Advances in Intelligent Systems and Computing 969

Pedro M. Arezes *Editor*

Advances in Safety Management and Human Factors

Proceedings of the AHFE 2019 International Conference on Safety Management and Human Factors, July 24–28, 2019, Washington D.C., USA

Springer

Advances in Intelligent Systems and Computing

Volume 969

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ISSN 2194-5357 ISSN 2194-5365 (electronic)
Advances in Intelligent Systems and Computing
ISBN 978-3-030-20496-9 ISBN 978-3-030-20497-6 (eBook)
https://doi.org/10.1007/978-3-030-20497-6

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

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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 and in society at large. 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 seven sections are presented in this book:

Section 1 Workplace Safety and Human Factors
Section 2 Safety Culture
Section 3 Safety and Human Factors at a Societal Level
Section 4 Safety Methods for Assessment and Evaluation
Section 5 Safety Perception and Behavior Analysis
Section 6 Safety Management and Digital Transformation
Section 7 Revitalizing Safety Management and Practice

Each section contains research papers that have been reviewed by 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 2019 Pedro M. Arezes

Contents

Workplace Safety and Human Factors

Human-System Interaction Design Requirements to Improve Machinery and Systems Safety

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Abstract. The Human-System Interaction (HSI) approach focuses on analysis, design, and evaluation of work systems for humans to interact with technical systems ergonomically designed for human use. An initial framework is developed for human factors and ergonomics (HFE) design requirements with regard to occupational safety and health (OSH). The framework refers to concept, criteria and intended user populations in work systems design. Some future work systems in industry 4.0 and cyber-physical systems call for emphasising human information processing with interchange of information variable and dynamic in quantity, quality and time. Taking into account new solutions and challenges in digital manufacturing, selected requirements, explanations, examples and references should inform manufacturers and health and safety experts at the shop floor level about HFE and OSH. Information presented at an internet platform, should assist in how to integrate these factors into construction of machinery or other technical installations, in workplace, equipment and software design and for practical use in HSI.

Keywords: Work systems design · Occupational safety and health · Human factors · Digital manufacturing · Design criteria

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 3–13, 2020.
https://doi.org/10.1007/978-3-030-20497-6_1

1 Human-System Interaction in Future Work Systems

Human-system interaction (HSI) refers to processes of understanding, designing and evaluating of work systems for use by humans interacting within the system [1] and emphasises human factors and ergonomics (HFE) design requirements regarding human information processing [2]. Investigations and procedures in HSI comprise four stages closely related to those in occupational safety and health (OSH, [3]). The initial step identifies situational characteristics; i.e. information acquisition, sensation, determination of work system components involved and work processes under investigation. The following step covers analyses; i.e. information analysis, perception, identification of health and safety, hazards and risks. Next comes assessment; i.e. decision-making, action selection, assessments of health, safety and risk. The last step may result in redesign; i.e. action implementation, intervention, prevention in OSH including design according to HFE strategies and principles and risk reduction [3–6].

When HSI design conjoins more closely to procedures of OSH in terms of the hierarchy of controls [3, 7], this will improve both OSH and HFE in work systems. The design of work system components and their interactions is to safeguard operational safety, effectiveness and efficiency of HSI at optimal levels of human operator workload [1, 8]. The effect should be visible in less design flaws, hazards and risks and prevented health impairments, near accidents and accidents. A health and safety perspective could also take effect in terms of prevention through design [9] as well as proactive health and safety strategies [10]. Application of HFE design requirements for HSI reflects compliance with legal regulations and contributes to basic system goals.

While some work systems will remain, others in digital manufacturing may evolve into cyber-physical systems. This causes new challenges for HFE and OSH disciplines. Dynamics and interactions become more important in function allocation, human-centred design, safety measures, and intelligent environments [11]. The working group of the ISSA [12] on “Human Factors, Ergonomics and Safe Machines” is reviewing, selecting and presenting design requirements and recommendations according to HFE and OSH. This is to inform the shop floor level about how to integrate HFE design requirements into machinery construction, workplace and equipment design and practical use in HSI. Initial requirements, recommendations, explanations and examples are accessible [12]. The paper provides a more systematic framework to imbed important design issues.

2 The Design of Work Systems

2.1 Work Systems Design – The Concept

In HFE disciplines, work systems design is a flexible and iterative process that takes into account components with their interdependencies. This is because the whole system is more than the sum of its parts. The work system comprises workers and work equipment acting together to perform the system function in the workspace, in the work environment, under the conditions imposed by the work tasks [1].

Work systems design aim to optimise all, overall system performance, operator physical and mental workload, and high level OSH [11, 13]. The endeavour is a challenging and continuously ongoing process since it is not limited to the design phase (e.g. construction of machinery, products) itself, but extends to implementation and especially to the initial period of use (e.g. context of working conditions, use of machinery and products at work). The design process goes beyond the design phase and addresses a life cycle perspective always in service to continuously foster HFE as well as OSH at work [1].

Simulation techniques have cleared their way for applied use in industry and services [14, 15]. Simulations do not substitute design processes according to text books by those processes used in practice, but they bridge the gap between them [16]. Simulation fosters new and effective approaches to address problems in work systems analysis, design and evaluation. Investigations will be feasible across the systems life cycle from development and construction, over application in its context of use, to modification and recycling [14, 17, 18].

In this context, existing HFE design criteria (e.g. freedom from impairment [19]), strategies (e.g. task orientation [6, 20]) and principles (e.g. compatibility [4, 5]) guide along an iterative design process for human-centred solutions in practice. This should support design procedures, risk assessments, simulation and task analysis techniques, scale models and mock-ups, and group discussions among those involved in work systems design. Based on knowledge and experience available, suitable HFE methods and techniques as well as the relevant literature, the activities of the working group in the ISSA-Section Machine and System Safety focus on HFE design requirements with regard to OSH, the work place, work equipment and software, and cyber physical systems.

2.2 Work Systems Design – The Criteria

HFE traditionally refers to four criteria (see Fig. 1) in the design of work systems [1, 11, 12, 19, 21]. They are similar to those relevant in human centred design of working conditions and with an increasing influence on OSH.

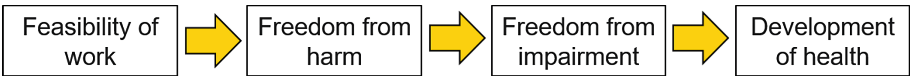

Fig. 1. HFE criteria for the design of work systems.

Feasibility of work is the basic criterion and requires consideration of generic human abilities in the process of designing work systems. It addresses human physical and mental capabilities, limitations and needs across the working life [1, 4, 5].

Freedom from harm goes beyond the latter criterion and specifically calls for prevention of severe occupational accidents and diseases as well as work-related health risks by design of safe and healthy working conditions. Even though work could be feasible according to human abilities and capabilities, due to safety and health risks it may be not be free from harm [3, 5, 18]. Design should adapt accordingly.

Freedom from physical and mental impairments avoids working conditions that impair human activities and conscious experience potentially resulting in accidents. Impairments such as mental fatigue, mental satiation, monotony and reduced vigilance result in deteriorations of human performance capabilities that may even manifest in harm when occurring frequently or over longer periods [1, 19, 22].

Development of learning, health and personality is strongly influenced by work and working conditions. While previous criteria intent to protect workers against risks this top-level criterion is prospective, aims at well-being and calls for a sustainable perspective on a broad range of factors in work systems design including inter-individual interactions and work-life balance [1, 6, 19].

Strategies to achieve higher levels across the four criteria refer to HFE knowledge available in terms of design requirements and recommendations or empirical investigations on effects of physical and mental workload [1, 22]. Work system design compatible with HFE design strategies and principles (e.g. task orientation [5, 6, 20] and compatibility [4, 5]) results in optimal levels of workload. Deviations from optimal levels may cause shifts in well-being, facilitating or impairing effects or safety and health risks [21, 22]. Suitable requirements and recommendations for work system design according to HFE and OSH should therefore be accessible to all [12].

2.3 Work Systems Design – Specific User Groups

HFE aims at work systems design for specified user populations. Design requirements often intend to include all human beings, percentiles or other descriptors that specify a range of prospective users. Discussions with regard to demographic change and inclusion of disabled persons, however, call for accessible design [23, 24].

Human characteristics increase and decline across human life span. This process varies inter-individually and over time across different physical, psychomotor and cognitive functions. This is due to aging of people but also due to lack of stimulation (e.g. see ergonomic design requirements for task design [11, 12]) over shorter or longer periods across the life span. Therefore, design is required that supports older workers and prevents younger from aging.

Vision, among other competencies and functions, often tends to deteriorate with early age of 45, however, can often be corrected by wearing glasses. Systems design should nevertheless always consider workers wearing glasses and provide task, interaction and information interfaces that foster visual acuity (e.g. clear shapes, high contrast, intensity of luminance, avoid clutter). In some cases and to a limited extent, emerging deficits may also be compensated for by experience or newly acquired skills [23, 25].

Accessible design calls for inclusion of humans with disabilities and impaired performance into an intended user population. Often, this only requires smaller or broader design modifications or adjustments. However, it may not always be possible due to safety and health requirements. Examples for small changes in design that cover a broader range of user population are as follows, e.g. displays and controls adjustable for height that include wheelchair users, dual coding and selection of colours that do not exclude colour-blind people [25]. Work systems design criteria aim at supporting intended populations equally well; i.e. without compromising safety and health.

3 Design Issues in Human-System Interaction

3.1 The Human Perspective in Work Systems Design

Health and Safety. OSH refers to all aspects of health and safety in the workplace and should have a strong focus on primary prevention of hazards (World Health Organisation, WHO).

According to WHO principles, *health* is described as a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity. Promoting workers health is prevention of disease and combating risks. Measures are suitable, when optimising physical and mental activity at work through systems design, promoting more healthy diets, and protecting cognitive and emotional well-being at work [11]. The effectiveness of health promotion and disease prevention interventions has been demonstrated in studies and reviews [26]. A multi-dimensional assessment of health risk takes into account the severity of the effects and health effects. Relevant risks are those that can basically be identified, significant risks are those that actually lead to injury or disease [27].

Safety still lacks a theoretical base and variations in meaning occur across contexts [28]. Safety as 'freedom from unacceptable risk' (safety-I, [29]) is often described in negative terms of kinds and frequencies of accidents, incidents and damage. In contrast to this more traditional view is the ability, to succeed, establish, maintain and improve safety in terms of things that go right under varying conditions (safety-II, [29]). This perspective not only changes understanding, analysis, design and evaluation of the safety performance of organisations, but also values efforts to establish safety controls and HFE design requirements to improve OSH at work.

Concepts of OSH vary with OSH legislation across countries. Usually measures for health and safety of employees at work and other forms of activities are included as are prevention of occupational accidents, occupational diseases and work-related health risks as well as working conditions according to HFE design requirements [3, 9, 30]. Despite differences in legal OSH regulations, the hierarchy of controls remains similar across countries and application contexts. It guides selection of effective measures for prevention and risk reduction in work systems design, following levels according a 'STOP!' principle [3, 7, 9]. OSH interventions along levels lower in hierarchy are assumed to be less effective, albeit required.

- Substitution measures (e.g. hazard elimination),
- Technical measures (e.g. safeguard),
- Organisational measures (e.g. time limitations),
- Personal measures (e.g. personal protective equipment, PPE), and at low level
- Information measures (e.g. instructional signs) [3, 9, 11].

Work Organisation. Organisational issues will be relevant in the given context and may refer to issues such as design of work-life balance, organisational safety culture, social relations at work, job rotation and working time arrangements. Working time is the second prevention measure in the design of human centred work. If workload cannot be optimised by changing the design of technical system components, it is possible to design time requirements (i.e. job rotation to limit time for specific tasks, sound pressure level limits in OSH usually refer to eight hrs working days and are higher for shorter periods of time). Human errors, accidents, diseases and work related risks (including working time risks) are likely to increase due to working at nights, on weekends, and the number of consecutive shifts; independent of worker qualification and work tasks [31]. Working time design calls for measures of risk reduction according to the hierarchy of controls [32]. With regard to monitoring and control operations, vigilance decrements are among relevant design requirements [33].

Work and Performance. Human performance, human failure and human physical and mental workload are relevant dimensions for HFE and OSH.

Human performance is a dimension used in HFE to describe human capabilities and limitations in physical and mental dimensions [4, 5]. Often, it is a descriptor of human behaviour in a specified context (e.g. human monitoring and control of machinery) referring to timing, quality and quantity of human work. Due to HSI, the design of technical systems has a strong impact on human performance. Knowledge (which to select), rules (when to apply) and skills (how to use) about HFE design requirements are relevant for improvements in human performance for the benefit of OSH.

Despite the broad range of potential measures of human performance (e.g. speed or time, accuracy, error, workload or capacity demands, preference), each set of few is relevant only when a rational is provided for specified settings of performance assessment [4]. Factors influencing the effectiveness of human performance and the likelihood of errors are e.g. design of displays and controls, fatigue, job design and environmental factors. Evaluations of human-system interactions always have two optimal results; one referring to optimal quality and quantity of interaction in terms of human performance and the other referring to optimal human physical and mental workload. Phenomena like degrees of learning or memory of concepts, mental models about equipment, the level of situational awareness and trust in automation are not reflected in performance measures; however, they do influence mental workload [4, 21]. A variation in human performance may be used as a compensational strategy to balance the level of workload [34].

Human errors happen and occur in all tasks and they are irrespective of training, experience and motivation. Several day-to-day incidents and near misses also involve human failures that become serious only in systems without protection. A traditional view that incidents and accidents can be attributed to human failures has been replaced by a model of stacked layers with different types of defences, which may be weakened only by simultaneous activity of immediate or underlying causes stemming from system design flaws and inappropriate organisational structures. Human failures should be avoided by activities in work system design [35, 36]:

- Use HFE design requirements to prevent slips and lapses.
- Design procedures to avoid tasks, which involve very complex decisions, diagnoses or calculations.
- Provide clear, concise, available and up-to-date job aids (procedures, instructions), accepted by the intended user population.
- Consider potential human errors in risk assessments.

Workload, i.e. physical and mental work stress, is the total of all assessable influences impinging upon a human being from external sources and affecting that person physically and mentally (19, 21). Physical and mental strain is the immediate effect of physical and mental stress within the individual. Their current condition may potentially have some moderating effect. Work stress and work strain are crucial for assessments of work system design quality. Multidimensional measurement and differentiation with regard to type, level and temporal dynamics of work stress are required for workload assessments [34, 37, 38].

3.2 Design Requirements of the Technical System – Work Place in Work Systems Design

Future industrial work places will require human mobile and stationary monitoring and control activities for a range of interacting technical installations. HFE requirements for work place design, therefore, should cover traditional design of physical human-machine interaction [39] and go beyond. Initial examples for work place design requirements have already been selected by the ISSA MSS working group [12].

3.3 Design Requirements of the Technical System – Work Equipment and Software in Work Systems Design

The task, the interaction and the information interface are three different but interrelated interfaces and core elements of human-system interaction in work systems design especially with regard to equipment and software [40]. The operator task is in the centre of a work system design strategy in HFE and OSH (primacy of task design [6]). Technical and organisational components of the system support the task by serving task completion, optimising physical and mental workload, and improving overall system performance. Initial examples for HFE requirements are already available [12].

3.4 Design of Human-System Interaction in Cyber-Physical Systems and Digital Manufacturing

Cyber Physical Systems (CPS). They are interactive technical production processes with software algorithms that monitor and control sensor technologies and machine-to-machine communication in networks. Sometimes, Human-Cyber Physical Systems are referred to as humanoid components or simulated human-like elements integrated in CPS. Even interactions with real humans will continue to exist; even with CPS. Therefore, digital manufacturing and industry 4.0 systems are highly relevant for OSH, e.g. when constructing, setting-up, monitoring, controlling or maintaining technical systems [41–43]. Development and use of CPS or human-CPS interaction call for HFE and OSH design requirements across the life cycle.

Digital manufacturing will heavily influence human-system interaction. It will cause shifts in human task requirements (e.g. action implementation superseded by perception and reasoning) and in hazards (e.g. mechanical superseded by mental). Perspectives for prevention should extend and adapt to human information processing requirements, since exchange of information variable and dynamic in quantity, quality and time is crucial in mediating OSH [8, 44]. Applications in human-automation interaction demonstrate challenges for HFE and OSH [15, 41, 45]. New technologies increase the variety of (e.g. tangible, organic, natural) user interfaces. This may improve the potential for HFE and OSH in work system design [11, 12] and opens up the chance to combat emerging risks with new technologies [42, 46].

Human-Automation Interaction. New technologies in digital manufacturing should be variable and dynamic and change with interactive partners. Similar to humans, they should analyse, assess and predict aspects of human behaviour in complex systems. Technologies designed according to HFE and OSH may assist (like a tool), partially supplement (like a prosthesis) or temporarily represent (like an agent) humans in interaction with technical systems. Input monitoring, remote control, language or gesture recognition and others will get involved in dynamic allocation of functions and approaches in adaptive and adaptable automation [11, 15, 47].

However, there are design challenges for HFE and OSH regarding [47]:

- Feedback: High degrees of automation impede information for reasonable human participation. Changes and errors in automation are difficult to identify, impossible to compensate for and may cause out-of-the loop unfamiliarity and skill loss.
- Human task structures: Automation in human-automation interaction that permanently takes away functions from human operators is clumsy, is error-prone, impairs human behaviour, avoids behavioural adaptation and should all be avoided.
- Relationship structures: Technology-centred design of automation causes non-matching operator behaviour, inappropriate trust and health, leads to unintended uses by operators and should all be avoided.

Dynamic Risk Assessment. Challenges for HFE and OSH regarding risk assessments in digital manufacturing refer to variability and dynamics in exchange of information, flexible shifts of states and functions and combinatorics of relevant components. Nevertheless, assessments are required to disclose potential hazards and risks in human-system interaction. It addresses functional, process and operational safety across operational states and extends to security as well as HFE design requirements [11, 12, 18].

In modular approaches, similar to process industries, an overall system is subdivided with clearly defined interfaces. This would allow risk assessments for individual modules and their combinations. In addition, applications of new technologies for adaptable and dynamic assessments are promising, when relevant information for assessments could be continuously generated by components integrated in the system.

4 Conclusions

Work systems design according to HFE and with a focus on human information processing will provide guidance on primary prevention in digital manufacturing. The concept of primary prevention supports prioritising high-level controls to combat hazards and risks at work across the life cycle from early on in order to lower rates of occupational accidents and diseases [9, 18]. The aim is to maintain complete physical, mental and social well-being for humans at work. A range of minimal health and safety requirements that include HFE design strategies and principles [4–6, 20] support manufacturers in designing safe machinery and products. While employers are held responsible for providing safe work equipment to employees, the latter are responsible to work according to the regulations. Information on HFE and OSH for the design of work systems should be accessible across countries; even though business decision makers and purchasers may not always request for it or manufacturers may not be able to create demand for it on the market.

The intention is to provide an initial framework for the presentation of HFE in work systems design requirements with regard to OSH. Selected HFE requirements and recommendations should support in how to use them for machinery construction, integration in workplace and equipment design and practical use in the design of human-system interactions. Suitable information should be accessible at ISSA-Section Machine and System Safety [12], because information update is possible for new challenges and solutions in the vivid field of digital manufacturing with ongoing developments in technology and research. The platform may also guide along activities for the prevention of occupational risks in general.

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A Susceptibility Model for Organizational Accidents

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Abstract. Social epidemiology "is a branch of epidemiology that focuses particularly on the effects of social-structural factors on states of health. Social epidemiology assumes that the distribution of advantages and disadvantages in a society reflects the distribution of health and disease. It proposes to identify societal characteristics that affect the pattern of disease and health distribution in a society and to understand its mechanisms" [1]. Social epidemiology studies the factors that affect the susceptibility of a population to disease. The authors of this paper believe that there are strong parallels between the susceptibility of populations to disease and the susceptibility of organizations to the occurrence and distribution of accidents. This paper will discuss some of those parallels and possible approaches to understanding and reducing an organization's susceptibility to accidents.

Keywords: Organizational accidents · Social epidemiology · Culture · Susceptibility

1 Introduction

In 1974 Cassel published an article [2] that briefly discussed the four principles that have guided the work of many social epidemiologists for more than half a century. Kunitz summarized those four principles as [3]:

1. *"In human populations the circumstances in which increased susceptibility to disease would occur would be those in which there is some evidence of social disorganization."*
2. *"[N]ot all members of a population are equally susceptible to the effects of these processes" (e.g., social disorganization). Dominant members of the population are less susceptible than subordinate members.*
3. *Both biological and social processes are protective. "Chief among [the latter] are the nature and strength of the group supports to an individual."*
4. *"[S]uch variations in group relations, rather than having a specific etiological role, would enhance susceptibility to disease in general." The importance of these group factors would be diminished "in preindustrial societies, living in small, tightly organized communities, [where] the exposure to highly potent disease agents may*

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P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 14–23, 2020.
https://doi.org/10.1007/978-3-030-20497-6_2

account for the major part of disease causation. Under these circumstances, variations in susceptibility due to social processes may be of relatively little importance. With increasing culture contact, populations become increasingly protected from such disease agents but simultaneously exposed to the social processes discussed above. Variations in susceptibility now assume greater importance in the etiological picture and the concomitant changes in such factors as diet, physical activity, and cigarette smoking will facilitate the emergence of new manifestations of such susceptibility."

Over that same half century, organizational psychologists, human factors engineers, and accident investigators have been researching events referred to as "organizational accidents." Organizational accidents are defined as accidents that "have multiple causes involving many people operating at different levels of their respective companies" [4]. These accidents have their roots in the complex interaction of humans, intra-organizational relationships, and operational factors, rather than solely the actions of an individual or the failure of a component. Given this complexity, the progression[1] of any organizational accident cannot be predicted in advance. Investigations after these accidents reveal latent conditions associated with the cultures of the involved organizations. However, given the frequency with which similar accidents recur, the correction of these conditions to avoid future accidents appears to be problematic.

Culture is the sum of the shared attitudes, customs, and beliefs that distinguishes one group of people from another. An organization's culture is the running summation of the values embedded by the organization's founders and original members into the organization's practices, lore, and codes of conduct, along with the influences of succeeding leaders and members. Culture is "how we do business." The organization's leaders are the managers of the culture, and it is their responsibility to change the culture when change is perceived to be necessary.

However, an organization's culture is also an artifact of the social environment within which it was created. Societal need inspires the organizations' creation, purpose and priorities; social values, practices, and lore shape members' behaviors; and social opinion determines the value of the organization's services. Hence, society decides if the organization will survive and thrive. As society changes, the organization must change or become irrelevant [5].

The idea that organizations are influenced by the society within which they exist, and that there is a relationship between that influence and the occurrence of accidents, is by no means new to this paper. Jens Rasmussen noted that:

However, it should not be forgotten that commercial success in a competitive environment implies exploitation of the benefit from operating at the fringes of the usual, accepted practice. Closing in on and exploring the boundaries of the normal and functionally acceptable boundaries of established practice during critical situations necessarily implies the risk of crossing the limits of safe practices. Correspondingly, court reports from several accidents such as Bhopal, Flixborough, Zeebrugge, and Chernobyl demonstrate that they have not been caused by a coincidence of independent failures and human errors, but by a systematic

[1] We refer to the sequence of events between the initial exposure to a triggering event and the ultimate consequence as the *progression* of the accident.

migration of organisational behaviour toward accident under the influence of pressure toward cost-effectiveness in an aggressive, competitive environment [6].

Similarly, the comparison between organizational weaknesses and disease agents is not new to this paper. For example, in the same paper [6] Rasmussen noted that James Reason discussed management errors and organizational factors as "resident pathogens." Recently, Hunter [7] proposed a psychotic continuum for organizations as "a worthy paradigm through which to view organizational opportunity, strategy, operations, and decision making, potentially capable of assisting in diagnosing the causes of organization dysfunction."

Cassel's four principles transcended existing theories focused on physical mechanisms of disease propagation. Instead, the principles focused on identifying the circumstances that increased the likelihood of disease dissemination; understanding how a population's social environment influences the spread of a disease, once an initial exposure to the disease agent has occurred; and applying that knowledge to reduce the likelihood of dissemination. Using an approach analogous to Cassel's, we propose that the distribution of advantages and disadvantages within an organization reflects the organization's susceptibility to accidents. We seek to identify the social circumstances that influence the likelihood of organizational accidents, and in that manner reduce the whole class of accidents.

2 Discussion

Cassel's approach to describing the four principles was to demonstrate each principle using experimental observations. Cassel begins with a discussion of over-crowding in animal populations, noting that the singular act of increasing the number of animals housed together creates a significant environmental stress. As a result, the animal population displays increased rates of a range of health effects. The increased rates are not due to increased exposure to disease agents, but rather to changes in homeostatic mechanisms that alter the animals' response to stimuli that are already present within the population.

The impact of stress and its related comorbid diseases on humans is now believed to be "responsible for a large proportion of disability worldwide" [8]. As Kalia notes [8]

Although the term "stress" is used in a wide variety of contexts, it has consistently been demonstrated that individuals with stress and related disorders experience impaired physical and mental functioning, more work days lost, increased impairment at work, and a high use of health care services. The disability caused by stress is just as great as the disability caused by workplace accidents or other common medical conditions such as hypertension, diabetes, and arthritis.

In daily life humans are exposed to stress from sources ranging from their local environment to large-scale disasters and wars. Also, the organizations within which humans work are significant sources of stress. Organizational stressors may be due to the environment within which the organization operates, the daily interactions of the members with each other and outsiders, or the importance of the organization's purpose [8]. Johnson [9] showed that an organization's structure and size alone are sources of stress on its members. Nyberg [10] found significant differences in the health of employees based on their treatment by managers and leaders. Supportive leadership was linked to good employee health, malevolent or self-centered leadership was linked to poor employee health. Hunter [7] reported that "firms and organizations can also show '*collective*' patterned behaviors just like individuals … [t]hese pathologies include the paranoid, obsessive-compulsive, attention-seeking, depressive, schizoid, and narcissistic typologies."

2.1 Social Disorganization

Cassel's first principle focuses on the central role that disorganization has in creating the environment in which disease can promulgate more easily. In Cassel's example, animal overcrowding creates "disordered relationships" within the population that "often have in common a failure to elicit anticipated responses to what were previously appropriate cues and an increasing disregard of traditional obligations and rights" [2]. The effect of significant stress on an organization is the same; as its leaders and members react to increasing stress their previous work relationships become disordered. Disorganization and disordered relationships are manifested by dysfunctional conditions such as unclear roles and responsibilities; insufficient or ill-prepared staff; poor or outdated processes; dissatisfaction or high turnover of employees; and high levels of deferred maintenance.

Besides representing significant sources of workplace stress, these dysfunctions represent significant vulnerabilities that increase the likelihood of an accident. Such dysfunctions are frequently recognized as contributing factors in investigations following organizational accidents. Like the spread of a disease agent within a population, disorganization and dysfunction can spread through an organization once it has been introduced within a subgroup of the organization. Two of the recognized social processes by which this spread can occur are described the Diffusion of Innovation Theory [11] and the Contagion Theory [12]. These two theories both describe processes by which information is communicated within a group, but there are significant differences in the underlying mechanisms.

Diffusion of innovation is a process by which ideas are communicated to other members of a group, whereas emotional contagion is a process by which the feelings of individual members can become the collective emotions of the group. We believe that disorganization and dysfunction spread through an organization via a combination of these two processes. The emotional contagion of distress caused by a localized dysfunction will motivate members of the group at large to seek methods of reducing that shared distress, thus encouraging the diffusion of information regarding methods found to be successful in reducing the distress. Recognizing that members of organizations tend to develop social systems as a defense against anxiety, and that those defense systems often impede the functionality of the organization [13, 14], the sharing of emotions and information regarding a localized dysfunction will tend to increase the level of distress and dysfunction within the organization at large.

The effect of stress on the health of an organization's members has been clearly documented and accepted; there is also evidence that demonstrate that organizational stress lead to dysfunctional processes in an organization. In her study of the decision to launch the Space Shuttle *Challenger*, Diane Vaughan evaluated the impact of production pressures on the groups involved in that decision.

Consistent with the conventional explanation, NASA's environment of competition and scarcity and the production pressure that resulted had a powerful impact on the teleconference proceedings. However, revising history, it did not operate as traditionally assumed. First, production pressure was institutionalized, affecting all participants' decision making prerationally [sic]. Second, production pressure alone does not explain what happened. All of the factors that contributed to the normalization of deviance in the history of decision making were reproduced in the teleconference exchange: the work group's production of culture, the culture of production, and structural secrecy. This event becomes a microcosm enabling us to see how these same factors combined in a single disastrous decision [15].

Given these considerations, we propose our first principle of accident susceptibility:

1. In organizations, the circumstances in which increased susceptibility to accidents would occur would be those in which there is significant evidence of social disorganization.

2.2 Domination and Subordination

In his second principle, Cassel noted that "not all members of a population are equally susceptible to the effects of these social processes [2]." Rivers [16] noted that within both animal and human populations dominant individuals display "behaviors directed at increasing or maintaining one's social rank in relation to others in the hierarchy. High-ranking or dominant individuals generally (but not always) hold power over others, whereas low-ranking or subordinate individuals generally do not." Dominance is associated with aggression, giving the individual an advantage in acquiring food, mates, and social rank. It was these benefits associated with successful aggression that helped the individual maintain a higher level of wellbeing and lower vulnerability to disease.

There is some difficulty in using dominance as an indicator of wellbeing; an individual could be dominant by possessing a high social rank or by aggressively seeking a higher social rank. In the first case the health benefits have been gained, in the second case the health benefits have yet to be gained. Rivers found that the relationship between dominance and health is complex, but a distinct positive relationship does exist between social rank and wellbeing [16].

Within organizations, dominance has a similar dual meaning. In the first case, a high ranking among competitors is indicative of a stable and effective organization with abundant resources, talented leaders, competent employees, and efficient processes. In the second case, the aggressive behavior is indicative of an organization under duress, with leaders willing to take significant risk with limited resources, strained employees, and inadequate facilities.

As a result of the ambiguity in using dominance, we propose that stability and ranking among peers are indications of affluence, effectiveness, efficiency, competence, and satisfaction. We propose this based on (1) a stable organization has developed the technical and social systems necessary to properly support the members as they carry out their tasks with a minimum of undue stress; (2) an affluent organization has sufficient resources to ensure adequate levels of staffing and training, and to maintain the systems to appropriate standards of care; and (3) a high-ranking organization is not engaged in undue risk-taking or aggressive behavior that would increase stress and anxiety on its members.

Accordingly, we propose as our second principle:

2. Not all organizations are equally susceptible to the effects of social disorganization. Organizations that are stable, affluent, and of high rank among their peers are likely to be less susceptible than organizations that are unstable, have insufficient resources, or are aggressively pursuing a higher rank among their peers.

2.3 Social Buffers

Cassel's third principle addresses factors that act to protect individuals from the effects of exposure to a disease agent. He separates those factors into two categories, physiological and social. Social buffers refer to the various interpersonal relationships within a group of highly social animals or humans that allow the members of the group to find relief from stressful experiences. Both physiological and social buffers and their contributions to the health of individuals have been extensively studied since Cassel wrote these words. The effectiveness of such buffers has been well established, although there are still some questions regarding the mechanisms by which they work [17].

Closely related to social buffers are social defense systems, which develop over time within an organization as "the result of collusive interaction and agreement, often unconscious, between members of the organization as to what form it shall take. The socially structured defence mechanisms then tend to become an aspect of external reality with which old and new members of the institution must come to terms" [13]. In other words, social defenses are mechanisms woven into an organization's culture that aid members in alleviating or avoiding anxiety associated with the tasks of the organization. Note that depending on the form they take, social defenses may act counter to the efficacy of the organization, and they can impede organizational learning and improvement interventions [14].

Social buffering and social defenses have significant roles in the effectiveness of an organization, but their impacts can be either beneficial or detrimental. As Cassel noted, their effect on individual members depends on the importance of those mechanisms for the group; the positions of the individuals affected by the mechanisms; whether the situation causing the stress has been previously encountered; and the nature and strengths of the mechanisms in supporting the individuals [2]. A variety of buffers and defenses will be active in an organization at any time, and their cumulative effect will be unpredictable if they are not recognized and managed effectively. There is adequate support for the presence and effects of social buffers and defenses within an organization, as previously cited in [13, 14, 17]. We conclude that if the organization's leaders understand the mechanisms of these embedded behaviors, they can modify the workplace environment such that detrimental impacts are minimized, and supportive impacts are enhanced. As Reason put it, "workplaces and organizations are easier to manage than the minds of individual workers. You cannot change the human condition, but you can change the conditions under which people work" [4].

There are also traditional organizational processes that provide protection against possible triggering events, such as training; procedures; supervision; hazard and accident analysis; facility and process design; safety management systems; and others. Since these processes must also be considered within the third principle, we refer to them collectively as *organizational processes*.

Based on these considerations we propose our third principle:

3. Social and organizational processes may be protective if adequately understood and supported. Unrecognized or unsupported social and organizational processes have the potential to increase social disorganization.

2.4 Generalized Stress

Cassel's final principle is a combination of general observations about the way social disorganization can influence the distribution of disease in a population. First, he notes that although increasing social disorganization enhances susceptibility of a population to disease in general, it does not play a specific role in the etiology of any disease. Second, he notes that if the population's exposure to the disease agent is very high, then the rates of disease occurrence would be independent of the degree of social disorganization present in the population. Third, he notes that social disorganization would have a greater effect on populations that have developed a higher degree of organizational structure [2].

Social disorganization within an organization has the potential to both increase the likelihood and be the source of the triggering event for an accident, although the progression of the accident would still be unpredictable. The natural gas distribution pipeline rupture that occurred in San Bruno, California in 2010 provides a good example of this. The investigation determined that the pipeline had ruptured after power was disconnected from a pressure regulating system during an inadequately planned maintenance activity. Social disorganization was the source of the triggering event. Furthermore, the occurrence and magnitude of the accident resulted from other dysfunctions within the organization, such as an inadequate pipeline integrity management program, ineffective communications between geographically separated groups, and insufficient emergency response and contingency planning [18].

In any situation where there is a potential for a triggering event to challenge a protective system, there is a possibility that the trigger will exceed the ability of the system to withstand it; consequently, if the rate of exposure to the triggering event is high enough then the rate of system failure will become independent of the level of dysfunction present in the organization. The claim that the potential always exists for a triggering event to lead to an accident is not based as much on logic as on pragmatism. As organizations become larger and activities become more complex, the potential for serious, unrecognized dysfunctions to develop and promulgate within the organization increases. As Johnson [9] showed, just increasing an organization's size and structure increases stress on its members. As activities become more complex or the degree of risk increases, the anxiety inherent in conducting the activity weighs more heavily on the members.

This leads to our fourth principle:

4. Social disorganization, rather than having a specific etiological role, would enhance susceptibility to accidents in general. The importance of social disorganization on susceptibility would be diminished where exposure to highly potent triggering events may account for the major part of accident causation. In small organizations conducting simple activities variations in susceptibility due to social and organizational processes may be of relatively little importance. As an organization or its activities become more complex, variations in susceptibility due to social and organizational processes now assume greater importance in the etiological picture.

2.5 The Healthy Workplace and Organizational Accidents

The fact that workplace stress plays a significant role in the occurrence of work-related injuries and illnesses has been well established [19, 20]. In reviewing this literature, we note that this recognition and the associated body of research and analysis focus almost entirely on efforts to improve the health and safety of the workers and the productivity of the organization. In contrast, we note that in the literature associated with organizational accidents there is very little if any focus on workplace stress and worker-related health as a contributing factor, except when "human error" is determined to be the direct cause of an accident. Instead, the study of organizational accidents typically entails the search for nebulous and often counterfactual latent conditions in the organization that can only be recognized after the accident.

There is evidence that structured organizational efforts to improve worker health and the work environment also have positive influences on workers' attitudes towards safety. Neal and Griffin [21] reported the results of a study that indicated that "when individuals perceive that there is a safe working climate, they will reciprocate by allocating effort to discretionary safety activities. This supports the arguments being made by many in the field that organizations attempting to improve safety should focus on changing the work environment to motivate people to actively participate in safety activities… However, the results suggest that it takes time for a change in employee behavior to result in a reduction in the accident rate." Furthermore, Avram and others [22] found that "job satisfaction is a partial mediator of the relationship between the safety climate perception and organizational trust. The positive perception of the safety climate is associated with a high level of job satisfaction, which is connected to a high level of organizational trust from the employees."

3 Conclusion

In this paper we propose four principles that can guide an assessment of an organization's susceptibility to accidents. Such an approach would aid in the identification of elements within the organization that may have either detrimental or beneficial influence on the its susceptibility to accidents. As stated in the introduction, an organization's culture is an artifact of the social environment within which it exists. Given this view of organizational culture, we suggest that it is the organization's leaders' responsibility is to monitor the organization for evidence of disorganization, determine the source of the disorganization, and adjust the organization to reduce or eliminate that source. If the source is internal to the organization, such as a lack of resources, poor working conditions, personnel mismatch, or outdated processes, the leaders must directly correct the source. If the source is external, it is likely to be a misalignment between the organization and the needs of the society it serves; in this case the leaders can attempt to address the source by changing their services accordingly. Regardless of the nature of the source, leaders must at least take steps to reduce the disorganization, strengthen the social buffers and defenses, and ease the stress on the organization's members.

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How Ergonomics Is Contributing to Overall Equipment Effectiveness: A Case Study

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Abstract. A study was conducted in an automotive industry in order to analyse the impact of the ergonomic measures in the Key Performance Indicators (KPI) of the Company. The KPI selected was the Overall Equipment Effectiveness (OEE) used to estimate productivity and measured by availability, performance and quality. Due to dimension of this company an Ergonomic Workplace analysis was conducted comprising a generalist ergonomic study allowing the identification of the workstation that presented the worst ergonomic situation. After, specific ergonomic evaluation methods were applied identifying the tasks that compromised workers' health. A list of measures to improve working conditions was proposed and implemented. In about a week, there was a 5% increase in performance and 91.7% of the ergonomic aspects previously evaluated by the workers improved, highlighting the overall satisfaction. General results showed that the implementation of the ergonomic measures contributed to improve company's OEE. This research will contribute to raise awareness to the importance of the ergonomic aspects when designing and organizing workplaces in order to contribute to the economic and social objectives of the organization.

Keywords: Key Performance Indicators · Ergonomics · Improvements · Automotive industry

1 Introduction

The work environment is characterized by the existence of a set of different occupational risk factors that are responsible for the development of Work-related Musculoskeletal Disorders (WMSD) while the operator performs his activity [1].

It is admitted that there is a greater exposure to critical situations at an ergonomic level for workers who essentially perform their activities as factory workers interacting continuously with machines. At occupational level, several factors can also be identified as critical such as, static work, repetitive efforts, exposure to vibrations, posture, strength, and absence without adequate recovery, intense work rhythm, working production organization or monotony of the tasks [2].

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 24–32, 2020.
https://doi.org/10.1007/978-3-030-20497-6_3

As presented in the statistical report of health and safety at work in Europe from 1999 to 2007 [3], industry is one of the sectors in which the occurrence of musculoskeletal disorders had a greater increase. Increasingly, WMSD have been associated with 3 types of contexts: automotive industry; electrical/electronic industry and computer operators [4].

In the automotive industry, more precisely of automobile components, production is mostly characterized by numerous assembly lines that are constantly in automation processes, which makes the performance of workers much more conditioned, since they must to respond to the rhythm imposed by the machines, being seen as an extension of the machines [5]. The problem lies in the devaluation of the "man" when designing the machines and defining working methods, with most of the attention turned to the productive component only. The most frequent WMSD in these industries are in the upper limbs, particularly at the wrists and hands [4, 6]. It is them critical to evaluate and monitoring all the industrial processes.

Nowadays, quality management are one of the fundamental bases for competitiveness. As such, Key Performance Indicators (KPI) can play an important role contributing to the effectiveness of the quality management system [7]. KPI are fundamental to an organization, essentially in the industrial sector. The indicators that constitute a process monitoring system are used to collect information and data from certain processes, in order to evaluate their performance [8]. An indicator can be defined as something to provide maximum information, to know to what extent a desired result is to be achieved or the quality of the processes that lead to that result [9]. Performance indicators also allow managers of organizations to select the company processes that need the most concern and where there are more opportunities for improvement [10].

Usually, companies use Overall Equipment Effectiveness (OEE) as the indicator to control productivity. This indicator is considered to be the gold standard for measuring productivity, being based on the evaluation of three factors: availability, performance and quality. In practice, this indicator identifies the percentage of the production time in which it is actually being produced [11].

A result of 100% for OEE means that the company is exclusively producing compliant products, as quickly as possible and without a single downtime [12]. To reach this level, it is necessary to obtain a percentage of 100% in the totality of the evaluated factors, that is, 100% of quality, 100% of performance and 100% of availability [11].

It is possible to relate ergonomic factors to motivation and, consequently, relate motivation to productivity. Ergonomic improvements can contribute to the well-being of workers. Increasing their motivation and consequently the productive performance. According to Abreu (2011) [13], if company works with motivated workers, it is expected that their productivity and efficiency will grow, as improvements in essential indexes such as attendance, turnover and quality of life at work will be verified.

The automotive industry, due to their manufacture process, integrates numerous assembly lines, motivating the implementation of measures in order to improve KPI. In view of all the problems previously discussed, it has become interesting to study the relationship between ergonomic conditions and the level of performance indicators in an industrial environment.

Following the previous work [14] where the main objective was to identify problems of ergonomic nature in the workstations of the most problematic productive line, news objectives was established and presented in the present paper:

"To improve KPI in an automotive industry by implementing ergonomic improvements" and;

"To raise the level of employee' satisfaction with the workplace' conditions".

To achieve the established objectives, the following research questions were asked:

"How can ergonomic improvements affect KPI in an automotive industry?" and;

"What will be the change in the employee' satisfaction implementing ergonomic improvements in the workplace?".

2 Materials and Methods

In order to fulfill the objectives of this work and answered the research questions, a case study strategy was developed in an industrial unit belonging to a Spanish multinational group, a global supplier that is dedicated to the research, development, manufacture and marketing of systems and parts for the automotive sector. The case study strategy was chosen as the research is developed within a real life context using a multiple sources for data collection to gain a rich understanding of the context [15].

This research was characterized as a longitudinal study, which analyzed the behavior of KPI over a period of time. It followed an approach, encompassing quantitative methods. With the application of specific methods of ergonomic risk assessment, quantitative data was collected.

The industry is focused in the: development, production and commercialization worldwide of door locking cables, hood cables, fuel release cables and seat holders. The team comprises 1443 employees, of which 1183 belong to production and 260 to offices, being 65% female and 35% male. The industry works 24 h a day; 7 days a week, with three fixed shifts.

The shop-floor is divided in 4 sections: Large Series section consisting essentially of assembly lines, also having production sites and cable cutting; Injection section that mainly disposes of injection machines of plastic, where work is more customized, also having some assembly lines and cable cut' process; Comfort Systems Section including plastic injection machines, also comprising cable cutting processes and assembly lines; and a Warehouse.

The methodology was divided in two mains stages: (1) corresponding to the general diagnosis of the working conditions and ergonomic assessment of the most critical section/work center and (2) definition and implementation of improvements and, analysis of the impact on companies KPI and workers satisfaction (Fig. 1). Details of the first stage, meaning points 1, 2 and 3 of the methodology presented in Fig. 1, can be found in scientific documents already published [14, 18]. Briefly, a diagnosis of the workers' perceptions was initially made regarding working conditions. For this, a questionnaire was applied to evaluate their general satisfaction. Results showed the most critical productive section of the factory unit (point 1 of the methodology Fig. 1). After, the Ergonomic Workplace analysis (EWA) was used to identify the most critical work center [16] (point 2 of the methodology, Fig. 1). This method was adapted to the context under analysis. The guidance of EN 12646-1 [17] was used to assess the illuminance item. After the selection of the more critical work center, different postures adopted by the workers were identified and registered, as well as all the materials manual handling (MMH) tasks. Methods of specific ergonomic evaluation were applied – Mital guide, Revised NIOSH Equation and RULA - in order to identify the tasks involving risk of WMDS [18]. These methods have tables with possible results that, when compared with the results obtained, reveal whether the tasks require intervention or not and the urgency of such intervention. (point 3, Fig. 1).

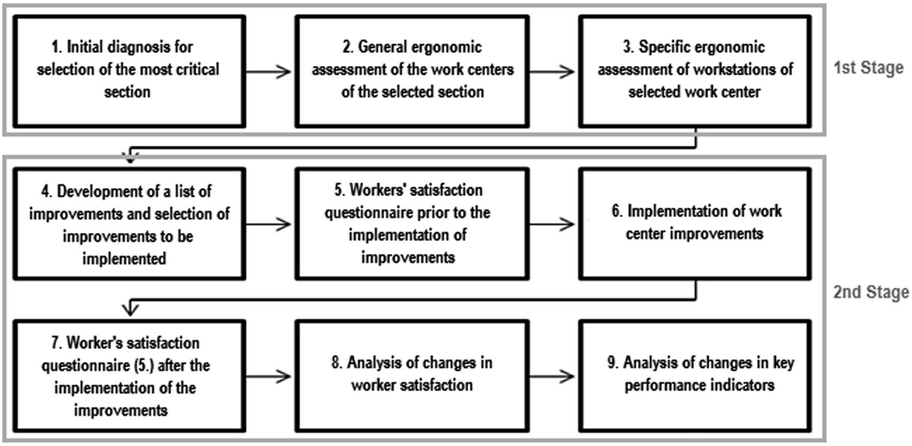

Fig. 1. Methodology plan.

Notice that stage 1 began in January 2017 and was developed in 17 months. The second stage last 5 months, ending in October 2018.

In the first step of stage 2 (point 4, Fig. 1) a document was done comprising several suggestions of changes to be made in the workplaces. The suggestions were based on literature review, previous research, International Standards and by testing several hypotheses in the specific methods that we used on the ergonomic evaluation. All the suggestions were evaluated by a multidisciplinary team, with members of the Occupational Safety and Health (OSH) and Continuous Improvement team, in order to select the most important, quick-to-implement and less costly. At this point, all the improvements to be implemented were already identified and listed. A questionnaire, consisting of 12 questions ranking from 0 (totally dissatisfied) to 10 (totally satisfied), was applied to assess workers' satisfaction in the before and after the improvements (point 5 and point 7, Fig. 1). Data was analyzed by calculating the mean for each item evaluated and comparing the averages of the ratings assigned to each item before and after the changes, analyzing their increase. Percentages of incidence of workers who reported feeling certain improvements were also generated (point 8, Fig. 1).

Notice that all the ergonomic methods that were used in point 3 (Fig. 1) were applied again in this stage highlighting the differences in terms of ergonomic risk value.

Ultimately, after working with the new methods during the 2 week trial period, OEE levels were compared before and after the implementation of line improvements (point 9, Fig. 1). The OEE was analyzed by comparing the general levels of production obtained in the two weeks of experimentation and in the previous weeks, verifying its increase or decrease and individually analyzed the specific factors considered in the OEE in the weeks before and after the implementation of improvements in the productive cell.

3 Results and Discussion

In this section, the results obtained related to the implementation of the improvements in the selected work center, an assembly line will be presented. The results of the first part of the research are already presented in previously prepared scientific documents [14, 18]. This involves the following steps: first the results of the ergonomic evaluation of the changed work stations, comparing the level of WMSD risk before and after the improvements. Then, the results of the employees' satisfaction with the job position during this change process will also be presented, and finally, the results regarding the impact of the improvements implemented in the organization's KPIs will be presented.

3.1 Ergonomics Improvements

Among the 42 suggestions for improvement and according to previous requirements (high importance, rapid implementation and low cost associated with implementation), 6 changes were made: (#1) maximum weight to be handled in a box of raw material to supply the machine was established; (#2) a machine-operated button was centralized; (#3; #4) procedures were established to restrict the placement of boxes of raw material on the floor of two workstations and, (#5; #6) illuminance levels were changed in two workstations. As it is possible to observe in Table 1, generally the risk of WMSD reduced nevertheless this decreases was more evident in #1 and #3. In these cases, results showed that after implementation no more actions were required.

Regarding illuminance (#5; #6) the recommended average illuminance value for general machine work is 300 lx (EN 12646-1 [17]). Measures made showed 980 and 900 lx for each of the analyzed situations. Also, results from the questionnaire that was applied to assess works' satisfaction (point 5 of the methodology), workers reported headaches and visual fatigue after a few hours of work; possibly indicating excessive illuminance. After reducing the levels of illuminance to 580 lx (possible value depending on the luminaires available for installation in the industrial unit) in both workstations, the workers ensured they felt more comfortable, ceasing to feel headaches. Regarding the uniformity, both before and after the changes, it complied with the recommended values, presenting values always higher than 0.7.

3.2 Improvements in Worker's Satisfaction

Through Fig. 2, is it possible to analyze the influence of the implementation on all the aspects considered. Twelve aspects were evaluated (higher the value, the higher is the

Table 1. List of improvements and recommendations.

No	Evaluation method	Timing	Value	Recommendations
#1	Mital Guide	Before	1,57	There is risk. Redesign the task
		After	0,89	No intervention is required
#2	RULA	Before	4	Need for more detailed research. Changes may be necessary
		After	3	Need for more detailed research. Changes may be necessary
#3	Mital Guide	Before	1,15	There is risk. Redesign the task
		After	0,10	Acceptable risk. No intervention is required
	RULA	Before	7	Research and changes are required immediately
		After	2	Need for more detailed research. Changes may be necessary
#4	RULA	Before	7	Research and changes are required immediately
		After	6	Investigation and changes should occur briefly
	Revised NIOSH Equation	Before	1,56	There is a risk for some operators. It requires intervention with organizational and engineering measures
		After	1,52	There is a risk for some operators. It requires intervention with organizational and engineering measures

satisfaction): overall satisfaction, motivation, organization, lighting, MMH, postures, upper and lower limbs pain, back pain, overall body pain, quickness and facility. The differences can be observed based on the height of each aspect's group columns from before and after the implementation. Eleven (91.7%) of them had a positive impact on the level of employee satisfaction. Only in the perception of pain felt in the lower limbs no improvement was observed.

With regard to the incidence of the number of workers on the line who experienced improvements, it differs according to the aspect under analyzes. Regarding overall satisfaction, MMH and perceived pain in the general body, 100% of the workers felt some improvement. Motivation, lighting conditions and spinal pain are also highlighted, with 85% and 75% of workers experiencing improvement. In the remaining aspects evaluated in the questionnaire, the percentage of workers who felt improvement was lower: 62.5% reported improvements in workplaces organization and postures adopted; 37.5% experienced improvements in upper limb pain; 50% reported that tasks were being performed more easily and 25% reported that they performed tasks faster.

