to accident, but 6% disagreed and 4% had opinion. Finally, 2% strongly disagreed and had no opinion respectively that, servicing equipment which is in operation leads to accidents but 45% agreed and strongly agreed respectively, whereas 64% of the respondents strongly agreed smoking, creating naked flame or sparks in areas where flammable materials are stored would lead to accident on the construction site and 28% agreed whiles 4% disagreed with a respondents mean of 4.53.

## 4 Conclusion and Recommendation

Construction sites accidents have been a major problem to all stakeholders. The most significant variables contributing to accidents on sites have been identified to be working under the influence of alcohol and without authority on the assigned task. Smoking, creating naked flame or sparks in areas where flammable materials are stored. It was concluded that supervisors should ensure that effective monitoring of all activities on sites arte in order to minimize accidents.

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