3.3 Overall Equipment Effectiveness Improvements

Subsequent to the implementation of the improvements, in the following two weeks (40 and 41, see light gray area in Fig. 3) there was a decrease in OEE, which goes against expectations. There are several authors who relate positively the improvement of the

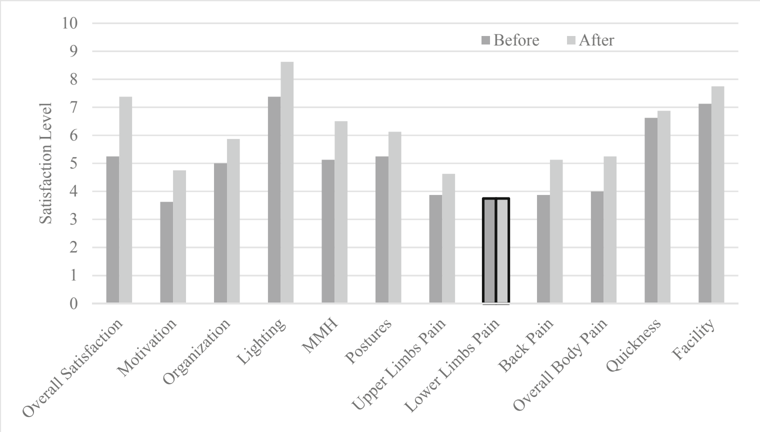

Fig. 2. Comparison of worker satisfaction within the ergonomic aspects of the workplace before and after the implementation of improvements.

ergonomic factors with the increase of productivity ([13, 19–21]). As mentioned previously (see Introduction), OEE is based on the evaluation of three factors: availability, performance and quality. Therefore, it is essentially to analyze in detail each factor.

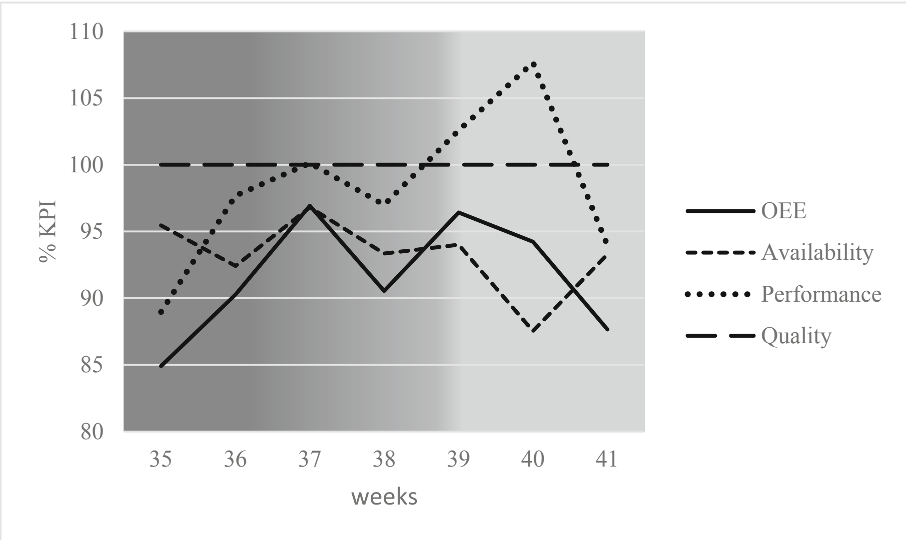

Fig. 3. Evolution of OEE before and after improvements (light gray corresponds to the time after the implementation of improvements).

As can be seen from Fig. 3, workers performance increased in the week following the implementation of the improvements (week 40), meeting the expectations and following the results founded in literature (e.g. [19–21]).

Indeed, from the three factors that are considered in the OEE indicator, performance is the one that could presents more variation as result of the changes implemented in the line. Notice that, its calculation is based on the quickness of the process without counting stops, specifically translating the quickness of the workers when performing the tasks [11].

4 Conclusions

This research show that ergonomic improvements can enhance the improvement of the key performance indicators (KPI) as also the satisfaction of workers with the workplace.

Regarding the impact on workers' perception of workplaces ergonomic conditions, the questionnaire applied revealed that 91.7% (11 in 12) of the aspects evaluated by workers improved compared to the prior situation to the ergonomic improvements in the line. The highlights of the improvements were the overall satisfaction of the workers with the workplace, reaching improvements of 21.3%, followed by MMH tasks, which improved by 13.8% and lighting conditions, pain in the general body and localized pains in the spine that increased employee satisfaction by 12.5%.

However, even if only minor changes were made to the line, all indications may have been that through the improvements implemented, in the first week, there was an increase in the performance of the workers in the order of 5%, reaching a level of performance that had not been verified for more than a month, which leads us to deduce that if the implemented improvements were those that would have the greatest impact on the ergonomic conditions, the more visible the results would be in terms of the increase in performance indicators.

The requirements defined by the company were a limitation, as only allowed to select 6 from 42 suggestions, namely: high performance, rapid implementation and low cost associated with the implementation. So, it is expected that the implementation of the remains suggestions the impact on the KPI could be higher.

Acknowledgments. This work has been supported by COMPETE: POCI-01-0145-FEDER-007043 and FCT – Fundação para a Ciência e Tecnologia within the Project Scope: UID/CEC/00319/2019.

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Integrated Management in Disaster: A Discussion of Competences in a Real Simulation

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Abstract. The frequent changes in the cultural, technological, social and environmental aspects of our society demonstrate the need for better crisis management and process safety. This improvement is not limited to industrial facilities, but should be extended to all organizations involved in crisis management. Knowing and understanding what actions to take during a disaster facilitates integrated management, which is crucial for successful operations. Prioritizing actions becomes challenging when multiple events occur. The time for action is short, requiring efficient communication between the parties involved and nimble decision making. This paper discusses a case study of the identification and analysis of human error during a disaster simulation and understanding the risks related to human decisions and actions in crisis management. Thus, the object of study is to evaluate the perception, decision, memory, competence, communication, emotional balance of the team and leader, in the treatment of emergency actions and contingency in disasters.

Keywords: Integrated management · Competence · Human factors · Disaster · Real simulation

1 Introduction

The changes in the contemporary, globalized and massified world are marked by the complexity of economic, social and environmental crises, inter and intra-States armed conflicts and national - transnational crime. Many African and European countries face

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 33–45, 2020.
https://doi.org/10.1007/978-3-030-20497-6_4

lasting crises, of varying degrees of intensity, with different origins, with different but common consequences in the suffering they cause in the populations and all with a direct impact on regional and/or international security.

The crisis is non-selective and unpredictable, that is, any country, institution or person can be affected by it at any time or anywhere. We know that the crisis will happen, but we cannot predict when. Therefore, companies, public institutions, security forces and especially their professionals cannot avail themselves of the possibility to prepare only when the critical event happens, we must be prepared to face any crisis.

Thus, the need for improved management and crisis analysis and human factors in process safety is evident. Social conflicts such as terrorism, ideological divergences, traffic accidents, natural disasters linked to climatic events, must be analyzed due to the impacts that lead to the possibility of disasters involving both human factors and climatic factors. However, the misunderstanding of signs, deviations and failures, can lead to shocking situations like a mass disaster.

This paper intends to discuss a case study on a real simulation of disasters in order to identify and analyze human errors, understand the security risks and human decision-making processes and in disaster situations and to emphasize the importance of investing in intellectual capital for competent management. The main goal of this paper is to study the evaluation of competences, communication in the scope of integrated management, documentary memory, besides human psychophysiological factors such as energization, decision speed, stress, cognitive failures, emotional balance and perception failures in actions of the leader and team. The paper also aims to discuss the importance of conducting and creating studies on risk and crisis analysis in real simulations as preventive measures, admitting the existence of uncertainty in similar events that may occur, as well as pointing out the necessary investments and what is the fundamental, governments, institutions and universities, in achieving competence management. The simulation was one of the topics addressed in III Congress of Mass Disasters – CIDEM, held in August 2018 in Feira de Santana, Bahia-Brazil. The simulation was a major mass disaster, with simultaneous events involving the launch of a truck carrying fuel oil, kidnappings, terrorist attacks, fires and vehicle explosions.

2 Literature Review

2.1 Learning Model for Simulations of Crises

Simulated exercises aim to prepare communities for disasters, from the establishment of a risk scenario. In order to be effective and prepare communities for future events, it is essential that they not be developed as isolated actions, but integrated into a process of risk management and training of professionals and the community involved.

The steps presented in Fig. 1 should be understood as a form of orientation and learning through a real simulation, verifying the actions taken in an integrated way, and as a result, being able to see the main flaws and needs to achieve a real management of competition in crisis scenarios in mega-events, in order to reduce the incidence of disasters or minimize their effects when they are triggered.

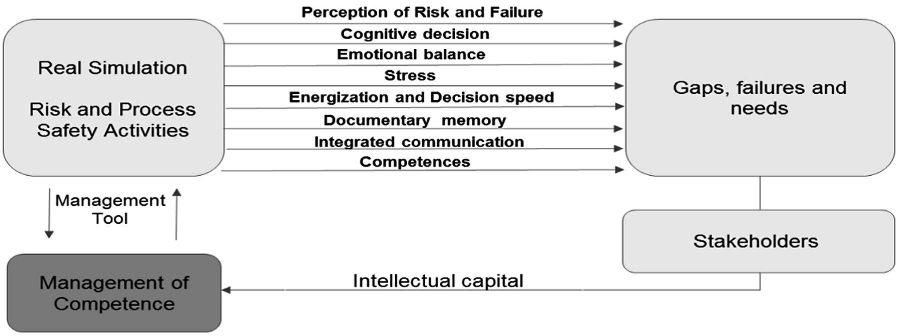

Fig. 1. Learning model on simulations of crises in mega-events.

Although Fig. 1 is presented in this structure, it is not a closed esquematization of the presented actions, but a guide model of reflection with practical orientations to reach the objective or expected result.

Importance of the Real Simulation Exercise. The attendance of occurrences of high risk requires of the institutions much more than good will, rusticity and accumulated experiences. One cannot admit in this branch of action, an amateur and empirical team. For actions in a crisis scenario gain prominence both nationally and internationally and certainly their possible errors will tend to be subject to disclosure, exposing the weaknesses found in institutions [11], hence the importance of the constant simulation and training. According to [5], the simulation is the practical training in which a certain emergency scenario is represented in a hypothetical way, being applied to it all the actions necessary for its effective control, as if it were a real emergency. It is observed that the control actions are not only the direct combat actions, but also the aspects of: communication, alarm, summoning emergency teams (internal/external), evacuation of personnel (internal and/or community), signaling isolation, combat actions, containment, decontamination, chain of command and missions, etc., until the emergency is considered closed.

Risk and Process Safety. Accidents are events of the risk activity that can have as consequence from the increase of cost until the loss of a business, this depends on the frequency, the impact, the perception of the society and the complexity of the communications. The high difficulty of analyzing the initiating causes, the promoting environment, and the secondary causes of top events is in the urgency to act in a corrective or preventive way [2]. The management of a crisis must be worked under an understanding of time and considering the most complex problems, be they social, economic, political and ideological.

Cognitive Processing. The low perception about the risk of a deviation becoming an event indicates low quality [1]; the attitude is considered intermediate [2] where part of the leaders is active and part is reactive; the history of decisions for such an event is low and the simulated ones are few – do not affect the emotional [1]; it is considered that the level of competence of the team is average for unusual situations involving fireball; the memory is intermediate because it does not include the deviations [2]; and the speed of action is rapid, which in some ways may also be a problem [10]. About the process of cognition in a crisis scenario stands out:

Perception of Risk and Failure. Failure to perceive the impact and possibility of occurrence of the event creates a comfort in the team that controls the danger until complacency in actions and risk aversion. The impact is diminished if the non-perception is in the deviation phase and the impact will be increased if the non-perception of the occurrence is close to happening. If we accept the non-perception of the impacts for the deviation, that is, the normalization of the deviation [6], surely the intermediate event will occur and perhaps the top event or the accident will happen.

Cognitive Decision. In the face of a situation of possible risk and crisis, urgency mainly affects the need for rapid decision making, where only having knowledge, skills and rule making available in the working group is not enough to contain the danger which goes beyond equipment and processes. Thus, based on experiences, investigations and discussions are suggested models for the leader and the team in the treatment of these crisis situations [1].

Emotional Balance. The discussion around solutions to support the emergency command requires special care to avoid emotional instability. This measure try to ensure that there are no biases in the information that can reduce the quality of the decision in the handling of contingencies. The components of the brigade must have practices and customs to carry out activities under stress, confirming that the cognitive does not lose quality against the maximum stress [7, 15].

Energization and Speed. The energization of the emergence moment depends on knowing the impending release of danger, which indicates a high risk of the top event occurring, the compliance state does not generate enough power to start emergency combat. The personality characteristics of the leader may be appropriate or not to promote energization for action in an emergency situation. The energization in decision must be accompanied by a state of minimal emotional balance although the high risk of the situation. If there is no such equilibrium the leader can "freeze" or even fade in a situation of risk [7]. In the cases of emergencies, often the leader does not have time for this cognitive recognition, If the memory is rescued quickly and assertively it has to be as clear as possible and with the necessary speed for the emergency decision. If speed does not meet the required demand, there will be a delay in decision making.

Learning. The evaluation of the results obtained in the simulation allows the construction of a guide of guidelines for the preparation of communities in the face of disasters, as well as help in the preparation of a guide of local contingency plans. It is necessary that everything that is judged to be important about the simulation or occurrence and with maximum richness of details (photos, interviews, filming, testimonials, manuscripts, reports, documents etc.) is recorded, that is, a Documentary Memory. This document can help future professionals and, furthermore, serve as one of the fundamental parts of a future legal process.

Documentary Memory. A serial of procedures, manuals, historic and technical specifications should be available for rapid memory retrieval and interpretation of emergency brigade problems. The memory of experts based on knowledge and practice should also be redeemable quickly through consultations or meetings. Thus, the emergency brigade support team must have adequate memory quality to answer to the rapid cognitive support of the leader [7].

Organization in Integrated Action. Integrated management, since there are several dimensions, aspects and factors that act in the production of risk and disaster, need to be articulated in a whole from the communication management to the competencies aspects of the professionals involved in crisis scenarios. It should be noted that risks and disasters do not belong only to certain professional categories or areas of knowledge, that is, they demand interdisciplinary actions, capable of articulating different knowledge and practices, especially those coming from populations that occupy risk areas or are in a situation of risk. All these people need to be prepared to deal with these situations and be able to participate in decision-making processes that relate to their own lives. Thus, investment in:

Integrated Communication. It is a precondition for the safe act and directly influenced by the organizational climate. An efficient communication system needs to enable the worker to retrieve the operation's memory and generate learning. Discussions on recorded information need to be discussed at shift exchange, as recommended by API **770** [8], this discussion is an opportune time for knowledge exchange and for the operator to make sure that his/her message has been understood [9]. Organizational influences strongly affect communicative behavior. Subjective factors such as judgments, culture of guilt and fear of damage to the image cause the worker to omit information that could contribute to the construction of barriers to avoid incidents and accidents. Factors related to training and language competence to compose the text can also limit the number of data in the records, as well as the supervisors' discourse, which can be motivating or otherwise.

Stakeholders. It is a strategic audience, we can understand this expression as describing a person or group who have an interest in a particular business, industry or service [13].

Intellectual Capital. Since disasters are characterized by predictability, high damage to society and little decision time, knowledge of preventive and mitigating actions provides people with adequate decision-making and response to the problem in a timely manner. In this case, knowledge management strengthened by the use of its tools helps the acquisition and dissemination of the information most appropriate to the process. It can also help decision-makers to do their work faster and more efficiently, as well as allowing multiple groups to share and reuse resources [3]. It reinforces the importance of knowledge generation in the context of natural disasters, with institutional commitment focused on disaster response or prevention investments [4] points out that although the importance of knowledge created in the relevant scenario is notorious, actions are focused on disaster prevention and response actions.

Competence. Understanding the causal nexus of the phenomena involved in the accident, having experience and experience similar to the activities related to the events, being able to deal with situations already seen and having the capacity to infer, extrapolate and test to recognize the existence of unusual situations is part of the characteristics for the process security leader. This measure of competence is the result of the application of examination of the technical culture confirming the level of knowledge and practice and whether they are sufficient for the command action in the emergency. Knowledge is integrated to practical and brings an immediate meaning as to the validity and quality of actions [7].

Crises Management Tool. Crisis management can be defined as a set of actions carried out by managers in order to avoid, prevent and solve situations of degeneration faced by companies, in order to recover their normal conditions of operation, profitability and competitiveness [12].

3 Methodology

The methodology used is based on the analysis of the scenarios of the real simulation during the III CIDEM to discuss the actions of the participating institutions (Table 1) for the development of skills for crisis management in mass disasters including university cooperation.

Table 1. Participating agencies and simulation functions

Institutions	Initials	Function
Military Fire Department of Bahia	CBMBA	Observation, rescue of victims and fire extinguishing
Battalion of Special Operations of the military police of Bahia	BOPE/PMBA	Rescue of abducted victims and capture of terrorists
Emergency Mobile Care Service	SAMU	Victim assistance
Brazilian Army	EB	Logistics Support
Navy of Brazil	MB	
Brazilian Intelligence Agency	ABIN	
Ministry of Defense	MD	Observers
Civil Police of Bahia	PC	Security of area
PMBA Cavalry	PMBA	
Federal Highway Police	PRF	Traffic safety
Federal Police	PF	
Association of Diplomates of the Superior School of War	ADESG	Logistics Support
Department of Technical Police	DPT	Expertise
Civil Defense of Feira de Santana	DC/FSA	ICS Planning
Municipal Guard	GMFSA	Security of area
Secretariat of Public Security of Bahia	SSP/BA	Security of area
Brazilian Institute of Environment	IBAMA	Monitoring the environment
Institute of Environment and Water Resources	INEMA	
Concessionária de Rodovias S.A.	VIABAHIA	Road safety
SUATRANS emergency service	SUATRANS	Chemical risk monitoring operations

(*continued*)

Table 1. (*continued*)

Institutions	Initials	Function
General Hospital Clériston Andrade	HGCA	Hospital support
Children's Hospital	HC	
Federal University of Bahia	UFBA	Observers
State University of Feira de Santana	UEFS	Coordination
International Criminal Police Organization	INTERPOL	Identification of victims' bodies
Aerial Grouping	GRAER/PMBA	Transport of victims

4 Case Study

4.1 The Dynamics of the Real Simulated Event

The event was divided into three phases: PHASE 1 - Accomplishment of the Incident Command System (SCI) course for all the main agencies that participated in the Simulation; PHASE 2 - Execution of the Table Simulation, with the discussion of the agencies involved, discussing the possible procedures to be established in the scenario under discussion, and finally, PHASE 3 - The Field Simulation. The general objective was disseminating through the knowledge transmitted in the lectures and in the realistic simulations, general information about the behaviors that the public and private forces must face, the mass disasters. The specific objectives were disseminate knowledge in the multiple victim approach, practicing the ICS methodology practice as well as the practice of agency procedures, the integration of public and private agencies and procedures under high stress.

The Incident Command System (ICS). The Incident Command System is a management tool created in the 1970s by the American Coast Guard to act on forest fires in California. It is born due to some findings during post-fire assessments. Throughout these 48 years of application the tool has undergone some changes to be adapted to any type of scenario [14]. The scenarios are diverse, ranging from planning a visit of a President of the Republic to a terrorist attack. The main objective of the SCI tool is to establish a crisis management process in any area of activity, interconnecting the various government agencies, maintaining their administrative, operational and political independence.

Training of Agencies that Participate in the Simulation. All training was preceded by the Incident Command System (ICS) course, for the agencies that would participate in the simulation. The course was a basic model of three days, after completion, a table simulation and a theoretical evaluation were done with the theme to be used in the field simulation. It was required that all representatives who were to participate in the field simulation were the same ones who had participated in the course and simulated the table, so that they could have an alignment of the actions to be performed in the practical field simulation.

Description and Comments

Unexpected Tragedy and the Culture of Opportunism. An unidentified terrorist group, taking advantage of a moment of celebration at the Feira de Santana Exhibition Park, decides to carry out an attack planning. One of the terrorist cells uses a truck that carries gasoline, projects itself against a truck carrying Benzene and a bus that transported the population to the Exposition Park. After the collision, large quantity of product begins to leak and much of the product pours towards a river. By realizing that volume of product being poured into the environment, the population begins the process of looting, carrying the dangerous liquid, into cans and drums into their homes and working environment (Fig. 2).

Fig. 2. Preparation of rescue teams

The Emergency. A representative of the Federal Highway Police and VIABAHIA, were the first to arrive at the scene and initiate the first actions. Through a binocular, it seeks to locate the safety panel and the risk label, it prevents the population from continuing the looting of the previously unknown product, signaling and isolating the site, preventing any approach to the area of the accident. At this point, people who were plundering the product begin to fall on the ground and become unconscious, with difficulty breathing (Fig. 3).

Fig. 3. Analysis of the scene and nature of the accident

The Victims Concentration Area (VCA) was set up and communicated to the local Emergency Hospital of possible victims who would be admitted to that hospital. At the same time, a decontamination corridor was also set up for the removal of the product chemical (Bezene) (Fig. 4).

Fig. 4. Large numbers of people arrive in the LCA region

Rescue victims who have been contaminated by BENZENO. By spontaneous demand, they gave entrance in the emergency of the General Hospital Clériston Andrade. The hospital had been prepared with some tents, provided by the Army, in order to make the first hospital screening (Fig. 5).

Fig. 5. Chemical decontamination

Terrorist Drivers in Action. The terrorists abandoned the truck at chemical risk, soon after they took the bus and took one of the passenger's hostage. As they left the bus they left a briefcase with an explosive device, just below the bus. The BOPE was activated and they set up a structure so that the pump that was in the case was disassembled. At that same time, the terrorists had displaced one of the hostages into a house and threatened to execute it all the time (Fig. 6).

Fig. 6. Deflagration of pumps and Sniper protects the team and the victims on the scene

After the abandonment of the truck the terrorists explode with sequencing there is a fire. A Fire and Rescue Firefighting team from the Fire Department initiates fire extinguishing (Fig. 7).

Fig. 7. Firefighters begin to extinguish fire from explosion

The Contamination of People and Logistics. Severe victims were taken by helicopter from GRAER to the helipad of Children's Hospital, which were taken to the HGCA, which is approximately 800 m away, by ambulance (Fig. 8).

Fig. 8. Helicopters transport serious victims to the hospital

Environment Condemned. Chemicals that were thrown into the river after the collision. Civil Defense Teams, IBAMA, INEMA, and the private company SUATRANS. They monitor the leaked chemical in the environment (Fig. 9).

Fig. 9. Monitoring of the chemical leaked into the river

Recognition of the Victims' Bodies. Assembly of the structure of legal medical research, to support local and international authorities, to research and identify the dead in the accident (Fig. 10).

Fig. 10. Forensic professionals work on the identification of dead victims

5 Results and Diagnoses

This article aims to evaluate the practice in the simulated exercise based on the Incident Command System, based on the observations during the evolution of the training, and thus discuss the gaps shared by the members of agencies that demonstrated in the their speeches, consistencies and inconsistencies in the performance of the simulation. In the training process and according to the literature dealing with disasters, the influence of factors that interfere in the development of skills and in the dynamics of the integration of emergency response teams is highlighted, especially when the event has the dimension of a disaster in mass.

The constructive nature of memory, the organization of knowledge, reasoning, decision-making, cultural approaches, perception and attention are factors that drive the development of competencies. It is observed that the motivation for effective participation of a training of this nature, with the opportunity to develop competences for the formation of a multi-professional team, should be the task of the leadership, together with its team. In this context, it is expected that response groups, in an integrated management, will be prepared to act in tune, in contingency actions, preserving cognitive memory, emotional balance, selective attention, physical exhaustion.

The communication tool, as far as critical action information is concerned, needs to be "double-handed," which means that the tactic is to communicate and receive the same information, such as confirmation of an activity that influences an important decision. Failure in this feature directly affects disaster response and avoids errors.

The distribution of resources in this simulation contributed to the agility of performing the critical tasks set out in the scenarios. However, in a situation where this availability does not exist, it can generate a gap (a gap to be observed). The excess and the misallocation of resources can impact in the case of the deficiency in the organization of the logistics, being able to generate opportunism.

The leaders responsible for their groupings need to establish quality in communication, listening ability, knowledge sharing, to the point of motivating their leaders to understand risk aversion, behavior that causes failures in actions and compromises decisions in a crisis environment and high stress.

In a realistic simulation scenario, it is necessary that the safety conditions are communicated and established in order to avoid accidents with the first responders and the communities surrounding the event. The isolation of the critical areas of the scenario is one of the safety procedures for the prevention of events.

6 Conclusion

The evaluation of the perception, decision, memory, competence, communication, energization, emotional balance, speed and actions of the leadership and the team, in the treatment of emergency and contingency actions, to achieve the reduction of the damages caused by the impacts generated by a disaster in it is pointed out that the integrated management of those responsible for disaster response makes it possible to recognize the factors that interfere with assertive decisions.

The exercise of a field simulation provides the mobilization of the various agencies that participate in contingencies in emergency situations. The crisis control tool, the Incident Command System, used in the simulation presented as training at the International Mass Disaster Congress in 2018, in the city of Feira de Santana - Bahia, Brazil, demonstrated the capacity of this learning tool can provide the members of the scenarios, representing the various disaster response institutions.

However, it should be pointed out that although there is planning and development of activities in the crisis scenarios prepared by experts in the disaster area, however, gaps are pointed out so that they can be reviewed and represent an opportunity to improve the training dynamics from the ICS, to be carried out in the state of Bahia, the contingency methodology for emergencies, an Integrated Management of the forces that represent the prevalence.

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Implementing the REPAIRER Human Factors Safety Reporting System Through MRM (MxHF) to Meet SMS Compliance in Aviation Maintenance

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Abstract. Reiterating the importance of having a human factor related safety reporting system for aviation maintenance to reduce human error and utilizing it to gain SMS compliance, the REPAIRER method of identifying and reporting human factors hazards in aviation maintenance is reintroduced. How and why the REPAIRER method system is of such importance in the implementation of aviation maintenance safety programs can be linked to the success and evolution of maintenance resource management and human factors programs which have been effective in reducing human error in aviation maintenance. These programs are rooted in effective communication methods, as well as the identification of human factor elements. To illustrate this point, the successes of maintenance resource management are discussed. Additionally, the incredible strides that the Federal Aviation Administration (FAA) has taken to propel a human factors-centered safety program in aviation maintenance are brought to light with the FAA's latest transition of MRM (Maintenance Resource Management) to MxHF (Maintenance Human Factors). This newly appointed program, which replaced a decades old FAA MRM program, highlights the significant changes in MRM, notably the emphasis on human factors. Given the significant shift from MRM to MxHF, the authors explore the implementation of the REPAIRER aviation maintenance reporting system under the new guidelines and demonstrate how it could fulfill many of the desired outcomes of both programs, while still gaining SMS compliance.

Keywords: REPAIRER Reporting System · SMS · MRM · MxHF

1 Introduction

In 2018, the authors presented a paper entitled, "The REPAIRER Reporting System for Integrating Human Factors into SMS for Aviation Maintenance" at the AHFE Conference linking together risk management with human factors in the form of a safety reporting system for use in aviation maintenance to satisfy the FAA's new encouraging policy of SMS for commercial aviation in the US. The theoretical aviation maintenance safety reporting system came in the form of an 8-step acronym called the 'REPAIRER' Reporting System [1]. ICAO's (International Civil Aviation Organization) SMS

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 46–57, 2020.
https://doi.org/10.1007/978-3-030-20497-6_5

Table [2] was used as the foundation to support the theory, as seen in Fig. 1, which contains four safety pillars (Policy, Promotion, Assurance, Risk Management). Although this model is a good fit for commercial aviation operations in the US, it was deemed deficient for commercial aviation maintenance operations in the US due to the fact that the SMS model lacked the integration of human factors. This deficiency was further supported by relevant research in aviation maintenance, which was compiled over the last 30 years. The results of that research indicated that maintenance error is consistently due to human error, with high percentages of error related to maintenance manuals and procedures. With human error in aviation maintenance established as a problem, the next step was to review the methods of human factors training currently in use, industry-wide. Two models were found; Transport Canada's 12 dirty dozen and the FAA's PEAR model. This ultimately led to the creation of the REPAIRER reporting system for aviation maintenance, as a new way that human factors could be merged into the SMS table via the Risk Management pillar. The new reporting system was also supported through the Safety Assurance pillar. In theory, the REPAIRER Reporting System appears to be a viable solution for aviation maintenance safety moving into the future. But how can something that looks so good on paper truly work in reality?

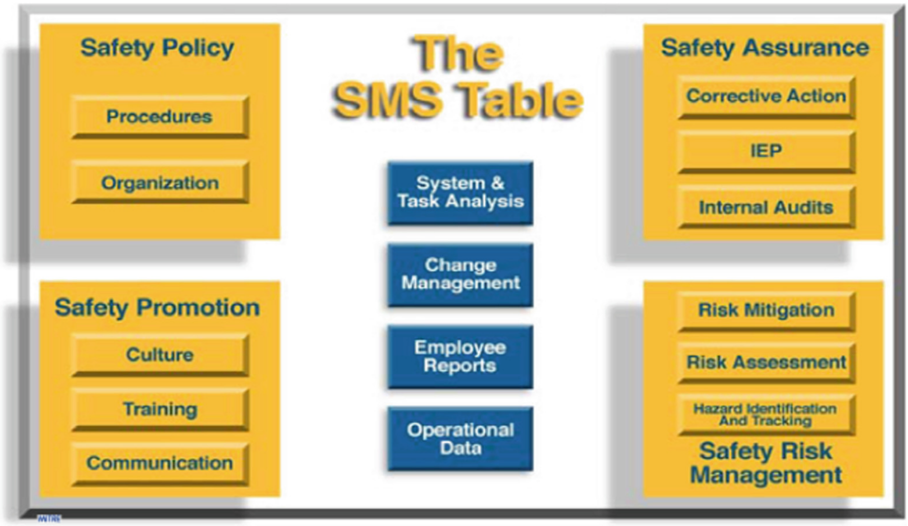

Fig. 1. The SMS Table [2]

2 Implementing REPAIRER into Aviation Maintenance

Where the REPAIRER Reporting System becomes a reality is by executing two more of the SMS pillars: Policy and Promotion. The Policy pillar is formally putting the REPAIRER into writing, by explaining how it will be implemented in the organization. The Promotion pillar is taking the Policy on REPAIRER, and training personnel on how to effectively use the system, ensuring adequate organizational support during the process. Although executing these two pillars seems straightforward, this is not always the case. Aviation maintenance organizations require high levels of output to remain profitable; at the end of the day, it is a business and as such is economically driven. Decisions are financially-based. Aircraft that cannot fly represents waste. It is crucial therefore, that aircraft maintenance be performed efficiently and effectively in order for these organizations to remain in business. There is also a balance that must be achieved between safety (through adherence to FAA regulations and inspections) and efficiency. Any imbalance of safety or efficiency can be dangerous. That is why the REPAIRER Reporting System, which emphasizes risk management and human factors in SMS, is so important. It balances both safety and efficiency in aviation maintenance.

The other challenge related to the REPAIRER implementation is culturally-based. In many cases, maintenance decisions are economically-based, leaving little room for debate or consideration. As long as FAA regulations are not compromised, the most efficient method is normally selected. After operating this way for years, introducing new processes may be met with resistance. However, there are examples of aviation maintenance organizations that have taken the next step and gained in safety and efficiency, due to what is notably referred to as Maintenance Resource Management (MRM).

3 MRM as the Historical Linkage to Making REPAIRER a Reality

MRM [3] origins can be traced to Cockpit Resource Management (CRM), which started at NASA and was then adopted by United Airlines in the early 1980s after United crashed a DC-10 in 1979 into a Portland, Oregon neighborhood after the aircraft ran out of fuel. The root cause of the accident was found to be miscommunication between the Captain and the crew members. The Captain mismanaged his time, while the crew failed to be assertive. Following the accident, United implemented what was to be a paradigm shift in the cockpit. The Captain was no longer the end all for decisions, and teamwork became the cornerstone of aircraft operations. United had so much success with their cockpit safety tool, that the rest of the industry soon followed. The FAA would eventually make CRM training mandatory on an annual basis for all US airlines. This training was, and still is, heavily centered around human factors and the tenants of teamwork, communications, assertiveness, task delegation, management and leadership. The industry-wide adoption of CRM in the US changed the cockpit culture from a dictatorship to one of teamwork and crew coordination that has reduced human error and greatly increased safety.

The idea of MRM came about roughly a decade after the United Portland accident in 1988, when an Aloha Airlines 737 lost a large section of the fuselage roof during departure from the Kona, Hawaii airport. Unfortunately, a flight attendant was lost in the decompression, but the pilot and crew did a magnificent job handling the emergency and were able to land safely at Kahului, Maui. The accident investigation revealed that failed inspections did not pick up 240 cracks in the skin of that aircraft's ceiling. Aloha's management group was technically knowledgeable and had the expertise, but organizational human factors had reduced the effectiveness of the Aloha maintenance program. From this accident the US airline industry and the FAA began to address teamwork deficiencies in maintenance and decided to design a product that would address human factors similar to those found in the cockpit and CRM. The idea was that CRM addressed immediate, critical effects of human error in the cockpit, so why couldn't a similar model be designed to address the often-latent critical effects of human error in maintenance? The MRM format focussed more on building better communications, teamwork, effectiveness, and safety in aviation maintenance, while at the same time it also is attentive to a wider audience of maintainers that includes AMNTs, inspectors, engineers, staff support personnel and managers. Eventually the FAA encouraged all commercial aviation organizations in the US to adopt MRM.

4 The Success of MRM in the US Industry

Continental Airlines was the first to implement an MRM program [4]. Taken from their successful CRM system, the Crew Coordination Concept (CCC) was formed. Designed specifically for maintenance personnel, the program leveraged communications and teamwork in order to improve safety and efficiency. Within one year, Continental Airlines realized a 66% reduction rate in lost workday injuries and mishaps after training 66% of its personnel. A three-year study of that program concluded with significant positive effects on safety, assertiveness, teamwork, stress management and dependability. CCC reduced maintenance error rates and improved human reliability, which further deemed the program a success. It was so successful that many other large airlines started MRM-related programs of their own. US Air [5] started a form of MRM in 1993 that involved not only US Air maintainers and management personnel, but also the labor union and the FAA FISDO. Teams were formed to rewrite the procedures manuals. This program was so successful that in 1996, US Air Management initiated a joint Labor-Management safety process and MRM was the vehicle to do it. Taylor [6] concluded in 1997 that employee involvement, open communications, and commitment to purpose, with improved technical content in a maintenance system, increased maintenance safety, efficiency and performance at both Continental and US Air. Taylor found that both Airlines reaped impressive returns on investment from using MRM programs. A major goal of MRM is to reduce human error through teamwork and effective communications. To determine the extent of this reduction, Patankor and Taylor [7] measured lost time injuries and aircraft ground damage variables at an airline maintenance facility from 1995 to 1999. The data resulted in a decline in both variables during the time period. The data also showed the importance MRM refresher training. However, in 2008, Patankor and Taylor [8] reviewed current MRM programs in the US industry and found that although initially personnel liked the new MRM programs, which in turn increased performance, this unfortunately changed over time. AMNTs and engineers became frustrated with management, which ultimately discouraged MRM initiatives. Trust between the AMNTs, engineers and management declined. The trust ingredient, along with good communications, are essential to promoting an MRM safety culture. The organization as a whole must have a strong commitment to MRM; these programs provide maintenance employees with nearly limitless tools. Without managerial and organizational commitment however, the best MRM programs cannot be sustained.

5 Success in US Military MRM Programs

After the US commercial industry integrated MRM into aviation maintenance programs with a good deal of success, the US military aviation industry took note and implemented it as well. The US Coast Guard employed MRM in 1998 and from 2002 onward had trained 100% of their maintenance personnel in MRM. As a result, Coast Guard accidents rates resulting from maintenance mishaps increased only slightly between 1998 and 2010. However, during this 12 year period, the cost per maintenance related accidents was kept stable. Considering the rising cost of parts during that time, this was truly a remarkable accomplishment for MRM. Although human error was not measured during the period, the relative stability of maintenance-related accidents for the US Coast Guard combined with the lower cost per accident is a noteworthy trend in support of MRM [9]. Another good example is that of the US Air National Guard. In 2005, an MRM program initiated by the Disruptive Solutions Process was implemented in US Air National Guard aviation units [10] in an effort to decrease maintenance-based aviation mishaps across its 88 flying wings. Over a three year period following the introduction of the MRM program, the US Air National Guard Wing reduced its aviation based maintenance accidents by 75%. In fact, the program was so successful that it was adopted by the US Air Force in 2006.

6 Who Must Use MRM and to What Extent Must They Use It?

Despite the research evidence and successes of MRM programs, the concept has not been formally mandated by the FAA. Although it has been highly encouraged, as quoted in the FAA Aviation Manual: "There are no regulations mandating any type of human factors training program, including MRM-specific knowledge or training." [11] However, the FAA does list elements of successful MRM programs [12] for maintenance organizations to develop. Understanding the complexities and varying types of aviation organizations, the FAA endorses the following five elements for a successful MRM program: senior management support, training for supervisors and middle managers, continuous communication and feedback, a systems approach and full participation. In addition to those elements, an MRM program usually consists of the following human factors related training themes: assertiveness, communication, team building, conflict resolution, stress management, decision-making and human factors performance elements [13]. Therefore, MRM is more of a recommendation than it is a regulation.

7 The Shift from MRM to MxHF at the FAA

Overall, MRM has been an excellent change agent for reducing human error in aviation maintenance, in both commercial and US military sectors. However, the MRM key elements to success (senior management support, training for supervisors and middle managers, continuous communication/feedback, a systems approach and full participation) can be somewhat difficult to achieve. Unfortunately, the continuous successful usage of the communications and teamwork themes that are taught in MRM do not always work. Failure of any of the key success factors can work against the continuous execution of the human factors practices MRM offers and ultimately hinder the entire MRM program. Management support, for example, can be difficult to foster during times of economic stress. Even if initial MRM training was well-received, if refresher training cannot be provided, the intent and continued success of the program could be lost. Another example would be the relationship between union leaders and managers. Communication and feedback, for example, could easily be affected during union/management contract negotiations. Additionally, using the FAA recommended optimal systems approach for implementing MRM through customized training, which is designed for each maintenance stakeholder, is not an easy task as it requires using an instructional design model like ADDIE (Assess, Design, Develop, Implement and Evaluate). Lastly, having the expectation of full participation in the MRM program is another challenging prospect in any commercial aviation maintenance organization. Disagreements between line technicians, maintenance engineers, and middle managers could result with tension and distrust, which undermines MRM philosophies. From these examples it is easy to see that no matter how good the intentions are to start and maintain an MRM program, neglecting any of the five factors listed could cause the program to fail.

The influence of critical success variables that loom continuously over the US aviation maintenance industry, combined with the fact that maintenance related communication and teamwork training using MRM principles is noteworthy in the prevention of human error in aircraft maintenance, the FAA set out to revise the MRM Advisory Circular of 2005. In 2017, it was upgraded to include a broader scope of aviation maintenance human factors training and reclassified as MxHF (Maintenance Human Factors Training). According to the new FAA circular, MxHF, formally known "A general process of maintaining an effective level of communication and safety in maintenance operations." [14]. The term MRM was used more widely in the 1990s than in the last decade. In comparison, MxHF is more descriptive, all-encompassing and widely used in the US aviation maintenance industry today.

8 MxHF

By being more descriptive and all-encompassing, MxHF takes on the following definition given by the FAA for human factors, "a multidisciplinary field that generates and compiles information on human capabilities and limitations, and applies it to design, development and evaluation of equipment, systems, facilities, procedures, jobs, environments, staffing, organizations and personnel management for safe, efficient and effective human performance." [15] Since 2005, Human Factors training has taken on important aspects related to communications and teamwork in aircraft maintenance environments through MRM. MxHF covers the human factors previously identified in MRM, but expands on it. Common topics that can be found in MxHF training programs include the following: human factors introduction, safety statistics, safety culture and organizational factors, human performance and limitations, the physical work environment, human error, physiological factors, communication at work, and hazards in the workplace [16]. With online training materials already available through the FAA or CASA (Civil Aviation Safety Authority of Australia) websites, MxHF training programs are not as difficult to implement. With more of an emphasis placed on comprehensive human factors training, the opportunity for an aviation maintenance safety reporting system is clear. The REPAIRER reporting system tool leverages human factors elements to effectively identify and prevent the occurrence and likelihood of human error in aviation maintenance. Such a system would bridge the gap between human factors and human error using MxHF and other safety protocols recently mandated by the FAA such as SMS.

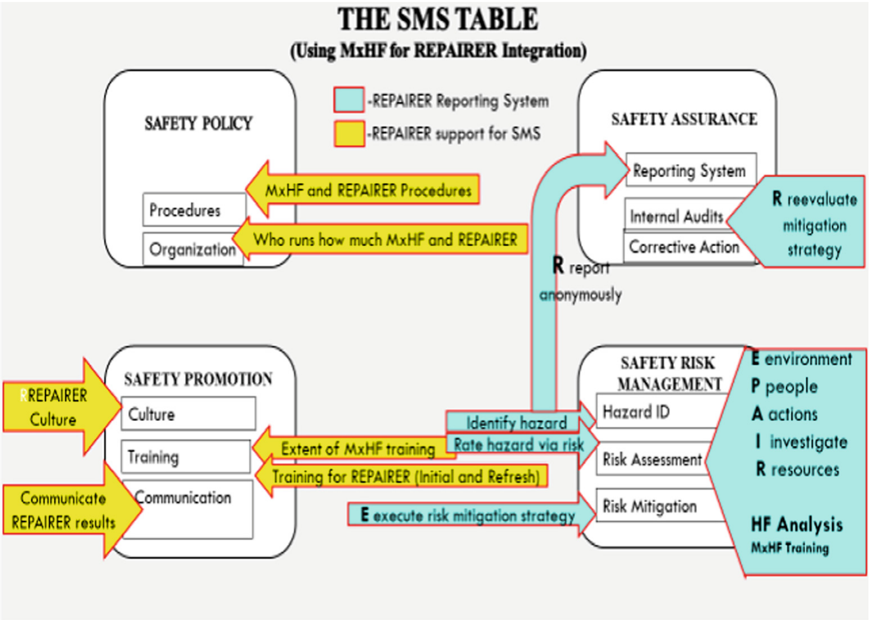

Fig. 2. The SMS Table [2] with the REPAIRER Reporting System fully integrated by using MxHF. All four support pillars of the SMS Table integrate either the REPAIRER Reporting System (blue) or REPAIRER system support (yellow). By Mark Miller 2019.

9 Integrating REPAIRER into the SMS Table Using MxHF

As depicted in Fig. 2, the implementation of the REPAIRER Reporting system into an aviation maintenance organization is now feasible. Through the recent creation of MxHF and the inclusion of the FAA's recent mandate that all US commercial airline maintenance organizations implement an SMS program, the new REPAIRER reporting system was formed. By replacing MRM, MxHF now encourages a broader range of human factors training. This element, combined with the SMS mandate, brings risk management and safety to the aviation maintenance environment more formally than in previous decades. Prior to these programs, most aviation maintenance organizations in the U.S. did not make optimal use of maintenance human factors (except in the form of team/communications through MRM) and even fewer were using a Risk Management process. As seen in Fig. 2, all four pillars of the SMS Table (Safety Policy, Safety Promotion, Safety Assurance and Safety Risk Management) can now be supported by both human factors and operational risk management through the REPAIRER Reporting System. To have such a system in aircraft maintenance that clearly addresses human factors hazards through an operational risk management process is of utmost importance for these organizations. The biggest threat in maintenance is human error. To stop or minimize this threat, the REPAIRER Reporting System must first be addressed via the Safety Policy pillar.

10 SMS Safety Policy and REPAIRER Integration

When implementing the REPAIRER Reporting System into an aviation maintenance organization, it is imperative to first formally write down the scope of the program, as depicted in Fig. 2 under the Safety policy pillar. Procedurally, the details of the REPAIRER Reporting System need to be laid out as a road map of how the REPAIRER Reporting System will be run in the organization and for legal liability protection. Because the REPAIRER Reporting System will rely on MxHF training, the specific human factors training which the organization desires must be written as a prerequisite in order to use the REPAIRER Reporting System properly. Once the MxHF training is designated (from what is available on the FAA website), the entire break down of the REPAIRER Reporting System must be explained in relation to that particular maintenance organization in accordance with how each letter of the acronym will be carried out. In doing so, the core area of 'Procedures' is carried out in support of the safety policy pillar and SMS requirements. The second core area in SMS Safety Policy that must be addressed is 'Organization'. It is important to determine who will be responsible for the MxHF training and the overall support for the REPAIRER Reporting System; for this is essential to the overall success of the system. Through both the 'Procedures' and the 'Organization' aspects of the SMS Safety Policy, the REPAIRER Reporting System essentially has an implementation starting point for the organization.

11 SMS Safety Promotion: Training for MxHF in REPAIRER

Switching now to the Safety Promotion pillar of the SMS table in Fig. 2, both cases of human factors (MxHF) and REPAIRER training, can be tailored and customized for the type and size of the aviation maintenance organization that will utilize the REPAIRER Reporting system. This is relevant as the REPAIRER Reporting System is meant to be cost effective, as opposed to MRM which was costly in terms of training and applicable implementation systems. The REPAIRER reporting system, however, leverages the human factors training materials provided by the FAA. Using the provided human factors analysis, the 'EPAIR' portion of the REPAIRER system is achieved. Other crucial elements that fall under the Safety Promotion pillar include culture and communication. To ensure optimal use, the REPAIRER Reporting System requires initial and annual follow-up training. Continued use allows the tool to be integrated into the existing aviation maintenance culture. Where MRM required a systems approach through the use of a detailed instructional design tool, REPAIRER only requires a computer-based instructional format, or a classroom format if needed. Ideally, the creation of a web computer-based training (CBT) which combined the specific human factors element along with the MxHF training materials would be the most effective form of low-cost training for both initial and refresher REPAIRER training.

12 SMS Safety Risk Assessment: Identifying, Risk Assessment, and Reporting Hazards – 'R' (Reporting Step in REPAIRER)

In the Safety Risk Management pillar of the SMS Table shown in Fig. 2, the first part of the first '**R**' in the REPAIRER Reporting System must be completed. In this initial step, the hazard within the maintenance environment must be identified and assessed using risk management. This would seem like an easy task, but sometimes the hazard can be somewhat difficult as it may be a confluence of human factors errors coming together. Once the hazard has been identified, it then needs be assessed utilizing a risk assessment matrix, noting the severity and exposure as critical variables. These two variables will ensure the hazard receives an accurate rating assessment ranging from low (non-threatening) to high (dangerous) and can be helpful in prioritizing the hazard. This form of rating has been proven successful in the U.S. military for over two decades in the form of Operational Risk Management. It is simple to use and highly effective. High rated hazards need to be addressed first, while low rated hazards can be addressed at a later date or when time permits. Rating the hazard initially also provides the maintenance organization with data on just how dangerous the hazard was prior to the implementation of corrective measures. Once the maintenance hazard has been thoroughly identified and rated, it then needs to be reported. To complete the minimum for reporting a hazard it must be identified, risk rated and then reported into the reporting system. To accomplish this, the '**R**' (Reporting step) shifts in the SMS table to the Safety Assurance pillar in Fig. 2. The idea is to create a Safety Assurance Reporting System which continuously demonstrates that safety is an ongoing process within the maintenance organization. Additionally, by setting up an anonymous reporting system, maintainers will be invited to continuously participate in safety without fear of retribution. If it the reporting system is set up properly, the maintainers will be able to see the hazard they reported and follow that hazard through the process.

13 SMS Risk Assessment: Human Factors Analysis of the Maintenance Hazard – ‘EPAIR’ (MxHF of REPAIRER)

What sets the REPAIRER Reporting System apart from other popular safety strategies is that it is process driven. It is based on criteria that must be met by each of the four pillars of the SMS table. Secondly, it is centered on being a Reporting System that involves all maintainers in the safety process. Thirdly, it utilizes a scientific risk management rating system and most importantly, it directly links maintenance human factors to human error. Human factors engage several aspects of aviation maintenance: physiological, psychological and ergonomic (human interface engineering). To properly use the elements in maintenance to correct for human error, it is necessary to infuse them into the REPAIRER model via the human factors analysis and risk assessment.

The ‘**E**’ in the EPAIR represents the specific maintenance environment where the actual hazard occurred. This includes the physical layout such as lighting and temperature, but also the internal organizational environment at the time of the hazard. The ‘**P**’ stands for the people involved. Basic things like poor qualifications and training need to be reported along with any physical, physiological, psychological and ergonomic issues that could be relevant to the hazard. The ‘**A**’ in the EPAIR human factors analysis method stands for the actions of the people involved. Because the aviation maintenance research points toward procedural problems in terms of human error causing a high percentage of 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 EPAIR method stands for the investigation of the proper procedure that was associated with doing the wrong maintenance action in the previous letter ‘**A**’ for action. This step is critical because it is imperative to know exactly how the maintenance action was performed incorrectly, but it is also equally important to know how it should have been done correctly. This step is important because there is a chance that the current procedure is unsafe or inefficient and needs to be amended. The next letter in the EPAIR to complete the human factors analysis in the REPAIRER Reporting System is the ‘R’. This is the second ‘**R**’ for the resources that were required in the hazard. If the resources required to complete the maintenance task were inadequate or used improperly in relation to the hazard, they will need to be reported here.

14 SMS Safety Risk Management and Mitigation of the Maintenance Hazard – the 2nd ‘E’ in REPAIRER (Executing Mitigation Strategy)

With the human factors analysis of the hazard complete, a sound mitigation strategy for the maintenance hazard can now be created. Not only is the human factors analysis a large part of the hazard assessment, but it also plays an important role in finding a solution. The goal of the mitigation strategy is to lower the initial risk rating of the hazard to acceptable levels, making the maintenance organization safe from that particular hazard. At first, the solution is simply a plan on a drawing board. But at some point, the plan will be carried out and the mitigation strategy becomes the 2nd '**E**' in REPAIRER for 'Executing'. It is important to make sure the mitigation strategy is executed and carried out successfully. The challenge with this step is following up on the strategy with some form of reevaluation to prove that it is meeting the original intent of reducing or eliminating the hazard. This is the last step in the REPAIRER Reporting System; '**R**' for 'Reevaluating' the hazard. To accomplish this, it is important to venture back to the Safety Assurance pillar in the SMS table of Fig. 2. Under the Reporting system are two important SMS methods that stand out to ensure that the hazard mitigation strategy was working as expected or not. Internal audits are perhaps the best option through tracking the hazard in the REPAIRER Reporting System and then seeing how successful the mitigation has been. If the audit proves the mitigation strategy successful and the risk has been reduced, then the mitigation strategy has completed its job. However, if the audit finds that it failed to reduce the hazard to safe levels, it is time to make a 'Corrective action' as listed in the Safety Assurance pillar in Fig. 1. and continue to audit.

15 Conclusion: Building a Safety Culture Through REPAIRER

The idea of using a safety reporting system like REPAIRER for aviation maintenance organizations to be the cornerstone of safety is not an unrealistic goal. It has all necessary elements (safety reporting, risk management, and human factors) working together to create an efficient and effective safety process. Timing is also important; in 2019 the FAA encouraged aviation maintenance organizations to use the MxHF aviation maintenance human factors training to replace MRM. To accomplish this, the FAA emphasizes the use of their online human factors training materials. Additionally, the FAA is also encouraging aviation maintenance organizations in the US to adopt the elements of the SMS Table. As demonstrated in the paper, the REPAIRER Reporting System either fulfills the SMS element requirements directly through the REPAIRER or through the necessity of support for the REPAIRER with one exception. The exception occurs under the SMS Safety Promotion pillar in the form of the 'Culture' element within the SMS Table in Fig. 2. To have true, impacting long term success in an aviation maintenance organization, the REPAIRER Reporting System would have to be adopted by the maintainers in that organization as part of their daily operations. To be a REPAIRER culture, everyone in the organization would have to believe in the system and actively work to support it. Maintenance personnel must understand that by using a combination of risk management and human factors that have been integrated with the proven SMS elements, the REPAIRER Reporting System will save lives, resources and improve morale. They will be motivated to use it as it something practical that will seamlessly blend in with their jobs. Organizations that develop successful cultures not only gain in efficiency, but also have highly motivated employees that are engaged and involved, ultimately giving the organization a competitive advantage. A REPAIRER Reporting system for aviation safety is waiting on the shelf and is poised to be implemented into an aviation maintenance organization to form a winning safety culture. The time is now.

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Influence of the Human Factor on the Risk of Work on Scaffolding

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Abstract. As a result of the identified safety threats in the construction, the research project have been developed in Poland entitled Scaffold Use Risk Assessment Model for Construction Process Safety SURAM—financed by National Centre for Research and Development –NCBIR- PBS3/A2/19/2015 in the period 2016–2018. This paper is focusing on human factor area and implementation of SMIs' mobile Eye-tracker and further data analyzed by Be Gaze tool, also provided by SMI company to estimate worker visual concentration as an potential predictor of probability of developing dangerous situation leading to the occupational accident.

Keywords: Human factors · Ergonomics · Scaffold · Eye tracker · Visual concentration

1 Introduction

Construction activity is still characterized by a high level of threat to the employees' health, as well as a high accident rate. The results of occupational accidents analysis in 28 countries of the European Union completed in 2014 indicate that the construction industry was in 3rd place among all sections of the economy regarding the total number of occupational accidents; in 2nd place regarding the frequency of accidents causing longer (more than three days) absence from work; and in 2nd place regarding the rate of fatal occupational accidents. Organizations costs spend on injured people in 2009, was an amount of 73.9 billion USD [1]. In 2006, OSHAs' reports show that lost productivity in 2006 due to injuries during work and illness cost companies $60 billion. Production accounted for 20% of all injuries to the musculoskeletal system [2]. The costs of accidents at work, as well as work-related illnesses and injuries are significant. According to EUROSTAT' s 2007 schemes, in the EU-27, 5.580 work-related accidents have been fatal, and 2.9% of workers had situation at work, that led to more

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 58–68, 2020.
https://doi.org/10.1007/978-3-030-20497-6_6

than three days of absence. In addition, over 23 million people suffered for health problems occurred or worsened by work over a 12-month period [3, 4]. In 2013, statistic of fatal accidents injuries shows for Britain (2.94 per 100,000 employees), Germany (0.81 per 100,000 employees), Italy (1.24 per 100,000 employees) and Spain (1.55 per 100,000 employees)) [5]. In 2013, 1.4% of peoples' sick leave was caused by injury that occurred at work (1.8%) in Italy (1.8%) and France (3.1%). At the same time in Poland there was (0.7%) [6]. In the same year, 1.9% workers' time off work was taken in consequence of work related health problems, as follow: UK, Italy and Spain, each (2.8%), France (5.4%) and Poland (7.7%) [6]. Healthy and safe work surroundings are not only desirable from the point of view of employees, but also increase productivity, the same affects economic growths. OSH affects the reduction of costs caused at work and related diseases, increasing the motivation of employees, which increases the competitiveness and productivity of enterprises. In addiction in the case of social and private insurance, there is soothes pressure by decrease of accidents and illnesses Health and safety hazards in the workplace abound with the world's current, showed by the International Labor Organization (ILO) estimates that 2.34 million have died from occupational injury or illness in 2008: 2.08 million from disease and 321,000 from accidents. Besides, calculations show that 317 million accidents without fatalities influences on absence for at least four days, especially in Southeast Asia and Western Pacific [7]. Further researches show that 160 million people are suffering in consequences of occupational exposure to harmful factors and occupational diseases (ILO, 2003). Consequences of accidents in industries can influence on environment, causing significant damages, that in the result effect on people. Developing countries are not the only ones affected by the increase in risk of occupational accidents. In the EU-27 in 2007, 5,580 accidents in working conditions resulted in death and 2.9% employees in consequence of work-related accident are absent at work at least three days. Approximately 23 million people suffered for health problems or worsened by work over a period of 12 months [5]. Probability of accidents differs due to gender location or industry. As researches shows it can reach, only in European countries the level of five fatal accidents per 100000 workers, like in Poland, or less than one, in countries like Denmark, Germany, Denmark or the Netherland, United Kingdom or Slovakia, although some figures may be subject to underreporting, as discussed later [8]. In terms of industries, within the EU-27 in 2009, the construction, manufacturing, transportation and storage, and agriculture, forestry and fishing sectors accounted for more than two thirds of all fatal accidents at work. The construction sector alone accounted for 26.1% of all fatal work accidents [5]. In addition to accidents, exposure to hazardous substances at work is believed to contribute significantly to mortality through carcinogenic and respiratory diseases. For example, exposure to occupational carcinogens alone is estimated to result in a global disease burden of 152,000 deaths and nearly 1.6 million disability-adjusted life years [9]. In addition, prevalence rates among European workers indicate that in 2007 a total of 23 million workers or 8.6% of the workforce (aged between 15 and 64 years) suffered from work-related health problems. The health problems most often reported in 2007 were MSDS (musculoskeletal disorders), stress, depression and anxiety [3]. These injuries and deaths not only cause human suffering for workers and their families but also result in significant economic costs to individuals, businesses, government and society. Potential negative effects include costly early retirements, loss of skilled staff, absenteeism, as well as presentism (when employees go to work despite illness, increasing the likelihood of errors occurring), and high medical costs and insurance premiums. Organization for Economic Co-operation and Development (OECD) countries already spend 2.4% of gross domestic product (GDP) on incapacity-related benefits (OECD, 2006). At the same time, the ILO estimates that many of these tragedies are preventable through the implementation of sound prevention, reporting and inspection practices. The ILO puts the loss of global GDP due to occupational diseases and accidents at 4% [10].

2 Method of Research

Taking into consideration the frequency of accidents and high occupational risk in the construction industry with scaffold use, it is crucial to take the effective action to reduce this risk. In these conditions the research project Scaffold Use Risk Assessment Model for Construction Process Safety (SURAM) - *PBS3/A2/19/2015* – financed by National Centre for Research and Development (NCBiR) has been developed in Poland from early 2016. The SURAM project's objective were to develop a model for assessing the risk of construction disasters, accidents and hazardous events at workstations using facade scaffolding, especially during construction work. According to data presented by Polish Central Statistical Office (GUS) in 2016-year report over 50% of occupational accidents are classified to one, that are caused by human factors [11–13]. As it shows, human factors couldn't be overlooked in the process of research.

The research project have been carried out within a consortium consisting of the following units: Lublin University of Technology, Lodz University of Technology, Wroclaw University of Technology. A number of 120 construction sites with scaffold use in Poland and 20 in Portugal (as the control group) were examined during the research project period. Instrumental methods were also involved to assess harmful and cumbersome work conditions:

- Technical scaffoldings' conditions (static strength calculations).
- The level of taking into account the ergonomics' requirements – safety engineering and regulations in shaping scaffolds.
- Workload, procedures and regulations of safety during assembly, usage and dismantling of scaffolds.
- Psychophysical condition of workforce working in the scaffold environment – stress, physiological parameters, staff experience, etc.
- External factors influence – noise, lighting, dustiness, external vibration, as well as climate conditions.
- Social-economic factors indirect influence.

Focusing on Human Factors' impact on the accident risk at workplaces with scaffold use 3 of research methods will be presented in more detail:

Monitoring the Basic Physiological Parameters of the Employee in the Work Process Using the Pulsometer. To monitor basic physiological worker parameters during the shift Garmins' with scaffold dedicated mode have been implemented during research project. The pulsometers selected for the research application were with surface GPS and TOPO mapping built-in sensors, include 3-axis compass, gyroscope and barometric altimeter as well as GPS and GLONASS capability that lets us mark entry and exit points for surface navigation. Features Elevate™ wrist heart rate technology[2] with multisport activity profiles that can be personalized for each worker examined [14]. Tool was chosen not only because of its simplicity in usage and resistance, but mainly because of its accuracy. As the Korean Society of Medical Informatics Publish in 2015-year accuracy of wearable devices for activity tracking and hart rate monitoring are in accuracy between 79,8% and 99,1%, placing the Garmins' tool on the top of all examined [15]. It was remarkable to describe human parameter such as heart rate, time of work, burned calories, during work on as well as near to scaffolding. Those parameters were presented in cooperation of direct place of work describe not only by high but also as a path presented on a accurate map. Those data are collected thanks to built-in GPS.

This tool was use at least on one randomly used worker from 3 up to 5 workdays on each scaffold that was examined during SURAM project. Worker that have been measured was also observed by a researcher, according to specification of the work position.

The Dedicated Research Questionnaire. The original, questionnaire have been prepared and previously validated for the research project. Questionnaire included 46 questions representing dedicated psychrometric scales modules. Both CAPI and PAPI techniques have been used to collect the data. Subsequently, a random sampling procedure was conducted to select individual workers at each construction site; 234 individual workers of those sites potentially exposed to occupational hazards were selected in the first year of the project. For the purpose of the SURAM 572 individuals have been interviewed. An original questionnaire for risk perception and safety climate assessment at the construction site has been developed. The questionnaire has been focused on six scales S_{SOC} (life coherence and social associations) – contain 11 questions, S_{LOC} (sense of control) – 10 questions, S_{IZZ} (occupational praxis and psychical attitude) – 10 questions S_{PR} (risk perception) – 8 questions, S_{LKZ} (health state) – 5 questions, S_{LWO} (value hierarchy) – 11 questions. Out of those scales there were also use other 7 predictors. Kaiser-Mayer-Olkin test have been used to measure sampling adequacy and Bartletts' test of sphericity has been involved for evaluating correlations [16–18].

Visual Concentration While Performing Work Tasks at Scaffold. As can be determined on the basis of the subject matter analysis (research rapport and literature studies) the first head mounted eye tracking tool have been developed in late 40's. However, its' still mainly used to carry out researches related to work on the visual information environment, websites analysis and computer applications, is rarely used elsewhere [19–22]. Eye tracking tool produced by SMI company contains protected glasses with built-in camera, which have and phone with built in software. This modern tool gives us opportunity to record, track and analyze visual concentration path, personalization of collected data is a result of calibrating tool to every single tasted separately [23]. In SURAM project we had only one eye-tracking mobile tool so we couldn't use it on each scaffolding to every worker so research of visual concentration was provided on randomly selected workers in scaffoldings surrounding, mainly in Lublin's area, but there were also control samples in Lodz, Warsaw and Gdansk. Total of measurements collected is 36 shifts. Time of single lot measurement was at least 30 min. On the beginning we tried to provide one measurement at least 1,5 h long, which is a time of long lasting one standard battery during measurement. Quickly we had reverse information that this seems to become uncomfortable after working with it more than 60 min, so we had to shorten period of single research lot to avoid research errors that could occur in consequence of subjective sense of comfort in the work process while using eye tracker mobile device. There was unique implementation of eye-tracking analysis in the real time at the construction sites and particularly at the workplaces with scaffold use. The saccade movements analyses and the visual concentration maps have been performed. Areas that should be recognized by workers, to increase safety are often overlooked, or the concentration on those points is negligible. We may conclude that behavior of scaffoldings' workers is more like following an amount of mini habits, which leads main focus of visual concentration out of work and often out of scaffolding area.

3 Results

3.1 Work Parameters

To present full view of worker, while analyzing his visual concentration, it is crucial to look wider and present those data in correlation of risk perception, work load level and finally visual concentration, as it have been shown in Table 1 below. There are presented three regions Lublin Voivodeship Lodz Voivodeship and Lower Silesia. As we can see workload of workers on scaffoldings are very high, placing from 88% up to almost 97% with Lower Silesia presenting comparatively lowest work load with minimum of 0,8869 allowed work load (8000 kJ per 8-h shift). With that high parameter of work load we can see that visual concentration is under 50%. What seems to be important that visual concentration decreases significantly, while workload increase, while we compare Lublin Voivodeship to Lower Silesia, but in Lodz Voivodeship decreases of work load is over 0,06, while difference between eye concentration is only a decrease of 0,0062. Risk perception felt by scaffolding workers is rated below average, which we can see from medians 0,375, 0,45, 0,4333. The differences presented in Table 1 were significant at CI = 95%. In the data presented below it is hard to find correlation of visual concentration and risk perception.

Table 1. Analysed work parameters in selected regions of Poland.

Analyzed Region & Variable	Valid N	Median	Min	Max	Lower (Quartile)	Upper (Quartile)	Percentile (10)	Percentile (90)	Quartile (Range)
LUBLIN Voivodship									
Risk perception (0,1)	146	0,4333	0,05	0,7167	0,3667	0,5167	0,2667	0,5667	0,15
Visual Concentration (0,1)	146	0,362	0,286	0,672	0,294	0,372	0,286	0,372	0,078
Work Load level (0,1)	146	0,9661	0,8733	0,9987	0,9009	0,9946	0,8733	0,9987	0,0938
LODZ Voivodship									
Risk perception (0,1)	98	0,375	0,25	0,6333	0,3333	0,4333	0,2833	0,4833	0,1
Visual Concentration (0,1)	98	0,3558	0,281	0,661	0,289	0,3657	0,2811	0,3657	0,0767
Work Load level (0,1)	98	0,9021	0,8379	0,9899	0,867	0,9774	0,8379	0,9899	0,1104
Lower Silesia									
Risk perception (0,1)	89	0,45	0,2167	0,6333	0,3833	0,5	0,3	0,5667	0,1167
Visual Concentration (0,1)	89	0,4366	0,345	0,811	0,3546	0,4487	0,345	0,4487	0,0941
Work Load level (0,1)	89	0,8869	0,8429	0,9536	0,8429	0,9536	0,8429	0,9536	0,1107

3.2 Pulsometer Results

As a result of collected data, among others, describing hart rate of scaffolding workers are presented on chosen examples below on Figs. 1, 2 and 3. The work cost could be determined using one of widely accepted methods [24]. As we have found out most of the monitored workers have work area maximum between 3 close levels of scaffoldings during one work day, as we can see more in detail on map like shown on Fig. 4

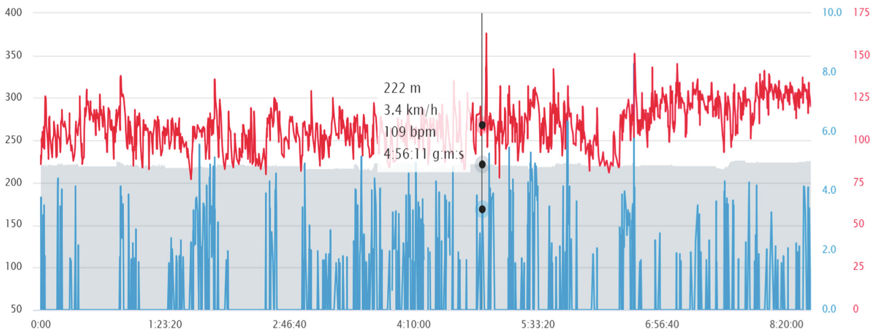

Fig. 1. Parameters collected by Garmin pulsometer - Hart rate (red), speed (blue), high (grey). Data collected on L15 Scaffolding 1st day of measurement.

movement are more often horizontally than vertically. Speed influences on a growth of heart rate but is not the key factor. Observation shows that often changing a position of body during work influences on slight growth of heart rate, like banding as well as turning in other directions, while working on scaffolding.

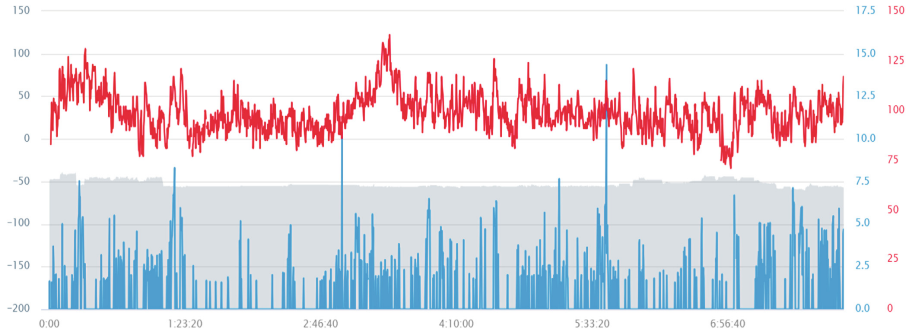

Fig. 2. Parameters collected by Garmin pulsometer - Hart rate (red), speed (blue), high (grey). Data collected on L18 Scaffolding 1st day of measurement.

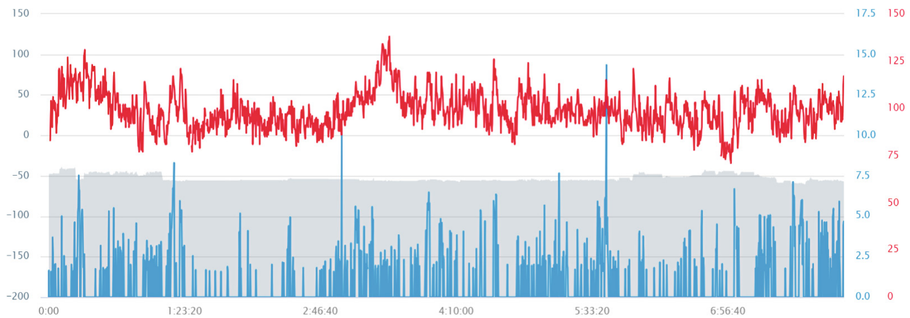

Fig. 3. Parameters collected by Garmin pulsometer - Hart rate (red), speed (blue), high (grey). Data collected on L24 Scaffolding 1st day of measurement.

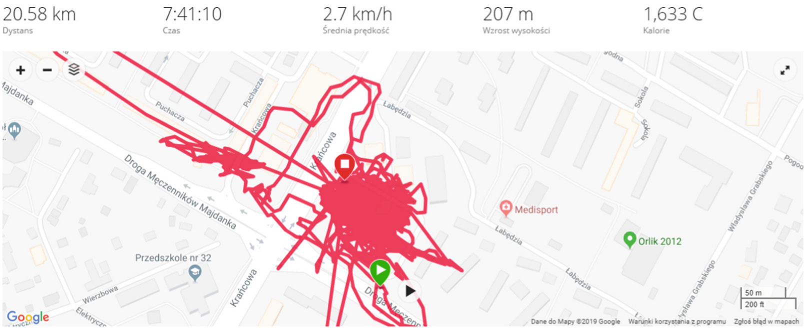

Fig. 4. Map of worker movement L24 Scaffolding 1st day of measurement.

3.3 Eye-Tracker Results

Measurement of eye movement and points of its concentrations shows how worker see his work area. That what we don't notice is that only those point of visual concentration is seen clearly, rest of surrounding we only see blurry. To determine safety of human factors, we find it very important to find out where are points of visual concentration. On example of one chosen worker we can see on Fig. 5 as well as on Fig. 7 that area of main visual concentration is out of scaffolding, next point of concentration is on work area. Scaffolding itself is not a point of a visual concentration, what exactly show scan path of visual concentration on Fig. 6.

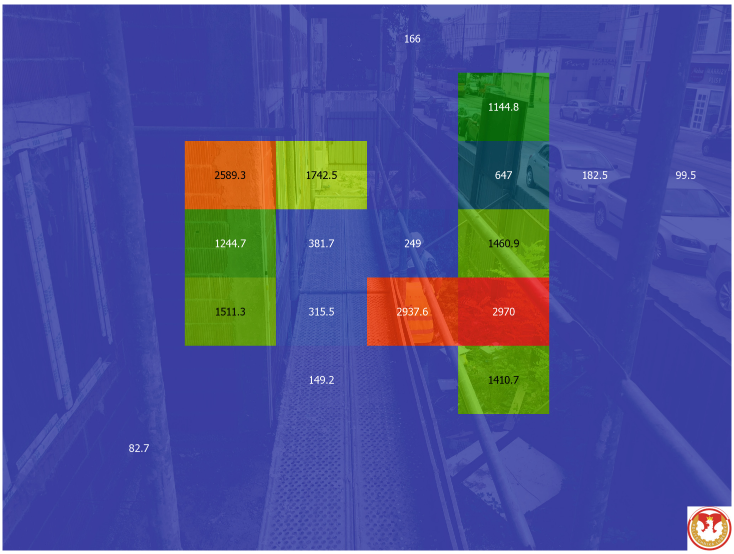

Fig. 5. Gridded AOIS measured by eye-tracker on E23 scaffolding in Lodz

Fig. 6. Scan Path measured by eye-tracker on E23 scaffolding in Lodz

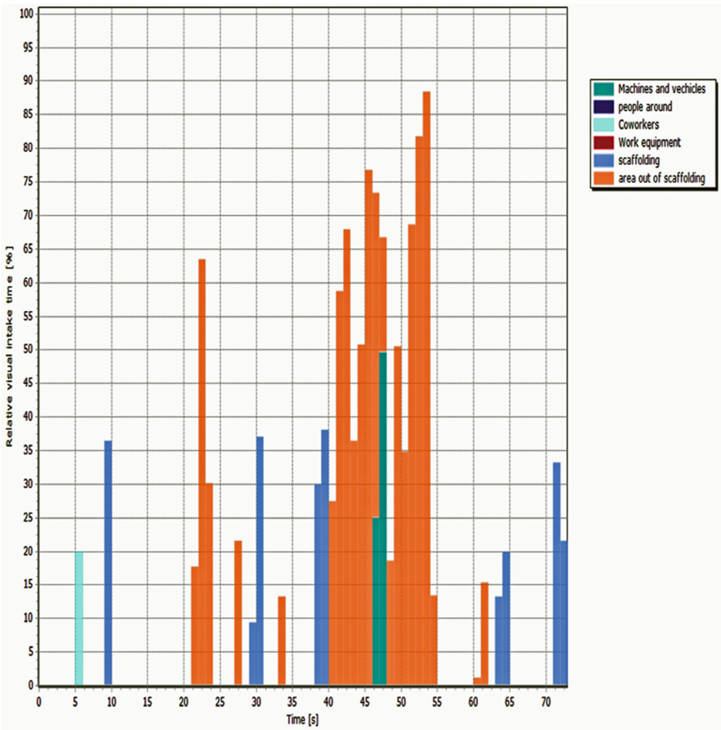

Fig. 7. Estimate time of eye concentration on scaffolding measured during SURAM project

4 Conclusion

While creating a visual concentration maps in usage of data collected by eye tracker, it seems that pattern appears, which shows area of workers visual concentration, which is out of scaffolding area and what is alerting, that even during movement on scaffolding visual concentration on scaffolding itself is negligible.

Another alerting factor is that part of the job on scaffolding is work on one small area of the work surface, which with the passage of time increases the number of visual focus points outside the work area. Results of our study shows that during assembly as well as disassembly of scaffoldings visual concentration (median value) on work area is reduced to less 50% of total observation time.

It seems that human factor and its lack of concentration on the work area affect directly on the increase of risk during work. The only factor, that seems, that correlate with increase of visual concentration on scaffold area is workload. According to this further research should be carried in the direction of founding solutions to increase visual concentration on scaffolding and decreasing a workload.

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The Sailport Project: A Trilateral Approach to the Improvement of Workers' Safety and Health in Ports

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Abstract. This work presents a novel method for the improvement of safety and health in ports. Traditional and consolidated approaches to this goal are based on questionnaires and training activities that Local Health Authorities and the National Institute for Insurance against Accidents offer to the personnel of the companies that work in the port. We propose to complement this method by means of quantitative and pervasive measuring of risks related to safety and health. For the former, we propose a system that measures the collision risk in relevant areas of the port by means of cameras. For the latter, workers wear inertial measurement units and EMG electrodes to estimate the biomechanical overload. The results of these three actions are then merged and presented to the selected companies to make corrective actions, in order to reduce the safety and health risks for the port workers.

Keywords: Workers safety · Work-related musculoskeletal disorders · Biomechanical overload · Machine learning · Surveillance

1 Introduction

Work activities inside ports expose workers to remarkable safety issues and ergonomic risks that endanger the quality of their lives, sometimes resulting in permanent injuries or death. Statistics related to injuries in ports witness a special need for a focused and strong action towards an improvement of safety. This is particularly difficult in ports, where workers from several companies share the same workplace. At the same time, working activities in the port are typically unstructured and characterized by high biomechanical overload risks causing a high incidence of Work-related Musculoskeletal Disorders (WMSDs) among workers. On this basis, the National Institute for Insurance against Accidents at Work (INAIL), Scuola Superiore Sant'Anna and the

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 69–80, 2020.
https://doi.org/10.1007/978-3-030-20497-6_7

Local Health Authorities (ASLs) for the surveillance over eight Italian ports have devised the Sailport project, a trilateral approach to improve both safety and health of dockers. The component actions are described in this paper. The first action (Sect. 2) targets risk prevention and its goal is to transfer best practices for the evaluation and management of risks to the companies working in the ports. The second action (Sect. 3) aims at improving safety within selected areas of ports by monitoring the collision risk. Finally, the third action (Sect. 4) targets dockers health, in particular regarding WMSDs, strengthening the biomechanical overload monitoring.

2 Improving Risk Perception

The first action of the Sailport project involves eight major ports along the whole Italian coasts: Livorno (together with the near port of Piombino), Civitavecchia, Taranto, Bari (and the smaller ports of Mola and Monopoli), Ancona, Ravenna, Venice (and the seamanship of Chioggia) and Trieste. The aims are to make companies and workers in these ports aware of the risks of their activities and to foster improvement of their risk management system.

The action is composed of eight phases: (i) INAIL and the ASLs have structured a common framework to draft prevention plans based on questionnaires, checklists, training initiatives and success indicators that monitor plans implementation in selected port companies. Questionnaires address companies' self-evaluation of their risks prevention and management systems and assess workers' self-perception of the level of risk of their activities. Checklists assist companies in the organization of their risk prevention and management system and help achieving best practices in the field. Training initiatives cover methods, in particular the injuries analysis model Infor.Mo, and resources available to improve the performance of risk prevention systems. Infor.Mo [1, 2] is a multifactorial model and allows to expose in a structured and standardized way the accident dynamics, or that sequence of events that led to the occurrence of the accident. The Infor.MO model is applicable in all sector working activities and to each type of event, so not only fatal but serious too, and even the near misses (accidents, near the so-called misses). The common framework was shaped by each ASL to fit the local port activities in terms of questionnaires scope, checklists items and training contents. (ii) A pool of companies has been selected and invited to participate in the prevention plan and (iii) to take relevant training sessions. (iv) The selected companies are using the self-evaluation questionnaires and checklists and taking training sessions. (v) ASLs are auditing the compliance of selected companies with the prevention plan. (vi) Workers are answering the questionnaires on their self-perception of risks. (vii) The answers of workers and audits results will be analyzed and compared with the indicators defined at step one to verify the intervention effectiveness. (viii) Results will be shared with companies to foster the emergence of best practice for risk prevention and management in port areas.

2.1 Analysis of Ports Local Context

Following the establishment of the common framework for the prevention plans, one major strand of the Sailport project activities has been the analysis of which companies operate in each port and which are their activities most significant for risk prevention and management. The goal was to provide a basis for implementing the first action in the participating ports. The information for this analysis came from surveillance systems implemented by ASLs, the co-operation with local port authorities and the results from previous initiatives analyzing and improving risk prevention and management in port companies.

Based on the local context analysis, the ports chose what activities are more relevant to become the Sailport actions target, and consequently adapted questionnaires and checklists, designed training interventions and invited companies to take them.

2.2 Specific Prevention Plans in Different Ports

The targets of the prevention plans are companies operating in the docks and within other port areas for loading and unloading of goods, containers and other material handling, and companies performing mooring and unmooring operations. Thus, the Sailport project can consider different risks, specific to the type of goods and tasks that characterize the participating ports. Furthermore, both the working tasks and the organizational aspects of the risk prevention systems of companies are addressed in the project. Therefore, different choices were made in different ports for the scope of the Prevention Plan (PP) developed.

The PP for the Venice port aims at verifying the appropriate implementation of safety management systems, investigates risk perception of workers aboard fishing vessels, and offers training for promoting safe behaviors of truck drivers operating in the port. In the Taranto port, handled goods are mainly related to the steel industry, cement and concrete products and the oil and gas industry. The PP addresses the organization of the workers' safety and health management in the port through the improvement of companies' procedures for risk evaluation.

The PP of the Ravenna port deals with the handling of large iron and steel industry products and includes the collaboration with an industrial engineering university department for testing the applicability in the port of technologies for a safer and more reliable movement of such large products.

The ASL of the Trieste port is already auditing the adoption of a model for the organization and management of safety in the port companies participating in the PP. One typical activity of this port is the handling of bags of green coffee beans. However, the companies participating in the PP are in general terminal operators, port services providers, logistics operators and staffing firms operating in the port.

The PP for the port of Ancona is aimed at developing and testing best practices for managing and reducing factors related to collision risks during loading/unloading operations. The targeted port area hosts in fact logistics and custom-related functions, ship loading and unloading zones, storage and truck parking facilities and silos for grain storage.

The PP devised by the ASL in the Bari area involves the port of Bari for dock activities, and those of Mola and Monopoli for activities on board fishing vessels. The PP for the dock area deals with the evaluation of risks due to interferences during goods load/unload operations and to the exposition to the dust and chemical agents during dry bulk handling. For the fishing activities, the PP includes video and photo shootings aboard the fishing vessels during operations. This material will be used for specific training interventions about the most relevant risks arising from fishing.

The PP for the Civitavecchia port chiefly addresses organizational improvements of the risk prevention and management systems of the companies operating in the port. Indeed, questionnaires and checklists were developed for assisting port services providers in analyzing their organization for work safety and implementing an improvement program of their organization for the general aspects of risk prevention and management and according to specific homogeneous groups of workers.

For the port of Livorno, the PP is focused on containers lashing operations inside the cargo ship and containers crane handling in the dock area. The port of Piombino is also involved for implementing this PP. Working tasks of companies within selected areas of these two ports are also the focus of the experimental campaign based on machine learning and wearable technologies underpinning the two remaining actions of the Sailport trilateral approach described in the following sections.

3 Monitoring the Collision Risk

This section explains in details what is the approach taken in the context of the Sailport project to monitor and assess the collision risk in port areas.

Collisions are one of the main causes of dockers' injuries. Although there exist safety rules to reduce the collision risk, the number of accidents is still high. Accidents take usually place in areas in which several companies, including ship operators, port companies for material handling and track companies act together, as in the proximity of a quay. Dockers and vehicles are often not coordinated, thus making rule violations increase the collision risk dramatically. Monitoring this risk is a solution to reduce it even in case of rule violation. The idea is to alert each actor in the selected area when the collision probability exceeds a given threshold. To monitor the collision probability, selected areas are equipped with cameras, which allow for obtaining co-located and synchronized video streams. State-of-the-Art (SoA) machine learning algorithms are applied to such images to identify people and vehicles. Co-location and triangulation allow to estimate their reciprocal distance as well as their velocity. In a first phase, this information is used to monitor patterns inside the area. Then these patterns allow to define heuristics to score the collision risk. Finally, we aim at using these patterns to make predictions of the collision risk in a short time horizon to provide dockers with a timely feedback about the collision risk (Fig. 1).

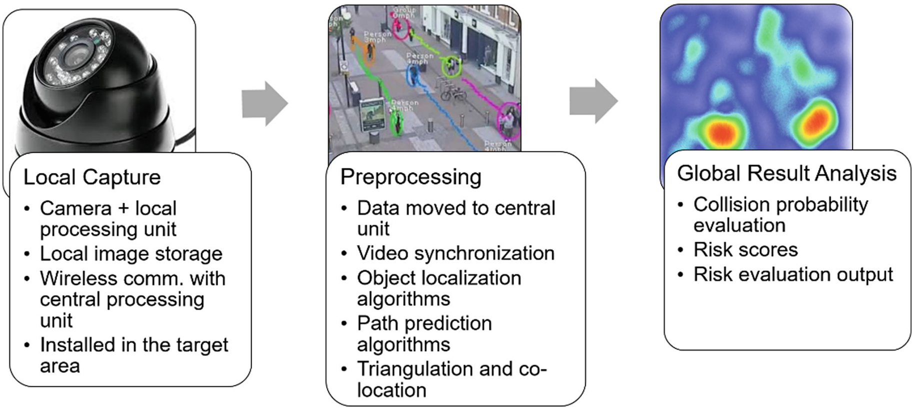

Fig. 1. Overall pipeline of the video surveillance and risk assessment system, from local acquisition and storage of images to high level results about human vehicle interactions.

3.1 Unambiguous Detection of People and Vehicles

The detection of people and vehicles from the video stream is entrusted to YOLOv3 [3], a popular and SoA deep learning-based localization algorithm that emits the bounding boxes of objects found in the scene.

YOLOv3 is fast and precise, configurable and extensible.

1. *Configurable* because a “detection threshold” can be set to arrange the desired tradeoff between the number of false positives and false negatives. That is, the higher the detection threshold, the lower the number of false positives.
2. *Extensible* because YOLOv3 can be “fine-tuned” to localize objects not present in the dataset it was trained with.

Nevertheless, as YOLOv3 is a deep learning-based method, it requires a powerful GPU (Graphic Processing Unit) to be run in a reasonable amount of time (less than one second per image). This implies that it cannot be executed by the computing nodes attached to the cameras. As a consequence, data processing is done offline by a remote server or by the desktop computer located on site. The approach requires the intervention of a human in two steps: first, the “fine tuning” process requires a human to label the bounding boxes of the objects that have to be recognized; second, YOLO outcome requires a few post-processing to avoid perturbed data.

Once the 2D locations of the bounding boxes are identified by the localization algorithm, it is necessary to understand which the bounding boxes are representing the same object in the various images.

A simple and tested solution is to compare the color histograms of each bounding box and assign an association between bounding boxes according to a given distance metric. The matching between bounding boxes should be bidirectional since the number of located objects in the two images may be different. Preliminary experiments suggest the use of the Battacaryya distance [4] as distance metric, even though the creation of a labeled dataset obtained from the video captures of the dockers is needed in order to assess the quality of the association. Figure 2 shows an example of a processed frame couple captured during a test performed in the parking area of the PERCRO laboratory.

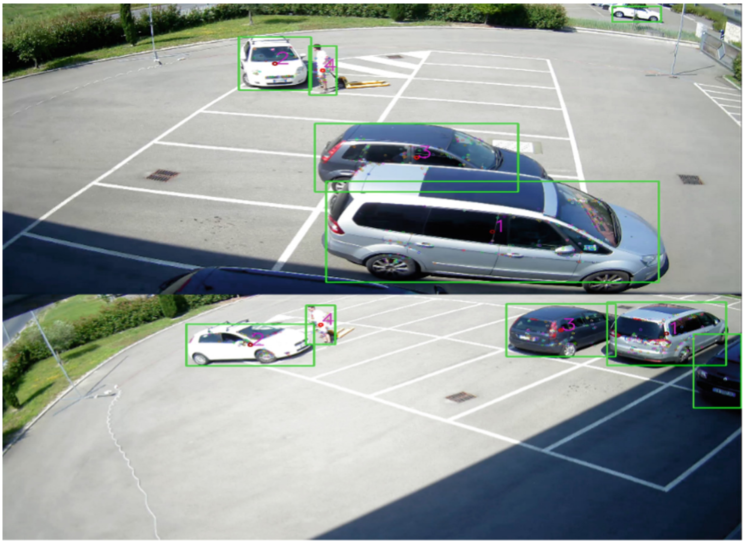

Fig. 2. Bounding boxes found by YOLO, bounding box association between the two images and SIFT (Scale Invariant Feature Transform) [5] features extracted from each bounding box.

3.2 Triangulation and Tracking

The exact knowledge of the displacement of two calibrated cameras, called *stereo calibration*, allows to reconstruct 3D points from couples of matching 2D points through the triangulation algorithm.

A rough estimate of the 3D position of the object can be obtained by triangulation of the centers of the bounding boxes. This can be improved by selecting more points on each bounding box. However, a more correct approach requires to triangulate a set of matching feature points belonging to a pair of associated bounding boxes. With this approach the probability of triangulating the same world point increases dramatically, but once again at the cost of computation time. A further improvement is obtained by selecting the relevant content in each bounding box, for instance applying a segmentation algorithm to the bounding box, such as DeepLab [6].

Some tracking algorithms can be also exploited in order to partially avoid errors in bounding box association. Tracking allows to estimate the position of an object at time t + 1 given the position of the object at time t. Because of its long living success, its numerous applications, and its small computational weight, the Kalman filtering has been chosen among all the others.

3.3 Risk Assessment

Detection, disambiguation, tracking and triangulation provide the necessary data for risk assessment at a given instant. During the planning phase, a deterministic approach and a machine learning approach have been considered.

The deterministic approach is based on the definition of a heuristic which associates the movement and position of objects to a risk level.

When a sufficient amount of data will be available, it will be possible to exploit a supervised machine learning approach where experts assign a risk level annotation for a dataset of situations. In this case, sequences of 3D points can be used as input features. Given their effectiveness in temporal sequence classification, Long Short-Term Memory (LSTM) networks [7] will be considered for final implementation.

An output of the automatic risk assessment system, which is immediately understandable by the companies' personnel is the generation of risk heatmaps along time. The heatmap is obtained dividing the surveilled area in a mesh of small areas and coloring each of them according to the risk score, as it is shown in Fig. 3.

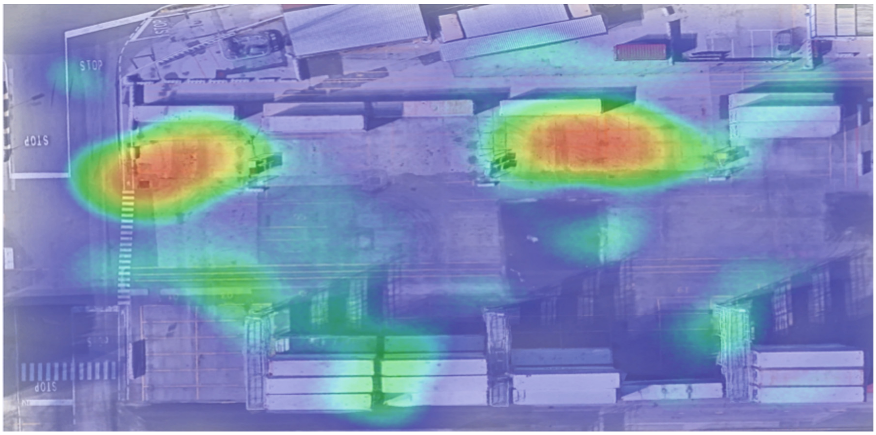

Fig. 3. An illustrative example of heatmap visualization of a surveilled area. Red areas are the ones most likely to be accident sites.

4 Biomechanical Overload Assessment

The third action targets workers health, in particular regarding WMSDs. Working activities in the port are characterized by high biomechanical overload risks that in some cases are related to the posture (e.g. crane driver) whereas they often involve manual material handling. Monitoring of such risks allows to identify the high-risk-activities and suggest correcting actions.

Currently, such a monitoring requires expert evaluators to visually inspect videos of the working activity while filling scoring sheets as suggested by the ISO 11228 norm. This takes the evaluators much time, thus reducing the number of workers that they can monitor. Analyzing many workers has two main advantages: an increase of the evaluation validity (reduction of the effects of a specific worker's task execution) and the possibility to have a personalized risk assessment.

Thanks to the wearable technologies advancements, different ergonomic evaluation systems that reduce the effort of a human evaluator have been developed. For instance, the system developed in the European project PAMAP by Vignais et al. [8] or the ergonomic evaluation software (ViveLabErgo Ltd.) [9] allow to track the human body movements and evaluate the biomechanical overload due to posture. However, external loads and muscle effort estimation are not considered. This is a strong limitation for many activities that involve manual material handling. Therefore, in our previous works [10–12] we devised a Wearable Sensor Network (WSN) able to track both the human limbs posture by means of Inertial Measurement Units (IMUs) and the effort level by means of the surface Electromyography (sEMG) signals. These data have been used to calculate relevant ergonomic risk indices such as the REBA (Rapid Entire Body Assessment) [13], the Strain Index [14], and the NIOSH [15]. As a result, the evaluator has a tool for a quick, reliable, and quantitative measurements of the anatomical and effort variables that are needed to fill the risk assessment sheets.

After a preliminary analysis of the working activities inside the ports, two activities have been selected based on their relevance and technical feasibility: containers lashing operations inside the cargo ship and containers crane handling in the dock area. The former is also called Roll-on/Roll-off (ro-ro) because it consists in loading and unloading the cargo ship with containers drove on wheel. Then the operators have to fasten the containers with specific chains. Thus, this procedure, implying both the manual handling of high load at low frequency and the load pulling, entails the application of both the ISO 11228-1 and ISO 11228-2. Differently, in the case of the crane driver the ergonomic risk is mainly due to the posture adopted during the operations entailing the use of the ISO 11228-1.

4.1 System Architecture

The planned approach implies the combination of the data streams generated by the IMUs and the sEMG sensors. After their synchronization and segmentation, the IMUs signals are processed to obtain the anatomical variables needed for the implementation of the aforementioned ergonomic evaluation methods and the sEMG signals are processed to extract the features representing the muscle effort and to estimate the external load (Sect. 4.2.2). Then, the processed signals are the input of the algorithms designed for the risk evaluation, obtaining a score for each part of the considered activities (Sect. 4.2.3). Figure 4 presents a diagram of the overall approach.

4.2 Motion Reconstruction

A large part of the IMU-based methods uses 9-axis IMU in which the accelerometer and gyroscope signals are complemented by the magnetometer signal. The use of this kind of technology has different issues [16] whose importance depends on the kind of algorithm chosen. The main problem to be considered for port activities, where dockers are often surrounded by metallic objects, is the sensitivity of the method to the

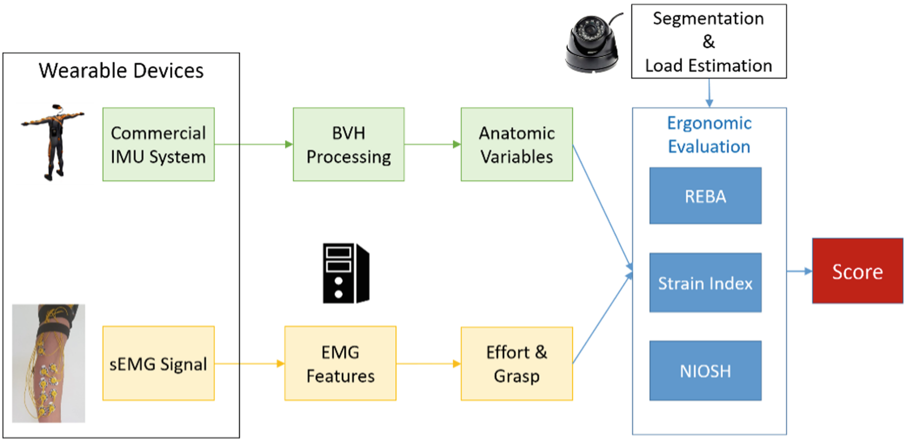

Fig. 4. Flux diagram representing the overall approach.

magnetic disturbances. Therefore, we considered two commercial solutions: the Xsens MVN (Xsens Technologies) and the Perception Neuron (Noitom Ltd.).

The Xsens MVN suit [17] is composed by 17 IMUs connected to a central unit, a battery pack, and a wireless transmitting system. Thanks to stress tests, performed both indoor and outdoor, the maximum transmission range even in the presence of metallic objects has been verified to be 40 m that is broadly enough for the selected activities. Although the Xsens is a very robust system, it is also very expensive. For this reason, the Perception Neuron [18] was also considered. This suit, compared to the Xsens, has a lower transmission frequency and, in the manual, it is reported that it is not so robust to magnetic field disturbances, which requires some tests to be performed to verify the usability in the selected activities. Both systems have IMUs distributed on the whole body, thus allowing a whole-body motion reconstruction and hence they are suitable to implement the REBA method.

Besides the suit, in both cases the proprietary software to calibrate the sensors, acquire and visualize the data, verify real time the motion reconstruction, and wirelessly transmit them in different formats is needed.

In particular, for the purpose of this project the BVH (BioVision Hierarchy) format [19] has been selected. This was further processed to extract the anatomical variables needed for the ergonomic evaluation. Therefore, software (C++) to intercept the data streams have been developed for each motion suit. Finally, an algorithm (Matlab) allows to extract the anatomical variables.

4.3 Surface EMG Data

For the recording of muscular activity, a custom and a commercial device were compared to each other. The custom device has been chosen because it has comparable features (e.g., Common Mode Rejection Ratio (CMRR), communication protocol, and physical characteristics) and, in addition, it has a considerably lower price than the commercial. We designed and developed this device to monitor the sEMG signals (see Fig. 5) of the users' forearms during the working procedure selected. The system provides 8 fully differential EMG channels plus an independent active electrode (right-leg driving). The Analog-to-Digital Converter (ADC) is able to manage the amplification and the conversion operation required and it is integrated with onboard hardware filtering to reduce the Electromagnetic Interferences (EMIs).

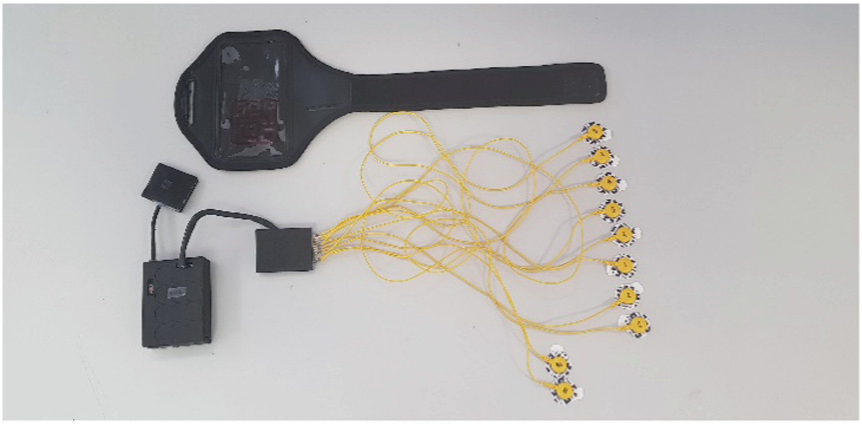

Fig. 5. Device for sEMG signals capture.

We used two devices, one for each arm: the electrodes are placed on the flexor muscles and the boards, thanks to elastic bands, are worn on the arm (biceps level). In this way the system is light and comfortable. The 16 sEMG channels are simultaneously transmitted via TCP/IP at high data rate to the central PC station where the signals will be synchronized with the IMUs data and further processed to extract the relevant features for the ergonomic evaluation.

Among them, we decided to use the Root Mean Square (RMS), one of the time domain features representing the amplitude modulation of the sEMG signal due to the muscle effort that is needed for the Strain Index method implementation.

In addition to the estimation of muscle effort, sEMG signals are used to evaluate the external load in terms of three classes (low, medium and high) as required for the implementation of the REBA method (Sect. 4.2.3). With this aim, the Linear Discriminant Analysis (LDA), based on a subject specific calibration, has been used to classify the RMS obtaining an estimation of the external load class. The LDA is generally used as dimensionality reduction techniques in pattern-classification and in machine learning applications, but it is also used as a classifier. The LDA approach allowed to classify the load level, as required in the REBA worksheet.

4.4 Algorithm for Ergonomic Risk Scoring

Software modules have been developed to implement the REBA, Strain Index, and NIOSH methods to accomplish the overall setup. The REBA method consists in 13 successive steps, each giving a score related to posture factor and external load value. The final score varies between 1 and 12: from negligible risk to high risk (8–12) when changes are needed, or even unacceptable risk (11–12). The Strain Index method focuses on the estimation of risk of the arms determining 6 factors related to the analyzed activity and extracting a risk index from them. The factors considered are muscle effort level and its duration, the frequency of the action performed, hand and wrist posture, the velocity of the execution and the duration in the overall shift. This index varies between negligible to unacceptable risk. The NIOSH lifting index fixes a mass reference based on the age and the sex of the operator that represent the ideal external load that the operator can transport. This mass is multiplied by 8 factors lower or equal to 1 obtaining the recommended weight to work with.

5 Conclusion

The three actions, that compose the proposed trilateral approach to the improvement of safety and health in ports, have been presented. The quantitative results of the monitoring of collision risks and of biomechanical overload allow us to strengthen the message that INAIL and ASL want to convey to port companies. At the same time, this approach allows us to have a detailed information about the risk sources and to devise specific interventions to mitigate it.

Acknowledgments. We would like to thank the personnel of the Local Health Authorities involved in the project as well as the Port Authority of north Tyrrhenian Sea. Sailport is a project co-funded by INAIL, the Italian National Institute for Insurance against Accidents at Work, under the BRiC 2016 programme (ID24-2016).

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Robots and Human Interaction in a Furniture Manufacturing Industry - Risk Assessment

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Abstract. In the last decade, a significant increase of robotic solutions' implementation has been verified across several industrial contexts, including the furniture manufacturing industries. The current study aimed at assessing the risks within different workstations with human-robots interfacing at a large furniture manufacturing company. With this purpose, a questionnaire to collect the workers' perceptions about risks was developed. For each workstation, the William Fine method was applied, in order to estimate the risk levels and to define the priority of intervention measures. The preliminary results demonstrate that even though some preventive measures are already implemented, the workers are still exposed to different risks (e.g. falls in height). Therefore, several preventive measures should be considered. The current study was also important to the design and implementation of a risk assessment methodology with the workers' active participation, and the results can be a reference for studies focused on risk assessment in other companies.

Keywords: Occupational safety · Risk assessment · Robotics solutions · Manufacturing industry · William fine · Workers' perceptions

1 Introduction

In the last decade, the Industry 4.0 paradigm leads companies to implement several technological solutions and process automations. This technological revolution aims to make industrial production more efficient, more flexible and of higher quality. This trend will predictively affect the work organization, the way it is carried out, and certainly the health and safety of workers [1].

In the furniture manufacturing companies, the tasks performed have been described as heavy and repetitive, involving frequent lifting, pushing and pulling of heavy loads, and the adoption of awkward static postures, like bending and twisting [2]. In order to increase production and protect the worker from these many difficult tasks automated solutions has been implement, where robots plays a major role mainly in handling,

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 81–90, 2020.
https://doi.org/10.1007/978-3-030-20497-6_8

welding and joining tasks [3]. Automation in manufacturing context replaces, to some extent, cognitive and physical human labor. Since automated manufacturing systems are perceived to be efficient, automation is often viewed as a tool that can potentially enhance manufacturing competitiveness [4]. This provides many bottom-line benefits for manufacturers, but they are also inherently dangerous, and it is the responsibility of manufacturers to ensure a safe production environment for workers.

Many view safety as a legal obligation, but industrial robotic safety can actually have many benefits, including the assurance of regulatory compliance and increase of productivity on the industry. In order to fulfill this goal, many occupational safety and health systems are available. They ensure the correct identification of hazards and assessment and management of occupational risks. It is important to identify the machines' conditions and work tools, the nature of work and the production process so that any hazards that may cause harm to workers can be noticed [5]. Moreover, the scientific literature shows that a careful and systematic risk assessment is one of the best prevention strategies to reduce the work-related accident occurrence [6].

As in this new trend, every individual worker assumes a wide new range of tasks, which will largely be defined by the specification, monitoring, and protection of production strategies [7]. The worker is the most flexible component of this robot-human interfacing and also the most fragile. With this change in the manufacturing, comes the need to assess the risk that workers are exposed, due to the inertia, structure and process forces posed hazards by industrial robot systems [8].

Therefore, this study aims to estimate the risk levels and, consequently, define the priority of intervention measures in the interaction among robots and humans in a furniture manufacturing industry. However, the current study consists in the first stage of an extended assessment process, serving as a test and definition of a risk assessment methodology.

2 Methodology

The risk assessment began with a first visit to the selected workplaces, where some priority risks were identified. After that, 8 visits were carried out in order to collect individual data from each workplace, information on work organization, physical and mental requirements, eventual workers' complaints/injuries, working conditions, tasks performed, dangerous conditions, occupational risks identified, and preventive measures implemented. Photographs and videos of the workers performing their tasks, were also registered. Each workplace risk assessment contemplated the following phases: (i) recording of workers' perceptions; (ii) risk assessment using the William Fine method.

In order to register workers' perceptions, a questionnaire was applied to workers, based on the Ergonomic Workplace Analysis (EWA) [9]. This questionnaire allows the assessment of workers' perceptions regarding several factors that influence the environment in which workers are inserted and that influence their exposure to occupational hazards. Topics covered included the following factors: workspace; physical activity in general; handling loads; postures and movements; risk of accident; repetitiveness of work; decision-making; lighting; thermal environment and; noise.

The identification of the risks for each workplace was carried out by direct observation of the workers during the normal execution of their tasks. During the visits to the workplaces, other relevant data were also collected to fill out a matrix (for each workplace), which includes William Fine's matrix for the calculation of the risk degree. In a participatory way, due to questioning of the workers and supervisors/Line Leaders, it was also carried out, among others, the assessment of their knowledge regarding the Lockout/Tagout system (LOTO), eventual manipulated chemicals, personal protective equipment (PPE) used and made available and the description of the tasks that make up the work. The risk assessment *per se* was based on the William Fine method, which is based on equations expressing control of hazards and the rationale for investments in deciding on preventive measures. It attributes a degree of risk that is computed on the basis of three factors: (a) the probability of the accident occurring (Table 1); (b) the degree of exposure to risk (Table 2); (c) the consequences of the accident (Table 3) [10].

Table 1. Classification of *Probability*.

General	Rating
Most likely	10
Quite possible 50–50	6
Unusual	3
Remotely possible	1
Extremely remote (has never happen after many years exposure)	0,5
Practically impossible ("one in a million")	0,1

Table 2. Classification of *Exposure*.

General	Rating
Continuously (or many times daily)	10
Frequently (approximately once per day)	6
Occasionally (once per week to once per month)	3
Unusually (once per month to once per year)	2
Rarely (it has known to occur)	1
Very rarely (not know to have occurred, remotely possible)	0,5

Given the classifications for each of these factors, the Risk Score (R_S) could be calculated using Eq. 1:

$$R_S = F_P \times F_E \times F_C \tag{1}$$

Where, F_P is the probability factor, F_E is the exposure factor and F_C is the consequence factor.

The Risk Score (or risk level), whose classification is presented in Table 4, allows the establishment of a prioritization of the actions to be performed.

Table 3. Classification of *Consequence*.

General	Consequence specifications	Rating
Catastrophic	Numerous fatalities	100
Critical	Fatalities or very serious injury, loss of limb (hand, arm, leg, foot)	50
Major	Serious, e.g. amputation of finger, thumb or toe; permanent loss or reduction of sight; crush injuries leading to internal organ damage; serious burns (covering more than 10% of the body or damaging the eye, respiratory system or other vital organs)	25
Moderate	Lost Time Accident (LTA), e.g. closed bone fractures other than to fingers, thumbs or toes; dislocation of the shoulder, hip, knee or spine; • Any burn injury (including scalding) which covers less than 10% of the whole body's total surface area; nail damage injuries • Acute poisonings and infections	15
Minor	No Lost Time Accident (NLTA), e.g.: open wounds requiring medical treatment (more than 3 sutures); closed fractures (only fingers, thumbs or toes); open wounds with infections requiring prescription of antibiotics; burns and scald (thermal) requiring medical treatment	5
Negligible	First Aid, e.g.: open wounds requiring no medical treatment or max. 3 sutures, sprains and strains with no immobilization e.g. rigid stays (gypsum); small burns without medical treatment	1

Table 4. Classification of risk level.

Risk level	Risk score	Priority
I	≥ 250	Immediate correction required, activity should be stopped until hazard is reduced
II	90 to 250	Urgent! Requires attention as soon as possible
III	18 to 90	Hazard should be eliminated without delay, but situation is not of an emergency
IV	≤ 18	Should be addressed when time is given

3 Results

3.1 Workplaces Selection

The current study results from cooperation between a university and a large furniture manufacturing company and aimed at assessing the risks within 600 different workplaces, being several of these workplaces composed by robots and human interactions. In a preliminary phase, 20 workplaces were assessed, being four of them characterized by human control of robots. This preliminary assessment was performed in order to define and test the assessment method and the 20 workplaces' selection was based on the high frequency rate of work incidents and accidents. This workplaces' set belonged to two packing lines of the company products. The functions of robots were related to the final packaging of furniture pieces and automatic palletizing. The workplaces with robots (WR) were the following: (i) box-maker (WR1 - Fig. 1); (ii) box-closer (WR2 - Fig. 1); (iii) automatic palletizing and strapping (WR3 - Fig. 2); (iv) automatic palletizing and filming (WR4 - Fig. 3). For each workplace with robots, there was a worker responsible for the supply of consumables, machines control/programming and problems solving.

3.2 Workers' Perceptions

As mentioned above, a questionnaire was applied in order to collect the workers' perceptions about the occupational conditions in their workplaces. The results (Table 5) show that across the four WR the factors with more negative scores were the following: risk of accident, work repetitiveness and thermal conditions.

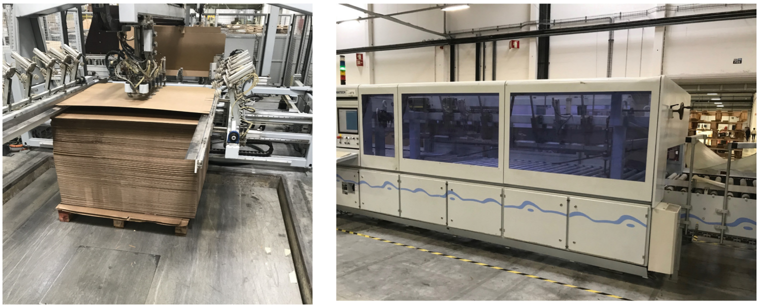

Fig. 1. Workplaces with the robots box-maker (WR1 at the left) and box-closer (WR2 at the right).

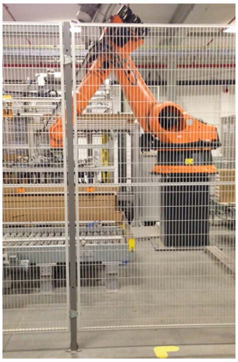

Fig. 2. Workplace with robots for automatic palletizing and strapping (WR3).

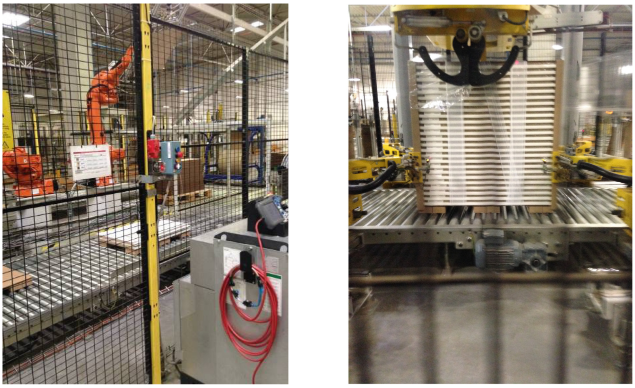

Fig. 3. Workplace with robots for automatic palletizing and filming (WR4).

3.3 Risk Assessment – *William Fine* Results

Starting from the workers' perceptions and the direct observation of real work activity, the risk assessment methodology was applied, being the main results presented at the following tables. Firstly, the Table 6 summarizes the risks directly related with the human-robots interfacing. The Table 7 present the summary of the main risks common/transversal to the all workplaces (including the WR) belonging to the production lines studied. For the different risks (Fig. 4 present some examples), the assessment team proposed several preventive and corrective measures to implement/improve at the WR considered.

Table 5. Summary of workers' perceptions about their workplace's conditions.

Factor	WR1	WR2	WR3	WR4
1. Workspace	+	++	+	+
2. Physical activity in general	+	++	+	−
3. Handling loads	−	+	+	+
4. Postures and movements	−	+	+	++
5. Risk of accident	−	−	+	−
6. Work repetitiveness	−	+	−	−−
7. Decision-making	+	+	+	++
8. Lighting	+	+	+	++
9. Thermal conditions	−	−	+	−−
10. Noise	+	−	−	+

Table 6. Summary of the main risks related with human-robots interfacing.

Risk	Risk level	Preventive measures
Contact with surfaces extremely hot	I	In the WR1, the workers have to supply the glue boiler. In this case, the use of thermal protection equipment (e.g. gloves) must be mandatory; and should be implement mechanics that physically prevent entry while temperatures remain high
Fall in height	I	At WR 1 and WR 4 exist robot areas with moats, so, in order to prevent falls it must be implemented physical barriers, signaling and increase the contrast between hole and surrounding pavement
Mechanical contact	II	Workers must always apply the LOTO procedure before entering the machine. For these reasons, at each entry in the robot area has to be placed visual safety advices and the respective tool LOTO
Contact with moving parts	III	In the supervision area, the pallets move over a mobile roller conveyor and the place is easily accessible by workers, because of that it should be implement an emergency stop system on the outside of this area; and apply signaling prohibition for persons passage
Collision with obstacles/objects	III	Mandatory use of protective cap when entering inside robot areas and place the PPE near the entrance (there have already been occurrences of head injuries against objects/parts of the robots). Implement protection/correction of sharp edges and fixing screws in areas with frequent passing/manual tasks

Table 7. Summary of transversal risks affecting the WR.

Risk	Risk level	Preventive measures
Psychosocial	I	Implement brief and more frequent breaks, since the cadence of work is imposed by the machines and the work rate is high
Electrical	II	Maintenance/replacement of degraded electrical cables or other components
Fire	II	In addition to the fire prevention and protection system, prevent accumulation of dust on machines and electrical elements
Exposure to temperature variations	III	Implement a climate control system and/or hot air curtain to protect the area when opening gates (workers complain about the existence of drafts)
Noise	III	Verify collective measures to reduce noise levels (such as machines maintenance, replacement some mechanisms by less noisy ones)

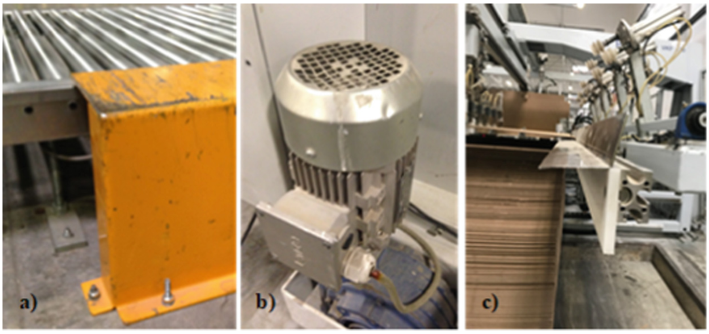

Fig. 4. Examples of physical conditions, which justify some of the risks assessed: (a) salient fixing screws; (b) degraded electrical cable and accumulation of dust on electrical motor; (c) different obstacles, sharping edges and uneven pavement/hole.

4 Discussion

In the WR assessed, considering the tasks performed within the robot's areas, the main risks are the falls and collisions with objects due to the existence of multiple obstacles (e.g. machine components, fixing screws – Fig. 4). As presented at the Table 6, several measures proposed should be considered in order to improve the physical conditions and organization within these areas, namely: protect sharping edges and corners; signalize the main obstacles; replace/correct the fixing screws; mandatory use of the cap protection (in addition to the gloves and footwear also used). In the WR, the contact with moving parts is also an important risk but prevented with the safety procedures implemented when power is cut-off when workers enter the area, applying the LOTO procedures. However, there is a need to reinforce the workers' training about this issue (some workers revealed doubts about LOTO procedures), as well as the need to place safety instructions and LOTO tools on all access robot areas.

Globally, the furniture manufacturing companies, as the company studied, have to improve the systematic risk management, improving the preventive measures and the procedures of first level maintenance (e.g. cleaning of the workplaces), in order to prevent a diversity of unsafe conditions and consequent risks to which workers are exposed [5]. Periodic maintenance plans should include all points that must be checked (such as checklists) and records of maintenance and alerts of future maintenance interventions should be defined in detail.

Regarding the assessment methodology applied, the William Fine method allows for assessing the occupational risks, with some numerical references and based on previous occurrences. However, when there are no records of previous occurrence of accidents or incidents in the Company, the assessment may become more subjective and less reliable. For this reason, it should highlight the need for companies to have a systematic and up-to-date record of all accidents and incidents occurred. Consequently, this risk assessment and the safety management process should be improved through the integration of the statistical control of occupational accidents. The statistical analysis could be useful in the hierarchy of the measures to be implemented to risk factors with the same risk level (obtained by the William Fine assessment).

Finally, the participatory strategy adopted in the current study, which included the involvement of workers in the assessment process, seems to be appropriate. The workers' perceptions were consistent with the William Fine assessment. For example, the workers' complaints related to thermal variations, noise exposure, risk of accident and work repetitiveness were justified by the work conditions verified along the assessment process.

In a previous study [2], results from an ergonomic participatory intervention which was developed in workplaces from a Brazilian furniture company, allowed for the conclusion that the workers' participation was crucial for the success of the ergonomic modifications. In this case, the workers demonstrated an increased motivation and satisfaction with the new work design, which were explained by improvements inserted as well as by the teamwork done. For these reasons, it is expected that the current study, focused on the risk assessment at workplaces, will be continued with the workers participation, as it was developed in this first stage presented in the current article. This workers' participation also allows to identify the need to update/reinforce workers' training about safety procedures.

In the future, several training sessions are planned, aimed at sharing and discussing the assessment results with the workers and supervisors, and therefore foreseeing the continuous improvement of occupational safety. The current study was also important to the definition and implementation of a risk assessment methodology, with the workers' active participation, which will be implemented trough the remaining workplaces. Hopefully, these results will also be a reference for studies focused on risk assessment in other companies.

5 Conclusions

In modern furniture manufacturing companies, with several human-robots interfacing different occupational risks have to be assessed and prevented. In this field, an assessment methodology including the workers' perceptions seems to be an appropriate strategy to maximize the effectiveness of the risk assessment and risk estimation since more accurate and detailed data is available.

In the current study, the assessed robots have already some preventive measures, such as a security perimeter, like a fence with an entry gate having an interlock switch that shuts down the machine (LOTO) or like sensors, that has the same effect. Notwithstanding, it has been shown that there are still existing different risks associated with the human-robots interfacing. Therefore, it is important to do a systematic risk assessment in order to anticipate all the factors that can harm the workers.

As a future work, it is recommended to carry out the risk assessment across the company workplaces, adopting the participatory strategy with complementary methodologies to the William Fine method (such as statistical control). It is intended that these results will also be a reference for studies focused on risk assessment in other companies.

Acknowledgments. This work has been supported by FCT – Fundação para a Ciência e Tecnologia within the Project Scope: UID/CEC/00319/2019.

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Safety in Date Palm Tree Work in Algeria: The Role of Belt Design and Use

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Abstract. BACKGROUND: In many developing countries, date palm farmers are still working in the cultivation of date palm trees using traditional tools such as the use of the belt to aid them in climbing and carrying out work on the date palm safely.
OBJECTIVE: This study aims to:

1. Evaluate the current designs of the work belt.
2. Investigate how farmers feel about the newly designed belt.

METHODS: The descriptive method is used.
RESULTS: For the first research objective, there are many types of belts, but they share two things: the wide strap and the rope. For the second, the majority of farmers believe the new belt is more comfortable, safer and stronger than the previous belts.
CONCLUSIONS: It is useful for farmers to gradually abandon the old belt and start using the newly designed belt.

Keywords: Date palm tree · Climbing methods · Algeria · Belt

1 Introduction

Immunity in developing countries cannot be achieved if their land is not the source of their basic nutrition and self-sufficiency. In addition, sustainable development cannot be achieved in these countries without a developed and prosperous agriculture capable of providing the people with a minimum of basic food items [1, 2]. Agriculture has always been known since ancient times as a difficult and volatile sector controlled by climatic and natural factors beyond the will of man, but experience has shown that these factors did not prevent developed countries from overcoming them and turning the land into fertile land. Agriculture has been and continues to be an extremely valuable economic sector that requires comprehensive and sustained attention to its development and improved returns for the benefit of the people.

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 91–99, 2020.
https://doi.org/10.1007/978-3-030-20497-6_9

Date Palm Work. One type of agriculture in many developing countries especially in those who are in the hot arid areas, is date palm farming [3–5]. Some developing countries especially Arab countries (Saudi Arabia, Iraq, Egypt, Algeria) depend greatly on date production in their national economy. In addition to providing dates (food), date palm is a multipurpose tree, providing shelter, timber and other traditional products [6, 7].

In Algeria, the best date palm species are located in four desert regions that are: the Zab, Souf, Ain-Salah and Touat and Guerrara regions. According to Moussouni et al. [8], in 2015, the number of date palms in Algeria reached 18 million. However, people working in date palm work are also in millions.

Date Palm Work Tools. Hand tools are basic necessities of almost any form of work. For palm farming, broadly they include the following:

- The climbing tools: They help the worker to climb (up or down) the trunk of the date palm. It is to note that the worker can climb without these tools, but the process is laborious. Some of these tools are depicted in Table 1.

Table 1. Some climbing tools

The tool	Picture of the tool
The belt (saddle)	
The Extension ladder	
The climbing apparatus	

- The working tools: They are multiple with the multiple tasks performed by the worker both under the crown of the date palm, or inside of the crown. Some of these tools are described in Table 2.

Table 2. Date palm working tools

Nature of task	Task	Tool
Under the crown tasks	Pruning dry leaves	Pruning saw
	Bunch covering	Plastic bags and thread
	Bunch cutting	Sickle
Inside of the crown tasks	Pollinating	Pollen duster
	Dethroning	Sickle
	Bunch thinning	Pruning shears (Secateurs)

We believe that research has scientific and practical significance at the same time. It provides very useful data about the belt with its various parts. It also helps to design a secure belt and reduces the fatigue of farmers working in palm farming.

Research Objectives. This research aims to achieve the following objectives:

1. Evaluate the current designs of the work belt.
2. Investigate how farmers feel about the newly designed belt.

2 Methodology

Method. The researchers used the descriptive approach to investigate all the research objectives. This approach has been used as it is the most appropriate method for this kind of research.
Sample:

1. **Sample of Workers.** To choose the sample of the study, researchers used the snowball technique where one worker identifies other date palm workers. This method has enabled the selection of 13 workers in date palm cultivation who were willing to participate. The average age of these individuals was 33.3 years (SD = 6.6). The average years of experience in date palm cultivation was 12.4 years (SD = 4.3). Two members of the sample had previously fallen while climbing the trunk of the palm. Fortunately, they suffered only bruising in the hands and in the buttocks area because the two date palms were short.
2. **Sample of Belts.** The researchers collected 13 belts. They were obtained from the sample members referred to above. Despite the formal variation of these belts, they are compatible with the components that make up each.

Data Collection Tool. Speaking about the checklists, Easterby [9] gave a comprehensive overview of these lists. He pointed out that "**Checklists are more practically useful for analytical, regenerative design as opposed to synthetic or generativeIy oriented design**". To achieve the goals of this research, a checklist has been developed in the light of Stufflebeam [10] and Gawande [11] guidance (Table 3).

Table 3. The checklist appraisal tool

Photo	Theme	Choices	Response
	Back part of belt strap	• Wide enough. • Padded. • Flexible. • Does not hurt the back. • Has an abdomen belt.	
	Stainless Steel Chain	- Strong - Tough - Light	
	Safety Bolt Anchor Shackle	• Strong. • Easy to use.	
	Rope	• The material of the rope - Nylon - Polyster - Hemp rope - Other • Rope diameter	
	Backup rope	• The material of the rope - Nylon - Polyster - Hemp rope - Other • Rope diameter	

3 Results

It has been already stated that this study aims to achieve two aims. The first being:

1. Evaluate the Current Designs of the Work Belt

The obtained results are depicted in Table 4.

As to the strap, we see that there is a full agreement between evaluators concerning the padding of the belt and the fact that it has an abdomen belt. Also, we see a large agreement between evaluators that the strap is wide enough and flexible. But in the item (Does not hurt the back), the agreement between evaluators was 76% being the smallest percentage in this theme.

Table 4. Current work belts evaluation results

Theme	Choices	Agreement (%)
Back part of belt strap	• Wide enough.	93
	• Padded.	100
	• Flexible.	93
	• Does not hurt the back.	76
	• Has an abdomen belt.	100
Stainless Steel Chain	• Available (yes)	93
	• Strong	100
	• Tough	100
	• Light	62
Safety Bolt Anchor Shackle	• Available (yes)	08
	• Strong.	100
	• Easy to use.	83
Rope	• The material of the rope	///
	- Nylon	62
	- Polyster	08
	- Hemp rope	00
	- Other	30
	• Rope diameter	09-10 mm
Backup rope	• Available (yes)	100
	• The material of the rope	///
	- Nylon	///
	- Polyster	///
	- Hemp rope	///
	- Other	///
	• Rope diameter	///

As for the steel chain, it has been found that it is available in 23% of working belts (03 belts only). Evaluators believe that steel chains that are used are strong (100%) and tough (100%). On the other hand, some evaluators (38%) see that it is slightly heavy.

As regards the anchor shackle, unfortunately it is found in one belt only. In the other belts, workers used metal cables to fix the rope to the chain. Evaluators believe that the shackle is strong (100%) and easy to use (83%).

As concerns the rope material, it is seen that in the majority of belts (62%), the nylon rope is used. Then the hemp rope is used in some belts (30%). However, polyester rope is used in few belts (08%). Evaluators agree that the rope diameter is 09 to 10 mm.

Finally, evaluators agree that the backup rope is not used in working belts.

2. Investigate How Farmers Feel About the Newly Designed Belt. It is designed with the following parts:

- The padded flat strap that backs the farmer’s back.
- The waist belt.

- The 10 (mm) nylon rope.
- The steel chain.
- The two anchor buckles, and
- The backup 08 (mm) rope.

After designing the new belt, workers (study sample) were requested to test it empirically in the field. Each of them was asked to fill in a questionnaire, after climbing a 06 (m) tall date palm with the aid of the newly designed belt (Table 5).

Table 5. Evaluating the newly designed belt

Item	Response			
	Comfort	Safety	Ease of use	Time taken at use
The padded strap	V	V	V	V
The waist belt	V	V	V	V
The 10 (mm) nylon rope	V	V	V	V
The steel chain	V	V	V	V
The two anchor buckles	V	V	V	V
The backup 08 (mm) rope	V	V	..	..

It is seen that workers believe that the newly designed working belt is much better that the traditional belt especially in comfort and safety. However, it the (ease of use) and (Time taken at use) workers think that the two functions may need much time.

4 Discussion

1. Evaluate the Current Designs of the Work Belt. We have seen that the traditional belt despite its benefits and usefulness for years, it needs some development. Workers are aware of the developments that the belt requires. Previously, workers used to work with no belt at all. After some years, they discovered that the use of a strap going around the worker's back and attached to a rope that surrounds the tree trunk. The workers found that this is important for both safety and comfort reasons. Later on, they realized that the use of a waist belt to fix the strap at the workers back is necessary to avoid falling with the negative consequences. Despite these positive developments in terms of safety and ergonomics, further progress may take years to come. Two major forces may be driving positive progress in the area of date palm work; scientific research and experience. The positive progress that we have seen especially in the design of work belt was mainly the result of experience and trial and error. Despite the fact that in Algeria, there are various centers (The Technical Institute for the Development of Saharan Agronomy, Biskra, Algeria, and the Center for Scientific and Technical Research on Arid Regions Biskra, Algeria) that are expected to help develop their working methods, unfortunately, the dissemination of knowledge that help workers achieve the expected development in hazardous work areas such as climbing the date palm barefooted is not seen.

Despite the fact that a lot of successful genetic transformations in date palm farming have taken place [12–14], many date palm farmers dream of getting engineers to some kind of a date palm that does not increase in length only after a great number of years.

2. Investigate How Farmers Feel About the Newly Designed Belt. Workers were pleased to see the newly designed belt. They mentioned that with this new design, workers will have the opportunity to have a lot of movement at work. It is this movement that gets rid of static work, which causes lots of stress. Researchers have previously shown that workers with much mobility at work have few negative effects of static work, compared to those whose work is characterized by a lot of static movement [15–17].

Associated with the newly designed working belt is the lack of fear that has been a part of work with date palm trees. Now workers work with feeling of happiness and comfort which fosters creativity at work. In psychological literature, it has been established that fear may decrease work motivation. High amounts of fear may hinder interest in work.

Formal research shows that a positive work environment will benefit both employers, and employees [18, 19]. On the other hand, a large body of research shows that full-of-fear work environment does not only harm work production, but also affects the worker negatively [20–22].

In addition, the backup rope is a very good idea that consolidates the safety. Previously some of the workers have fallen because of the rope either of tear and wear or they accidentally cut it while working. Now with the spare security rope, the problem is solved.

Maintenance of the work belt is another issue the workers have mentioned. Previously workers were not really considering it in a regular manner.

Here we would like to refer to a widespread issue in developing countries, namely the lack of full attention to maintenance. Thus, it is a characteristic of developing countries in comparison to developed countries that are characterized by a strong maintenance culture. Many researchers have referred to this issue [23–25].

Therefore, the lack of maintenance of the belt is an integral part of the lack of interest in maintenance system.

Limitations of This Study. The major limitations of this study are:

1. **Sample Size:** It was noted above that the sample of this research comprised of 13 workers. Therefore, it will be difficult to generalize the results to members of the date palm industry.
2. **Method:** The researchers used the quantitative descriptive approach. They know that this approach, if supported by a qualitative approach, would have produced more accurate and realistic results.
3. **Data Collection Tool:** The researchers used the checklist for data collection. Similar to other data collection tools, checklists have positive and negative aspects which may affect scientific research.

5 Conclusion

Current research sheds light on some aspects of date palm farming in Algeria. This paper focused on the belt workers use while climbing date palms. It has been shown that the traditional belt still exists today. Even though some developments in the design of traditional belts have been seen, but researchers believe that the above-mentioned encouraging achievements are not enough. Therefore, a new belt was designed. It has been found that workers have shown positive attitudes towards the newly designed belt.

Acknowledgements. The authors would like to express their very great appreciation to the date palm workers who participated in the research.

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Development of Assistive Technologies in Additive Manufacturing (AM) for People with Disabilities

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Abstract. This research subject is focused on the development of Low-Cost Assistive Technology, in Additive Manufacturing, for people with physical disabilities, aiming to improve the safety and health conditions at work. The objective of the study was to analyze assistive material for work activities and orthoses developed by the Group of Addictive and Tooling Manufacturing - NUFER. The possibility of implanting an Additive Manufacturing Laboratory is also evaluated, establishing a partnership between the Federal Technological University of Paraná and civil society, aiming to include people with disabilities in the work environment. This study is performed in the applied research field and it has as product creation methodology the proposal of NUFER of UTFPR - Brazil. The data indicates the social relevance of such a project, since it helps to promote inclusion in the work environment, providing more safety, health and productivity.

Keywords: Work environment · Additive manufacture · Disabled people

1 Introduction

This study intends to demonstrate the development of low-cost assistive technologies for people with disabilities, using Additive Manufacturing (AM), as a mean to provide for this public a better health and safety conditions in their work environments. This approach is justified by the understanding that the work is a social right and it is an essential dimension of human dignity. Therefore, people with disabilities must have equal opportunities with others and the provision of Assistive Technology can help them to be included in the work. From this perspective, the NUFER (Additive and Tooling Manufacturing Group) studies has experience on the manufacturing assistive technologies development that help to elaborate methodologies to create accessible and low-cost products.

In order to better understand the importance of having an improved work quality for people with disabilities in Brazil, this study brings a brief presentation about: (1) Brazilian legislation and social advances – in the work perspective; (2) People with Disabilities and (3) Assistive Technology (AT).

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 100–110, 2020.
https://doi.org/10.1007/978-3-030-20497-6_10

After this presentation, it will be exposed the low-cost AM methodology to make products that aid work and orthoses that are based on the NUFER studies of the Federal Technological University of Paraná (UTFPR) – Curitiba. This method is divided into seven stages: case selection; acquisition of anatomy, 3D scanning; 3D modeling, 3D printing; finishing and, finally, evaluation of the product. The process involves directly the user, knowing their social context, functional needs and abilities, evaluating their physical and sensorial potential with the support of a multidisciplinary team.

Finally, it is evaluated the possibility of implanting an AM laboratory, establishing a partnership between UTFPR - Ponta Grossa and the civil society, taking as fundament the fact that public policies are not clear regarding the provision of AT for people with disabilities at work. Furthermore there is a great bureaucracy that municipalities face for bidding processes. The possibility of creating the laboratory is justified since the results of the case studies point to a significant improvement of the working conditions of people with disabilities, with a personalized and low-cost product. The data point to the social relevance of such a project, since it helps to promote inclusion in the work environment, providing more safety, health and productivity.

2 Brazilian Legislation and Social Advances

The public policies implemented in Brazil since the Federal Constitution of 1988 allowed progress in the people with disabilities integration regarding the education, professional qualification and work. It should be emphasized that, even if there are laws that guarantee the social rights of these people, such as work, the labor environment needs to be prepared to receive them, given their peculiarities, because without this care there will be a gap between the laws and its effectiveness.

With the 1988 Constitution enactment, the people with disabilities in Brazil had fundamental issues about equality and human dignity structured, such as health, education, accessibility, leisure, culture and work. At this moment of significant advances that the inclusion policies direct the institutional protection system to the people with disabilities in the country.

In 1991, it is established the vacancies legal reserve or “Quota Law” and the access to work, Law No. 8,213 (Social Security Benefits Plan). The article 93 creates the quota system: “the company with 100 (hundred) or more employees is required to fill from 2% (two percent) to 5% (five percent) of their vacancies with rehabilitated beneficiaries or persons with disabilities”.

Data from the Annual Social Information Relation (Rais)[1] indicate that there was a significant increase of people with disabilities in the formal labor market, accounting 418,521 in 2016. According to Rais, there was a growth of 3.79% in relation to 2015, when there were 403,225 people with disabilities employed. Among these data it is included employers from the private sector, direct and indirect public companies and public agencies. In 2017, the contingent of employed people reached 441.3 thousand

[1] The Ministry of Labor and Employment accounts with an important data collection instrument called the Annual Social Information Relation - RAIS. It has as one of the objectives the availability of labor market information to government entities.

employment bonds and, in relation to 2016, there were 22.8 thousand new jobs filled by people with disabilities, representing a growth of 5.5% [1].

These data are even more significant if it is considered that the unemployment[2] in Brazil, according to data from IBGE, approached 8.6% in 2015 and increased to 11.5% in 2016 and 12.7% in 2017. It means that despite the strong economic crisis that hit the country, causing a growing number of unemployed, the contracting of people with disabilities followed an inverse path, increasing employment bonds. There is no doubt that the Law of Quotas collaborated for this statistic.

The Ministry of Labor and Employment also points out that, in 2017, in the three states of the southern region of the country, namely Paraná[3], Santa Catarina and Rio Grande do Sul, the physical disability is the one that most fills vacancy jobs, with a total of 36,637 people with disabilities employed. It is also the disability that had the second most growth in relation to 2016, with a total of 4.1% (+8.3 thousand jobs). The multiple or severe deficiency was the one that increased the most using the same 2016/2017 comparison, with a growth rate of 5.1%, but they had only 370 filled positions [1]. Based on these data, it is noticed that, although the Quotas Law allowed a significant advance in the formal fulfillment of job posts, "there are a significant number of people, especially those with more severe disabilities, excluded from the labor market waiting to perform one of the most important rights of citizenship: that of work itself" [2].

One of the most recent national laws, the Brazilian Inclusion Law - BIL (Statute of the Person with Disability) no. 13,146 of 2015, is "designed to ensure and promote, on an equal basis, the exercise of fundamental rights and freedoms by the person with disabilities, aiming their social inclusion and citizenship" [3]. BIL is considered a watershed in the history of Brazilian inclusion, its relevance is perceived in the fact that the focus is in the person, not in the disability, emphasizing the role of the society and the need to break the barriers for the accessibility.

Regarding the work, the BIL is innovative in several approaches and perspectives, as in the mandatory provision of AT to include people with disabilities in the work environment. The Chapter VI, Section III, article 37, states that "it is a way of including the person with disability in the workplace and competitive placement, in equal opportunities with other people, under the terms of labor and social security legislation, in which accessibility rules must be attended with the provision of assistive technology resources and a reasonable accommodation in the workplace".

[2] Unemployment data collected by the Brazilian Statistic and Geography Institute – IBGE in 2018.

[3] Paraná is a state from the Southern region and the only Brazilian state that has the Federal Technological University – UTFPR. With 13 Campuses, it is in Curitiba Campus that it is installed the NUFER and it is studied the possibility of creating an additive manufacturing lab in Ponta Grossa Campus.

3 People with Disabilities

Throughout history, people with disabilities had different treatment. It is important to understand that each folk traditions and beliefs are driven by their social conditions, types of knowledge and their laws, and they are responsible for explaining the different ways of seeing the deficiency and, consequently, people with disabilities. It means that the achievements that exist today in each country were built through different aspects and peculiarities of each region and population.

Nowadays the disability is no longer seen from the medical model perspective, with a look limited to the body structure and function, but by the biopsychosocial model. That is, the person is not seen because of his/her disability but as a person, showing his/her human dignity, considering environmental factors, social rights, culture, among other aspects. Therefore, the terminology used is "person with disabilities" and no longer deficient bearer or other terms.

There is a dialectical movement in the biopsychosocial model that is based on the binomial of equality and difference. It means that it is necessary to the society to respect the diversity but understand that there are elements that equal a certain group of individuals. People with disabilities form one of these groups, because everyone has in common the disability issue. However, the dialectical movement manifests itself within this circle, since there are different types of deficiency, as in the case of people with visual, physical and hearing deficiency. It must be considered that all people are different even if there is one or more characteristics that equals them, but all of them must have their particularities and rights respected that is equal to all citizens, according to the Brazilian Federal Constitution.

Even the terminology used must be aligned with the country's laws, conceptualizing the people with disabilities by the biopsychosocial model, considering their equity in society participation and the barriers for such inclusion. According to the Brazilian Inclusion Law, it is considered "a person with a disability the one who has a long-term disability of a physical, mental, intellectual or sensorial nature, which, in interaction with one or more barriers, may obstruct their complete and effective participation in society on an equal basis with other persons" [3].

4 Assistive Technology

There are many Assistive Technology (AT) concepts. For the Technical Assistive Committee - TAC (2009) AT is "a knowledge field with an interdisciplinary characteristic that involves products, resources, methodologies, strategies, practices and services, which aim to promote the functionality related to the activity and participation of persons with disabilities, incapacities or reduced mobility, aiming at their autonomy, independence, life quality and social inclusion".

Although the terminology "assistive technology" is recent, its concept has been used since prehistory. An example of its usage was when the man had a fractured in his leg and built an improvised cane with tree branches to aid his March. This term was implanted in Brazil in 1988, with the purpose of differentiating some hospital and medical equipment and standardizing them [5]. The AT is developed for the user such as orthotics, walking sticks, daily life adaptations, unlike the stethoscope and the sphygmomanometer, which are equipment to aid medical professionals.

Orthoses are therapeutic devices applied to several body segments with the purpose of support or rest, immobilization or functional assistance, whether for traumatic, orthopedic or neurological reasons. According to Trombly "orthoses is a device that adds itself to the body to replace a missing movement power, to restore the function, to aid a weak muscle, to position or immobilize a part of the body, or to correct deformities" [6]. The Renato Archer Information Technology Center (ITC) collaborates with the researchers for the development of AT in Additive Manufacturing (AM) in Brazil, and the records show that in 2001 occurred the first TA production in the of prosthesis and orthosis category [7].

The use of AM for the orthoses production is an excellent resource of low-cost manufacturing technology that makes it possible to help people with disabilities avoid or better musculoskeletal disorders related to work. For Radabaugh, technological development has made it easier or more comfortable for people without disabilities to make everyday tasks, but, for people with disabilities, technology makes these activities possible [8]. It was verified, in this work, that there is a constant growth of the formal jobs for the people with disabilities. However, it is not enough to guarantee the access and permanence of these workers, but it is necessary that the social inclusion happens with good health and safety conditions.

However, the AT commercialization is not always attractive to companies, since this technology is directed to a specific part of the population, and serial production is not always feasible, because the peculiarities of everyone must be considered. Many companies that produce these technologies end up raising their prices, precisely to compensate these production amount issues, which are inaccessible to many people with disabilities. Therefore, it is reiterated that low-cost AM is a great way to make AT accessible for people with disabilities.

In Brazil, the use and benefits that orthotics provide are accepted and recognized, but the 2010 report of the Working Group of the National Health Council stated some difficulties for these devices' usage. It happens, according to this document, that the Unique Health System (UHS) provides some orthoses models for the population, but the municipalities do not have the understanding about the acquisition procedures. Another obstacle that is faced by the public spheres to obtain these devices are the lengthy and bureaucratic bidding processes, which often delay the AT delivery and this fact causes to the patient treatment losses. This Working Group also reported that the orthoses assigned or commercialized by the UHS do not have a tests standardization to establish these devices qualities and characteristics. Other Brazilian control establishments, such as the National Sanitary Surveillance Agency (Anvisa) and the National Institute Metrology, Quality and Technology (Inmetro) also do not present or guide the standard testing procedures. Finally, the report points out that the management system for the acquisition of these technologies is in deficit [9].

5 The Fabrication of the Assistive Product

This study is under development and it has the base on the literature review of NUFER academic productions. The nature of the research is applied, and it has as a premise the evaluation of the possibility of implanting an AM laboratory in the UTFPR Campus Ponta Grossa, using the low-cost AT production method of NUFER, through a partnership between the University and civil society, intending to improve the working conditions of the people with disabilities of that city.

5.1 About the NUFER

The Addiction Manufacturing and Tooling Group (NUFER) of the UTFPR Campus Curitiba is a research group registered in CNPq (Research National Center), which began its activities in 2002. Throughout this period, it has produced several teaching, research and extension activities in the areas of Additive Manufacturing and Rapid Tooling. Associated to the Mechanical and Materials Engineering Graduate Program, it has a team of professionals working in the AT area and with academic production of theses, dissertations and scientific articles.

One of the target group for the technologies developed by the NUFER are the people with disabilities. The NUFER develops low-cost orthoses using AM. The optimization of the orthosis manufacturing process, using digital technologies, is an excellent path to produce AT for people with disabilities, especially for those with less economic power, emphasizing even more the significance of NUFER's work.

This group was also responsible for the partnership signed in 2017 through the Agreement no. 08/2017, that is a Technical Cooperation Agreement signed between the Federal Institute of Paraná - IFPR and the Campo Largo Municipal Government, in which they agreed to use the low-cost orthoses production methodology of NUFER for the AT development for the disabled municipality population.

Three-dimensional (3D) printers had a very high cost and were restricted to industries. However, these machines were popularized, and it allows the use of this technology to produce custom and low-cost AT products. The constant advancement of the technology, attached to a cost drop in the manufacturing, has made these devices increasingly accessible [10].

The most popular AM technology use materials such as polymer filaments, for example PLA[4] and TPU[5]. The AM manufacturing processes make a product by stacking layers of material that are deposited based on a computer-made drawing. In this way, the work aid materials production and the personalized orthotics for the people with disabilities can increase significantly since there is the possibility of developing these devices with a specific design for the patient because it can be acquired their anatomy. Another advantage is that is easier to replace the product when necessary.

[4] PLA - Polylactic Acid is a biodegradable synthetic thermoplastic, and it has been replacing the conventional plastic.

[5] TPU - Thermoplastic Polyurethane has high resistance and flexibility in low temperatures.

5.2 The Product Fabrication Method

The steps described below, illustrated by the Fig. 1, are used in the AM for low-cost orthotics fabrication process, therefore the recommended applicatives are mostly free and with academics' versions. Consequently, the partnerships established between public spheres and universities are an excellent way to make the low-cost AT acquisition process feasible, since it promotes teaching, research and extension activities for people with disabilities, and it also help to overpass the bureaucratic obstacles and the lack of clarity of the public policies for orthoses provision and other assistive technologies.

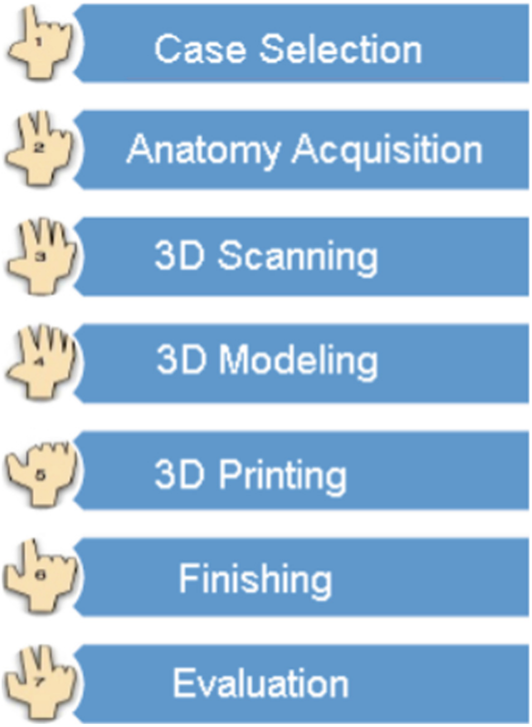

Fig. 1. Methodology used by NUFER – UTFPR for orthoses production in 3D printer [9].

5.2.1 Case Selection

Based on the Technical Cooperation Agreement signed between the public spheres of IFPR and the Campo Largo Municipal Government, the case is selected by a multidisciplinary team of the municipality, emphasizing the inclusion of people with disabilities at work. The Campo Largo Rights of Persons with Disabilities Municipal

Council[6] is also present in this process, because the Public Labor Ministry[7] is notified when the Quotas Law is not complied, and they inform the Municipal Council, which makes a survey in the institutions and associations linked to the municipality about the number of available disabled people for work that are employed/unemployed and passes the data to the Public Labor Ministry.

5.2.2 Anatomy Acquisition

The acquisition of the patient's anatomy is done by a specialized professional such as the physical therapist and the occupational therapist, with the use of a plaster splint, which is inexpensive and quick to apply.

5.2.3 3D Scanning

It allows to obtain 3D models through scanners or cameras. The case studies models scan presented in this research were done with photographic cameras. The geometry is obtained indirectly, that is, it is scanned a plaster bandage template containing the anatomy copied from the patient. It is used the Autodesk® ReCap Photo program that has a free version for academic purposes. This software allows to scan from a set of photos of the object, which offers to the user a digital model of the object. It is important to emphasize that this technique requires a well know measure object to be positioned around the model when it is made the scan in order to obtain the correct scale afterwards.

5.2.4 3D Modeling

The photos scanned by ReCap are not in the correct scale, so it is essential to make a scale correction. After this step, it needs to be done the mesh correction or surface modeling. The software used for the correction of the mesh is called Meshmixer, and it is also free with a version for academic purposes. A solid modeling may be necessary for some orthotics by drilling or cutting. For this process it is usually recommended the SolidWorks. This software is not free, but there are versions for academic institutions. The files are exported to the STL format (stereolithography) before printing.

5.2.5 3D Printing

It consists of a manufacturing process by the addition of flat layers of material, obtained directly from a 3D geometric model. The most known process uses material extrusion technology. In order to obtain a 3D print, there is a heated extruder nozzle head that performs movements on the x and y axes by depositing molten material. The tray is usually responsible for moving the z-axis, performing the third-dimension printing.

[6] **The Campo Largo Rights of Persons with Disabilities Municipal Council is a organ of permanent and joint collegial deliberation between the Public Government and the Civil Society, with deliberative, normative, advisory and oversight power of the Social Inclusion Policy of the Person with Disability.**

[7] **The Labor Public Ministry's role is to supervise and comply the labor legislation when there is a public interest.**

A material filament (and sometimes this material strut) is aligned with that heated head. In this research the assistive technologies were printed on the Microbras company's Cloner 3D printer.

5.2.6 Finishing

Sometimes it is necessary to use strut material that is removed after the printing. It happens because some printers have only one extruder nozzle and some regions of the orthotics needs to be suspended. This requires a post-processing for surface smoothing. In order to offer a better comfort for the user, it is usually used EVA (ethylene vinyl acetate) in the skin contact region, being fixed with adhesive glue (cyanoacrylate). Some orthotics are fastened with Velcro straps. These strips are sewn or placed in the orthoses with rivets that are covered with the EVA.

5.2.7 Evaluation

This step is led by a physical therapist or an occupational therapist. The evaluation is divided into two stages: the first one when the device is put in place, based on the professional and user opinion; the second assessment occurs after a few days using the device and it is based on the technical literature, characterized by the user's opinion expressed through a questionnaire that consider following assistive product aspects: safety, simple design, adjustable size, cost, attractive appearance, comfort, easy application and removal, maintenance, hygiene, resistance and Velcro location (for orthoses that have this kind of fastening). The user must respond by assigning a numbering between 0 and 10 for each item according to their level of satisfaction. It is also highlighted that after the device daily use it is necessary to the user reports pressure points, redness or injury [11].

5.3 The NUFER Experience

The NUFER has a research line of AM application in the health field, which has as one of the objectives the AT low-cost manufacture [12] (Fig. 2).

Fig. 2. 3D printed hand orthoses [11].

The NUFER's experience in additive products fabrication for the health field demonstrates the feasibility of low-cost production. Although the focus is not on the work environment, it is significant that the methodology developed, and the experience gained, can make an important contribution for the orthosis's fabrication aiming to improve working conditions.

An example of a positive experience is an orthosis produced for a spastic hand. Throughout a research in the literature and various product design methods with a low-cost alternative approach, they developed a $10 bracing that was evaluated positively by several people who participated in the process. For the final evaluation, a Semantic Differential was developed, in which the professionals involved in the orthosis preparation debate about meaning and perceptions regarding the case.

The article, at last, states "this evaluation demonstrated the complexity involved in the development of this product, which has strong disease-related stigma and also functional, aesthetic, and symbolic demands" [13].

6 Conclusion

Based on the current Brazilian legislation and the experiences of NUFER in the low-cost Assistive Technology fabrication, it is concluded that it is feasible to develop these products focused on the work environment, aiming at the social inclusion of people with disabilities.

It is important to note that there are still few studies about this subject. Therefore, it justifies the implementation of a specialized laboratory to conduct studies and improve methods focusing the improvement of the health conditions and work safety for the people with disabilities using additive manufacturing. Although AT is already used in the workplace, it is conditioned to a certain kind of disability [14]. Consequently, the AM can help in the expansion of AT, considering that it can be developed in a personalized way.

The people with disabilities inclusion process in the work starts with the access, with the legislation, for example, and it needs to be continued with the permanence with equal conditions to others. In many cases, the AT is fundamental for the process of inclusion to occur successfully. One of the great challenges of this project is to work together with companies in order to overcome the difficulties in implementing assistive solutions and to promote the maintenance of people with disabilities in the labor market. It is also important to raise the employer's commitment for this proposal [14].

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Welders' Knowledge of Personal Protective Equipment Usage and Occupational Hazards Awareness in the Ghanaian Informal Auto-mechanic Industrial Sector

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Abstract. This study explored the knowledge of informal auto-mechanics welders on personal protective equipment (PPE) usage, and their levels of occupational hazards awareness associated with the welding activity. Guided by OSHA's 2014 Hazards Assessment Checklist, and interviews, data was collected from three auto-mechanic shops engaged in welding activities in Volta Region of Ghana. Based on the analysis, it is established that the informal auto-mechanic welders generally lack knowledge on significant PPE requirement associated with the welding activities. they also lack awareness of occupational hazards associated with physical elements of the welding activities, even though they showed semblance of awareness in relation to others that are chemical-oriented. It is concluded that though the informal auto-mechanics engaged in welding activities have the requisite expertise and skills to perform their tasks, their knowledge of PPE usage and their awareness levels of occupational hazards associated with the welding activities seemed to be generally constrained.

Keywords: Welders · Welding activity · Personal protective equipment · Occupational hazards awareness · Auto-mechanic shop · Informal industrial sector · Ghana

1 Introduction

1.1 Informal Sector Auto-mechanics

The International Labour Organization (ILO) defines automobile mechanic as a worker who engages in repairing and overhauling of automotive vehicles, or their systems and parts [1]. Automobile welders are engaged in fusing together metals by applying pressure, heat, flame or electric arc [2]. Auto-mechanics who engage in the automotive repairing and allied services are referred to as 'road-side mechanics' because their makeshift garages are commonly found along-side motorways and in spaces within residentially areas. Auto-mechanics in Ghana operate in the informal sector, which consists of small and micro firms with 5–7 workers and offering a 'one-stop' technical services, mostly on vehicles to clients in Ghana and from other West African countries.

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 111–122, 2020.
https://doi.org/10.1007/978-3-030-20497-6_11

The informal auto-mechanic industry has a low level of persons with formal education. The low formal educational levels and lack of paper documentation translates into ineffective monitoring of safety precautions in this industry [3]. informal auto-mechanic apprentices are engaged in the vocation through verbal negotiation with the owner of the garage or shop [3]. The informal auto-mechanics include workers, such as transmission mechanics, car-body maintenance mechanics or welders, tune-up technicians, auto electricians and sprayers [3, 4] and [5]. Informal auto-mechanics who successfully complete their apprenticeship periods are identified by their masters based on the knowledge acquired and a satisfactory display of skills acquisition. Upon graduation, apprentices who display high commitment and evidence of satisfactory skill acquisition are given the opportunity of working with their masters for a while before establishing their own enterprises.

1.2 Work Environment of Informal Auto-mechanics

Auto-mechanics are part of Ghana's informal sector. An essential element of health and safety practices in the operations of the auto-mechanics is the environmental condition under which they work. The unstructured nature of the informal auto-mechanics sector and it being unregulated has given rise to ignorance towards the incorporation of health and safety measures in the activities of operators. Informal sector auto-mechanics suffer exposure to many hazards within their work environment which include; paint pigments, asbestos, automobile exhaust, anticorrosive substances and solvents [6] and [7]. Yet, the level of occupational health hazards awareness, knowledge of personal protective equipment (PPE) and PPE usage among informal sector auto mechanics engaged in welding activities in Ghana remains unexplored. The purpose of this study, therefore, was to assess the knowledge of Informal Sector Auto-Mechanics engaged in welding activities on PPE and its usage, as well as the level of their awareness of occupational hazards associated with their welding activities and the measures used to safeguard health and safety.

2 Work Safety and Performers' Health

A good national occupational health and safety system is critical for the effective implementation of national policies and programs to strengthen the prevention of occupational diseases [8]. To this end, technical-engineering, ergonomic, medical and psychosocial studies have focused on eliminating as many dangers and risks from the workplace as possible and to reduce the number and severity of injuries [9]. According to [10], chronic health effects occur because of prolonged exposure to hazards and are of long duration. However, the workers in these and similar occupations, particularly in developing countries, were generally believed to lack knowledge on the occupational health hazards [11]. Similarly, [11] identified that auto mechanics were unlikely to take protective measures against the hazards. Studies showed that, workers at the workshops face a range of hazards, workplace risks and exposure. Hazards faced by informal auto-mechanics have been identified by [12] to include physical, accidental, chemical, biological and ergonomic hazards. These may result in occupational health issues among mechanics such as respiratory ailments, eye injuries, accidents, fume inhalation, hearing loss and eye injuries [12].

2.1 Informal Auto-mechanic Welders' Knowledge of PPE

Welding is associated with systemic and several ocular hazards which calls for adequate protective measures [13]. Exposure to welding hazards could lead to low vision and blindness among welders. In a study to ascertain the relationship between knowledge of PPE and its usage among auto-mechanics in Eastern Nepal, [14] found a significant relationship to exist between the auto-mechanics' awareness of hazard, awareness of PPE and use of PPE. A similar study by [15] in Nigeria showed that auto-mechanics' awareness of hazard increased significantly with an increase in education level.

In a study which assessed eye protection practices and symptoms among welders in the Limpopo Province of South Africa, [13] found that welders may be inadvertently exposed to arcs of nearby welders even when not directly engaged in welding activities. Based on experience, welders generally shield themselves from harmful radiations and mechanical injuries using PPEs such as helmets, face shields and safety goggles [16]. The South African Occupational Health and Safety Act [17] further states that all other persons exposed to welding hazards should be warned and provided with suitable protective equipment where partitioning of workplace is not practicable by [17].

Other studies have found welders to use ordinary sunglasses during welding activities [13] and [18]. According to the American Federation of State, County and Municipal Employees [19], different optical densities of filters (shade numbers) exist for different types of welding. Shade numbers, such as Plasma arc cutting and spraying (15), atomic hydrogen welding (10–14), shielded metal arc welding (10), gas shielded arc welding (4–8), silver brazing (3 or 4) and soldering (2) have been categorized by [19] as appropriate shade numbers for welders. The use of ordinary sunglasses though may protect against ultraviolet radiation [19], the lack of side-shields exposes welders to flying particles, dust and fumes which may cause serious eye injuries [13]. A study by [13] on the eye protection practices and symptoms experienced by 150 welders in South Africa, established that very few welders (1%) knew what welding shade numbers meant, while majority of them (99%) have no knowledge of it means. This is despite [13]'s finding of most welders indicating that they always wear protective devices when engaged in welding activities.

2.2 Informal Auto-mechanic Welders' Awareness of Occupational Hazards

In developing countries, welding is one of the occupations that contribute to work related accidents and diseases [21]. A positive association between awareness of occupational hazards and PPE knowledge which enhances PPE usage [2]. Mechanics who had no formal education were less aware of hazards associated with their work [2]. According to [2], the Zambian curriculum for primary and secondary school education includes technical skills subjects which are compulsory or optional depending on management's choice in different schools. As a result, welders who had at least a primary education could have come across hazards and PPE information formally in these subjects [2]. Thus, compared to mechanics that were literate and aware of hazards of their work, those who had no formal education were less aware of hazards, less aware of PPE and therefore reported less PPE use [2].

In a study of welders' awareness of occupational hazards, [20] found a significant association between workers' hazard awareness and presence of workplace safety regulations. Based on this finding, [20] noted that information is vital and helpful in designing intervention strategies targeted at promoting safety standards in this working group. A study in India by [21] on informal auto-mechanic welders' knowledge on PPE usage established that the non-usage of protective gears for face and eyes was greater among welders who were unaware of occupational hazards associated with the welding activities [21].

3 Methodology

3.1 Sampling

A purposive sampling was employed to select informal sector auto-mechanics engaged in welding activities in the Volta Region of Ghana. Auto mechanic shops considered to have welder categories, encompassing master-welders, worker-welders and apprentice-welders were considered. Subsequently, three (3) interviewees with rich experience in welding who agreed to participate in the study were selected.

3.2 Data Collection Approach

Data was collected firstly, using the OSHA Hazard Assessment Checklist [22] to identify hazards associated with the work of the welders, and secondly, through follow-up interviews. The Hazard Assessment Checklist is multi-dimensional instrument consisting of general work environment, personal protective equipment, hand tools and equipment, portable (power operated) tools and equipment, abrasive wheel equipment grinders, machine guarding, welding cutting and bracing, compressed gas and cylinders, environmental controls, flammable and combustible materials, fire protection, noise, material handling and ergonomics.

In the data collection approach, introductory letters from the Department of Organization and Human Resource Management of the University of Ghana Business School was sent to the Regional Secretariat of Ghana National Association of Garages (GNAG) through the Regional Chairman. The GNAG Chairman then contacted the various GNAG Zonal representatives to inform them about the study. Upon approval, the welding shop owners were informed by the researchers about the purpose of the study and assured of confidentiality. The first step of data collection involved an expert activity where the researchers individually assess the shops using the OSHA Hazard Assessment Checklist [22] as guide. In the second step, follow-up interviews were conducted with the shop owners using outcomes from the first data as interview guide. The average duration for the interviews was forty-five minutes.

3.3 Data Analysis Approach

A two-steps analytical approach was used. In the first step, the observational data generated using the Hazards Assessment Checklist [22] was analyzed. In the second phase, the transcribed interviews data were analysed using descriptive analysis qualitative approach.

4 Results and Discussion

4.1 Analysis of Respondents Demography

The distribution of respondents' demographics showed that all the interviews (3 males) between the ages of 40 to 60 years with more than 10 years working experience as welders in the informal sector. Two (2) of them had basic education and the third had technical education. Two (2) of them put in more than 10 h of work daily as welders, while the third works between 8 and 10 h daily. Welding activities in the three welding shops (WS) are shown in Fig. 1 below.

Fig. 1. Welding activity in WS-1 (left), WS-2 (middle) and WS-3 (right)

4.2 Analysis of Welders' Knowledge of Personal Protective Equipment Usage

The result from the researchers' assessment of the informal auto-mechanic welders' knowledge of personal protective equipment (PPE) usage, from the perspectives of the prevailing PPE situation within the workspaces of the three welding shops (WS), using the Hazards Assessment Checklist [22], is summarized in Table 1 below. The results show that aside WS-1, which did not meet the standard requirement of permitting only authorized and trained welders to use welding, cutting and brazing equipment, the owners of WS-2 and WS-3 have knowledge on such requirement and thus enforce it. On the contrary, aside WS-3, which met the requirement of using care in handling and storage of cylinders, safety valves, relief valves, and the like, to prevent damage, as well as making suitable fire extinguishing equipment for immediate use, the owners of WS-1 and WS-2 have no knowledge on such requirements for them to ensure compliance. Also, aside WS-1 which met the standard requirement of taking environmental monitoring tests and providing means of quick removal of welders in case of emergency when working in confined places, the owners of WS-2 and WS-3 did not have no knowledge on such requirement for them to ensure compliance.

Table 1. Assessment results of welders' knowledge of PPE usage in welding shops.

Assessment indices	Assessment results		
	WS-1	WS-2	WS-3
Only authorized and trained personnel are permitted to use welding, cutting and brazing equipment	No	Yes	Yes
All operators have a copy of the appropriate operating instructions and are directed to follow them	No	No	No
Compressed gas cylinders are regularly examined for obvious signs of defects, deep rusting, or leakage	No	No	No
Care is used in handling and storage of cylinders, safety valves, relief valves, and the like, to prevent damage	No	Yes	No
Cylinders are kept away from sources of heat	No	No	No
Sign reading: Danger, no-smoking is posted	No	No	No
Care is taken not to drop or strike cylinders	No	No	No
Red is used to identify acetylene (and other fuel gas) hose, green for oxygen hose, and black for inert gas and air hose	No	No	No
Electrodes are removed from the holders when not in use	No	No	No
Suitable fire extinguishing equipment is available for immediate use	No	No	Yes
The welder is forbidden to coil or loop welding electrode cable around his body	Yes	Yes	Yes
It is required that eye protection helmets, hand shields and goggles meet appropriate standards	No	No	No
Employees exposed to the hazards created by welding, cutting, or bracing operations are protected with personal protective equipment and clothing	No	No	No
When working in confined places, environmental monitoring tests are taken, and means are provided for quick removal of welders in case of emergency	Yes	No	No

All the three shops did not meet the requirement of providing their welders with copies of the appropriate operating instructions and directing them to follow suit. Similarly, all the shops did not meet the standard requirement of regularly examining compressed gas cylinders for obvious signs of defects, deep rusting, or leakage. Additionally, all the three shops assessed were found lacking, in terms of the following PPE standard requirements;

- keeping cylinders away from sources of heat.
- posting signs to read: Danger, no-smoking, matches or open-lights allowed.
- taking care not to drop or strike cylinders was not met.
- use of red to identify acetylene (and other fuel gas) hose, green for oxygen hose, and black for inert gas and air hose.
- removing electrodes from the holders when not in use.
- Ensuring that eye protection helmets, hand shields and goggles meet appropriate standards.
- protecting employees exposed to the hazards created by welding, cutting, or bracing operations with personal protective equipment and clothing.

It is evident from the above assessment results that, the informal auto-mechanic welders generally lack knowledge on significant PPE requirement associated with the welding activities. Thus, in a bid to understand why it is not only authorized and trained mechanics who are permitted to use welding, cutting and brazing equipment, the owner of WS-1, in an interview, indicated that during peak periods of work, apprentice welders who may not be as qualified as other welders, but display rapid learning skills, are allowed to assist with some of the welding jobs. This is because, they do not want to lose their clients.

Again, in a bid to understand why operators did not have copies of appropriate operating instructions, all the three auto-mechanic shop owners interviewed indicated that new machines they purchase usually come with operating instructions. On the contrary, the used-machines purchased by the welders do not usually come with operating instructions. As such, they use their operational knowledge of similar machines to operate them. As it is observed by the owner of WS-3 in the following comment:

> Unless you decide to go for home-used machines, a lot of our machines come with operating instructions. That one is not a problem, but can we all read and understand it? No. Fortunately, in some of the manuals, they draw pictures to show how to go about the usage. That is what helps us sometime.

On the issue of why electrodes are not removed from the holders when not in use, all the interviewees were of the view that the electrodes were small and could easily get missing. Thus, when there is the need to weld again, the welders do not have to go searching for the leftover electrodes, and by implication reducing wastages in their systems. This is observation is highlighted by the owner of WS-1 in the following comment.

> When you are done working for the day the electrodes can be removed from the holder. But if it is not the close of day yet, you must leave the electrode in the holder, because, if you remove it and another person is going to weld, they will pick a new electrode instead of continuing with the piece of electrode that you have, which ends up creating waste. So, we leave the electrodes in the holder to avoid the wastage. Even the pieces can be used to work.

All the interviewees intimated that not all PPEs are always available for usage in their welding activities and are compelled to improvise in some occasions, as it is observed by owner of WS-1 in the following comment.

> We improvise a lot especially, when it comes to our eyes, you have seen the wood with the shade in it. Ahaa, that is what is available to us and other things. But since the PPEs are not things that we use regularly, we are not so much into standards.

Furthermore, the shop owners indicated that in some instances, the PPEs and clothing are provided, but their workers do not use them, because they view the PPEs, firstly, as slowing down their work speed, and secondly, because welding activities generate heat, wearing the full complement of PPEs and clothing in the midst of the heat becomes a challenge, as it is highlighted in the following comments by owners of WS-2, and WS-3.

> We work in the open unless a contract takes us out of the shop. But when we go, we are still on the lookout and work with caution so as not to get hurt [Owner, WS-3].

And,

> Whenever you see us working in confined spaces, you should know that it is not permanent. It means we have just been called to go and work somewhere. Someone will have to call you before you go out. So, you check to see if the material you are welding or working on would not fall on you or if it is a high place, you would not fall [Owner, WS-2].

It could be derived from the analysis above that the welders displayed knowledge on welding activities. The welders however exhibited limited knowledge on proper use of safety measures which are important towards preventing and reducing a variety of health hazards they are exposed to when engaged in welding activities.

From the above analysis, the shop owners could not insist on the use of PPE or monitor its use because some of the owners themselves did not use them regularly and did not pay much emphasis on PPE usage training. These findings agree with [23]'s observations that master craftsmen are unable to insist on PPE usage, because despite their skills and experiences in welding activities, they themselves neither use PPEs regularly nor conduct personal safety training for their workers. The finding also agrees with that of [21], who found that welders' irregular usage of protective gear usage is informed by their ignorance of its importance.

4.3 Analysis of Welders' Level of Occupational Hazards Awareness

The results of the researchers' assessment of the occupational hazards awareness, in terms of environmental control and material handling in the three informal auto-mechanic welders' shops (WS), using the Hazards Assessment Checklist [22] is summarized in Table 2 below. The results in Table 2 shows that aside WS-1, which did not carry daily inspection of motorized vehicles and mechanized equipment prior to use, the owners of WS-2 and WS-3 undertake such daily inspection, thus indicating their awareness of its associated occupational hazards. It is also indicative that all the three shops engage in the following activities, which manifest their awareness of the occupational hazards associated with them.

- Identifying hazardous substances which may cause harm by inhalation, ingestion, skin absorption or contact.
- Controlling employee exposure to welding fumes by ventilation, use of respirators, exposure time, or other means.
- Securing trucks and trailers from movement during loading and unloading operations.

Table 2. Assessment result of welders' occupational hazards awareness

Assessment indices	Assessment results		
	WS-1	WS-2	WS-3
Instructing employees in proper first aid and other emergency procedures	No	No	No
Identifying hazardous substances which may cause harm by inhalation, ingestion, skin absorption or contact	Yes	Yes	Yes
Controlling employee exposure to welding fumes by ventilation, use of respirators, exposure time, or other means	Yes	Yes	Yes
Providing welders and other workers nearby with flash shields during welding operations	No	No	No
Using and maintaining personal protective equipment provided, wherever required	No	No	No
Provision of written standard operating procedures for the selection and use of respirators where needed	No	No	No
Instructing employees in the proper manner of lifting heavy objects	No	No	No
Properly shielding equipment producing ultra-violet radiation	No	No	No
Daily inspection of motorized vehicles and mechanized equipment prior to use	No	Yes	Yes
Securing trucks and trailers from movement during loading and unloading operations	Yes	Yes	Yes

On the contrary, all the three shops did not engage in the following activities, thus, manifesting their lack of awareness of the occupational hazards associated with them;

- Providing welders and other workers nearby with flash shields during welding operations.
- Using and maintaining personal protective equipment provided, wherever required.
- Provision of written standard operating procedures for the selection and use of respirators where needed.
- Instructing employees in the proper manner of lifting heavy objects.
- Properly shielding equipment producing ultra-violet radiation.

It is therefore evident from the above assessment results that the informal auto-mechanic welders generally lack awareness of occupational hazards associated with physical elements of the welding activities, even though they showed semblance of awareness in relation to others that are chemical-oriented.

In a bid to understand the level of the welders' awareness of the hazards associated with the non-usage of PPEs, such as flash shields, as protective tools during welding operations, all the three shop owners interviewed indicated their awareness of such hazards. Yet, they credited their non-usage of PPEs, such as flash shields, to the discomfort they experience in its usage when performing welding tasks, especially, under vehicles. Concerning the absence of written standard operating procedures for the selection and use of respirators where needed in all the three shops, it emerged from the interview that all the shop owners lack awareness of the relevance of such procedures, as could be derived from the following comment by the owner of WS-2;

> We scarcely use respirators, because we work in the open. Mostly, the respirators are used by persons who work in the big factories. We do not use them, because we do small, small work.

Regarding the shop owners' awareness of hazards associated with the non-proper shielding of equipment producing ultra-violet radiation, they all had the notion that unlike welding activities in larger factories, which are performed in confined spaces (welding booths) with welders well-protected from equipment producing ultra-violet radiations, their welding activities are carried out in open spaces. As such, since all activities are carried out in the same shop, equipment producing ultra-violet radiations are not isolated from each other, as well as the welders operating them, thus exposing the welder to the radiations, as it is highlighted below by owner of WS-3;

> The welding processes come with sparks and produces ultra-violet radiations. Since our welding activities are not isolated from other activities in our shops, we advise those around not look directly at the sparks, because it is not comfortable. So, we try as much as possible to avoid direct watching;

Concerning the shop owners' awareness of hazards associated with non-daily inspection of equipment prior to use, it emerged from the interview that such awareness is minimal, for the shop owners, inspection is due necessary only when they detect faults on equipment. When alerts to such faults are not received, equipment are deemed to be in good condition and are continually used, as it is highlighted in the following comment by the owner of WS-2;

> If you detect a fault with equipment, that is when you will be concerned. If there is no fault, you will just be using the machines like that.

It could be derived from the findings above that the level of the welders' awareness of occupational hazards associated with their welding activities is low and corroborates those of [21] and [24].

5 Conclusion

This study has shown that informal auto-mechanics in Ghana who are engaged in welding activities have significant safety management challenges relative to knowledge in PPE usage and occupational hazards awareness. Based on the findings, it is concluded that though the informal auto-mechanics engaged in welding activities have the requisite expertise and skills to perform their tasks, their knowledge of PPEs and awareness of occupational hazards associated with their work seemed to be generally constrained. The implication is that, there should be enhanced commitment from informal auto-mechanics engaged in welding activities who own shops towards best practices on health and safety. Health and safety should always be maintained in relation to practices, procedures and general environment to ensure safety of workers and clients always. Training on PPE usage should be enhanced and strict compliance on usage should be ensured to significantly reduce workplace hazards. Shop owners should make PPEs available for use in their shops, and should serve as role models to their workers who learn a lot from them through observation.

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Determination of Safe Work Practiced in a Confine Space Work: A Case Study Research of an Organisation in Onne, Nigeria

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Abstract. In developing countries like Nigeria, it is generally reported that confined space accidents and injuries are still prevalent in the industries, which could be due to several factors including-poor efficiency at managing confined space work activities and enforcing required legislation/standards following safe work practice. A case study research was carried out using both exploratory designs for a quantitative approach, and explanatory design for qualitative approach bring the approach to a mixed method choice for evaluation using Confine Space Regulation, 1997, Questionnaire and Observation as an instrument for data collection for analyses.

Summary of findings are; Safe Working Procedure Reviewed before the start of work, Poor Use of Communication Methods, Poor Supervision, Failure to Use Personal Protective Equipment, Ignoring Safe Work Practice. Recommendations were made for the improvement of organisations system to enhance a safe process following best practice guidance; with the aim of reducing the level of accidents and fatalities to workers working within a confined space.

1 Introduction

According to the United States Occupational Safety and Health Association, (OSHA) standard, defines a confined space as “a space that is large enough and configured that employees could enter and perform work, has limited openings of entry or exit and is not designed for continuous occupancy” (Botti et al. 2017a, b, c; Burlet-Vienney et al. 2015 and Wang et al. 2016). Furthermore, the Canadian Quebec Regulations on Occupational health and safety (ROHS) describes confined space as an enclosed area or any area that is entirely or partially enclosed, which has the following conditions: not designed for human occupation, nor intended to be, but may occasionally be occupied during work; with access which can only be made via restricted entry and exits (Burlet-Vienney et al. 2015). Similarly, the United Kingdom Confined Spaces Regulations (1997) states that for a space to be termed a confined space, there must be a significant level of an enclosure (but may not always be completely enclosed); besides, it must present at least one recognisable risk.

Moreover, the American Occupational Safety and Health Administration (OSHA) standard is the generally recognise Permit-Required Confined Spaces (PRCS) standard,

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 123–133, 2020.
https://doi.org/10.1007/978-3-030-20497-6_12

commonly applied in industries for confined space work (Botti et al. 2017a, b, c). The standard provides a general definition of confined space, as well as practices and procedures required to safeguard industrial workers from hazard associated with the entry of permit-required confined spaces (Botti et al. 2017a, b, c).

In an industrial setting, all work performed in a confined space requires a permit, these includes work conducted in tanks, pipes, flues, tunnels, trenches, chambers, pits, silos, wells (Hu 2011). Also, an operational sewer system, manholes, ducts, sumps. Are considered as a permit-required confined space (Smith et al. 2014), (Confined Spaces Regulations 4, 1997, pgs. 10 & 32).

In Nigeria, working in confined spaces both in private and public organizations could potentially be associated with a myriad of risks. However, some people who work as contractors to multinational organizations and operate by standard rules set by their organization may be less affected by potential risks from the confined work environment. Umeokafor et al. (2014) added that established international or multinational organisation have existing standard practices and legislations guiding them in respect to confined space activities, but the majority do not have standard practices set by any organisation or governing body in Nigeria to follow. Fleming (2015) and (Dumortier and Hendel-Blackford 2011a, b) believes that both those who operated by standard procedures and practices and those who do not, still have fatalities or injuries that will lead to subsequent health challenges from the confined space activities.

In developing countries like Nigeria, is it generally reported that confined space accidents and injuries are still prevalent in the industries, which could be due to several factors including- efficiency to observe a safe system of work while carrying out a confined space work activity and enforcing required legislation/standards (Umeokafor et al. 2014).

The American standard regarding confined spaces gives recommendations on the management programmes to be set in place. It specifies the duties and responsibilities of people involved, the types of planning (including training, response plan in the event of an emergency), and implementation of programs (such as entry permits), (Burlet-Vienney et al. 2015).

Adherence to Standard Safe Work Procedures is required that, before entering the confined space work area where an unsafe situation has been established, it must first be ventilated (Smith et al. 2014). It was reported by (Burlet-Vienney et al. 2014) that 33 cases of confined space incidences which occurred in Quebec between 1998 and 2011 showed that there was no pre-established safe working procedure; consequently, employers could not detect hazards associated with the confined spaces; also, planning for safe work conditions in confined space and management of risks were not conducted and subsequently led to 41 deaths (Burlet-Vienney et al. 2014).

Company x which was used as a case study, is an indigenous company located in Federal Lighter Terminal (FLT) of Onne Oil and Gas Free zone, Onne, River state, Nigeria. The company was established in the year 2001 as a subsidiary of INTELS (Nig) Limited and later transferred to an indigenous investor through appropriate legal transactions. It has a staff strength of 102, with a dedicated group of 78 staffs trained in confined space work, which are sub-divided into four working groups.

The results of the study could potentially assist in disproving or reinforcing the proposition, and additionally providing a viable basis for suggestions or recommendations regarding aspects of confined space work, which could potentially lead to improvements in the efficiency or level of workers safety.

2 Methodology

A case study research with a single case design was chosen with the aim to provide the author with an in-depth study of the group (organizations work procedure/activities. The qualitative research method was adopted in implementing the study with the combination of two research data instruments (questionnaire and observation).

The first instrument was the Confine Space Regulation, 1997 for confined space working as a checklist during participants' observation to compare standard procedure for operation in the case study, to produce qualitative data for analysis. The second instrument used was a questionnaire with close-ended questions that were relevant to the information the author intends to use in obtaining quantitative data for analysis.

These methods were used to provide further understanding and test the reliability of the respondents' view concerning the observation. The data for this study was gathered from both primary and secondary sources in conformity with the quantitative and qualitative approaches adopted.

The questionnaire was considered appropriate for this study because of its flexibility, practicality and broader coverage to the participants in the focus group. On the other hand, the primary qualitative data was conducted through participant observation of a focus group involved in confined space work activity using a non-probability sampling was adopted because of its flexibility, time effective and opportunity provided when dealing with small population.

This study analysed its data using both numerical and descriptive/interpretative approaches. Moreover, the primary data collected through questionnaire was coded using the SPSS software (20.0), where the two-tailed test was used in analyzing the data. Subsequently, the correlation was checked using Pearson before its interpretation and synthesis of finding.

3 Result/Findings

This study sought to identify gaps in the working procedures, with a view to exploring answers to The compliance level of employees working in a confined space, to safe practices and standards in place? Investigate safe working principles for the development of better practices in this sector, hence helping to reduce fatalities. The researcher used analysed data gotten through qualitative methods using observation as a tool for collecting data from the company under review in Onne, Nigeria.

3.1 The Researcher Observed the Nature of Confined Space Job That Was Carried Out and Collected Qualitative Data as Shown Below

Tank cleaning activity in a seaworthy vessel was carried out, and six tanks were cleaned on the vessel. Previous content was Automotive Gas Oil (Diesel fuel), and the next content will be Ethanol. The residue left in the tank was pumped into a mobile waste collection truck where it was to be sent for treatment in the Containerized Incinerating System or Thermal Desorption Units before final disposal of residue.

3.2 The Researcher Looked at the General Management of Activity Before a Confined Space Work Is Carried Out and What Is Expected During and After the Work, Such as Required by Confined Spaces Regulation 1997, Including-Supervision, Ensuring Competence, Risk Assessment, and Job Hazard Analysis, Issuing Permits to Work and Suitable Access/Egress, Ensuring Stand by Personnel, Safe Work Practices

There were a supervisor and a safety office on board the vessel. The supervisor held a toolbox meeting where he informed the workers about the hazards associated with the work to be done and how they should ensure safety and follow precaution.

Activity started with the extraction of fluid from the underground tanks and ventilation of the space. The safety officer monitored the atmospheric condition in the tank, using an air monitor and recorded the results.

Supervision was not efficient enough because the cleaning up activity was poor; the work area was not cleared; equipment and items that could cause trip and fall littered the surrounding.

Workers were not properly kitted and ready for the job. Some workers wore no gloves. While some were working, others sat eating snacks in the environment.

Essential equipment for confined space work like- life-lines, breathing apparatus was not positioned at the tank entrance, and radios were not used though there was some entrant personnel outside the space communicating by vocals means.

Permit to work was signed at a multinational company yard before the commencement of the work, without prior supervision by chevron staff.

A supervisor from company x whose vessel was being cleaned came on site to inspect the on-going work in their vessel. He went through what was expected using their checklist and then signed the permit to work for the work to proceed. An organisation under investigation had no specific checklist of their own for the work. They solely depended on the checklist from a multinational company because they were merely working for a client.

3.3 Provision of Entrance and Egress

A suitable entrance and egress to the vessel were provided, but no safety sign was placed on them. Safe work practice was averagely ensured as a lot of unsafe acts were observed, and safety precautions were not strictly followed during tank cleaning.

3.4 The Process of Removing Residues from the Confined Space Was Observed

An access hole was created into the tank, and the content was sucked into the mobile septic tank that was stationed near the vessel. All remaining residues, including the waste products, were extracted safely. The process was well monitored, a fire extinguisher was on standby in case of ignition or fire outbreak.

3.5 PPEs Provided by the Employer for Confined Space Work Included Permanent and Temporary Coverall, Safety Shoes, Helmet, Rubber Glove, Combination Glove, Dotted Glove, Disposable Coverall, Dust Mask, Full Face Chemical Respirator, Chemical Suit, Safety Goggles, Rubber Boot (Steel Toed), Hard Hats and Safety Boots and These Are Required by the Confine Space Regulation, 1997, to Be Worn or Used Depending on the Nature of Job

Some workers did not wear their gloves, instead worked with their bare hands. Those workers working within the confined space were not wearing face shields to protect their face from liquid splashes. Safety goggles were not worn, apart from the supervisor who worn his. Ear protection was not worn to prevent excessive noise within and around the workplace. No first aid box was available on the deck/site for quick emergency treatment; no barricades were placed around the confined space work zone (Fig. 1).

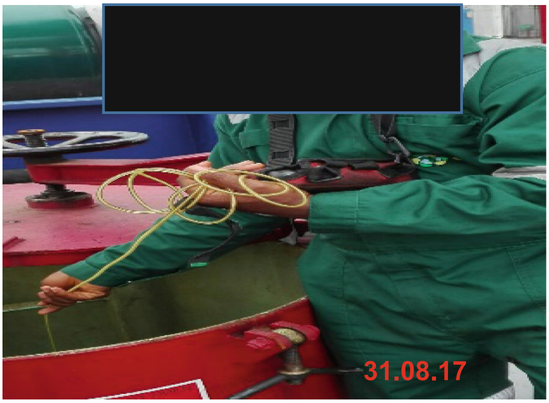

Fig. 1. Showing the tester working without a glove. Source: Researchers field work.

3.6 The Time Spent by Each Worker in Performing His Task Was Observed, also Was the Amount of Work Done Within the Period

Each pair of workers were made to complete their cleaning task in each tank before they were asked to come out. The supervisor or safety personnel did not time. Their stay within the space. The cleaning activities took over four hours without a break.

Workers had to bring in their food on board, while the job was going on to eat their lunch. It is the researcher believes that eating in such contaminated and unhygienic environment can lead to ingestion of contaminants, with the consequence of severe injury or ill health.

3.7 The Researcher Observed the Plan for Emergency and Rescue Designed by the Company for Managing Emergencies and the Data Are Shown Below

Emergency procedure and rescue plan on the ground was excellent and active, as an ambulance well equipped with a nurse was on standby throughout the duration of the work, this covered both the day "Team A" and the night "Team B."

4 Research Findings from Questionnaire

The findings are presented as follows, the second part of this work utilized a questionnaire in investigating the practices in a confined workspace. Information was received from 74 respondents and were all valid responses.

The sample population was based on people undertaking confined space work. The following demographic information was obtained from the 74 respondents. A lopsided distribution was observed with 98.6% of the respondents being males, and only 1.4% were female.

Respondents were asked to rate their level of compliance to safe work practices in the confined workspace, 80% claimed it was very good, with 20% admitting being good in following safety protocols as related to working in the confined workspace. While the distribution of workers responses to what they thought was responsible for accidents despite the control measures. Majority of respondents 36.5% said inadequate training was the reason, 25.7% claimed that the lack of continuous monitoring of space was responsible for accidents, 23% blamed faulty equipment, and 14.9% said poor risk assessments in the identification of hazards was responsible for accidents encountered in confined space. No responses were elicited for ignoring safety procedures and practice (Fig. 2).

The graphs above showed the result obtained from the case study questionnaire showing respondents percentage on various themes with not less than 50% performance rating from the themes selected. Having a level of awareness and method of communication at 78.4%, which is very good, followed by risk assessment having 73% for non-routine jobs been carried out for specific jobs and 59.5% of for routine jobs carried out when necessary.

The evaluation process for oxygen testing and hazards summed up to 59.5%, while 70.3% agrees that management process should be improved.

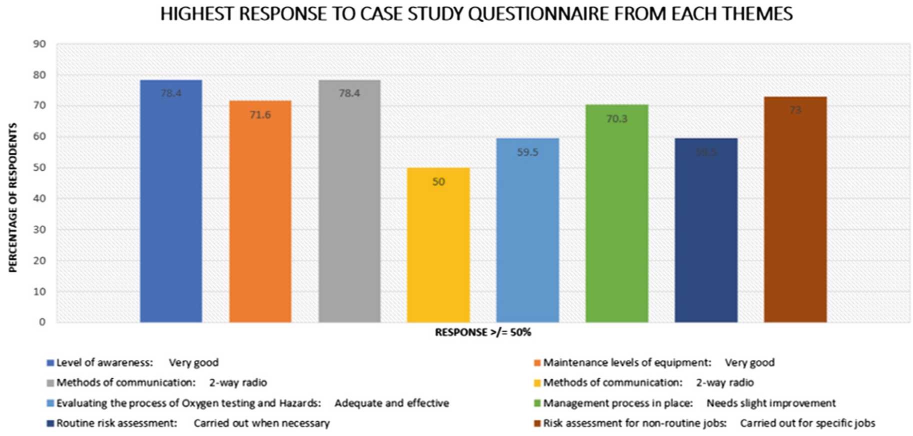

Fig. 2. Graph showing the highest response to case study Questionnaire from each theme.

5 Discussion

In validating the results, participant observation was done by participating in the work activity to get the direct and factual result required to answer the research question. Although beneficial, the researcher believes that not being able to be an invisible observer may have affected the behaviour of workers by being more conscious in carrying out their various task as they were aware, they were being observed.

The situation was impossible to be an invisible observer because the researcher needed to be involved in the activity to get more information, which the questionnaire could not reveal. However, it was better to be a participant observer than not participating at all.

Risk assessments are carried out for identification, elimination and control of different hazards types that exist in the space and the capacity of the employer to eradicate them was beneficial to ensuring the safety of workers who work in these sites. The researcher observed work activity on site. The supervisor and a safety officer did a risk assessment before the commencement of the task at hand.

The researcher noted that while observing risk assessments, those disparities existed between the works of the supervisor and the safety officers; and, in comparison to what the workers thought about the risk assessment.

For routine risk assessment checks, most respondents were inclined to thinking it should be carried out when necessary; while for non-routine jobs, it should be done depending on the job.

Considering the effectiveness of their company's risk assessments: the majority thought it is adequate and effective. This contrasts with what was observed on site. The researcher noted poor adherence to the checklist on the part of the company, with some instances of negligence. Supervision of the task was not efficient enough to eradicate physical hazards that could cause trips and enforce compliance to safe practices concerning wearing appropriate PPE for the job and delegation of duties.

The researcher thought most of the respondents answered strictly on an academic level (as majority 51.4% had high school certification, while 28.4% had diploma, 13.5% postgraduate and the least 1.4% had primary level of education, and all of them had training certification to carry out work in a confined space) and knew what the safety procedures were but their compliance to the safe work practice during the activity observed did not precisely reflect the true state of regular events while carrying out risk assessments compared to the result claimed from the survey carried out.

We are assessing the management process and testing procedures, testing procedures aid in detecting hazardous materials and preventing potentially harmful conditions that occur in confined spaces. Testing for oxygen concentration, atmospheric hazards, and removal of wastes and harmful substances are essential components of the management of hazards in confined spaces.

Majority of the respondents were shown to be in favor of the techniques used by the company in the management and testing of these hazards and trust the abilities of testers to carry out these processes. However when enquiring about what needed improvement, the majority of the respondents still highlighted the techniques as needing improvement. Only a few answered it as personnel training. It is worthy of mention that while the company carried out these procedures at the beginning of work, the provision for constant monitoring was over 30–40 min. Hu (2011), noted that not only should testing be continuously done but also at the various depths. The importance of this is that some gases may form after the initial checks as a result of the chemicals used and retained residues could cause gasses to settle within the chamber during cleaning. This is usually missed putting workers safety at risk.

The company was observed to have used a piece of equipment not adequate for the required depths. Even though readings were taken and adjudged optimal for the sake of record keeping, it was difficult to be sure that this was the case.

In assessing the communication process, the conditions in confined spaces vary and might pose some difficulty with the observation of workers health and safety during work. Hence, the use of communication equipment's has been put in place for checking workers in case of distress and evacuation, and for general monitoring of activities in the confined space. The researcher noted that most respondents claimed to be satisfied with their communication process, saying it was adequate and effective. The two-way radios were commonly used alongside voice, visual and lifeline methods. Since all of the workers had some form of education, the use of signage is not misplaced as signage works as a constant or caution reminder to workers on safety protocols. Workers were seen routinely using only vocal means to communicate during the observed activities, ignoring other safer methods of communication.

Results from quantitative data collected showed that all appropriate means of communication in confined space are available, but none was used for this task as observed. Only voice-vocal was used for communication between entering and entrée. No lifeline or radio was used in the task observed, which is contrary to confine space regulation 4, 1997. Also observed was poor signage at egress points, which did not adequately meet the requirements of confined spaces regulation 1997.

The assessment of the equipment used in these work sites are somewhat sensitive, hence the need for maintenance. Most confined space equipment provided by the employer was not on site, with the assumption that they were not needed against the instruction laid down in confined spaces regulation 4, 1997. Most of the respondents agreed to the effectiveness of this equipment. It is, however, the duty of the company to monitor and maintain this equipment. Calibration is usually done every six months, most likely as company policy. The confined space regulation, 1997 subsection 184, pg. 41. States that "calibration should be done in accordance with the manufacturer's specification." We note how the margin of error may affect the readings gotten, and that could cause severe harm. The researcher noted that while most of the respondents said personal protective equipment are adequate and effective in the prevention of risk; on observation, some did not make use of this personal protective equipment even though it was provided; creating room for potentially dangerous incidents.

It is somewhat foolhardy to judge someone's compliance levels based on what they say; hence, the researcher corroborated this with what was observed on site. Majority of the respondents claimed to comply with protocols and have very good compliance levels. However, observation of workers in the site while they carried out their duties showed otherwise. Some showed a lack of awareness by working without personal protective equipment, tester bending downwards into the space to test for gas, poor housekeeping, and inadequate signage on egress and workspace; also, some workers were eating in the work environment where ventilation, extraction, and gas testing exercises were going on.

There were no breaks at the interval for over 7-h period of operation. Botti et al.'s (2017a, b, c) agrees with OSHA in saying confined spaces were not for continuous occupancy to prevent harm it is very vital to observe the exposure limits recommended in the confined space regulation, 1997. This showed blatant disregard to safety practices on the part of both the workers and management.

In the bid to answer the research question on knowing what the compliance level is, of employees working in a confined space towards the safe practices and standards in place?

Similarly, reviewing company x incident report presented over a period of 8 years, it has also been observed that most of the root causes of incidents were either as a result of wrong or poor communication, the release of gases, dizziness, hydration, improper P.P.E, wrong equipment, explosion, and slips. The researcher is inclined to thinking that these conditions are as a result of inadequate supervision, ignoring safe work practices and negligence in the part of the worker and apathetic approach of management to safety protocols.

The condolence of this practice may be as a result of not statutes locally on the laid down appropriate procedures for this sector, hence permissible. Subsequently, the 8-year duration for only 15 incidences shows some level of safety compliance in company x but reviewing the observation findings, the survey carried out, and incident data report seen, it shows that the level of compliance following the ranking for the survey is Somewhat effective on the scale 3. Hence effort needs to be put in place to improvement to their safety procedures and safe work practice to a Very Effective State to the scale of 5.

Therefore the summary of findings is, Safe Working Procedure Reviewed before start of work, Poor Use of Communication Methods, Poor Supervision, Failure to Use Personal Protective Equipment, Ignoring Safe Work Practice, Confined Space Equipment not adequately positioned during work, eating during Confined Space Activity and in an unhygienic condition, Poor Monitoring of Atmospheric Condition in the tank, Insufficient Training, Poor Process of Isolation from atmospheric hazards, No Staff Break.

The two methods used for data collection aided in providing a clearer picture of what is obtainable in this industry. Nevertheless, the incident data reviewed also gave a clearer picture of the past issues while correlating it with the present results gotten, to help draw up conclusions of the study and make recommendations for best practice guidance.

Finally, 70.3% of respondents agreed that the management process in place needs slight improvement. The researcher agrees with the aforementioned factors responsible. However, refereeing from the observation carried out during the task observed, a lot of unsafe acts and ignoring safe work procedures were observed.

Hence, the researcher believes Ignoring; Safe Working Procedure should be accepted and added among the identified factors that are responsible for accidents within the workplace. The reason is that it is referred to as non-compliant to the safety procedures outlined in the confined space regulation 1997, which can be referred to as one of the major problems, why accident still happens irrespective of the safety measures put in place.

While Ignoring Safe Procedure and Practice had 0%, contributing factors. In the researcher's view, it seems that employees do not want to take responsibility for their unsafe actions because they know its implication.

Management needs to improve on their system to enhance a safe process following best practice guidance with the aim of reducing the level of accidents and fatalities to workers, working within a confined space.

6 Conclusion

This study investigated the compliance levels to safety practices in confined space work, using company x a local company in Nigeria.

In view of these potential risks, safety precautions and measures should be put in place to protect workers from harm. The use of a permit to work (PTW) System is required in ensuring the extension of a safe system of work.

Despite some of the workers having adequate knowledge and experience in confined space work, there still exists a lag in compliance levels, evident from their mode of operation, which appears to be in contrast with the company's protocols.

The researcher is inclined to think that standard practices for these workers may be purely academic or cephalic rather than what is an everyday practice. This may explain why accidents still occur in confined space work in the industry.

It is worth mentioning that the lack of national industry standard or the absence of a regulatory body for local companies overseeing confined space activities may have created a leeway in the operations of these industries as opposed to their international counterparts, as concerning adherence to strict procedures and standard practices.

In line with Confine Space Regulation 4, 1997, avoid working in confined space expect, where work cannot be avoided then an effective, safe system of work should be followed.

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Occupational Psychosocial Toxicology in Health Workers of Radiological Units in Bogotá-Colombia

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Abstract. The radiological units in Bogotá-Colombia present working conditions that put physical and mental health at risk.

Exposure to ionizing radiation in low doses and dysfunctional work environments generate environments of high physical and psychological toxicity.

The study carried out an analysis of work and health conditions for an approximation to the work reality. Determination of disrupters and psychosocial predictors for promotion and prevention programs. Study carried out in 20 radiological units with 229 employees and sample of 220. Signature of informed consent. Use of Instrument Battery for the Evaluation of Psychosocial Risk Factors. Levels of reliability in the questionnaires; intra-labor of 0.957 and stress 0.83.

Main psychosocial toxic risk and precursor "imaginary of safety at work" in 95%. Disruptors, low salary level and no risk training. Protective factor the relationship with your family.

Keywords: Management · Toxicology · Psychosociology · Risk prevention · Ionizing radiation

1 Introduction

Our society faces a substantial change in living conditions, situations such as increased migration, greater desire for independence and changes in family and gender roles are facts that affect the new workforce.

This leads the workers to stay longer in their place of work, and consequently require a greater work capacity for their daily performance [1]. In addition, your family life must be intervened in such a way that the worker does not lose his main support network.

It is important to emphasize that work is the result of social interaction between individuals and their own characteristics, where the lifestyle, the sociodemographic context and the aging of the person, together with the work dynamics that each individual experiences in their daily practice, participate.

It should be noted that the ability to work is directly affected by health, situations such as heaviness, insomnia, difficulties in concentration, over and under nutrition,

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 134–142, 2020.
https://doi.org/10.1007/978-3-030-20497-6_13

sedentary lifestyle, muscle disorders that cause pain and anxiety, are the main ailments, which decrease the worker welfare [2].

Now, the individual and his capacity for the development of his work activity is related to factors of psychosocial, physical and environmental order, besides being determined by his individual characteristics and his level of training.

Age has a high influence on the development of the individual that is why the characteristics of personality, coping and their way of relating to society, determine the adjustment and work performance [3]. However, in society, age is synonymous with loss of ability to work, due to the fact that, according to work and life habits, this process decreases or accelerates [4].

The development at work has a direct relationship with the activity. This one has a direct relation with the activities and the physical exigencies of movement or repetition, muscular force, and transport and lifting of loads that generate a greater physical wear. Likewise, the mental load represented in unclear office, time pressures, conceptual deficiency in the activities carried out, high levels of responsibility and limitations in autonomy, trigger negative situations that diminish the worker's capacity [5].

It is therefore necessary to highlight the direct influence that health has on an individual's ability to work, however, mental health has been little related because fatigue is only associated with situations of a physiological order, which after a development Chronic or acute, generates behavioural changes. This as a reaction to the situation that the worker faces with his physical ailment.

Thus, workers who develop activities with a high emotional level, such as health personnel, experience high levels of pain and suffering that erode them emotionally.

Another factor identified is the organizational management with rigid hierarchical structures, overwork, low personnel and low remuneration that leads to feelings of job dissatisfaction and increased rates of absenteeism.

The long working hours, night time and oversized demands, develop psychopathologies derived from work stress such as; burnout, anxiety, depression, among others, and leave in evidence inadequate conditions of work order that alter the health of these workers [6].

However, in making the above consideration, it is necessary to take into account the concept of psychosocial toxicology. This in order to identify the poisoning caused by the environment in which this staff develops and as a possible "psychosocial precursor". The foregoing in order to review the work performance and the possible reactions caused by situations that increase the stressors, when the worker lives adaptive situations. The above identifies possible disruptors in the chemical-metabolic body dynamics that triggers in the worker a systemic intoxication, with capacity to affect the nervous system, tissues and organs, due to its harmful potential. In addition, to generate physiological outcomes that lead to disabling situations such as occupational disease and death in exposure to a lethal dose [7].

Therefore, it is determined as necessary to take into account situations that influence the behaviour of workers as something that is part of daily work, considering Organizational Culture [8].

Studies have shown that inadequate environmental stimuli lead to situations of work stress, based on the response that the agency triggers in the face of situations that exceed their individual capacity. Due to this situation, high physical, mental or social activities trigger favourable or unfavourable effects on these workers [9].

It is therefore necessary to review how the World Health Organization, when verifying the occurrence of work stress, typifies it as an "epidemic", having the potential to affect any type of working population [7].

Another criterion of inclusion was that the workers belonged to health units, with the use of ionizing radiation as a basic raw material for the development of the process.

This, exposing them to a low release of "Linear Energy Transfer" to the environment, with the ability to travel over large distances, and penetrate into low doses in the primary interaction [10, 11].

Nowadays organizations are still in processes where the concepts of unified labor relations and wellbeing remain outside the administrative management in such a way that the only objective continues being permanent productivity in a criterion of man as part of the great industrial machine [8].

Companies with deficiencies in this management, provide environments for the development of arbitrary work climates that goes against the welfare of work [12, 13].

For all the above, it is necessary to determine psychosocial factors intra-labor that trigger situations of alteration in workers. In addition, the organizational and administrative management conditions, the exposure to demanding situations for the service performed daily and the contamination by ionizing radiation.

2 Method

Applied research study, of mixed order that correlates data obtained from the individual and intra-labor conditions with possible symptomatology associated with work stress, describing the found association findings.

The above in order to define promotion and prevention strategies that involve the population for the improvement of the health and well-being of the population included in the study.

The population taken into account for this study was, health workers who are part of radiological units that in their daily activity make use of ionizing radiation in the examinations that practice their patients.

The included population was 229 with a sample of 220 workers from 20 radiological medical units in the city of Bogotá in the town of Kennedy.

The non-probabilistic sample of voluntary participants, which for this study was 96%.

Saving respect to the participants, he socialized; the implications and uses of the information collected. Then he elaborated on the informed consent form.

The inclusion criteria established were:

a. Attendance at the informative talk.
b. Elaboration on the Informed consent.
c. Be part of the service unit with an age greater than 6 months.
d. Be part of a radiological unit included in the study.
e. Be part of the process of taking tests with the use of ionizing radiation.

For the development of the study stages were determined that allowed to fulfil the stated objective, starting this process the general information of the study, signature of informed consent, collection and analysis of the information, which led us to the realization of an intervention proposal for said population.

2.1 Inventory of Used Instruments

Application of "Instrument batteries for the evaluation of psychosocial factors" [14].

This battery of instruments validated by the Ministry of Labor for use in the national territory whose scope is the identification of sociodemographic and occupational data of workers to establish the presence or absence of psychosocial risk factors intra-labor, extra-labor and stress. The extra-labor questionnaire was not used for this study.

The instruments used are based on the Demand-Control and Social Support models [15, 16] and the model Imbalance - Effort - Reward [17],

The stress instrument evaluates physiological symptomatology, social behaviour, intellectual, work and psycho-emotional [18].

The instruments used were:

1. **Informed consent form** made in accordance with the considerations of Colombian legislation regarding the protection of personal data and the criteria for the use of information and protection there of as part of the occupational health record for occupational safety and health.
2. **Individual Conditions**, that allows identifying the sociodemographic characteristics of each worker in order to determine their own and individual profiles.
3. **Intra-labor Conditions**, with a reliability level of 0.944, this consists of two (2) types of format:

Type A: for the collection of information in personnel whose occupational level are management positions, with personnel in charge, assurance of management and responsibility for results in a certain section or process. In addition, for professionals or technicians whose knowledge is qualified and who in their work activity makes decisions or has a high level of autonomy.

Type B: for auxiliary personnel with positions that require technical knowledge with less autonomy and that permanently develop orders, and for operational positions where the staff does not require special knowledge and follow orders all the time.

4. **Conditions of stress**, with a reliability level of 0.83, this applies to all charges and identifies the physiological symptoms of social and occupational, intellectual and psycho-emotional stress in workers.

To answer the questionnaires, it was carried out on Likert scales with five levels and a single response alternative, being these; no risk or negligible risk, low risk, medium risk, high risk and very high risk.

The application modalities used were of hetero-application and self-completion.

2.2 Stages of the Study

First Stage: Socialization of the ethical considerations and implications of the study, in addition to the management of the information and its use for safety and health at work. This led to the consent of the workers after being informed, signed informed consent, which formalized their participation in this investigation.

Second Stage: The application of the questionnaires was in the workplace and in the work environment.
The formats applied were:

1. **Individual Conditions,** that has the variables of analysis of sex, age, marital status, educational level, occupation, city or place of residence, socio-economic scale, the type of housing and the number of people who depend economically on the worker.
2. **Intra-labor conditions**, in either of its two (2) forms A or B, and it ends with the completion of the stress questionnaire, in order to make the response of the same, with a completion of more to fewer items to be resolved in each Format.

The variables analysed for the "Intra-labor Conditions": leadership and social relations at work, control over work, work demands and rewards, constituted by 20 items for format A, and 17 for format B. and for stress 35.

It is important to bear in mind that for this study "Leadership and Social Relations at Work" consists of leadership as a type of social relationship between the different positions and their heads.

The "Social Relations at Work" as the interaction established with other people in the workplace and "Reward", determined as the compensation that the worker gets for his work effort.

3. **Stress of Conditions** established variables to determine physiological symptomatology, social, intellectual, labor and psycho-emotional behaviour.

Third Stage: After the application and processing of the questionnaires under the criteria established in the methodology, the scores were determined according to a scale.

Fourth Stage: For the identification of priority situations of attention in the population, we proceeded to list the situations found from one (1) to three (3), where level 1 corresponds to a very high and high level of risk; Level 3, low or no risk.

Fifth Stage: With the established priorities, formulate the promotion and prevention strategy for each radiological unit.

3 Results

3.1 Individual Conditions

A population comprised of 195 women and 34 men. Ages 22 to 50 years old. With an average age of the population of 36 years, being a young adult group.

Level of studies of the participants (Table 1):

Table 1. Level of studies of the participants

Schooling (last level of studies)	n	%
Full graduate	16	6,99%
Incomplete postgraduate	0	0,00%
Full professional	4	1,75%
Incomplete professional	4	1,75%
Technical - Technological complete	200	87,34%
Technical - Incomplete Technology	4	1,75%
Full baccalaureate	1	0,44%
Incomplete baccalaureate	0	0,00%
Incomplete primary	0	0,00%
Grand total	229	100,00%

The 90.8% of the workers have technological and professional studies, the most representative being the technological one in 87.34%, since the care positions are the most used for this work.

3.2 Intra-labor Conditions

It was found that in the variable "Rewards" in 86% of the workers, the recognition and compensation is the situation with the highest incidence in this group, because they express a low contribution received with respect to the efforts and achievements, in addition, the Salary does not compensate for exposure to the physical risk of ionizing radiation. Another indicator of risk was that the company neglects the welfare of workers.

The 80% of workers score at "very high" level of risk in "Control over Work", identifying themselves as situations with a higher incidence in 95% of them, the poor training that the institution provides to staff and the null development opportunities and of the change management within the institution by 78%.

Regarding the demands of the work, 100% of the population presents a "High" level of risk with respect to the "Quantitative Work Demands", because the time they have to perform the work is insufficient to meet the volume of exams.

And regarding "Leadership and Social Relations in the Workplace", it is determined that the highest level of risk is found in the "Performance Feedback", due to the non-existent information provided that prevents an improvement of the processes, this in 59% of Workers.

3.3 Stress Conditions

The 68% of workers reveal symptomatology associated with stress.

Next, the results in Table 2 describe the discomforts referred by the workers, where 42% of the population presented disabilities greater than 3 and up to 10 days in the last 3 months:

Table 2. Discomforts that most affect the health of workers

Symptom	Discomforts	Affected population
Physiological	Muscle pain in the neck	67%
	Gastrointestinal disorders due to irritable bowel and constipation	
	Tension headaches	
	Daytime sleepiness	
	Palpitations	
Social behavior	Feeling and overload at work	15%
	Feeling of irritability	
Intellectuals and labor	Feeling of frustration	13%
	Fatigue or reluctance	
Psychoemotional	Consumption coffee or cigarette	79%
	Sensation of isolation and disinterest	
	Rigid behavior and stubbornness	

All the symptoms represent some type of alteration in the workers. However, the most representative corresponds to the psycho emotional with 79%, followed by the physiological with 67% for "High" risk.

4 Discussion

"High" correlation in form A and B for 74% of the data. The 20% a medium influence - high, medium or medium - low and 6% a low influence, although significant.

The working conditions of health workers who perform their work in nuclear medicine tasks, have conditions that promote "unhealthy" environments with loss of quality of life and health of workers.

For the intervention plan, it was determined as Priority 1. The verification of wage conditions of workers, as Priority 2. The development of plans and programs that lead the worker to generate behaviours towards the "protection" of "ionizing radiation" with which he works daily, and as Priority 3. It was established, the revision of the number of users, regarding the number of teams and workers that perform the exams, in addition to the identification of communication and information mechanisms suitable for Performance feedback in this population.

5 Conclusions

This research provides an important contribution to health, with respect to the expanded knowledge of the workers of this sector, who belong to radiological units, and this knowledge allows us to address the development of promotion and prevention strategies for personal protection.

Occupational precariousness exists due to "subcontracting in chain and submerged economy", in addition to evidence of incorporation of personnel to these units that come from Venezuela, as they do not have papers that formalize their labor legality.

Little or no organizational management for aspects related to health and safety at work that increases the risk of exposure of workers to low doses of ionizing radiation due to the "non-use" of personal protection elements.

Confirmation of the main occupational psychosocial toxic risk found as a precursor "the imaginary of security in the workplace" in 95%.

Workers with employment relationship in 3 radiological companies and shifts from 5 to 6 h in each of them for 72% of the study population.

Evidence of physical alterations in some cases due to infertility or alterations in thyroid and depressive symptoms in 21% of them.

Regarding the limitations of the study, it is necessary to consider that companies do not wish to identify psychosocial risk factors, considering that ionizing radiation is its most important risk.

The development of this type of studies, allows knowing unexplored situations in relation to labor risks, and the organizational management in which the companies operate.

This is due to situations little verified by the presumption that everything complies with the requirements of law, without being true. The vast majority of cases put at risk those who are part of this population.

Therefore, it is necessary that the governmental entities that have in their realization, the verification of the risk conditions; Promote the monitoring and control of psychosocial risk within companies, using tools and mechanisms to obtain results that verify the organizational conditions in which this population attends.

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Theory of Safety Quantification and Equivalence Oriented Industrial System

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Abstract. Nowadays kinds of research about safety of industrial system greatly improved the knowledge about this field. After 10 years' research and experience about safety and investigation the related research in recent decades, the author found safety discipline worldwide mainly consists of three parts: safety system theory, safety methodology and the relationship between safety and other factors. All of them were studied deeply in its own area.

However, some further problems need to be answered about this topic. For a company or organization, how safe is the safety system and is it safe enough? How much of our safety system we can see? How to balance safety and other factors as we know there won't be definitely safe situation while we still should keep the whole thing safe enough? Is it possible to connect different theories in a simple way? The paper aimed to find a way to integrate achievements in this field and presented a new method to solve the problems mentioned above.

At first, the theory clarified identification and the important figuration of safety. In mainstream works, Safety has different identification. The theory agreed that safety is the state and confidence without unexpected losses, not mentioned the cases with intent to do harm. The safety is a subjective concept but also can be quantitative in a sense. As an inter-discipline, the safety is born to rely on some other profession. That is why most of safety research has a specific background. These are premises of the theory.

Secondly, the theory summarized main factors to indicate the important value of industry safety: safety redundancy. The value of safety redundancy can be calculated and insisted a group of equations. These equalized factors in mathematics constitute main bridges between diverse safety areas. The paper demonstrated and verified the rationality of equations furthermore.

At last, the theory took electric power industry as examples to introduce these equations making the systems united and how to organize our safety management via united systems. Electric power industry is one of the most complex systems in the world. This system offers interrupt power supply, it's too crucial to tolerance even power off for a little while. The fatal factor in this field is the safety and stability of the electric power grid. The industry includes design, plan, construction, maintenance, repairing, upgrading and so on, which placed to strict desire to numerous engineers in the industry. Not only they should assure the grid and the devices are under control, but also, they should keep safe when working in the field. So the application in electric power system also may benefit to other kinds of industry.

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 143–152, 2020.
https://doi.org/10.1007/978-3-030-20497-6_14

Keywords: Safety quantification · Safety equivalence · Industrial system · Industrial Safety Cup Theory

1 Introduction

Industrial safety topic has been existed even thousands of years before. According to ancient literature there are occupational industrial safety management officers in Qin period (BC221-BC207) in Chinese history [1]. It is an expectation of human about their lifestyle and development. In recent centuries this topic has been studied and the whole discipline has shown a prototype.

In recent decades worldwide research about safety focused in three main area: safety system theory, safety methodology and the relationship between safety and other factors [2–10]. All of them were studied deeply in its own area.

As a discipline what the safety it is and what are the values and characters of it should be clarified. It is the base of the development of the discipline. It is a subjective concept and affiliated discipline but also can be quantitative in a sense. As an interdisciplinary, the safety is born to rely on some other profession. That is why most people wouldn't know what happened if it didn't become an accident. Safety is also kind of culture and mentality. It is easy to be combined some other mental causes but hard to be separated.

2 Recent Situation and Difficulties in Safety Discipline

The safety discipline-oriented industry has developed greatly. However, there are still difficulties when making overall progress. The concrete problems focus in three aspects.

(1) The cognition and insight about the safety topic is not enough. Masses of research are concentrating how it works. However, the understanding about the safety itself and its character is neglected. Everything we achieve in this area should be related to its own value and character by some way.
(2) The achievement about research on safety is scattered in some extend. Human kinds do the research only when accidents happen, and they want to avoid them. So, this discipline is born to be dispersive.
(3) Some of the research is too complex to be put into practice. When the company or organization needs to make a decision, they still don't know how to balance the safety and other factors such as major business and so on.

3 Structure of Theory of Safety Quantification and Equivalence Oriented Industrial System

3.1 The Characteristic of Safety

There is no doubt about that the safety discipline is an interdisciplinary and existed in all of kinds of industries. Human is born with safety sense even before the industry appeared. If we want quantitative the safety and make it equal to something else, we need to start it from what exactly it is.

(1) It is affiliated to some traditional vocation and hysteretic in some way. The safety helps the industry make profit, but it cannot make profit itself. It is impossible for safety to become only or No.1 goal.
(2) It is a negative discipline. It is hard to be proved right.
(3) It is a subjective but also should be quantitative and controlled by objective ways. Everyone has different opinions even on the same event. Managers and engineers often need to make a subjective decision even when they don't have enough information. When accidents happen, there are many factors can be contributing to but how to affirm the really important causes need some principles.
(4) It is a balance among safety and other factors such as cost, it cannot be put into practice in a absolute way.
(5) Safety means reliability and possibility in some extent.

3.2 How Is the Theory Should Be?

For industrial area, the paper assume that most risky factors cannot cause accidents ultimately but some of them can be. The industrial safety is maintained by human, no matter the human factors, the devices factors or environment factors. And the structure of human resources can adjust itself to form appropriate shape to keep safety, such as arranging the right person to the right place. Furthermore, the theory assumes the ability of human and the value of assets can be equal to money. The ability of human is equal to his or her salary. So, the mainly goal of the safety or preventing hazard is tolerance the risk and prevent it becoming the accidents.

For social area, keeping industrial safety has two kinds of significance, preventing unpredictable losses and ensuring social benefits or confidence for this industry. So, in the social level, keeping industrial safety is preventing unpredictable economic loss and social benefit losses by predictable expends.

Overall, the theory is a quantitative balance between social resources. We cannot research safety problems without social resources consideration, mainly referred as human resources and financial resources. As the content mentioned above, the theory should be a kind of reasonable and simple balance, being compatible for most research recently. Human find safety methods by original thoughts about safety.

3.3 Attribution of Accidents

For now, the author cannot find a complete theory about attribution in the world. Something happens, such as accidents, there are many causes in different levels and viewpoints. So how to attribute to the accidents is a complex question itself. The paper chose that the significant attribution principle for accidents can be predictable, controlled by human and affiliated to accidents at high frequency, if the purpose of attribution is preventing accidents.

As we know the hazard of industry consists of human factors risk and device factors risk. In many researches there is one more factor risk, environment factor risk. Considering the environment factors risk are caused by human or devices, so in this paper the environment factors risk are not independent.

For the device factor risk, the paper chose the lack of three kind of value or part of them to attribute to, the visible and controllable value, Independence value and reliable value. The paper uses these three values to define and predict the device factor risk.

For the human factor risk, previous papers of the author [12] analyzed full picture of 100 accidents or near miss belong to a major. The analysis included two steps: primary analysis oriented accident factors, further analysis oriented the reasons based on the primary analysis. The primary analysis selects 12 possible factors (top 9 listed in Fig. 1). The further analysis is attributed to lack of risk control based on the primary analysis. The paper classified the risk control by 4 types: institution control, organization control, technical skills control and safety culture control. Institution control is setting standards of procedures, rules and measures to control working procedure or equipment specification rule-based, making the work more measurable too. Organizational control is to minimize the safety risk through appropriate deployment of resources including human resources, tools, time and schedule. The technical control is reducing the risk by experienced workers or supervisors with higher safety skill. Safety culture control is that individuals have a strong sense of safety awareness, the department or team has rich safety culture overall. Any accidents can be attributed to the lack of some aspects. The reasons statics are listed in Fig. 2 and the accident countermeasures can be easily made up. And the accident countermeasures probably effect more than one aspect, ones effected higher accumulation aspects should have priority. After countermeasures has been put in use, the number of accidents and near misses of this major decreased to less than half.

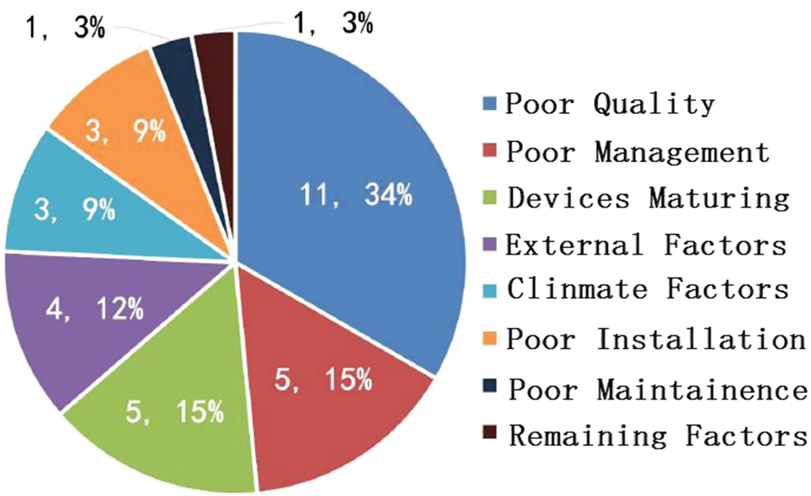

Fig. 1. Primary analysis: factors statistics of accidents in recent years

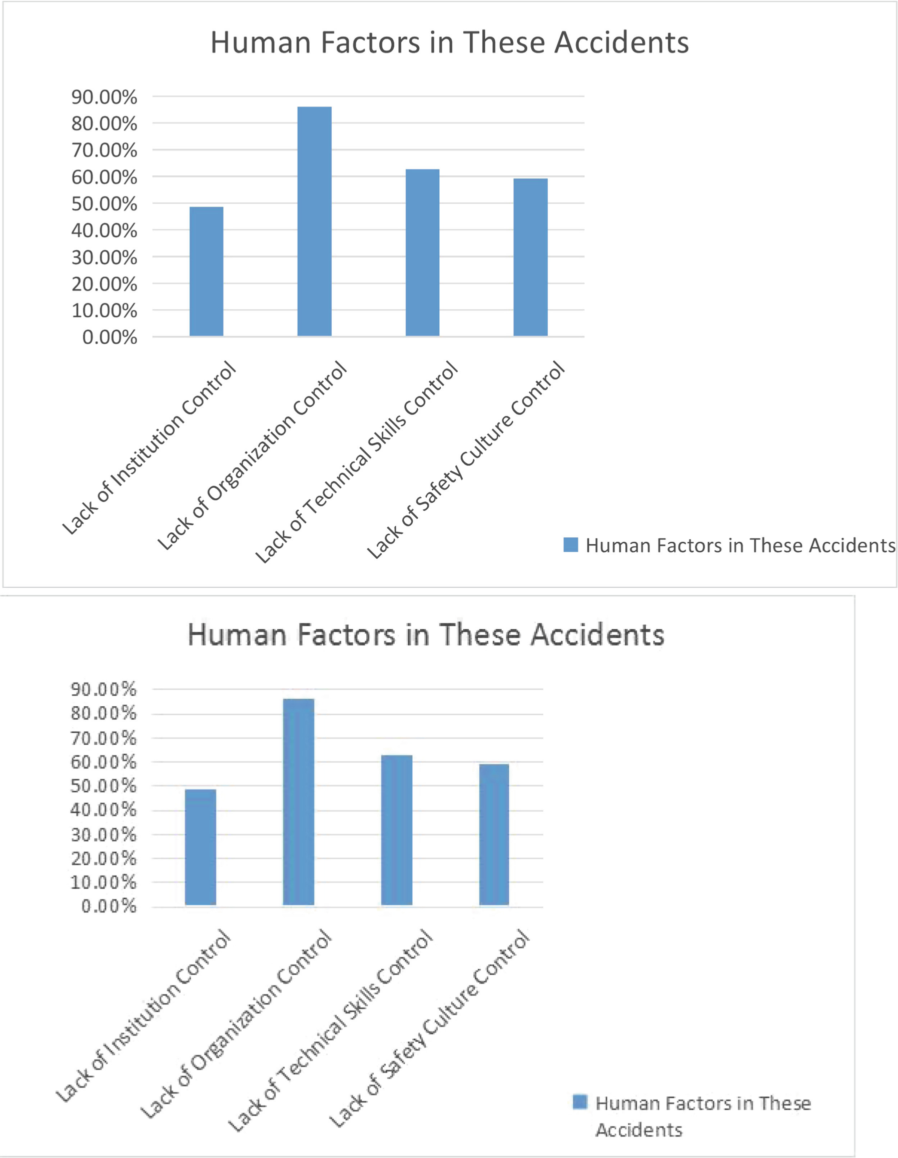

Fig. 2. Further analysis: human factors in these accidents

3.4 Cup Theory of Safety

As the difficulties mentioned in Sect. 2 and the characteristic of safety mentioned in Sect. 3.1, the paper presented the Cup Theory of Safety to provide a method to integrate and solve the problems by quantitative subjective goal in a simple way. After some experiences, the theory took the cup as the concrete model. The safety is ultimately designed and operated by human, so the cup is total ability of safety control. The risk is the water in the cup and consists of human risk and devices risk. If the cup is full of water, the water is easy to spill out, which means that the accidents happen. On the other hand, if the water level is too low, the industry is too safe to make profit. In this case the company can choose include more risk to make more profit. The Cup is shown in Fig. 3. The Cup represents the safety control ability, the water represents the risk. The risk existed but cannot being predicted when to become accidents. If the amount of risk gets high enough it certainly becomes accidents, just like water in the cup.

Basically, the risk means the probability of unacceptable accidents; it mainly consists of human factors and devices factors. The author took 100 accidents or near misses to do investigation, and found the number of accidents or near misses including human false causes are direct proportion to the number of devices. So the theory assumed that the risk of human false factors is direct proportion to the number of devices. The paper defined a coefficient "H" for human factor risk base on the number of devices.

For the devices, after studying thousands of accidents partly caused by defective devices, the author found that the systematic devices have complex structure and influence for accidents. Three mainly factors were abstracted to define and predict the device factor risk, the visible and controllable value, independence value and reliable value. And the defined "D" as the total probability of accidents of devices factors risk.

Both "D" and "H" is the cases number of "No Backup" situation. It means there is no way to recover but praying for luck. It is equal to "unsafe condition" in the work of Heinrich [11].

As most references indicated, the accidents occurred because the risk existed. Besides, most of industries have a period. Take substation engineering as an example. In its period, it should be planed, design, construction, inspection, maintains, retire and so on, and the risk should be supposed to be included in each step. And the probability of accidents is in direct proportion to the time of risk exposure. So the paper selected "T" to indicate the total time of existed risk for all devices and average losses of accidents is indicated by "L".

The safety necessary amount "N" is sum up as follows

$$\mathrm{N} = \mathrm{T}(\mathrm{D} + \mathrm{H})\mathrm{L} \tag{1}$$

Because the ability of keeping safe is being come true by human and resources equal to human. As the theory assume the ability of human equal to his payment, the total resources "R" can be sum up by the number of the stuff "S" multiply the average payment "P" and the financial resources "F".

$$\mathrm{R} = \mathrm{T}(\mathrm{S} * \mathrm{P} + \mathrm{F}). \tag{2}$$

At last, the safety redundancy "Rd" is a proportion as follows:

$$\mathrm{Rd} = 1 - \mathrm{N}/\mathrm{R} \tag{3}$$

According to statics in 10 years, When Rd ≧ 0.38, no unacceptable accidents had been found, which means the safety extend is enough. It is also the golden ratio section.

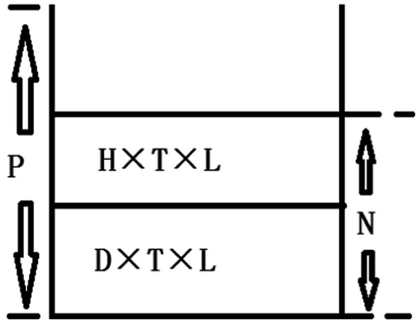

Fig. 3. The Cup and the water

3.5 Typical Kinds of Research About Safety and Cup Theory of Safety

After 10 years' research and experience about safety and investigation the related research in recent decades, the author found safety discipline worldwide mainly consists of three parts: safety system theory, safety methodology and the relationship between safety and other factors.

For the safety system theories, such as STAMP from Prof. Nancy [13], Function Hazard Analysis (FHA), Preliminary Hazard List Analysis (PHLA), Subsystem Hazard Analysis (SSHA), Fault Tree Analysis(FTA) and so on [14–22]. The Cup Theory of Safety can offer a quantitative way to help them put into practice.

For safety methodology, such as the management methods of safety information [23], Chemical process safety management and technology [25], Safety management in a competitive business environment [24], their achievement can provide measure methods for concrete factors.

For the relationship between safety and other factors, such as safety and economy, safety and physiological, their achievement also can provide measure methods for concrete factors.

4 Case Study

The paper took a common safety method for example to demonstrate the how to put the theory into practice. Many companies or organizations pay attention to the accidents occurred in similar devices or areas. Such as Boeing 737-Max crashed in early 2019 and most airplane suspend the 737-Max flight plan. In industrial field this kind of inspection is more systematic and objective. If the same type of devices appears some defect in A company, B and other companies will check and deal with it too. In this era large scale industry provide the same product to masses of companies. So it inspection about the performance of the devices worldwide can be a good way to insure the safety. Because it means if the defects or problems don't appear in your company for the first time, you have chances to deal with it and make it never happened in your company. The author calls it "external supervise".

So, whether the "external supervise" is worthwhile for a company to execute and how much equalized human resources should be paid?

Let's assume that the situation of company is like this. The sampling period is one year. The company of industry maintains energy girds in an area. Without "external supervise", they owned 400 stuff and about 20 million dollars for external service. The average payment for stuff the 200 thousand for one year. About 60% of the resources were used to keep safe. So the total resources R is as follows:

$$R = T(S * P + F) = 1 * (400 * 200000 + 20000000) * 60\% = 6 * 10^7 \quad (4)$$

The company maintains about 20 thousand devices, according to historic data their average unexpected failure rate without "external supervise" is about 1%. The average losses for accidents equal to 2 million once. Additionally, 90% of devices has enough redundancy so about 10% of failure can lead to "No Backup" situation. The times of "No backup" situation caused by human error is 3.

$$N = T(D + H)L = 1 * (20000 * 1\% * 10\% + 3) * 2000000 = 4.6 * 10^7 \quad (5)$$

$$Rd = 1 - N/R = 1 - 77\% = 23\% \quad (6)$$

If they choose "external supervise" to devices, the company arranges 2 persons to do the work. It means their number of stuff for the same work before will decrease by 2. However the information the 2 persons get cannot cover all the defect of their devices. They only can decrease the unexpected failure rate by 9%.

$$R' = T(S' * P + F) = 1 * (398 * 200000 + 20000000) * 60\% = 5.976 * 10^7 \quad (7)$$

$$N' = T(D' + H)L = 1 * (20000 * 1\% * 10\% * 91\% + 3) * 2000000 = 4.24 * 10^7 \quad (8)$$

$$Rd' = 1 - N'/R' = 1 - 71\% = 29\% \quad (9)$$

So after chosen "external supervise" to devices, the whole safety redundancy of the company for this year increase from 23% to 29%. Obviously, it is a good bargain. However, if the company choose "external supervise" to human, their work make rare sense to improve the safety. Decreasing human resources will reduce the safety redundancy.

5 Conclusion

The Cup Theory is focus on the existed industrial problems need to be answered about this topic. For a company or organization, how safe is the safety system and is it safe enough? How much of our safety system we can see? How to balance safety and other factors as we know there won't be definitely safe situation while we still should keep the whole thing safe enough? Is it possible to connect different theories in a simple way? The Cup Theory finds a way to integrate worldwide achievements in this field and presented a new method to solve the problems mentioned above.

The Cup Theory clarified identification and mentioned social meaning of safety. the theory is a quantitative balance between social resources. We cannot research safety problems without social resources consideration, mainly referred as human resources and financial resources. As the content mentioned above, the theory should be a kind of reasonable and simple balance, being compatible for most research recently. The safety is a subjective concept but also can be quantitative in a sense. As an inter-discipline, the safety is born to rely on some other profession. That is why most of safety research has a specific background. These are premises of the theory.

The theory summarized main factors to indicate the important value of industry safety: safety redundancy. The value of safety redundancy can be calculated and insisted a group of equations. These equalized factors in mathematics constitute main bridges between diverse safety areas. The paper demonstrated and verified the rationality of equations furthermore. At last, the theory took “external supervise” to devices or to human as examples to introduce the theory.

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Safety Culture

Safety Culture as a Team Sport: The Football Metaphor

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Abstract. Safety culture remains an elusive concept, not only for scholars and practitioners but for the workers who actually have to deal with safety on a daily basis as well. The metaphor of football provides particular working groups a medium to explore the meaning of safety culture by drawing parallels with team roles, changing working conditions, the importance of production vs. safety and the creation of safety therein. Being a familiar team sport in many countries, the football metaphor can also function as a communication device within work teams to facilitate and promote a shared understanding of work and safety.

Keywords: Safety culture · Organizational culture · Metaphors · Team roles · Creating safety · Shared understanding

1 The Concept of Culture

1.1 Introduction

Culture is a complex concept used by various social scientists as well as practitioners to describe and explain shared consistencies in artefacts (symbols, architecture, dress codes, and so on), visible behaviors (rituals, expressions of emotions, language, and so on) and mental models (assumptions, understandings, values, norms, and so on). These professionals apply the concept of culture to either groups or categories of people; for example, organizational culture, professional culture, national culture, steel industry culture, and on and on. Within organizations, culture is also used as a qualifier; for instance, this organization has a 'good quality culture', a 'bad reporting culture', or a 'macho culture'. So far, so good. However, there is substantial disagreement on what is considered cultural as well as its influence on individual and group behaviors.

With regard to the latter, two positions can be taken, a strong position and a weak position. A strong position means that one assumes that culture has a strong impact on the comings and goings of a group or cultural unit; that is, the (strong) assumption is that culture has a substantial impact on a group's doings. You can find this position with many culture scholars [1–4].

Taking a weak position implies that one does not attribute culture as having meaningful influence, it is merely seen as how a group or cultural unit understands its world.

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 155–166, 2020.
https://doi.org/10.1007/978-3-030-20497-6_15

Whether such shared understanding has implications for their actions, is secondary, although a minor influence is nevertheless assumed.

Making a distinction between what is cultural and what is not, is simply a matter of definition. Some definitions encompass both expressions of culture (artefacts, visible behaviors) and its underlying mental models, while some definitions lean more towards expressions (a system of behaviors, e.g., 'The *way* we do things around here'), others towards mental models (a system of *ideas*). Various models have been created to describe the distinction between the visible and the invisible parts of culture, often compared to the rings of an onion. There are multiple 'onion' models around, with different amounts of layers, and with different labels for these layers; however, one of the more common models is the model put forward by Schein. It makes a distinction between the tangible part of culture, Schein calls these artifacts (objects, rituals, dress codes, and so on), statements people make when asked about their culture (*espoused values*) and the invisible and often also tacit part of culture (*basic assumptions*).

1.2 Espoused Values

What makes Schein's onion model intriguing is his middle layer, the espoused values. Schein possibly borrowed the term from Argyris, who makes a distinction between *espoused theories* (the notions people state they act according to) and *theories-in-use* (the notions they seem to actually apply when they act). The espoused values are the statements people 'espouse' when asked about their culture (or, perhaps, even the things they consider when they think about their own culture). So, Schein drives a wedge between the things people state or espouse about their culture and the things they fundamentally believe and implicitly seem to enact. Furthermore, and this is important, it is the beholder who interprets the group's behavior in relation to their own basic assumptions; Schein talks about 'deciphering', which in this model, and all the other onion models, means providing an *outsider's view* on a group's culture. However, while the outsider needs to interpret the culture, based on what he sees and hears, it is further complicated by the insider not having direct access to his true cultural assumptions also, nor would the insider view his culture as a layered concept. Culture is embedded into his being, to a greater or lesser extent, and reveals itself in the way he understands and approaches his world (weak causal position), or the way he tends to act in various circumstances (strong causal position).

Envisioning culture in this way, both the outsider and the insider need to use some form of interpretation, or deciphering, to reach their cultural assumptions. Such assumptions then need to be compared to the cultural expressions (behavioral patterns, statements, artefacts, and so on) to see if they somehow match. It is this matching exercise that should lead, in the end, to an understanding of a culture. Therefore, the chain of reasoning is as follows: observing expressions of culture → deriving cultural assumptions → comparing these assumptions with shared and consistent expressions or enactments of culture.

This chain of reasoning might appear contradictory, as we initially have discarded expressions of culture as mirroring underlying basic assumptions, yet we nonetheless use these expressions to compare to our derived cultural assumptions. However, to be able to validate our derived assumptions we still do need to compare these with expressions of a culture to see if they are actually put into practice.

1.3 Reification

One of the more difficult aspects of the cultural interpretation process is an interpreter's tendency to treat culture as a real and tangible thing, which is called reification. Reification can happen with both expressions of culture (observation of behaviors, symbols, and so on) and interpretations of culture (descriptions of assumptions). Especially with the qualifications of culture, e.g., 'This is a bad reporting culture (qualification of the culture) because people do not report much (expression of the culture)', one runs into this issue. Moreover, it is also language itself that reifies, as the noun 'culture' needs to have some referent in the world; otherwise, it refers to nothing. Furthermore, as a warning, reification brings along manipulation because one can hold 'something', manipulate 'it' and perhaps also control 'it'.

Hence, although culture is a construct and not a thing in itself, it is nevertheless impossible to write or talk about culture as a construct without any reference to the real and tangible world; that is, as 'it', as a thing. Additionally, expressions of culture are used to derive culture, and it is sometimes desirable to treat these expressions as culture themselves.

1.4 Culture and Behavior

According to some scholars and practitioners, culture is the plural of behavior, the shared behaviors of a group of people. The reasoning is as follows: 'I notice patterns of shared behaviors with the members of this group. Therefore, one must assume the members of this group share something which makes them behave in this particular way. This is culture.' This reasoning can be extended with: 'I want to change these patterns of behavior, and my interventions are aimed at changing these patterns. When the patterns of behavior change, the culture will have changed also.' Again, we recognize a strong link between behavior and culture, and when one changes, the other will change also. Furthermore, the key to culture change is behavior change, that is, according to this line of reasoning.

When taking a weak position vis-à-vis culture, culture is a shared understanding about the world that has grown within groups while collectively acting in this world, with each other, with and within their surroundings. From this position, culture still has grown out of behaviors, i.e., coordinated actions, but has become somewhat separated from these behaviors, for instance, through collective generalization processes (i.e., induction). This is a bottom-up process linked to a group and its experiences while coordinating their actions. This process will be described in more detail below.

1.5 Enculturation

Of course, not the full content of culture is acquired through experience, on the contrary. Much culture content is acquired through upbringing, schooling, education and being a member of communities that purport and support particular values and ideas.

Through this process of enculturation, people acquire many layers of culture content stacked on top of each other. Because this content is often buried in stories, sayings, statements and warnings, this learning is highly implicit without the receiver being aware of it. People usually do not have to verbalize this content, neither to themselves nor others, and it is, therefore, difficult to express when they are asked about it. This is also the reason Schein calls such statements 'espoused values' because that is what they basically are.

According to social construction theorists, the 'real' world (of objects, of experiences, or of whatever) is in itself meaningless and, therefore, people have to first ascribe meaning to it. However, no such ascription is value-free; that is, the particular ascription and the application of some material object that ensues from this ascription, implies a certain choice. This means that any ascription is imbued with the values the particular ascription supports. For instance, the ascription 'plastic water bottle' brings along values about design, the employment of certain materials, the use of a bottle as a container for fluids, and so on (example taken from Gergen [5]). However, such choices are necessary, because without an ascription a 'plastic water bottle' is nothing and we would not know what to do with it or even be able to make it in the first place.

The world people live in is filled with ascripted objects and, hence, also with the values that accompany these ascriptions. Again, we adopt these values unwittingly, and we are not aware of them unless we are confronted with other ascriptions for the same objects (or behaviors, for that matter). Although this might seem far-fetched to some, it is this feeling of far-fetchedness that really drives the point above home: people learn about the world, its objects, and their symbolic meanings without being aware of it. To quote the anthropologist Clifford Geertz, 'man is an animal suspended in webs of significance he himself has spun' [6]. So, it is precisely these webs that provide meaning, or significance, to his world.

Importantly, conceptualizing culture this way is not without contention and difficulties. Opposed to the world-is-imbued-with-culture-view, is the position that culture is an aspect system, an aspect of a group, organization or society. Furthermore, this aspect can be isolated and analyzed separately and often breaks down into several dimensions, factors or components. This stance is usually called the 'functionalist' view and is rooted in a post-positive research tradition.

The view outlined above, is also problematic in the sense that if everything is culture, nothing is culture. In order to make this position productive, we just need to be more specific. Using a metaphor for culture might provide this required specificity, as it frames culture in a particular way.

In summary, culture is a complex concept to grasp and to pin down. Although a group of people shares culture, because it is taken for granted, it is neither obvious to them nor to the outsider who is observing the culture. To frame culture, some scholars make use of metaphors to write and talk about culture. In the next sections, we will provide an overview of metaphors and their relationship to culture and safety. First, we will present a list of metaphors sometimes used to describe culture, and then we will discuss several metaphors specific to safety culture. Finally, we will introduce the game of football as a new metaphor for safety culture and show how this game (or any other team sport) might reflect a group's endeavor to be both productive and work safely.

2 Organizational Culture Metaphors

A metaphor can be an excellent vehicle to frame abstract concepts. In this sentence already, we have used two metaphors: framing and vehicle. A frame clearly delineates a concept and puts it in perspective. A vehicle transports an item from A to B, where B is a certain, intermediate or final destination.

Organizations are abstract entities and therefore difficult to comprehend. In his book, *Images of Organization*, Morgan [7] introduces several metaphors for organizations, each highlighting a quality all organizations might present or sometimes enforce. To give just a few examples: organizations as a machine (the Taylor-made organization: it 'runs' smoothly), as a psychic prison (the organization demands a high degree of commitment of its employees), as an organism (the DNA of an organization, its growth, its maturity), as a brain (the 'learning' organization), and so on. In a way, these metaphors can function like lenses, through which all organizations can be viewed and understood.

In a similar vein, Alvesson [8] explores several metaphors for organizational culture. We will discuss these more extensively, as they have relevance for the metaphors for safety culture. In his book, Alvesson describes the following six metaphors (for organizational culture):

1. **Culture as an exchange regulator**. In exchange for long-term rewards the (organizational) culture functions, in this metaphor, as a control system, providing common values and a common reference system (i.e., shared social knowledge), which employees internalize, and which might prevent otherwise opportunistic behavior in ambiguous situations. Sharing a common goal molds the group into a clan that operates in the group's best interest.
2. **Culture as a compass**. Here culture provides fundamental values which put the group in the right direction. 'Wrong' or misaligned values lead the group astray as the compass is failing. The fundamental values are indeed fundamental so that even (new) leaders will have to obey these values, which are considered 'traditions' rooted in the history of the organization.
3. **Culture as social glue**. This metaphor stresses the informal part of organizing, separate from the structural and formal part of the organization. The glue functions as a harmonizer, preventing conflict and fragmentation and fostering mutual support and teamwork. Both strong and weak types of glue might exist; a strong bond can emerge as a result of groups working tightly together to reach a common goal, while the latter, a weak bond, can emerge in the form of glue applied by (top) management to uphold commitments to their employees. This glue needs maintenance to keep working as a substantial integrative force.
4. **Culture as a sacred cow**. Culture here pertains to organizational values which have grown into strong beliefs that lead to certified success. These values are often the founder's values, with which his followers identify, even at an emotional level.
5. **Culture as an affect regulator**. This metaphor draws attention to the emotional side of organizational life. On the one hand, culture pertains to strongly held beliefs, which arouse emotions when they are challenged or threatened. And it is emotions of personnel that managers in particular should handle when the organization is

going through a cultural change process. On the other hand, organizations might require the expression, or oppression, of particular emotions from their employees, e.g., joy or playfulness.

6. **Culture as a mental prison**. We have already seen this metaphor with Morgan, and it draws attention to the deeper embedded meaning of organizational culture. Here, culture is something that is often mystical, shadowy, and speculative but with a definite impact on the organizational members' thinking and doings. Organizations can become 'cults' with a distorted version of reality being spoon-fed to the employees.

These metaphors can be used in several different ways. For instance, they might be used as a sensitizing concept, i.e., as a comprehensive term, encompassing an observer's primary impression of an organization's culture. However, that is just what it is: a primary, compound impression. Furthermore, metaphors can be used as lenses, as ways of looking at a particular organization to see to which extent the metaphor is applicable. In this way, they sensitize the observer to the various ways a culture might operate within an organization. Finally, metaphors can also be used as a communication tool, like a mirror that is held in front of the organization. This might elicit a reflective process among members of the organization. For example, members may question how the organization currently presents itself to outsiders, and whether that impression is what they intend to achieve.

All in all, metaphors can function as useful tools to summarize, analyze and classify culture data and communicate with both insiders and outsiders about organizational culture. In the next section, we will now discuss a few metaphors for safety culture.

3 Safety Culture Metaphors

In line with Morgan's and Alvesson's metaphors described above, throughout the years Guldenmund has also explored a few metaphors for safety culture [9, 10]. According to Alvesson, a metaphor should be sufficiently rich and should have sufficient depth, to truly add to our understanding of a complex concept [8].

1. **Safety culture as a convenient truth**. A convenient truth is a truth that is easily accepted by many people. It might be that the label 'safety culture' is sometimes used for this reason, especially as a 'root cause' for large-scale accidents. When the safety culture is to blame, everybody is basically involved; therefore, nobody, in particular, is to blame. The metaphor also draws attention to the notion of truth as well as to the notion of cause. However, the label can also be applied to address deeper levels of organizational functioning. In that case, the purpose is to initiate more significant change rather than just the standard and more superficial responses to accidents.
2. **Safety culture as a mirror**. A mirror can be used in many different ways, but here the metaphor refers to the act of a safety culture self-assessment. It means that the organization looks at itself critically in the mirror, rather than admiringly. The mirror metaphor evokes associations to the amount and type of lightning (assessment methods), positioning in front of the mirror (viewpoint), size of the mirror

(extent of assessment), distance to the mirror (reflecting, for instance, the depth of assessment), and so on.

3. **Safety culture as a grading system**. For some organizations, the concept of safety culture is not interesting in itself, but rather it is interpreted as a competitive issue. Conveniently, it also means that a single number can be assigned to the whole, or a significant part, of the organization, which expresses its current safety culture's state of affairs. While this number can be 'sub-standard', or 'average', it can nevertheless be 'improved', preferably in the short run. This metaphor describes the most superficial reading of the concept of safety culture, and it is appealing to many managers who want to make a good impression regarding their safety efforts with a single grade. Scientifically spoken, this approach is a travesty and an insult to serious culture scholars. However, it is possible that interventions initiated to obtain a higher score, might have an impact on how safety within the company is understood. In that case, the grade functions as a catalyzer for company investments in shared safety understandings.
4. **Safety culture as a liaison**. Much has been written about the distinction between (safety) culture and climate. Safety climate is a psychological variable, pertaining to the overall impression workers have of the priority of safety in their company. Climate is assessed through self-administered questionnaires, and the resulting data can be aggregated to different levels and groups within the organization. Furthermore, being a quantitative variable, it can be related to numerous other quantitative variables, resulting in many liaisons. This metaphor lacks depth as it merely refers to the numerical structural networks that can be built with safety climate and other data. However, much writing about safety climate has this same superficial quality, as the building of quantitative networks appears to be a goal in itself rather than an opportunity for a deeper understanding of worker perceptions regarding safety.

These metaphors together describe the various practices regarding safety culture at the moment. Indeed, *practices* are more about the actual assessment of safety culture, rather than reflecting about its definition, content and meaning. Describing the content of culture is notoriously difficult, as it is both local, tacit and therefore (very) hard to pin down. In order to grasp how a (safety) culture might form in groups of interacting people, a process model of culture can be put forward. It describes how a group grows to understand safety and risk while carrying out their work. The next section discusses this model.

4 The Process Model of (Safety) Culture

The process model of culture is depicted in Fig. 1, and its five steps can be described as follows [11, 12]:

1. **Sensemaking.** This is not Weick's [13] sensemaking though, which is a more extensive process, but rather the assigning of meaning to the (working) environment. This is a fully automated and therefore unconscious process, comparable to the process of perception, that also takes place without awareness. However, the result is an awareness of the environment, as well as of possible risks therein.

2. **Exchanging.** At this step, an interaction takes place; this interaction is important for culture formation because culture is a group phenomenon. Furthermore, the interaction takes place about some dilemma, or an ambiguousness (Weick calls this equivocality). It might be about an unexpected situation or an unexpected state, but there is also a risk involved. If the situation is resolved successfully and safely and participants are (sufficiently) satisfied with its resolution, the solution might be employed again, when the same or a similar situation occurs.
3. **Formalization.** Individuals develop behavior patterns by going through a habit-forming loop multiple times. This *habit loop* has the following steps: Cue – Routine – Reward [14]. In order to become cultural, the groups needs to understand the newly formed habits as the right and perhaps the only way to solve this dilemma (or equivocality). At that moment, the situation is not ambiguous anymore, and the group understands its nature and its solution. This might be written down, or be passed on as tacit knowledge, often as an extension or an exception to the written down rule.
4. **Transmitting.** Now the tacit knowledge, or the otherwise formalized rule, can be passed on. This might be through the process of enculturation, education, training and, for instance, modelling and mimicking.
5. **Reinforcement.** This is not the reinforcement known to the Behaviorists, although reward and punishment might also play a role here. The reinforcement in this step means the strengthening of the rule; that is, by applying the rule, an employee is actually reinforcing it. People learn by example, by imitation. This is our inborn herd behavior or group-instinct. When multiple workers employ the rule in the same way, others will usually follow.

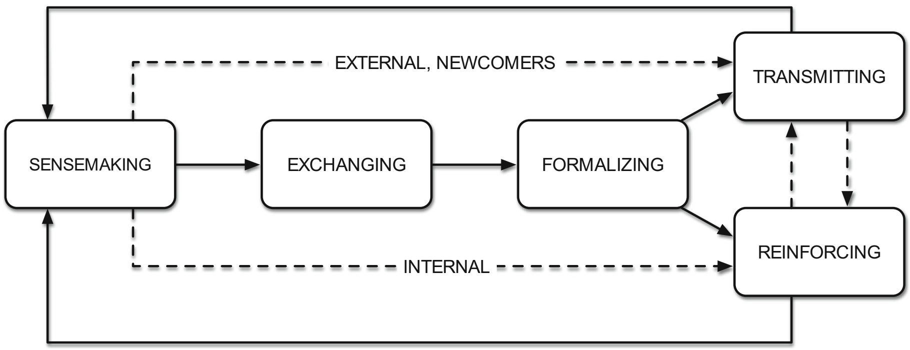

Fig. 1. The development model of culture

We should point out that this five-step model is initiated only when something does not really make sense, i.e., is equivocal or ambiguous. In many cases, however, a situation will make sense and a (culturally) *appropriate* action is carried out. Importantly, by carrying out a culturally appropriate action, its appropriateness is actually confirmed, hence the dotted line going from the box *Sensemaking* to the box *Reinforcing*. Furthermore, for newcomers, some situations do not make sense, and so they will have to be informed through some sort of transmission process (dotted line going from *Sensemaking* to *Transmitting*).

This development process is a bottom-up process and satisfies the notion that culture formation is a dynamic, continuous process, and not simply the faithful application of traditional rules, enforced by the group at large. It also describes how local deviations from traditional rules can occur and might overrule the traditional ones [15]. Furthermore, this bottom-up process might also produce new rules, e.g., in the form of 'best practices', that might evolve to general rules applying to the group at large.

Importantly, culture involves both processes, the bottom-up and the top-down process. The top-down process refers to basic assumptions, the core values, the shared understandings of the organization. They define the rules of the organizational culture game. And it is the team sports metaphor that describes this state of affairs quite well. It will be explored further in the next section.

5 Safety Culture as a Team Sport

5.1 Football

Each game, each sport has a set of rules and people will have to play the game according to the rules. Furthermore, a game or sport at a professional level has one purpose: winning. Of course, some people play the game for its social aspect (socializing), they do not have to win themselves, but they still need to comply with the rules.

For instance, the game of football has certain strict rules. The field (pitch) upon which the game is played has certain dimensions, and it has lines and circles drawn at certain positions (Fig. 2). There are requirements regarding the size and weight of the football. Furthermore, there are two teams, each consisting of eleven players. They play two halves of 45 min, and in between halves they take a break of 15 min. There are rules for how the ball must be handled when the ball is in play, and when it is out of play. Importantly, there are rules and repercussions for foul play.

The people are well-trained for many different situations that might occur during the game. The team will play according to tactics outlined by the coach. Moreover, many so-called standard situations are practiced, like corners (the ball has passed the end line of one team, due to one of its member's actions and is now shot from one of the corners of the end line by the other team) and free kicks (a member of one team has committed a foul, so the other team may kick the ball from that position). However, the game is dynamic, and the circumstances are too. The trainer cannot predict how the game will develop because of many uncertainties (the opponent might play the game in unexpected ways, weather conditions, the nature and state of the playing field, and so on). The team, therefore, must adapt to the situation at hand and often has to improvise.

The purpose of the game is to score as many goals as possible. A goal is made when a team deposits the ball in the goal of the opponent. This might be through the use of the head or the body or the feet. However, no arm or hand should be involved. Furthermore, an important strategy for the team is to prevent goals from the opponent.

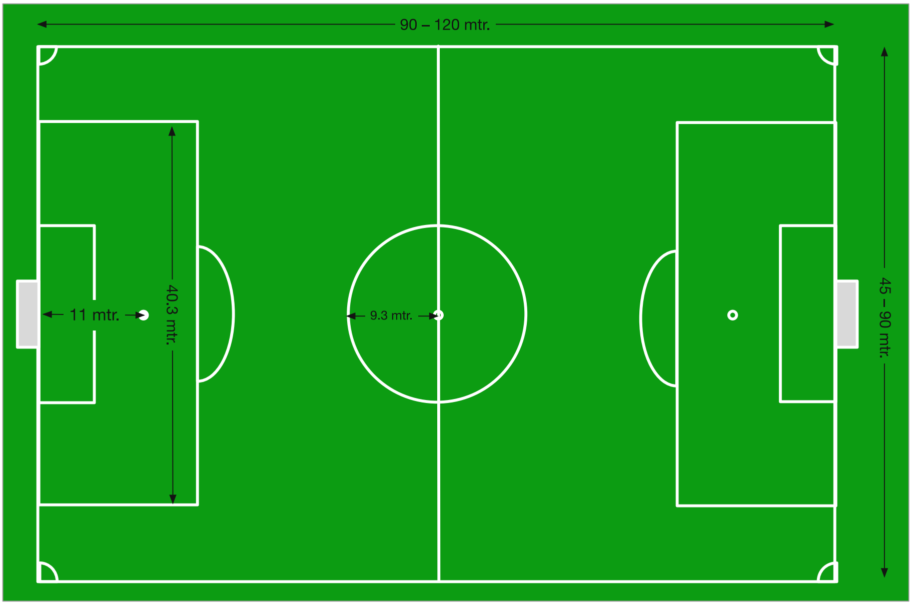

Fig. 2. The playing field (pitch) of the football game and its dimensions

5.2 How Does All This Compare to Safety Culture?

Safety is the name of the game (*we play football, not basketball, ice hockey or water polo*), and various distinct rules come along with this particular game. However, we are primarily here to produce (i.e., *we should make as many goals as possible*), while preventing the opponent from scoring (*we should prevent incidents or accidents*). We need to play the game according to the rules (*there are safety rules that always apply, and we should never violate, the so-called life-saving rules, or golden rules or red rules*). Nevertheless, local adaptations are sometimes required (*we sometimes need to adapt the rules to the circumstances*), we cannot foresee all opponents and conditions, yet we should always prevent the opponent from scoring (*we should always avoid incidents or accidents*).

In this metaphor, the two culture processes, top-down and bottom-up, are embedded. There are general rules that apply to the game, and there are multiple situations in which the rules take shape. This is a team effort, and by playing the game, the players come to understand the nature of the game, its possibilities, its limitations. It also learns from setbacks, from lost games and how their play should be improved.

With the football game, there are also referees. They oversee the rules and whether the players play the game fairly. With safety, there are supervisors, and safety professionals, who also oversee the safety game. Yellow and red cards might be drawn, but one should be careful with those. In contrast with the football game, the referees are not always around when the safety game is played. This could mean that when the referee is not around, different rules apply. There is a famous maxim in some production companies – Do it safely or do it at night. Obviously, this is not desirable.

We could take the football metaphor perhaps some steps further. Football teams might be compared to organizational cultures, with each team having a distinct playing style, and a fanbase often originating from a particular social-economic stratum. There are different players – e.g., Forward, Mid-field, Keeper, and so on – with different roles and tasks. How do these roles compare to the workers in an actual working group? Do group members indeed have different roles and is the group both comprehensive and heterogeneous (when their tasks require such variety)? Who is the Keeper then, and who closes the gaps in tasks, as various Mid-Fielders are supposed to do? And what about the coach, is that the supervisor? How does the coach motivate its team, and how does he deal with various challenges, like incidents, hiring, or workers leaving?

In football there are new developments; for instance, the video referee (VR). It enables the referee to look at particular situations anew and reconsider his initial ruling. How does this compare to a work setting? Is it Big Brother watching, e.g., management or the regulator, or is it the notions of fairness and learning that drives such a measure?

The metaphor provides multiple possibilities to draw comparisons, which might help working group members better understand their roles, their work and how they create safety while carrying out their primary tasks. However, it also sheds light on how work teams that face adverse circumstances create safety on a daily basis.

6 Conclusion

Culture, and therefore also safety culture, is a complex topic, both for scientists and practitioners. It is hard to define, to grasp and to pin down. However, to make the concept of culture more tangible, metaphors can be used. A metaphor draws parallels between its referent and the concept to which it is compared. In this way, the concept can be understood from the particular view the metaphor offers.

The football metaphor for the safety game appears to have some face value. It captures both the top-down and bottom-up processes of cultural development and dissemination. Moreover, because many people are familiar with the game of football, they can relate to this metaphor and will therefore also appreciate that safety can be interleaved with their daily, risky activities.

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Developing a Safety Culture Index for Construction Projects in Developing Countries: A Proposed Fuzzy Synthetic Evaluation Approach

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Abstract. The establishment of a construction safety culture index is of specific significance as it offers an objective measurement of the status of safety culture on construction projects. Considering the dynamics and complexities in the construction industry, the safety culture on a project may differ from other projects. This paper formulates a safety culture index to quantify the level of safety culture on construction projects in developing countries using the fuzzy synthetic approach (fuzzy set theory). The safety culture index consists of six safety culture categories; these include management commitment, accountability, worker involvement, supervisory leadership, communication, safety education and training. Professionals in developing countries can use the safety culture index to objectively determine the status of safety culture in a more practical way. In addition, application of the safety culture index would be useful to efficiently and factually compare the relative safety culture levels of different projects for benchmarking purposes.

Keywords: Safety culture · Fuzzy synthetic evaluation · Safety culture index · Safety management · Developing countries

1 Introduction

The construction industry plays a significant role in developing countries in fostering economic development and providing employment for construction workers. However, recent data from International Labour Organisation (ILO) and the World Health Organisation (WHO) indicate that overall, occupational accident and disease rates are slowly declining in most developed countries but are levelling or increasing in developing countries [1]. For instance, the ILO report suggests that in developing

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 167–179, 2020.
https://doi.org/10.1007/978-3-030-20497-6_16

countries[1], occupational injuries in the construction industry increased by 17.3% in 2017 [2]. A review of current safety management practices revealed that the major concern is the lack of a sound safety culture in the industry [3].

Safety culture is a subset of organisational culture, which refers to individual and organisational features that influence health and safety [4]. Safety culture has been defined in a variety of ways. A common definition is "the product of individual and group values, attitudes, perceptions, competencies, and patterns of behaviour that determine the commitment to, and the style and proficiency of, an organisation's health and safety management" [5, p. 23]. In assessing safety culture, three aspects are generally considered; psychological, behavioural, and situational. The situational aspects are reflected in the organisation's policies, operating procedures, management systems, control systems, communication flows, and workflow systems, measured using audits of safety management systems [4]. The behavioural aspects can be measured via peer observations, self-reporting, and outcome measures [6]. The psychological aspect of safety culture refers to the beliefs, attitudes, values, and perceptions of individuals and groups at all levels of the organisation [4]. This can be assessed by measuring people's perception of safety using safety climate questionnaires [6].

The main reason for assessing safety culture is to evaluate and benchmark it. Three measurement scales are represented in the safety culture assessment toolbox; nominal, ordinal, and interval. Each value on the nominal scale depicts a unique identity, ordinal scales satisfy identity and magnitude, and interval scales have equal intervals [7]. Grading only starts at the ordinal level since safety culture types such as market and clan are only different labels and not ordered at the nominal level [7]. This suggests that with the nominal measurement scale, comparisons for benchmarking purposes are not easily made, hence hindering opportunities for improvement in a safety system. Evaluative techniques used at the ordinal level are often depicted by ladders such as the maturity models by Westrum [8] and Hudson [9]. For instance, Hudson [9] puts forward five stages of safety culture; from pathological, reactive, calculative, proactive, to generative. Advancement along these stages is established in growth in maturity in addressing safety issues with the technique [7]. However, safety culture assessments have progressed up the measurement hierarchy leading to the interval level of measurement, which is often carried out with standardised questionnaires [7]. At the interval level, safety culture is measured using safety climate questionnaires. Numerous studies have assessed safety culture using these questionnaires; however, most analytical methods used in these studies cannot fully solve the subjectivity of safety culture assessment [10]. These studies rarely consider a characteristic of safety culture evaluation factors such as uncertainty or fuzziness [11]. For this reason, authors such as Guldenmund [12] refer to the questionnaire surveys in such studies as 'dirty'. He explains that the likelihoods to control unwanted influences affecting the responses from these questionnaires are limited and therefore they include a lot of random 'noise', hence the term dirty [12]. The outcomes of these are biases and uncertainness associated with the assessment results in portraying the true safety culture.

[1] Low income and lower-middle income groups.

This phenomenon is much severe in developing countries such as Ghana where research on safety culture is limited to the Oil and Wood industries [e.g. 13]. To manage and improve safety culture on construction sites, an objective measure of the construct is required. A construction safety culture index is one measure that has been suggested to provide an objective evaluation of the level of safety on sites [14]. This present study uses the fuzzy set theory (fuzzy synthetic evaluation approach) [15] to develop a safety culture index (SCI). This offers an inclusive, objective, and hands-on technique for evaluating the safety culture of a construction project considering the fuzziness and subjective judgement inherent in human decision-making processes. Due to the complex nature of safety culture, this study decomposed safety culture into measurable dimensions which can be used as indicators for an organisation's safety culture performance [16]. Literature review revealed six common dimensions used in assessing safety culture (management commitment, accountability, worker involvement, supervisory leadership, communication, and safety education and training) which provide a good starting point for developing the SCI. The sources of these dimensions are provided in Appendix A.

2 Fuzzy Synthetic Evaluation

This study employs fuzzy synthetic evaluation (FSE), a modelling technique of the fuzzy set theory to formulate a SCI equation for construction projects in developing countries. This method is more suitable to the traditional weighted method because it can objectify and handle subjective judgements inherent in human cognitive process [17]. The traditional weighted method such as the Delphi cannot handle evaluation involving multiple factors with nonsignificant weighting differences which may omit some essential information with smaller weighting [18]. The theory of fuzzy set has been used to develop numerous indices in various domains as well as construction safety, such as a quality assessment safety index [19], project safety hazard index [20], and safety performance [21]. One of the limitations of these studies is that they did not include organisational culture factors as they primarily dealt with the assessment of trade works such as concrete. The use of the FSE addresses uncertainty, the complexity of human behaviour, and the linguistic-scale measurement [20], which are commonly rated on an interval scale. In addition, the FSE is able to deal effectively with multi-attributes and multi-dimensions. Since this study employs dimensions of safety culture with various attributes that require evaluations subject to human judgement on a linguistic scale, it is appropriate to employ the FSE approach to develop the SCI.

3 Research Method

A questionnaire survey was adopted from Dodge Data & Analytics [22] to develop the FSE evaluation model. A seven-point Likert scale (from not important to most important) was employed to measure 29 attributes of safety culture. The set of safety culture dimensions and their attributes are shown in Appendix A. A seven-point Likert scale has an advantage of reducing leniency and central tendency problems that characterises ordinal scales [23]. A pilot study was performed in order to validate the contents of the questionnaire in the context of Ghana, with all contents of the questionnaire being retained. This assured the appropriateness of the survey instrument in the context of Ghana. Next, 240 questionnaires were distributed to 55 construction organisations.

Selection of expert participants was sieved through predefined criteria that are (1) respondent should have substantial knowledge on the research and practice of safety management, and (2) respondent should have at least one-year experience in the construction industry. Participants were approached at project sites, conferences, training centres, and workshops. To have a comprehensive range of construction practitioners participate in the survey, availability to the survey document was opened to available email addresses (D2K2, D3K3, and D4K4) of construction organisations belonging to the Association of Building and Civil Engineering Contractors of Ghana (ABCECG) in the Ashanti region of Ghana. After data collection, data screening was performed and 104 cases out of the 240 questionnaires were valid for the analysis representing a response rate of 43%. This response rate was deemed adequate because it satisfied the recommendations of numerous researchers that a sample size of 30 for any group could be deemed representative [24]. This sample (104) is more than Patel and Jha [20] sample of 64 in developing a project safety hazard index and hence was deemed sufficient to develop the SCI. Majority of the respondents held high technical and managerial positions such as quantity surveyors (29%), and project/construction managers (22%). Architects and engineers formed 18% and 17% respectively based on their professions. A group of respondents who indicated belonging to others constituted 14%. Such respondents comprised of safety officers, supervisors, etc. Most (33%) had 1–5 years of practical experience in the construction industry, while 31% had 6–10 years' experience. 31% of the respondents had 11–20 years of practical experience, and 5% had over 20 years of experience. Majority (54%) of the participants was in the supervisory category only, and 30% belonged to the management category only. Few participants (16%) were involved in both supervisory and management categories within the hierarchy of their firm.

4 Analysis, Results, and Discussion

Statistical analyses were performed using mean score ranking, reliability analysis, normalisation, and FSE analysis. Prior to developing the SCI, reliability analysis was performed using the Cronbach alpha with a coefficient of 0.96. This was greater than 0.7 indicating internal consistency within variables [25]. Mean score ranking was used in establishing the relative significance of the selected attributes of safety culture (SC), method widely used in construction management research to determine the significance of factors. Table 1 shows the mean scores of each safety culture attribute (SCA). In selecting the critical SCAs, only attributes with normalised values of 0.50 or more were considered, an approach that has been used by previous studies to determine the most significant factors [e.g. 17]. From this, the first 20 SCAs were considered for the next phase of the analysis, with the remaining nine were not deemed critical.

Table 1. Ranking of safety culture attributes.

Safety culture attributes	Mean	Rank	Normalization[a]
MC2	5.51	1	1.00
ST3	5.50	2	0.98
CN1	5.47	3	0.93
CN2	5.45	4	0.89
WI1	5.44	5	0.87
AC1	5.42	6	0.84
ST2	5.42	7	0.84
ST5	5.41	8	0.82
SL1	5.38	9	0.76
ST4	5.37	10	0.75
MC8	5.36	11	0.73
CN3	5.35	12	0.71
CN4	5.34	13	0.69
SL2	5.30	14	0.62
AC2	5.29	15	0.60
ST1	5.29	16	0.60
WI2	5.27	17	0.56
MC7	5.25	18	0.53
WI3	5.25	19	0.53
WI5	5.24	20	0.51
MC5	*5.15*	*21*	*0.35*
MC6	*5.15*	*22*	*0.35*
WI6	*5.13*	*23*	*0.31*
SL3	*5.09*	*24*	*0.24*
MC3	*5.07*	*25*	*0.20*
AC3	*5.05*	*26*	*0.16*
MC4	*5.01*	*27*	*0.09*
MC1	*5.00*	*28*	*0.07*
WI4	*4.96*	*29*	*0.00*

[a]Normalised value = (actual value − minimum value)/(maximum value − minimum value).

4.1 Formulating the FSE Tool for Evaluating SC

The proposed fuzzy model consists of two levels of membership functions (MFs) [15]. The first level is the safety culture groupings (SCGs) and the second level is the SCAs. The FSE tool is used to determine the objective weightings of each SCG considering the 20 attributes as input variables in the evaluation expression. Subsequent sections illustrate the application of the FSE in developing the SCI.

Calculate the Weightings for each SCA and SCG. The weightings for each SCA and SCG are calculated using Eq. (1) based on the mean scores from the survey:

$$w_i = \frac{M_i}{\sum_{i=1}^{7} M_i}, 0 < w_i < 1, \sum_{i=1}^{n} w_i = 1. \tag{1}$$

Where w_i = weighting function of a SCA or SCG, and M_i = mean score value of a SCA or SCG. Using Eq. (1) the weightings are calculated and presented in Table 2. For example, to calculate the weighting for 'MC2', Eq. (1) is adopted as:

$$w_{MC2} = \frac{5.51}{5.51 + 5.36 + 5.25} = \frac{5.51}{16.12} = 0.342.$$

Same approach is used to calculate the weightings for the remaining SCAs and SCGs.

Table 2. Weightings for SCAs and six SCGs for construction projects.

Safety culture attributes	Mean of SCA	Weighting of SCA	Total mean of SCG	Weighting of SCG
MC2	5.51	0.342		
MC8	5.36	0.333		
MC7	5.25	0.326		
Management commitment			16.12	0.150
AC1	5.42	0.506		
AC2	5.29	0.494		
Accountability			10.71	0.100
WI1	5.44	0.257		
WI2	5.27	0.249		
WI3	5.25	0.248		
WI5	5.24	0.247		
Worker involvement			21.20	0.198
SL1	5.38	0.504		
SL2	5.30	0.496		
Supervisory leadership			10.68	0.100
CN1	5.47	0.253		
CN2	5.45	0.252		
CN3	5.35	0.248		
CN4	5.34	0.247		
Communication			21.61	0.201
ST3	5.50	0.204		
ST2	5.42	0.201		
ST5	5.41	0.200		
ST4	5.37	0.199		
ST1	5.29	0.196		
Safety education and training			26.99	0.252
Total mean values of SCGs			107.31	

Determine the Membership Functions of each SCG and SCA. First, the MFs of the SCAs are determined. The MF of a SCA is computed from the overall assessment of the survey participants through Eq. (2). Using 'Safety/health is a key part of strategic planning (MC2)' for illustration purpose, the survey results showed that the participants rate its importance as follows: 0% as 'not important'; 0% as 'least important'; 3% as 'fairly important'; 12% as 'neutral'; 34% as 'important', 36% as 'very important'; and 16% as 'most important'. Hence, the MF for MC2 is derived as:

$$\mathrm{MF}_{(\mathrm{MC2})} = \frac{0.00}{\text{not important}} + \frac{0.00}{\text{least important}} + \frac{0.03}{\text{fairly important}} + \frac{0.12}{\text{neutral}} + \frac{0.34}{\text{important}} + \frac{0.36}{\text{very important}} + \frac{0.16}{\text{most important}}. \tag{2}$$

The MF can be expressed as (0.00, 0.00, 0.03, 0.12, 0.34, 0.36, 0.16). Similar approach is used to compute the MFs for the remaining SCAs (See Table 3). After computing the MFs for all the SCAs, the MF for each SCG is established using Eq. (3):

$$\mathrm{D} = w_i \circ R_i. \tag{3}$$

Where w_i is the weighting function of all SCAs within each SCG, $^\circ$ is a fuzzy composite operation, and R_i is the fuzzy evaluation matrix. Using 'SCG2 – Accountability (AC)' as an example, the MFs of all the SCAs in this group can be expressed through Eq. (3) in a weighting function and fuzzy matrix as:

$$\begin{aligned} \mathrm{D}_{\mathrm{AC}} &= w_{AC} \circ R_{AC} = (w_{AC1}, w_{AC2}) \times \begin{vmatrix} MF_{AC1} \\ MF_{AC2} \end{vmatrix} = (0.506, 0.494) \\ &\times \begin{vmatrix} 0.01\ 0.01\ 0.08\ 0.11\ 0.26\ 0.33\ 0.21 \\ 0.00\ 0.02\ 0.07\ 0.18\ 0.26\ 0.28\ 0.19 \end{vmatrix} = (0.00, 0.01, 0.07, 0.14, 0.26, 0.30, 0.20). \end{aligned} \tag{4}$$

The MFs for the remaining SCGs are calculated using the same procedure, and results shown in column 4 of Table 3.

Table 3. Membership functions for all SCAs and SCGs.

Safety culture attributes	Weighting for SCAs	Membership function for level 2 (SCAs)	Membership function for level 1 (SCGs)
Management commitment			
MC2	0.342	(0.00, 0.00, 0.03, 0.12, 0.34, 0.36, 0.16)	(0.00, 0.02, 0.06, 0.16, 0.26, 0.30, 0.20)
MC8	0.333	(0.00, 0.02, 0.10, 0.17, 0.17, 0.30, 0.24)	
MC7	0.326	(0.00, 0.03, 0.07, 0.19, 0.26, 0.24, 0.21)	

(*continued*)

Table 3. (*continued*)

Safety culture attributes	Weighting for SCAs	Membership function for level 2 (SCAs)	Membership function for level 1 (SCGs)
Accountability			
AC1	0.506	(0.01, 0.01, 0.08, 0.11, 0.26, 0.33, 0.21)	(0.00, 0.01, 0.07, 0.14, 0.26, 0.30, 0.20)
AC2	0.494	(0.00, 0.02, 0.07, 0.18, 0.26, 0.28, 0.19)	
Worker involvement			
WI1	0.257	(0.00, 0.02, 0.02, 0.14, 0.29, 0.38, 0.15)	(0.00, 0.02, 0.05, 0.15, 0.29, 0.32, 0.16)
WI2	0.249	(0.02, 0.03, 0.05, 0.14, 0.28, 0.32, 0.17)	
WI3	0.248	(0.01, 0.01, 0.08, 0.16, 0.27, 0.31, 0.16)	
WI5	0.247	(0.00, 0.03, 0.06, 0.14, 0.33, 0.30, 0.14)	
Supervisory leadership			
SL1	0.504	(0.00, 0.02, 0.04, 0.17, 0.26, 0.34, 0.17)	(0.00, 0.02, 0.05, 0.15, 0.27, 0.36, 0.15)
SL2	0.496	(0.00, 0.02, 0.07, 0.14, 0.28, 0.38, 0.13)	
Communication			
CN1	0.253	(0.00, 0.04, 0.06, 0.08, 0.27, 0.34, 0.22)	(0.00, 0.02, 0.04, 0.12, 0.24, 0.36, 0.20)
CN2	0.252	(0.02, 0.02, 0.04, 0.14, 0.22, 0.31, 0.25)	
CN3	0.248	(0.04, 0.01, 0.05, 0.12, 0.23, 0.38, 0.18)	
CN4	0.247	(0.02, 0.03, 0.02, 0.15, 0.23, 0.40, 0.14)	
Safety education and training			
ST3	0.204	(0.00, 0.01, 0.07, 0.14, 0.22, 0.34, 0.23)	(0.00, 0.02, 0.06, 0.16, 0.22, 0.31, 0.22)
ST2	0.201	(0.01, 0.01, 0.07, 0.16, 0.19, 0.33, 0.23)	
ST5	0.200	(0.02, 0.02, 0.03, 0.18, 0.20, 0.31, 0.24)	
ST4	0.199	(0.01, 0.02, 0.05, 0.17, 0.23, 0.31, 0.21)	
ST1	0.196	(0.00, 0.02, 0.10, 0.14, 0.26, 0.28, 0.20)	

Next, the MFs in level one are substituted into Eq. (5) to compute the SCI for each category.

$$\mathrm{SCI} = \sum\nolimits_{i=1}^{7} \mathrm{D} \times \mathrm{k}. \tag{5}$$

Where k is the adopted grade alternative (i.e. from 1 = not important to 7 = most important). Using ‘worker involvement’ for example, the SCI for SCG3 is calculated as:

$$SCI_{SCG3} = (0.00 \times 1 + 0.02 \times 2 + 0.05 \times 3 + 0.15 \times 4 + 0.29 \times 5 + 0.32 \times 6 + 0.16 \times 7) = 5.300.$$

Following this approach, the indices for each category are computed and presented in Table 4.

Table 4. Safety culture index for each SCGs for construction projects in developing countries.

Safety culture groupings	Safety culture index	Ranking	Coefficients[a]
Communication (SCG 5): CN	5.402	1	0.168
Safety education and training (SCG 6): ST	5.401	2	0.168
Management commitment (SCG 1): MC	5.372	3	0.167
Accountability (SCG 2): AC	5.365	4	0.167
Supervisory leadership (SCG 4): SL	5.338	5	0.166
Worker involvement (SCG 3): WI	5.300	6	0.165
Total	32.180		1.000

[a]Coefficient = (SCI for SCG/$\sum SCI$ for SCG).

Based on this study, the SCI for construction projects in Ghana can be expressed as:

$$SCI = (0.167 \times MC) + (0.167 \times AC) + (0.165 \times WI) + (0.166 \times SL) + (0.168 \times CN) + (0.168 \times ST). \tag{6}$$

Table 5. Linguistics for interpreting the safety culture index.

Linguistic variables	SCI values[a]
Extremely low	(1.0:1.4)
Very low	(1.5:2.4)
Little low	(2.5:3.4)
Neutral	(3.5:4.4)
Little high	(4.5:5.4)
Very high	(5.5:6.4)
Extremely high	(6.5:7.0)

[a]7-point Likert scaled, round to one decimal place

In Table 4, CN attained the highest coefficient, followed by ST, MC, AC, SL, and WI. Communication among managers and workers has been found to be one of the top valuable safety management practices. This finding is consistent with Glendon and Litherland [26]. In Glendon and Litherland [26] study, communication explained the highest variance of 18.300% out of the total cumulative variance of 69.100%. Therefore, a reliable and consistent communication channel among diverse organisational hierarchies is crucial to the success of safety. Communication, and safety education and training had similar scores indicating how important both constructs are in attaining a good safety culture. For example, effective communication is essential for successful safety campaigns and safety awareness programmes. Safety education and training is one of the most broadly used interventions to advance workplace safety [27]. Integrating task-specific training into traditional safety practices for workers could create awareness during the execution of high-risk trades. In Table 4, Management commitment is important. Though accountability attained relatively lower importance, it still has the same coefficient (0.167) with management commitment. Hence, accountability is significantly related to explaining management commitment to issues regarding safety. Supervisory leadership ranked fifth suggesting a lower important factor which may be the reason for the low involvement of workers. However, when supervisors display a consistent pattern of action supporting safety, it promotes a shared perception among the workers of the importance of safety and enhancing behaviours are increased [28]. Workers involvement ranked sixth suggesting it is the least important factor. Similarly, Choudhry and Zahoor [29] reported that workers involvement in safety and health is the fourth most neglected factor in Pakistan. A good safety culture should involve site workers in safety and health developments and organisation safety policy initiatives.

Construction processes in developing countries share similar characteristics in terms of adoption of technology, construction methods, cultural environments, and regulations [30]. Therefore the findings of this study may be of relevance to other developing countries.

5 Conclusions, and Implications for Research and Practice

A model for evaluating safety culture for construction projects in Ghana has been proposed as shown in Eq. (6). Essentially, this study has developed an objective measure of safety culture on construction projects in Ghana. This evaluation model makes it possible for professionals to objectively evaluate the level of safety culture on their construction projects using questionnaire surveys. This study contributes significantly to construction safety management research and practice, literature on fuzzy set theory, and the critical attributes of safety culture that would be impactful and valuable to policymakers and management in charge of construction projects. For practitioners to determine the status of safety culture on a given project, they have to rate the extent to which the 20-safety culture attributes under their respective safety culture dimensions are important on the 7-point Likert scale (since it was used in developing the SCI). The average scores for each SCG should be determined and substituted in the safety culture model (Eq. 6). The final score produced should be compared with the ranged values in Table 5 to determine the status of safety culture on their project. In addition, practitioners can use the same procedure to evaluate and compare the safety culture levels on other projects in a given portfolio. This serves as a benchmark to maintain or improve their current safety initiatives. For the researcher in safety management, this study offers a novel technique of applying the FSE to generate weightings that can be used to formulate expressions for safety evaluations. This study recommends that practitioners should often use the safety culture index model as a tool to evaluate their safety culture levels. Researchers in developed countries could uptake this FSE research approach of evaluating safety culture to benchmark, and compare with other already existing assessment tools.

Appendix A

List of safety culture dimensions and their attributes*.

No.	Dimensions of safety culture and their attributes
1	Management commitment (MC); Ali and Shariff [31]
1.1	Formal process for safety-related correction action (MC1)
1.2	Safety/health is a key part of strategic planning (MC2)
1.3	Company has joint worker/management safety and health committee (MC3)
1.4	Safety/health is a top agenda item at meetings (MC4)
1.5	Clearly defined safety and health expectations (MC5)
1.6	Management participates in all safety and health meetings on jobsite (MC6)
1.7	Practice prevention through design (MC7)
1.8	Use safety and health data for improvement (MC8)
2	Accountability (AC); Molenaar et al. [16]
2.1	Hold everyone accountable for safety (AC1)
2.2	Near-misses taken seriously and investigated (AC2)
2.3	Use external safety and health audits (AC3)
3	Worker involvement (WI); Molenaar et al. [16]
3.1	Workers encouraged to report unsafe conditions (WI1)
3.2	Workers encouraged to report near-misses (WI2)
3.3	Workers asked for input on site safety and health conditions (WI3)
3.4	Workers given stop-work authority (WI4)
3.5	Workers involved in safety and health planning (WI5)
3.6	Workers involved in job-hazard analyses (WI6)
4	Supervisory leadership (SL); Zohar [32]
4.1	Supervisors lead by example (SL1)
4.2	Subcontractors monitored on safety practices (SL2)
4.3	Subcontractors mentored on safety practices (SL3)
5	Communication (CN); Frazier et al. [33]
5.1	Safety and health communicated clearly to all employees (CN1)
5.2	Safety and health policies communicated consistently (CN2)
5.3	Managers regularly engage with workers one-on-one (CN3)
5.4	Safety and health policies coordinated with all subcontractors (CN4)
6	Safety education and training (ST); Molenaar et al. [16]
6.1	Safety and health training provided for supervisors and jobsite workers (ST1)
6.2	All employees receive orientation training when starting work on a new site (ST2)
6.3	Supervisors required to have basic safety and health training (ST3)
6.4	Supervisors required to have safety and health leadership training (ST4)
6.5	All jobsite workers required to have basic safety and health training (ST5)

*Attributes from Dodge Data & Analytics [22]

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Aggregate-Level Data Characteristics of Safety Climate with Different Likert-Type Scales

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Abstract. Safety climate is an important construct for determining construction safety. This study aims to examine the validity and reliability of a safety climate scale on the basis of its aggregate-level data characteristics, with the use of 5-, 7-, and 10-point Likert-type scales, and to investigate the influence of the number of response categories on the validity and reliability of a safety climate scale. A total of 104 construction workers participated in this study. Results showed that the mean, variance, and internal consistency reliability of the 5-, 7-, and 10-point Likert-type scales had no considerable difference. Among the three scales, the responses for the 7-point Likert scale tended to be normally distributed. Therefore, this study provides theoretical contributions to the literature on construction industry safety climate and suggests the use of the 7-point Likert scale in measuring safety climate in the construction industry.

Keywords: Construction safety · Likert-type scale · Safety climate

1 Introduction

The construction industry has long been regarded as one of the most dangerous industrial sectors due to its high number of accidents and fatalities. According to the Labour Department [1], 3902 accidents and 22 fatalities occurred in the Hong Kong construction industry in 2017, accounting for 35.2% and 75.9% of the total numbers of industrial accidents and fatalities, respectively. In addition, the accident and fatality rates per 1000 workers were 32.9 (17.2 for all industries) and 0.185 (0.045 for all industries), respectively. This unsatisfactory construction safety performance has also been observed in other regions, such as the UK, New Zealand, and Australia [2], and has aroused wide concern from safety researchers and relevant authorities.

Researchers have focused on understanding the behavior of construction workers, such as safety [3] and risk-taking [4] behaviors, for a few decades. They have also used different methods of predicting construction worker safety performance, such as safety climate [5]. Despite the wide recognition of the importance of safety climate in construction safety, the consensus about scale formats (e.g., 5-, 7-, and 10-point Likert-type scales) of measuring safety climate has still not been reached.

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 180–189, 2020.
https://doi.org/10.1007/978-3-030-20497-6_17

2 Literature Review

2.1 Safety Climate

The concept of safety climate was initially proposed by Zohar [6] in his seminal work published in 1980. Zohar [6] defined this construct as workers' shared perceptions regarding their organization's procedures, policies, and practices about the importance and value of safety within that organization. Previous meta-analyses have proven that safety climate is an important leading indicator in assessing safety outcomes within an organization (e.g., severity and frequency of injury incidents) [5, 7–9].

Since 1991, the concept of safety climate has been introduced to the construction industry. Dedobbeleer and Béland [10] were the first to examine safety climate among construction workers by using a three-factor structure developed for the American production industry. After the work of Dedobbeleer and Béland [10], construction safety researchers began to dedicate themselves to construction safety climate studies. The remarkable increase in the number of construction safety climate studies was realized. In an extensive literature review by Alruqi et al. [5], the results from 2000 to 2016 showed that approximately 60% of 107 articles on construction safety climate were published in the last five years. Thus, construction safety climate has been an increasingly popular research topic in occupational safety research.

Generally, two types of measurement for assessing safety climate are available, namely, industry-specific safety climate scales [11] and general safety climate scales [12]. The latter allow researchers to compare safety climates among different industrial sectors. Huang et al. [12] developed a shortened general safety climate scale with eight items via item response theory analysis with a sample of 29179 frontline workers from various industries to measure two types of managerial-level safety climate: (1) organizational-level safety climate, which includes workers' perceptions about the intentions and actions of the company and top management for safety promotion, and (2) group-level safety climate, which includes workers' perceptions regarding their direct supervisors' or workgroup's safety practices. This shortened scale is valuable for safety climate studies and practical implications in the improvement of occupational safety.

2.2 Likert-Type Scale

With the advancement of the research on psychology, a diversity of approaches have been developed for assessing constructs, such as attitudes, character, and personality traits [13]. The difficulty of assessing constructs includes transferring these qualities into a quantitative measure for data analysis purposes [14]. To address the difficulty of measuring a construct, Likert [13] developed a procedure for measuring scales with five response alternatives, namely, (1) strongly approve, (2) approve, (3) undecided, (4) disapprove, and (5) strongly disapprove. The responses from the series of questions were combined to create a measurement scale, namely, a Likert-type scale. Data were analyzed in accordance with the composite score from a Likert-type scale rather than on individual questions.

Since Likert [13] introduced the summative method, Likert-type scales have become increasingly popular in social science research. Despite such popularity, the decision on the number of response categories in a scale has not reached a consensus. Bendig [15] discovered that instruments that use a 2-, 3-, 5-, 7-, or 9-point Likert-type scale have equivalent reliability. However, Dawes [16] found that a 5- or 7-point Likert-type scale tends to generate slightly greater mean scores than a 10-point Likert-type scale. Moreover, Krosnick and Presser [17] identified that the increase in reliability becomes level-off after the use of seven points. Preston and Colman [18] affirmed that the 10-point Likert-type scale is the most preferred by respondents, closely followed by the 7- and 9-point Likert-type scales. Leung [19] compared the normality and psychometric properties of the Rosenberg Self-Esteem Scale by using 4-, 5-, 6-, and 11-point Likert-type scales. No discrepancy was found among these scales in the light of reliability, mean, and standard deviation. Moreover, the 6- and 11-point scales were normally distributed, whereas the 4- and 5-point scales did not follow a normal distribution, thereby implying that the scales that use more scale points are further likely to be normally distributed.

2.3 Research Gap

The consensus about the scale formats (e.g., 5-, 7-, and 10-point Likert-type scales) for measuring safety climate in the construction industry has still not been reached. Providing a guideline for selecting a scale format in measuring construction safety climate is urgently required. Therefore, this article aims to examine the validity and reliability of a safety climate scale on the basis of its aggregate-level data characteristics, with the use of 5-, 7-, and 10-point Likert-type, and to investigate the influence of the number of response categories on the validity and reliability of the safety climate scale.

3 Methodology

3.1 Measurement of Safety Climate

The shortened safety climate scale with eight items developed by Huang et al. [12] was used in this study. Table 1 shows the item contents of the scale. In the study of Dawes [16], the scales with 5-, 7-, and 10-point formats were used to examine the aggregate-level data characteristics. Hence, participants must complete the safety climate scale three times, each time with one type of scale format. Determining the appropriate anchor labels for each scale point was difficult due to the inclusion of a 10-point scale, and merely end-defined anchor labels were used for all scales, in line with the fact that middle labels may lead to a distraction from the interval nature [20]. The end scale points on each n-point Likert-type scale were labeled (1 = strongly disagree, n = strongly agree). To minimize the order effect on the results, the participants were randomly distributed with a questionnaire, which contained one of six combinations of the order of the three scale formats of the safety climate measurement. Table 2 lists the six combinations.

Table 1. Item contents of the safety climate scale [12].

Item contents	
Organizational-level Safety Climate (OSC)	Top management in this company
OSC1	Attempts to improve safety levels in each department continually
OSC2	Requires each manager to help improve safety in his or her department
OSC3	Uses any available information to improve existing safety rules
OSC4	Provides workers with substantial information on safety issues
Group-level Safety Climate (GSC)	Direct supervisor
GSC1	Discusses how to improve safety with us
GSC2	Uses explanations (in addition to compliance) to guide workers to act safely
GSC3	Reminds workers to work safely
GSC4	Ensures that all the safety rules (not only the most important ones) are followed

Table 2. Six combinations of the order of the three scale formats of the safety climate measurement.

Combination	Order of the three scale formats of the safety climate measurement
1	5-, 7-, 10-point Likert scales
2	5-, 10-, 7-point Likert scales
3	7-, 5-, 10-point Likert scales
4	7-, 10-, 5-point Likert scales
5	10-, 5-, 7-point Likert scales
6	10-, 7-, 5-point Likert scales

3.2 Participants

A total of 104 Hong Kong construction workers participated in this study. Written consent was obtained from participants. To reduce possible response bias, participants were informed of their right to quit this study activity anytime and that the collected data would be handled with absolute confidentiality.

3.3 Data Analysis

Rescaling the data of the formats can facilitate the data characteristic comparison to examine the data characteristics of scales using 5-, 7-, and 10-point scale formats. As a result, the rescaled data have the same upper limit. The rescaling method proposed by Dawes was followed. Specifically, Table 3 shows how the 5- and 7-point scale data were rescaled.

Table 3. Rescaling method [16].

5-point scale		7-point scale		10-point scale	
Original value	Rescaled value	Original value	Rescaled value	Original value	Rescaled value
1	1.00	1	1.00	1	Unaltered
2	3.25	2	2.50	2	Unaltered
3	5.50	3	4.00	3	Unaltered
4	7.75	4	5.50	4	Unaltered
5	10.00	5	7.00	5	Unaltered
		6	8.50	6	Unaltered
		7	10.00	7	Unaltered
				8	Unaltered
				9	Unaltered
				10	Unaltered

After the data of 5-, 7-, and 10-point scales were rescaled, the basic internal structure properties (i.e., mean, variance, and Cronbach's alpha), as implemented in the study of Leung [16], were computed to examine the influence of the number of response categories on the internal structure of scales. Then, the normality of the safety climate of 5-, 7-, and 10 point scales was investigated with three evaluation steps, namely, (i) skewness and kurtosis, (ii) Kolmogorov–Smirnov test, and (iii) normal Q-Q plot, as suggested by Dawes [16]. Statistical Package for Social Sciences 22 software was used to conduct these data analyses.

4 Results and Discussion

4.1 Internal Structure Properties

Table 4 lists the mean score and standard deviation for each scale item with different scale formats. Results showed that the three scale formats attained a mean score of at least 7 out of 10. No considerable differences were observed among the mean scores and standard deviations for each scale item and the overall scale.

Table 4. Mean score and standard deviation of items with 5-, 7-, and 10-point scales (n = 104).

Scale item	5-point scale		7-point scale		10-point scale	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
OSC1	7.382	2.369	7.274	2.150	7.481	2.323
OSC2	7.426	2.417	7.274	2.229	7.385	2.231
OSC3	7.553	2.219	7.418	2.265	7.212	2.464
OSC4	7.599	2.288	7.389	2.261	7.375	2.466
GSC1	7.512	2.365	7.216	2.512	7.240	2.436
GSC2	7.599	2.373	7.346	2.376	7.423	2.412
GSC3	7.853	2.296	7.635	2.239	7.490	2.385
GSC4	7.555	2.285	7.275	2.361	7.442	2.314
Overall	7.560	2.327	7.354	2.299	7.381	2.379

The values of Cronbach's alpha, a measure of internal consistency reliability, for 5-, 7-, and 10-point scale formats were 0.960, 0.967, and 0.975, respectively. On the basis of Arbuckle's interpretation on Cronbach's alpha [21], a value over 0.9 indicates excellent internal consistency reliability. Excellent internal consistency for these formats was obtained because the values of Cronbach's alpha were greater than 0.9.

4.2 Normality

Normality test results (Table 5) showed that all scale items with the three scale formats had negative skewness, presenting a tail on the left side of the distribution, thereby suggesting that the construction safety climate in Hong Kong was ranked high by the majority of participants. This finding was consistent with that of Dawes [16], who found that scores for Likert-type questions often have negative skewness. The kurtosis for the three scale formats was also negative, indicating that the data exhibited a "flat-topped" distribution. Figures 1, 2 and 3 display the mean score distributions of safety climate with 5-, 7-, and 10-point scale formats, respectively. Among the three scale formats, the 7-point scale format had the smallest skewness and kurtosis, implying that its mean scores were more normally distributed than the 5- and 10-point scale formats. The Kolmogorov–Smirnov test result suggested that the mean scores for the three scale formats did not follow a normal distribution in the entire population probably because the sample size (n = 104) in this study is small. Figures 4, 5, and 6 show the normal Q-Q plots of safety climate with 5-, 7-, and 10-point scale formats, respectively. If data are normally distributed, then the scattering of the normal Q-Q plot will form a straight line. The three plots show a similar pattern in general. On one hand, the scattering in the plots of 5- and 10-point scale formats cannot show a straight line. On the other hand, the 7-point Likert scale is most closely aligned with the straight line. This result further shows that the mean score distribution of the 7-point scale format was closer to normality than those of the other two scale formats.

Table 5. Skewness and kurtosis of items with 5-, 7-, and 10-point scale formats (n = 104).

Scale item	5-point scale		7-point scale		10-point scale	
	Skewness	Kurtosis	Skewness	Kurtosis	Skewness	Kurtosis
OSC1	−0.683	−0.094	−0.550	−0.005	−0.906	−0.189
OSC2	−0.905	−0.287	−0.610	−0.058	−0.968	−0.476
OSC3	−0.752	−0.163	−0.712	−0.025	−0.824	−0.150
OSC4	−0.597	−0.521	−0.662	−0.410	−0.895	−0.189
GSC1	−0.705	−0.256	−0.668	−0.499	−0.689	−0.512
GSC2	−0.674	−0.539	−0.524	−0.652	−0.676	−0.596
GSC3	−0.937	−0.263	−0.706	−0.244	−0.780	−0.313
GSC4	−0.788	−0.059	−0.671	−0.294	−0.713	−0.437
Overall	−0.755	−0.273	−0.638	−0.273	−0.806	−0.358

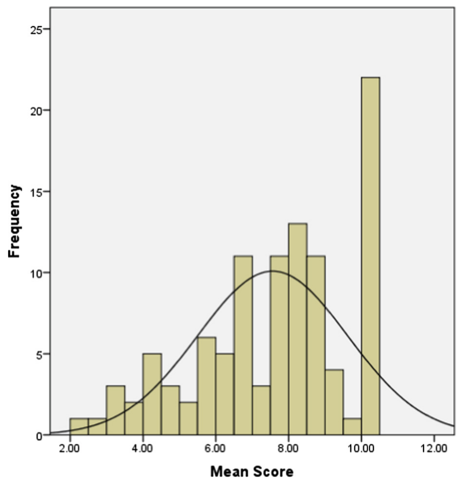

Fig. 1. Mean score distribution of safety climate with a 5-point scale format.

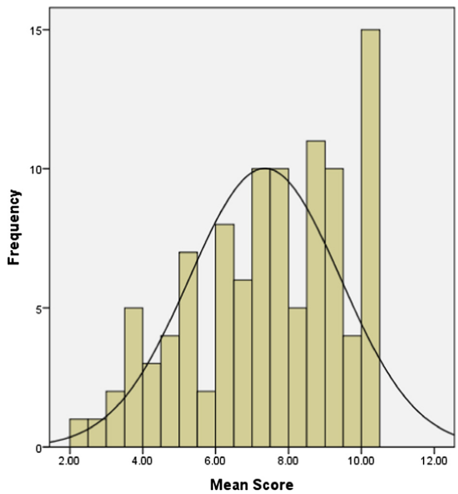

Fig. 2. Mean score distribution of safety climate with a 7-point scale format.

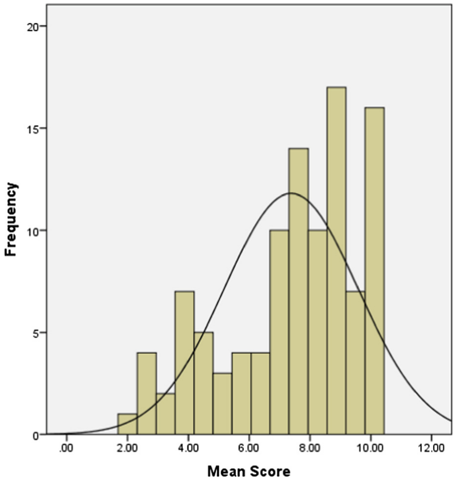

Fig. 3. Mean score distribution of safety climate with a 10-point scale format.

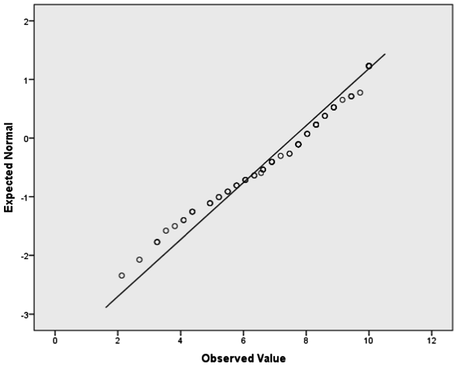

Fig. 4. Normal Q-Q plot of safety climate with a 5-point scale format.

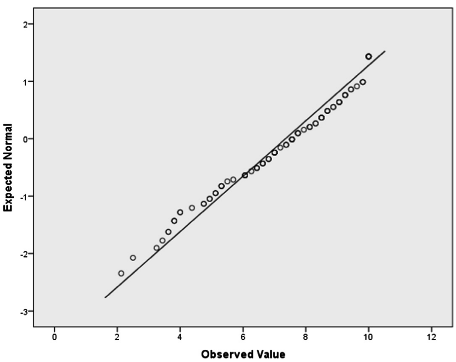

Fig. 5. Normal Q-Q plot of safety climate with a 7-point scale format.

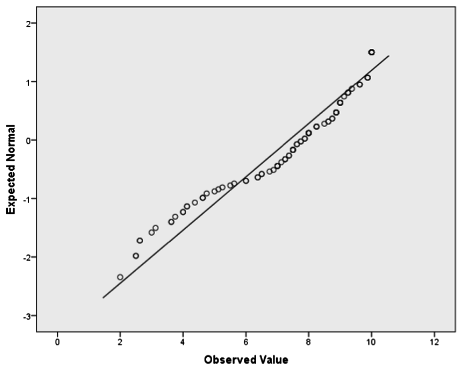

Fig. 6. Normal Q-Q plot of safety climate with a 10-point scale format.

5 Conclusion

Recently, safety researchers have focused on the validity of safety climate scale in the construction industry. This study provided valuable evidence for supporting the use of 7-point scale format in measuring construction safety climate due to its tendency to be normally distributed and in indicating a good safety climate in the Hong Kong construction industry.

In the future, this study should be replicated with a large sample size in other regions to confirm the study results and to test the normality of the three scale formats using the Kolmogorov–Smirnov test. In addition, the influence of the number of response categories on the test–retest reliability and the factor structure of the safety climate scale should be further investigated.

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Role of Human Safety Intervention on the Impact of Safety Climate on Workers Safety Behaviours in Construction Projects: A Conceptual Model

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Abstract. Over the last 30 years, the rise in studies relating to safety behaviour in the construction industry demonstrates its importance to construction safety management. In improving safety behaviour, safety climate has been used to mould the perceptions workers form about their organisations. However, recent findings suggest that there is a lack of a comprehensive and well-accepted safety climate model to fully capture a true picture of safety behaviour. This sparks the need for further novel schemes and resolutions. This paper proposes a conceptual model by integrating human safety intervention to play a mediating role between group safety climate and workers safety behaviours. The conceptual model was developed based on the organisational climate and behavioural safety theories. The model could serve as the theoretical basis to provide a better understanding of workers safety behaviours. This insight will assist construction organisations to strategically focus their efforts to ensure the success of safety.

Keywords: Safety climate · Safety behaviour · Human safety interventions · Conceptual model · Construction workers · Safety management

1 Introduction

The construction industry has consistently been among the top few industries with the highest number of accident rates and serious claims. Despite a significant improvement in occupational safety and health (OSH), the construction industry remains a high-risk industry with a high rate of injury and fatality worldwide [1, 2]. For instance, the construction industry employs about 7% of the world's workforce but is responsible for 30–40% of fatalities [3]. Work-related injuries, fatalities, and illnesses impose costs on employers, workers, and the community. Reducing the number, rates, and costs of such accidents, incidents, and injuries is an ongoing challenge for researchers, policymakers, and practitioners, and requires a detailed comprehension of how accidents are caused

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 190–200, 2020.
https://doi.org/10.1007/978-3-030-20497-6_18

[4]. Whereas the accompanying causes of these accidents in the construction industry are primarily due to being hit by an object, lifting, pushing or pulling, and falls from a height, the underlying cause may not be the workplace system failure but by human behaviour. Many studies argued that majority of fatalities/injuries on construction sites are attributed to workers' unsafe behaviour [5–7]. Lingard and Rowlinson [8] also reasoned that 80–90% of all accidents are caused by unsafe behaviour that could have been controlled by the employee or monitored by management. Due to the improvement in the reliability of technical systems, the focus has turned to human causes of accidents [9]. In particular, unsafe behaviours are recognised as a major cause of occupational accidents [10]. To address these issues, construction organisations around the globe are implementing OSH and environmental systems to reduce injuries, eliminate work-related illnesses, and to provide a safe work environment for their employees [11]. Also, in developed countries, technological advancements have been made towards improving safety systems [12]. In spite of these dramatic improvements in recent decades, the safety record in the construction industry continues to be one of the poorest [13].

This suggests that notwithstanding technical advances and the execution of robust OSH management systems, the construction industry's chronic level of fatalities, severe injuries, and ill health seems resilient to change [14]. This has prompted researchers and practitioners to focus on organisational and social factors, including safety climate, to encourage positive change to the industry's poor OSH performance [14]. In curbing unsafe actions, safety climate has been used to mould worker's behaviour through the perception workers form about how organisations reward and support safety [15]. This is because safety climate is a factor that influences how employees behave concerning safety issues [16]. Consequently, "a positive safety climate is likely to contribute to good safety behaviours and/performance" [17, p. 820]. The influence safety climate has on safety behaviour has been well established in the construction safety literature. Mohamed [18] reported a significant positive relationship between safety climate and safety behaviour. Guo et al. [6] found a significant positive effect of safety climate on safety behaviour of construction workers. However, variations linked with different safety climate constructs and their divergent features offer a challenge in determining which of them best exemplify a transparent and full picture of safety climate [19]. Besides, researchers and practitioners are still divided on how to define and measure safety climate, and which safety climate interventions are likely to succeed [20]. This implies that the mechanisms required to considerably improve safety behaviour of construction workers have not been well captured. This has led to the absence of a comprehensive and well-accepted model available to explain safety behaviour of construction workers [21]. More so, despite persistent efforts by researchers to promote construction safety through fostering safe behaviours, fatalities still plague the industry. This sparks the need for further novel schemes and resolutions [4].

In view of these inconsistencies, Zohar [22] calls for a shift from practical to more theoretical and conceptual issues. He further adds that "the time has therefore come for moving to the next phase of scientific inquiry in which constructs are being augmented by testing their relationships with antecedents, moderators, and mediators, as well as relationships with other established constructs" [22, p. 1521]. This move is geared towards reducing ambiguity and inconsistencies relating to discussions surrounding safety climate. Similarly, a deficit of studies considers third variable effects that could explain some of these relationships [23]. To address this research demand, an intervention is required to improve safety performance particularly safety behaviours of workers [24]. A significant outcome of a safety intervention as pointed out by Neal et al. [25] is its potential to change unsafe worker behaviour to safe worker behaviour. In order to improve safety behaviours of construction workers, a suitable intervention is required to effectively mould the perceptions workers form about the policies, procedures, and practices relating to safety. The human level of safety intervention includes interventions to change human knowledge, competence, attitude, motivation, or behaviour related to safety [26], and hence it is appropriate to examine their influence on worker safety behaviours considering the uniqueness and complexities of the construction industry. Thus, the present study proposes a conceptual model taking in account human safety intervention to play a mediating role between the impact of safety climate on safety behaviours of construction workers.

2 Key Concepts

2.1 Safety Climate

The term ‘safety climate’ first made its appearance in the academic literature in 1980 when Zohar [27] measured workers’ perceptions of various aspects of work safety in industrial organisations. He defined safety climate as “a summary of molar perceptions that employees share about their work environment” [27, p. 96]. Grounded in the organisational climate theory by Schneider [28], such perceptions and behaviour-outcome expectations can guide and direct work behaviours accordingly [27]. It is with this intent the concept of safety climate was developed. Safety climate can be functional at the individual, group, and organisation levels. Zohar [27] conceptualizes the construct of safety climate at both group and organisation levels [20]. Safety climate can also be conceptualised at the individual level, which is termed as psychological safety climate [20]. Neal and Griffin [29] distinguish psychological safety climate from group safety climate as individual perceptions of policies, procedures, and practices relating to safety in the workplace, and group safety climate as aggregated and shared perceptions of the group as a whole.

Previous studies have mostly investigated the impact of psychological safety climate on safety outcomes at the individual level [30]. However, group safety climate has stronger relationships with safety performance than psychological climate [29]. Similarly, Lingard et al. [31] argued that, the group safety climate should be a stronger predictor of safety performance than organisation safety climate, especially in large organisations, because most workers have little contact with top management and are more likely to be influenced on a daily basis by interactions with members of their immediate workgroup, including the supervisor and co-workers. Zohar [32] explains that the group safety climate stems from patterns of behaviours and practices as opposed to isolated events or environmental circumstances. In other words, for perceptions to be shared among individuals, an objective reality in the external environment must be tangible and sufficiently influential that people can agree in their perceptions [29].

Consequently, perceptions of group members are expected to converge. Although available literature stresses the relevance of psychological safety climate in predicting individual safety behaviour, recent empirical evidence revealed that group safety climate impacts and predicts both individual and group safety behaviours [20].

Given these discussions, it seems that well aligned and consistent perceptions about safety matters are better derived from a group-level analysis of safety climate. Zohar [22] provides some instances of group-level analysis of safety climate as co-worker practices or supervisory. Accordingly, in reducing the inconsistencies and ambiguities associated with safety climate measurements, the conceptual model developed in this study employs the group-level analysis of safety climate particularly coworker practices.

2.2 Safety Behaviour

Originating from psychology studies, the behavioural theory of accident causation and prevention is often referred to as behaviour-based safety (BBS). There is no agreed definition of BBS, but it is often used as a phrase for a variety of safety interventions that focus on front line workers' safety behaviour [24]. Interest in safety behaviour at the workplace developed in the 1930s after accident reports revealed that 95% of workplace accidents were caused by unsafe employee actions [33, 34]. Accidents can occur through individuals' participation in their work. According to Health and Safety Executive [9], approximately 80% of accidents may be attributed, at least in part, to the actions or omissions of people. A construction accident analysis in Australia further revealed workers' actions/behaviours as the topmost causative factor, followed by site layout and suitability of materials/equipment [35]. Despite persistent efforts by researchers to promote construction safety through fostering safety behaviours of workers, fatalities still plague the industry.

2.3 Human Safety Intervention

Safety intervention is a maneuver to change or institute practices to improve safety [26, 36]. There are three main safety interventions; management safety intervention denotes the top management strategies and safety managerial actions; technical safety intervention refers to any method that guarantees a safe working climate; and human safety intervention suggests methods to change human understanding and reasoning, in view of safety practices that directly affect the employee [26, 37, 38]. A significant outcome of a safety intervention is its potential to change unsafe worker behaviour to safe worker behaviour [25]. However, different characteristics of the construction industry such as majority of the workers on site from diverse cultural backgrounds require a study to determine the type of intervention that is appropriate to promote safety behaviour within a specific region [38]. In selecting an appropriate intervention, numerous variables must be appraised since each country has its own uniqueness and dissimilarities [39]. A suitable intervention could change an organisation, design, or environment at work [26]. In addition, implementing safety interventions can lead to a drop in accident rates and safety-related costs [40].

A distinctive feature of the construction industry is the inevitable cultural diversity among the workforce. Research has shown that cultural uniformity in relation to OSH does not exist in organisations [41]. Lingard [41] adds that this is particular in construction where productive work is performed in locations removed from corporate offices. For instance, in Australia, around 20% of all workers in construction are from overseas [42], and it is anticipated that migration will continue to be a source of labour supply for the construction sector since homegrown labour supply will be in decline as baby-boomers retire, participation rates plateau and growth in young workers falls [43]. Behaviours of workers in the construction industry are coated and subjective to the complex constellations of national culture [44]. Goh and Binte Sa'Adon [45] sought to examine the cognitive factors influencing safety behaviour of not anchoring a safety harness when working at height on a construction site in Singapore among 40 migrant workers (27 from Bangladesh, 11 from India, and 2 from China). Country comparisons from Hofstede's 6D model [46] revealed that the four countries (i.e. Singapore included) had different culture scores and hence suggested that the national culture of the migrant workers and the location of work has great influence on the workers' decision to anchor their harness or not [45].

The safety of construction workers is a complex phenomenon. Managing workers with different cultural backgrounds at the construction site require appropriate safety intervention practices to improve workers' safety behaviour [38]. The human level of safety intervention includes practices to change human knowledge, competence, attitude, motivation, or behaviour related to safety [26], and hence it is appropriate to examine its influence on safety behaviours of construction workers looking at the uniqueness of the industry. This is well aligned with the behavioural theory of accident causation where positive reinforcement in the form of rewards and incentives is used to promote the safe behaviours and to discourage unsafe behaviours. Besides, behavioural models, which involve human activity, are relevant to the human level of safety intervention [26].

3 Conceptual Model Development

3.1 Dimensions of Safety Climate

Operationalising the safety climate construct however is open to debate [20]. Numerous studies continue to propose "ideal" safety climate dimensions, however this has further contributed to dimensional inconsistencies and debate lingering around the safety climate concept. Nevertheless, some dimensions such as management commitment are common among these studies suggesting a certain level of consensus. In an early study by Zohar [27], eight safety climate dimensions were proposed: management commitment to safety; safety training; level of work risk; status of safety officer; work pace; safety committee status; effects of safe conduct on promotion; and effects of safe conduct on social status. Based on Brown and Holmes's [47] model, Dedobbeleer and Béland [48] proposed nine dimensions of construction safety climate: management's attitude toward safety practices; management's attitude toward workers' safety; foreman behaviour; safety instructions; safety meetings; proper equipment; perceived control; perception of risk-taking; and perceived likelihood of injuries. Mohamed [18] identified ten dimensions of safety climate through an exploratory interview with construction practitioners: commitment; communication; safety rules and procedures; supportive environment; supervisory environment; workers' involvement; personal appreciation of risk; and appraisal of physical work environment and work hazards. Health and Safety Executive [49] also proposed ten dimensions of safety climate: organisational commitment and communication; line management; supervisors' role; personal role; workmates' influence; competence; risk taking behaviour and some contributory influences; some obstacles to safe behaviour; permit-to-work systems; and reporting of accidents and near misses. Schwatka et al. [50] identified eight commonly measured dimensions in construction, namely: general management commitment to safety; safety policies, resources, and training; supervisor commitment to safety; general organisational commitment to safety; co-workers commitment to safety; safety communication; worker involvement in safety; and risk appraisal and risk taking.

These dimensions when validated are also used as tools in measuring safety climate. Dimensions often presented in most recent reviews of construction safety climate seldom identify associated measurable/observable items. These dimensions have merely passed the validation stage and hence remain unsuitable to capture a true picture of safety climate in this present study. Both tools developed by Mohamed [18] and Health and Safety Executive [49] have been adopted in many countries such as Australia [e.g. 18, 51], Hong Kong, India, and Mainland China. Health and Safety Executive [49] recommends that their instrument is "a generic tool that can be used in any industry sector" [49, p. 12]. However, when a larger number of industry-specific scales are made available, contributing a diversity of tangible climate indicators, it would be able to deduce underlying or tacit sense-making processes through which shared climate perceptions emerge [22]. To prevent underestimation in our conceptual model, it is essential to consider many variables in the hope to have detailed shared perceptions concerning safety. Since Mohamed [18] proposed quite a substantial number of dimensions (10) specific to the construction industry, the conceptual model to be developed includes eight dimensions (i.e. those related to group-level) to give a comprehensive aggregate view of shared perceptions regarding safety.

3.2 Types of Safety Behaviour

Drawing on Borman and Motowidlo's [52] distinction between task and contextual performance, they differentiated two types of safety behaviour, safety compliance and safety participation. Neal and Griffin [29] referred to safety compliance as the fundamental activities that individuals need to carry out to maintain workplace safety. Whereas safety participation denotes behaviours that do not directly contribute to an individual's personal safety but do assist in fostering an environment that supports safety [29]. In other words, compliance refers to the behaviours that are compulsory in nature, while safety participation refers to the behaviours that are voluntary [53]. Meta-analysis of safety research by Christian et al. [23] revealed that safety compliance behaviours are the main hypothetical mediators used in most studies.

In measuring construction workers safety behaviours, Mohamed [18] used two approaches, (1) a respondent self-reports safety behaviour, and (2) a respondent reports co-workers' behaviour. However, Patel and Jha [19] found that the measure of co-workers behaviour is a more generalized and reliable measure than the one in which a respondent reports his/her own behaviour. As put by Pousette et al. [54, p. 404] "we do not know to what extent people really do what they claim to do". In other words, with the co-worker measure of safety behaviour, the bias in reporting is also reduced to some extent. Moreover, the coworker measure of safety behaviour is well synchronised with the group-level analysis of safety climate which particularly considers coworker practices. Zohar cautions that "the practice of mixing items associated with divergent levels of analysis must be discontinued in order to avoid level discrepancy errors in safety climate measurement" [22, p. 1521]. In this regard, the coworker measure of safety behaviour is integrated into the conceptual model.

3.3 Practices of Human Safety Intervention

Safety interventions are important to include in a conceptual model to act as effect-modifying variables [26]. An effect-modifying variable is one which alters the size and direction of the causal relationship between two variables [26]. For instance, we propose that human safety intervention is the mediating variable between group safety climate and workers safety behaviours. Because human safety intervention (mediating variable) explains how or why group safety climate (independent variable) affects workers safety behaviours (dependent variable).

Zaira and Hadikusumo [38] identified fifteen practices of human safety intervention through literature review. These practices were further arranged to form an 11-item survey instrument, namely: BBS programme; safety training; safety inductions for new workers; safety awards, safety promotion, safety incentives; safety supervision; safety awareness programme, safety campaigns, safety knowledge programme, safety education; safety information, safety bulletin boards; requisite safety expertise for high-risk operations; job hazard analysis, job safety analysis; daily tailgate, toolbox meeting; and penalty, accident repeater punishment programme. These observable variables are considered as the measures of human safety intervention in our conceptual model.

4 Relationships Among Safety Climate, Human Safety Intervention, and Safety Behaviour

The latent constructs of the discussed concepts and their possible relationships are shown in Fig. 1. The positive impact of group safety climate on safety behaviour of workers is, therefore, possible to be mediated by human safety intervention. Accordingly, the following hypotheses are proposed:

1. Group safety climate has a positive impact on construction workers' safety behaviours (H1);

2. Group safety climate has a positive impact on human safety intervention (H2); and

3. Human safety intervention significantly mediates the impact of group safety climate on construction workers' safety behaviours (H3);

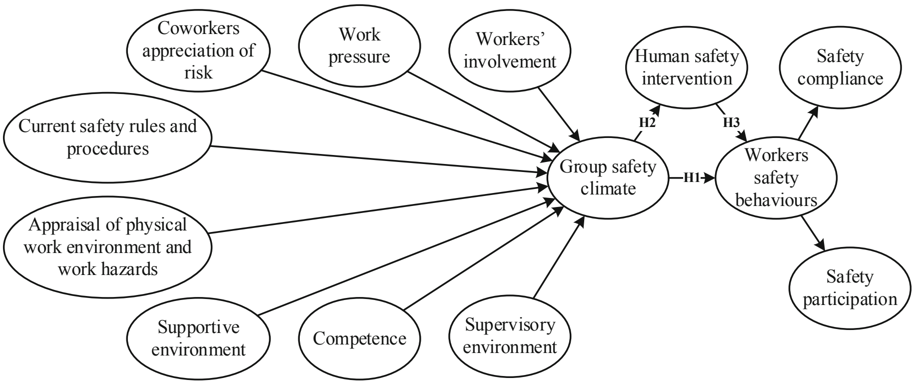

Fig. 1. Conceptual model for workers safety behaviours.

5 Conclusions

This study contributes to organisational climate theory, behavioural theory of accident causation, and construction safety management practice. For the construction practitioner, this study provides a pathway to institute appropriate mechanisms to equip workers to perform safely considering the complexities and difficulties of monitoring safety behaviours of workers. Though previous studies have made significant contributions in explaining construction workers safety behaviours, the lack of a comprehensive and well-accepted model reflects the current state of the discussion. This state of debate has been attributed to (1) the inconsistencies and ambiguities surrounding mechanisms such as safety climate required to capture safety behaviour; (2) the need for an intervention to augment the relationship between safety climate and safety behaviour; and (3) the call for more empirical evidence of the influence of group safety climate on workers safety behaviours. To address these issues, a comprehensive conceptual and theoretical approach has been demanded. In response, this study develops a conceptual model for measuring construction workers' safety behaviours by incorporating human safety intervention practices, group safety climate dimensions, and types of safety behaviours. The model serves as a theoretical basis to provide a better understanding of workers safety behaviours. This insight will assist construction organisations to strategically focus their efforts to ensure the success of safety. It is anticipated that this study will stimulate further empirical research to test the proposed hypotheses.

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Management of Atmospheric Hazards in a Confined Work Space in Nigeria: A Case Study Research of an Organisation in River State, Nigeria

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Abstract. Several atmospheric hazards exist in confined spaces in several industries such as chemical, construction, transportation, municipal and agricultural sectors of the numerous potential hazards present in such confined spaces.

This study will seek to identify gaps in the working procedures, attempt to explore answers on why accidents still occur in confined space work despite measures and standards put in place to ensure the safety of the work environment. The study aims to investigate the management of atmospheric hazards in confined space work, to ensure the safety of workers in the industry located in Nigeria.

Results revealed that despite having knowledge of, and experiences in confined space work, poor testing procedure and improper monitoring, lack of adequate provision of confined space equipment during work activity, lack of adequate compliance is an issue of grave concern which answered the research question of why accidents still frequently occur in confined space work.

1 Introduction

In recent times, a variety of industrial processes involve work within a confined space (Burlet-Vienney et al. 2015); such as silos, pits, pipelines and storage tanks (Wang et al. 2016). The hazardous atmosphere could occur in such confined spaces when the air is contaminated by toxics or oxygen deficiency. This could present severe dangers in certain industrial settings, particularly where some work processes or activities create a hazardous atmosphere that inadvertently renders a regular workspace that may be anticipated as safe to suddenly become unsafe to people working in it (Smith et al. 2014). Several industrial activities involve work carried out within a confined space and such activities could present hazardous conditions due to atmospheric contaminations such as oxygen deficiency.

Several atmospheric hazards exist in confined spaces in several industries such as chemical, construction, transportation, municipal and agricultural sectors (Burlet-Vienney et al. 2015). Of the numerous potential hazards present in such confined spaces; the ones that are of concern include atmospheric (such as poisoning,

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 201–211, 2020.
https://doi.org/10.1007/978-3-030-20497-6_19

asphyxiation, explosion), biological, and physical (including mechanical, electrical, engulfment, falls, lighting, outside traffic) (Burlet-Vienney et al. 2015). Confined space hazards are characterized into three major categories namely - biological, physical and atmospheric hazards as seen in Smith et al. (2014). Concerning this, (ENHESA 2011) and (Guardian.ng 2017) opine that hazardous incidents associated with working in confined space have claimed many lives and caused health injuries to so many workers in Nigeria.

Atmospheric hazards are frequently the hardest to identify because they could remain undetected, except with the aid of a gas monitor (Hu 2011). Three major types of risks related to confined space work were identified (Botti et al. 2017a, b). They include electrical, mechanical and chemical risks. It explained that electrocution in a confined space commonly results to electric shock injuries and death; and gave examples of mechanical related risks to include entrapments, asphyxiation, drowning as a result of being engulfed or falling objects (Botti et al. 2017a, b).

In a recent case in Nigeria, the Lagos State Fire Service Director Rasak Fadipe, on 31 March 2016 reported that more than 26 emergency rescue calls were received between 2015–2016, regarding people drowning in a domestic well or trapped in confined space. He explained that the rising cases of workers drowning is a serious concern to the government, and has therefore charged the public especially artisans, whose activities involve working in deep wells or confined space to put in place required safety precautions (Guardian.ng 2017). He also reported another incident that happened on the 25th March 2016 at Ojodu Berger area in Lagos Nigeria where two men were trapped underground inside a petroleum tank in a petrol filling station. One of the workers was working inside the tank and cried for help but collapsed immediately. The supervisor on duty went in immediately to rescue him and also became a victim. The two men were found dead when the fire service rescue team was called to the site (Guardian.ng 2017).

Smith et al. (2014) describes Atmospheric Hazards as toxic gases, vapors, fumes and either shortage of oxygen or excessive oxygen. A publication by WorkSafeBC (2012) categorizes these hazards as High, Moderate and Low hazards. Where the High Hazard Atmosphere is spaced were workers are exposed to the risk of death, acute illness, injury or condition that may impair the worker's ability to come out of the space without any aid in the case were respirators or ventilated system fails.

The Moderate hazardous atmosphere is where the air present in the space is unclean but is respirable and when respirators or ventilation fails, the worker will still be able to come out of space unaided. The Low hazard atmosphere is an atmosphere where testing and control measures have detected hazards have been put in place to clean up air at the pre-entry stage or were tested and certified air clean and respirable without any likely change during the work activity.

According to Smith (2017), the main danger involved in working in a confined space is that of an untested atmosphere that could either contain contaminants or may be oxygen deficient. The worker physiologically is unable to identify these dangers; hence an Atmospheric Monitor or a Gas Detector must be used to test the condition of the environment within the space. While, Taylor & Francis (2017) current study reveals that, Where the atmosphere has been identified as dangerous enough to cause any Health issues, ventilation of the atmosphere should be done immediately to eliminate the hazards present or control by respiratory protective equipment's and continuous monitoring of the atmosphere to certify it safe for work.

According to Smith et al. (2014) in their reviewed literature shows that Hazardous atmospheres in confined spaces may be noticeable when a source of air contamination or oxygen (O2) deficiency is recognized. Such is often the case in general industry settings, especially with work processes which create hazardous atmospheres that may be anticipated. Hazards present in active sewers are also well recognized; but the possibility that O2 deficiency or high airborne contaminant concentrations may exist in new construction sewers or storm drains has been repeatedly ignored with deadly results (Smith et al. 2014). Low O2 and high carbon dioxide (CO2) concentrations may exist in new construction manholes that have not yet been connected to an existing sewer or drain system, and these concentrations have been shown to vary over time. A recent incident is described where workers repeatedly entered such a confined space without incident, but subsequent entry resulted in a fatality and a near-miss for a co-worker rescuer. Additional cases are discussed, with an emphasis placed on elevated CO2 concentrations as a causative factor (Taylor and Francis 2017).

Quite a lot of atmospheric hazards exists in confined spaces in several industries such as chemical, construction, transportation, municipal and agricultural sectors (Burlet-Vienney et al. 2015). Of the numerous potential hazards present in such confined spaces; the ones that are of concern include atmospheric (such as poisoning, asphyxiation, explosion), biological, and physical (including mechanical, electrical, engulfment, falls, lighting, outside traffic) (Burlet-Vienney et al. 2015). The presence of Carbon monoxide in a confined space can cause chemical asphyxiation, and CO2 can cause simple asphyxiation and create physiological conditions which effects are breathing rate (Simpson et al. 2016).

The US National Institute for Occupational Safety and Health (NIOSH) defined values of 1200 ppm and 40,000 ppm respectively, as the Immediately Dangerous to Life or Health (IDLH) levels of Carbon monoxide and Carbon dioxide respectively; these values do not, however, consider the potential for oxygen deficiency, which would heighten the impact (Simpson et al. 2016). Meanwhile, the Workplace Exposure Limits (WELs), in the UK, for carbon monoxide and Carbon dioxide are given as 30 ppm and 5000 ppm respectively (Simpson et al. 2016). The HSE Approved Code of Practice (ACOP) to the Confined Space Regulations 1997, "states that there are substantial risks if the concentration of oxygen in the atmosphere varies significantly from normal (i.e.; 20.8%); and deficient oxygen concentrations (i.e., below 16%) and these can lead to unconsciousness and death" (Simpson et al. 2016).

This study is relevant to organizations carrying out confined space work activities as it is aimed at ensuring the safety of workers working within a confined space. It will help identify the gaps in management level of atmospheric hazards in confined space work with a view to reducing incidents and fatality rates, and thereby promote the safety of workers working within the space.

This work also aims to add to the body of knowledge and literature in a country where little is known about the subject because of the scarcity of data and records also to aid policymaking. This study focuses on the management of atmospheric hazards within a confined space in Nigeria. Physical hazards are often eliminated using appropriate controls where viable; however, leakage of atmospheric gases could occur at times, even after screening and certification of space to be fit for operation. Hence, the management of these hazards is essential for the safety of those working within the space. The purpose of this study is to improve the knowledge of workers, supervisors, and management working within a confined space in Nigeria using international best practices as a guide for improvement and control of atmospheric hazards.

The suggestion that this may be due to either lack of awareness of the atmospheric hazards involved with the confined workspace or negligence in the part of both the management and workers working within the confined space is a valid one; hence, to attain optimum safety in confined space work in Nigeria, maximum compliance with appropriate regulations and strict enforcement by necessary authorities needs to be ensured (Umeokafor et al. 2014).

2 Methodology

An extensive literature review was carried out using various sources including, academic journals and appropriate regulations & standards applicable to confined spaces work activities and management processes. A case study research was carried out to understudy the chosen organisation whose work activities are centered on confined space jobs. The case study is an exploratory case study that used prospective case method with the aim of gathering adequate information. In addition, a quantitative approach was used in collecting the data from the single case study, using a closed-ended questionnaire as an instrument for collection of data while coding with SPSS (20.0) software and the two-tailed test for analysis of the data. Results were after that obtained and presented for discussed.

3 Result/Findings

The study seeks out gaps that were identified while carrying out work activities in a confined workspace attempting to explore answers on why accidents still occur in confined space work despite measures and standards put in place to ensure the safety of the work environment. In the bid to answer this question, a field investigation was carried out using a company referred to here as company x, a case study from a chosen site located in the Niger-Delta region of Nigeria.

The Result reveals the findings from the chosen case study. The results are presented by means of empirical data collected through questionnaire and a participant observation, where the observer as a participant was identified and participated in the work activity to investigate the management of atmospheric hazards in confined space work and acquire a first-hand understanding of the level of safety practices implemented in the industry located in Nigeria.

Acknowledging that there are several elements in the confined space regulation 1997 outlined for a safe system of work, only the central element associated with this study was identified and used from the confined space regulation 1997 as a checklist for the observation carried out.

The author identified five key themes in this study that will aid in representing values associated with the research questions of - why accident still happen in confined spaces despite all safety measures put in place by regulatory bodies to ensure workers safety, and aid in achieving the study objectives. With reference to the confined space regulation 1997, these themes were selected from the elements given in pages 23–33 of the confined space regulations; and the study only used elements relating to the field of study. Data collected during observation and questionnaires used in the study are presented as follows.

4.1. The process of removing residues from the confined space was observed. An access hole was created into the tank, and the content was sucked into the mobile septic tank that was stationed near the vessel. All remaining residues, including the waste products, were extracted safely. The process was well monitored, a fire extinguisher was on standby in case of ignition or fire outbreak.

4.2. Recognizing that ventilation is highly essential in the control of atmospheric hazard as recommended by confined space regulation 1997, the ventilation procedure to eliminate hazards in the atmosphere or control them was observed. Ventilation of the atmosphere in the confined space was carried out before space was tested and declared safe for work. The enterer went into the space to clean it; there was still some left-over residue, the enterer had to remove them by moving the hose about the area where the residue needed to be extracted. At the point where the work was being carried out, there was no further ventilation. The six tanks were ventilated including the one that was detected to have carbon monoxide at 3 ppm, which was reventilated after evacuating the residue until it was safe to work in. The ventilation equipment was not properly placed and was very dirty.

4.3. Isolation procedure from gases, other flowing materials, and liquids within the confined workplace was observed. There were no flowing materials like particulate matter in the confined workspace but had liquid waste and residues from previous content and the risk of gas exposure although space was initially tested and certified safe, there was no procedure for isolating gases from workers in case there were hidden gases. The enterer and stand by personnel outside had no respiratory mask and standby respirators or breathing apparatus in case of emergency. Face shields were not worn to prevent splashes of liquid on the worker’s faces as they scrub liquid from the confined space. A worker who entered the confined workspace wore gas detectors that were expected to beep if there were gasses present in the atmosphere.

4.4. Atmospheric Testing: According to Smith (2017), the main danger involved in working within a confined space are that of an untested atmosphere that could either contain contaminants or may be oxygen deficient. Hence test was carried out to determine the condition of the atmosphere in the confined space. All six tanks were tested and their readings recorded until space was declared safe for operation. As the test was going on, the tester tested the top and bottom to determine the space condition, but the sensor rope could not get to the base accurately to monitor the bottom areas hence, the tester kept bending towards the space in other to get accurate readings. While the work was going on, the space was tested at intervals of 20 min.

Source: Researchers field work.

Picture 1. Showing tester is bending towards space to take readings.

It was also observed that the gas monitor brought for testing the space by (ANLW) supervisor was not functioning (Picture 1).

The effort to turn it on proved abortive, hence the gas monitor from (company x) was used to reaffirm the initial result obtained.

4 Presenting Results from the Closed – End Questionnaire Analysed

In an attempt to gain insight into the most common potential hazard encountered in the confined space. About 28.4% alleged that CO_2 and CO were the main hazards workers are being exposed to, followed by lack or excess of O_2 ranked second at 27%. 13.5% of the respondents said poisonous vapour dust is the main hazardous threat to working in confined spaces (Fig. 1).

Respondents view to potential hazards that are encountered in confined space, showed that 28.4% agreed that carbon monoxide (CO_2) and carbon oxide (CO) is the most common hazards encountered followed by Lack or excess Oxygen within space at 27%. This gives the employers and employees the awareness of the hazards they are most likely to be encountered and how to manage it. Although high dust concentration at 16.2, poisonous vapours dust at 13.5 and LEL flammable at 14.9 are of lower in percentage, this may be due to the nature of work or task being carried out here but can be higher in percentage on other job hence they are also classified as potential hazards that may have a to be identified with awareness of control measure to eliminate or reduce the hazards to its barest minimum (Fig. 2).

Subsequent to the result obtained, 36.5% of our respondents blame the reoccurrence of hazards and accidents on Inadequate Training of employees, which also aligns

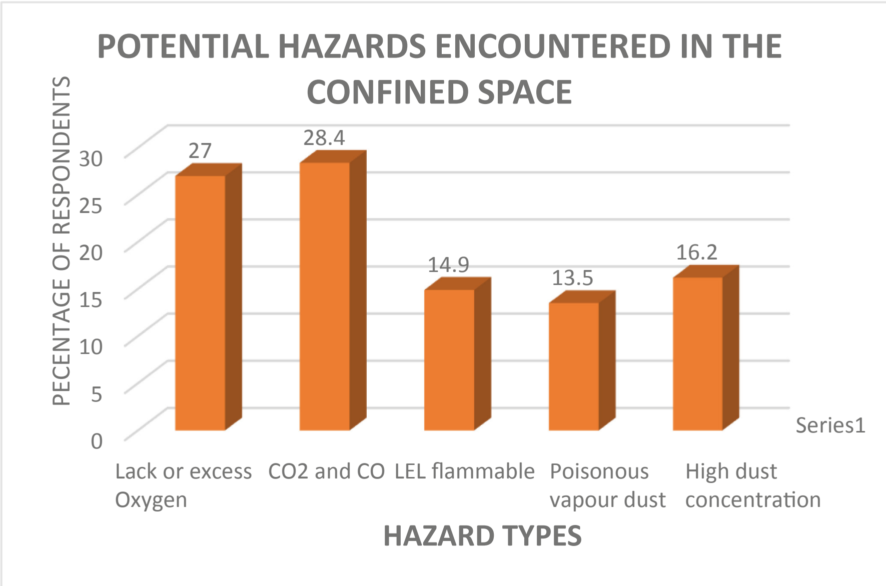

Fig. 1. Graph showing Potential Hazards encountered within confined space.

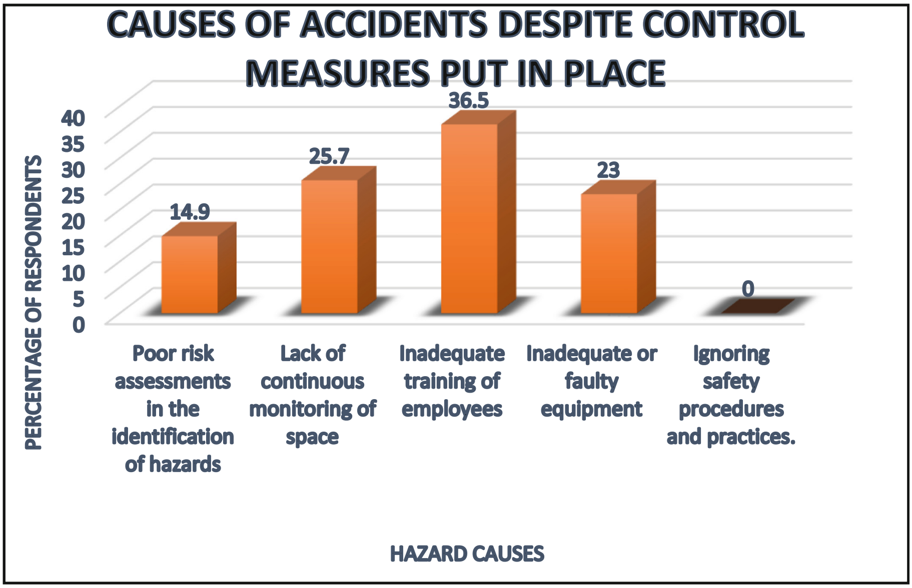

Fig. 2. Graph Showing Causes of Hazards despite control measures put in place.

with the researcher's view, as this is an integral part of employment following the Health and Safety at Work Act 1997. In confined space entry work, training is mandatory but re-trainings are most often not carried out regular and specific training to ensure competency on their various responsibilities are often not done but reliance on experience and skills for job progression, promotions and responsibilities are jobs often practiced rather than Training and retaining of employees.

Lack of continuous space monitoring at 25.7%. Inadequate or faulty equipment at 23% and Poor risk assessment in the identification of hazards were also factors calmed by respondents to be the contributing factors to reoccurring accidents within space despite measures put in place. While Ignoring Safe Procedure and Practice had 0%, contributing factors. In the researcher's view, it seems that employees do not want to take responsibility for their unsafe actions because they have the knowledge of its implication.

The researcher agrees with the aforementioned factors responsible. However, refereeing from the observation carried out during the task observed, a lot of unsafe acts and ignoring safe work procedures were observed. Hence, the researcher believes Ignoring; Safe Working Procedure should be accepted and added among the identified factors that are responsible for accidents within the workplace. The reason is that it is referred to as non-compliant to the safety procedures outlined in the confined space regulation 1997, which can be referred to as one of the major problems, why accident still happens irrespective of the safety measures put in place (Fig. 3).

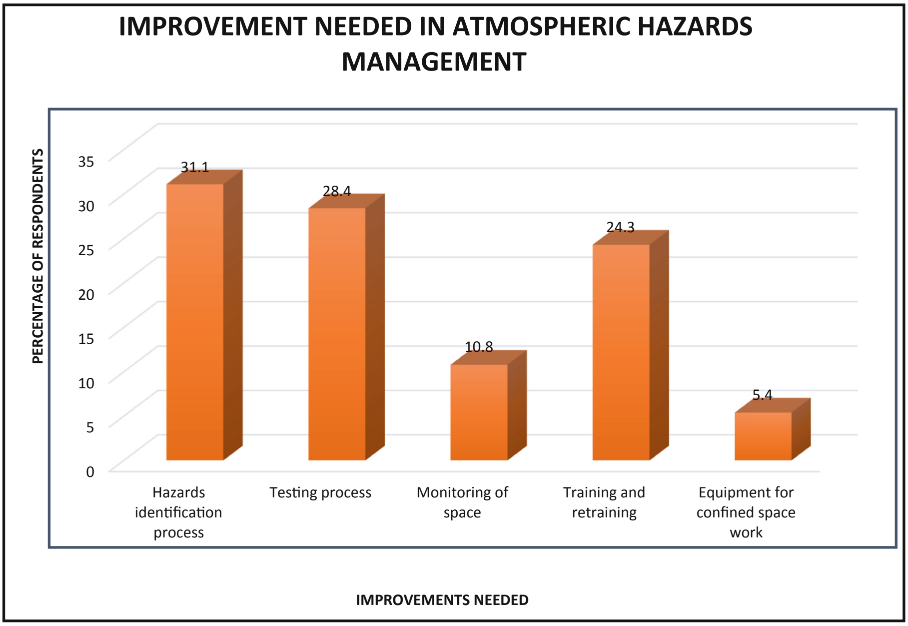

Fig. 3. Graph Showing Improvement needed in Atmospheric Hazards Management.

The above graph showed the level of improvement required from each theme in managing atmospheric hazards in confined space.

Having 32.1% respondents agrees to Hazard Identification Process, as the most section that needs to improve, and 28.4% of them are of the view that Testing process also needs improvement while 24.3% thinks Training, and Re-Training needs to be improved.

Monitoring of Space and Equipment for confined space are of both 10.8% and 5.4% respectively and are rated low but are also very important in ensuring safe work practice. Hence, the researcher thinks that attention should be a focus on the improvement of all elements especially the ones with the highest percentage in other to get each process safe for operation and sees each element as important in achieving a safe working procedure as recommended by confined space regulation 1997.

5 Recommendation

1. The tester should stand upright when testing and not place head downward into the space. While testing or re-testing intervals should be more, frequent and based on the risk assessment of the space, depth of testing the atmosphere.
2. A dedicated time and hygienic environment should be provided for the workers to have their lunch break, as eating within a contaminated environment may lead to ingestion of harmful substances, with serious health consequences.
3. The use of automated operation like Liquid Jet Spray Cannon, Pipe Cleaning & Inspecting Robot. Also, use of Electronic Nose for sensing tanks in confined space workings, for example, an M6 iBrid Gas detector, which can monitor between 1–6 gases and incorporates a full-colour LCD and 24 sensor options with in-built high-speed detectors with wide coverage able to detect gas within space (Figs. 4 and 5).

Fig. 4. MX6 iBrid Gas Detector by (predictive solution, 2017). MX6 gas detector it can detect one to six (1–6) Gas when monitoring.

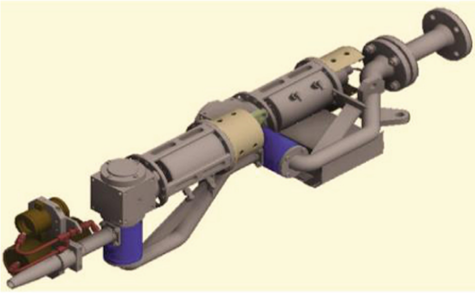

Fig. 5. Liquid Jet Spraying cannon (Botti et al. 2017a, b).

This could be used for cleaning confined spaces such as in chemical and crude oil tanks (Botti et al. 2017a, b) (Fig. 6).

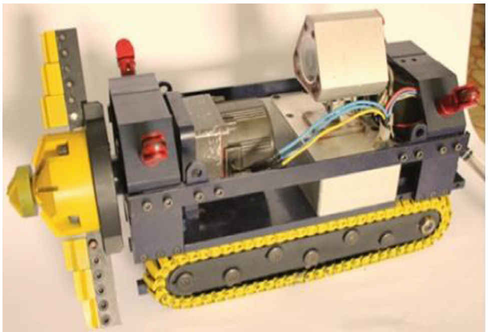

Fig. 6. Pipe cleaning and inspecting robot (Botti et al. 2017a, b).

4. Risk Assessment should be carried out by competent personnel, who will be able to consider the suitability of the task to be done, and the individuals assigned to carry out the task.
5. The use of suitable Resuscitation equipment, emergency and rescue plans should be provided and readily available on site before the commencement of any confined space work activity in line with Confine Space Regulation 5, 1997.
6. Provide a suitable plan for safeguarding rescuer in other to avoid rescuers being overcrowded by the same conditions of victims.
7. Fire Safety Measure suitable to control the type of Fire that may occur during the work activity depending on the nature work carried out within the space should be in place.
8. Regular Health Checks on employees are required in line with Health and Safety at Work Act 1974, section (2) subsection (1) which oblige employers to ensure the health, safety, and welfare of their employee as far as reasonably practicable.

9. The establishment of a regulatory body (in Nigeria) to oversee the compliance levels and safety practices of companies in the industry. This would require an act of Legislation that would bring to life a steering committee made up of players ranging from confined space-related industry, Certified Health and Safety professionals, coming together with definite ideas using the international best practice guidance in instituting an Act that will guide confined space work activity and also to institute a penal code system for defaulting companies.
10. It is worth mentioning however, that the lack of a binding national industry standard or the absence of a regulatory body, in developing country like Nigeria, to checkmate the activities of local companies may have led to the aforementioned issues, as opposed to their international counterparts who are adequately regulated by appropriate bodies in their respective countries.

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Safety and Human Factors at a Societal Level

Parent Awareness of Smartphone Use and Its Health Impact

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Abstract. Smartphones remain one of primary devices of choice for communication for many people. For children ages 10–12 this is especially true. These devices are used daily and for some multiple hours each day. As more applications are made available, it becomes increasingly difficult for children to minimize their screen time. This study aims to assess whether there are differences in what parents believe about smartphone use and what the child reported. Thirty-two children, ages 10–12, and one parent per child completed a questionnaire regarding smartphone use. Findings show parents are unaware of the total hours of use and the impact of smartphones on the health of children. Such information is important as screen time is not limited to home but is also increasingly expanding in the classroom. As well, the age of first time users continues to decrease.

Keywords: Musculoskeletal disorders · Age · Mobile phone · Children

1 Introduction

Over 50% of all homes and apartments in the United States have only a cell phone [1]. Though the shipment of phones were down in 2018, vendors shipped 355.2 million units during the third quarter of 2018 [2]. Where cell phones were once purchased for adult use, many children now expect to also have a cell phone. Many parents oblige and now purchase phones for children. Therefore, a high percentage of smartphone users are children; as greater than 75% of American children under eight had access to a smartphone or tablet, in 2013 [3]. The average age of children getting their own smartphone is ten [4, 5] and in 2017, 42% of children eight and under had their own tablet [6]. While the purchases of smartphones and tablets for children are well intentioned, there could be some negative consequences.

Brain scans of children who spend more than seven hours of their day viewing screens show a thinning of the cortex—the outer layer of neural tissue responsible for processing information from each of the five senses [7]. Other findings indicate that even more than two hours per day of screen time can be harmful [8]. Of interest, as well are the distraction and addiction of cell phones [9–13]. While these are important, other hazards such as smartphone radiation are overlooked [14–16]. Additionally, the physical demands of electronic games and portable or mobile devices, especially as they pertain to children also go unnoticed. As more applications are made available,

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 215–225, 2020.
https://doi.org/10.1007/978-3-030-20497-6_20

children have a hard time turning away from the small screens. The daily use for multiple hours each day put the developing musculoskeletal systems of young children at risk of developing musculoskeletal disorders.

This study aims to assess the thoughts, responses, and awareness of parents and adolescents about the use of smartphones and to determine if there is an effect on the musculoskeletal system of young children.

2 Methods

2.1 Experimental Design and Equipment

This research is part of a broader study on the use of mobile devices. Two questionnaires were designed by the researcher, one for the child participants and another for the parents or guardians. Both questionnaires were developed using the ©2017 Qualtrics LLC survey tool. Microsoft Excel version 15.31 was used to perform descriptive statistics. When parents did not use their own device, a 16 GB iPad Mini 4 was used for collection of data from the parent questionnaire.

2.2 Participants

Thirty-two children, ages 10–12 and one who was 13 by the time of the appointment, participated in the study. There were 17 males and 15 females, with a mean age and standard deviation (SD) of 11.3 years (±0.81). Mean height of the participants was 60.23 in (±3.7) and the mean weight was 103.4 lbs (±30.87). The mean grade was 6 (±1). 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. Twenty-four parents or guardians (85.7%), representing 28 children, completed the adult questionnaire. Three parents, representing four children, did not complete the survey. Both participants and the 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 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. Demographic data was collected from the participants and responses to the questionnaire were entered in Qualtrics by the researcher or assistants. The parent questionnaire was emailed prior to the participant's appointment. Parents or guardians completed their questionnaires via their own computer or cell phone or an iPad upon arrival to the lab.

3 Results

3.1 Reported Smartphone Use

Participants' responses to the questionnaire revealed 17 owned a smartphone, while 14 had access to a family member's phone and two had access to a friend's phone. Three participants had no access to a cell phone or smartphone. Of those who either owned or had access to a phone, 21 participants (72.4%) owned or used an Android phone, seven used an iOS phone, and one person used both. Responses to the questionnaire revealed the types of activities for which phones were used. Twenty-three (72%) used their phones to play games, 65.6% used their phones to make phone calls, and in each of three cases, 56.3% texted, searched the internet, and listened to music. Another 47% watched movies or TV programs on their phone and 34% use the phone while doing homework. Fewer used their phone for social media – Instagram and Snapchat (8 out of 32) 25%, read (19%), and navigation/GPS (9%). See Fig. 1.

When comparing the differences in how parents believe their children used their cell or smartphones and how children reported using smartphones, there were similarities and noticeable differences. Parents (83%) stated children used phones to play games. Eighty-three percent also believed their children used the phones to make phone calls. Seventy-five percent of parents believed phones were used to search the internet.

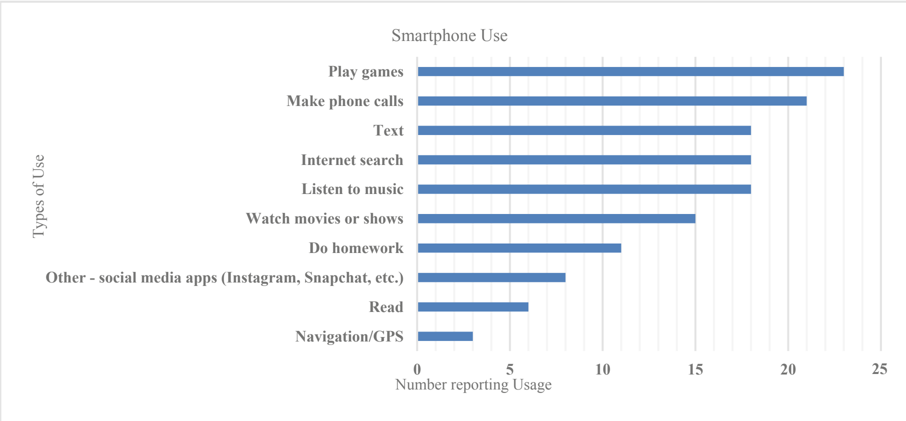

Fig. 1. Reported smartphone activities (n = 32)

Fifty-four percent of parents stated the phone was used for watching movies and television. While 50% of parents stated their children used the phone to read. Only 21% of parents stated the phone was used for homework. No parents reported the phone was used for navigation and 4% of reported the phone was used for social media – Instagram and Snapchat. No parents indicated phones were used for texting and listening to music. Figure 2 shows a comparison of parent and participant responses.

When participants were asked if they used an external device when using a phone, of the 29 participants with access to a phone, seven (24%) reported always or most always and 16 (55.5%) stated sometimes. Six (20.7%) reported they never used an external device (Fig. 3). Sixteen of the participants wore earbuds and seven wore head phones. The responses of the participants were confirmed by the parent responses. Parents were also asked about their personal use of external devices. Approximately 32% of parents reported they do not use an external device (earbuds, head phones, or Bluetooth). The remaining parents, 22.7% reported always or most always wearing an external device and 45.5% sometimes wore a device.

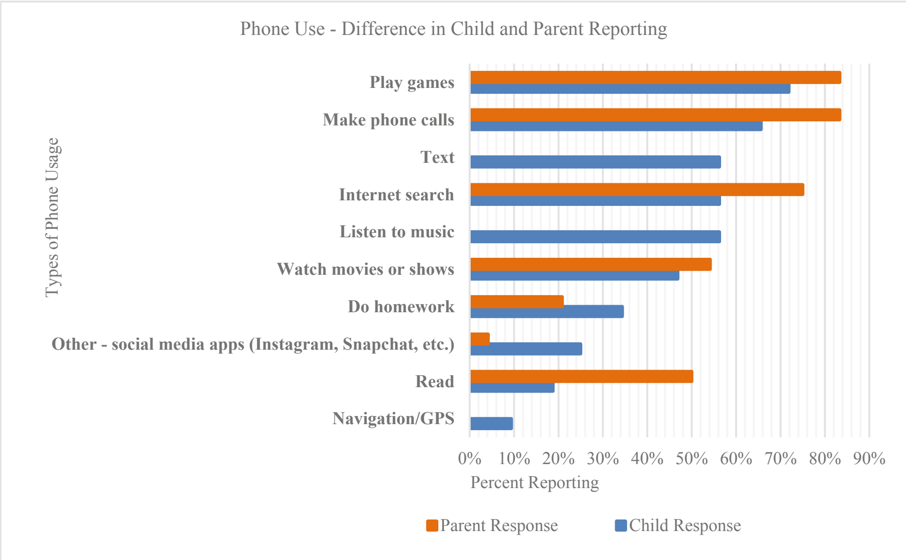

Fig. 2. Parent and child reporting of how phones are used

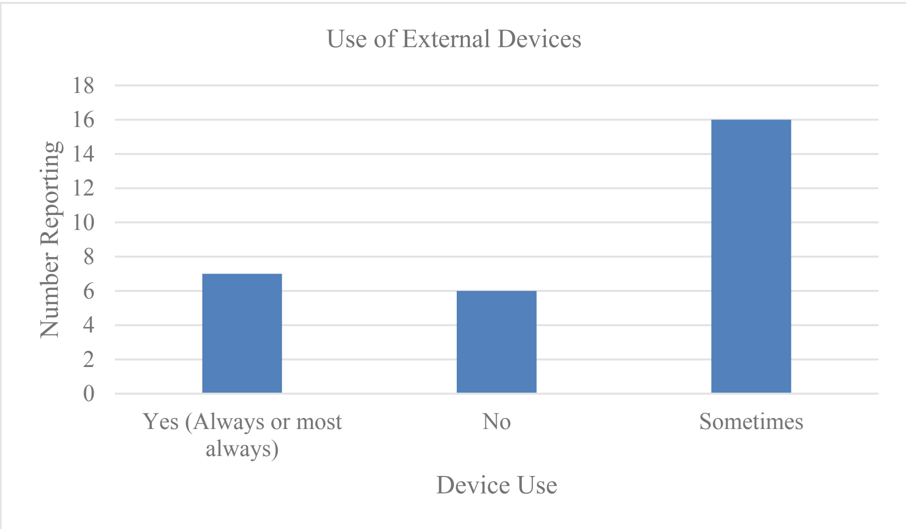

Fig. 3. Participant use of external devices when using or talking on phone (n = 29)

Participants in the study were asked how many hours per day they used a cell or smartphone; hours of usage ranged from <1 h (9 participants or 31%) to ≥ 8 h per day (2 participants). Of those who owned a phone or had access to a phone, 10 participants (34.5%) was ≥ 2 h but <4 h per day. Six (20.7%) of the children used a phone at least 1 h but <2 h per day and two at least 4 h but <8 h per day. Three did not have access to a phone. See Fig. 4.

The parental questionnaire asked parents if they placed restrictions on daily phone use. Thirteen (54.2%) indicated they did restrict daily phone use. The maximum hours per day was not requested or reported. However, parents were asked how many hours they believed their child used a phone. Of the parents who restricted phone use (Fig. 5), 61.5% revealed their children used the phone <2 h per day and 30.7% revealed ≥ 2 h but <4 h per day, with only one person (7.7%) indicating ≥ 4 but <8 h. For those who did not restrict daily phone use, 63.6% reported their children spent <2 h per day of phone use and another 9% reported ≥ 2 h but <4 h of use. The other 27.3% reported ≥ 4 h of use, with one those (9.1%) being ≥ 8 h per day.

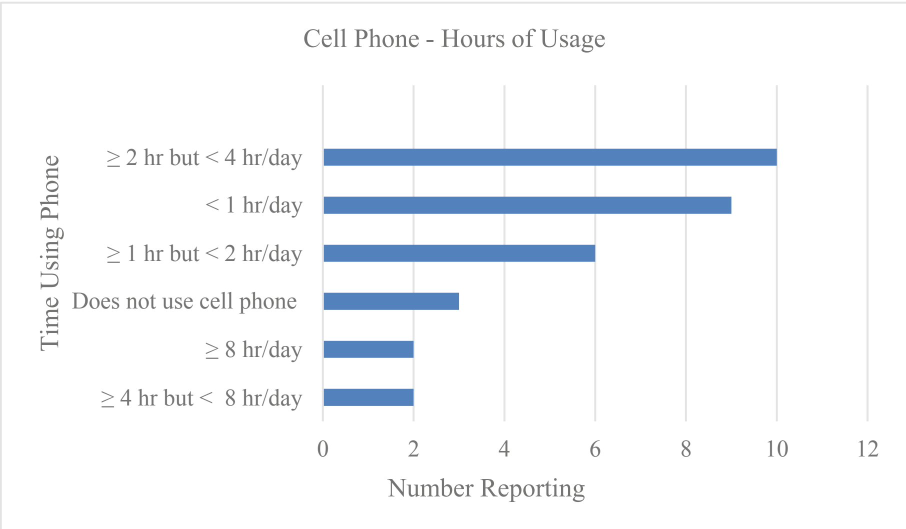

Fig. 4. Number of hours per day phones are used (n = 32)

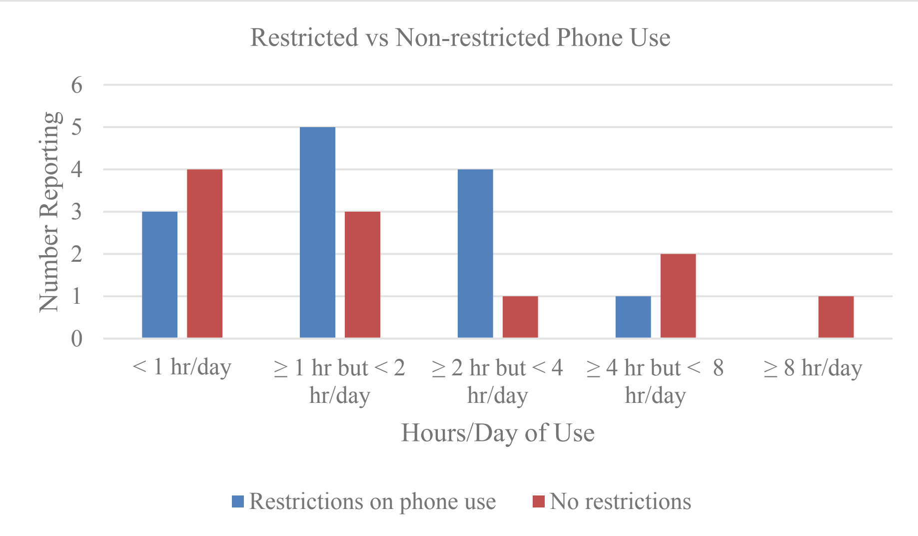

Fig. 5. Parental report of children's phone use per day

3.2 Effects of Smartphone Use

All parents were asked if their child complained of discomfort or pain when using or after using a cell phone. Twenty-two (91.6%) stated their child never complained of discomfort or pain. Only two stated their child reported feeling some discomfort or pain. See Fig. 6. When the two parents were asked what body area their child felt discomfort or pain, one replied the upper back and the other a headache. When choosing between frequency options – occasionally, often, or always – both stated occasionally. When rating the pain on a scale from 1(minimal) – 5 (severe), each indicated a discomfort level of 2.

When the participants were asked if they felt any discomfort or pain when using or after using a cell phone, the response was 13 (44.8%) yes and 16 (55.2%) no; shown in Fig. 6. When those who responded yes were asked to identify the regions of discomfort, eight body areas were identified – neck, wrist/hands, upper back, lower back, head/headache, shoulders, forearms, and elbows. Nine (69%) reported discomfort or pain in the neck, the most often reported area. See Fig. 7. Four reported discomfort in the wrist/hands and four discomfort or pain in the upper back. Discomfort was reported by three in lower back, and two reported in each the head/headache and shoulders. Forearms and elbows each had one person reporting discomfort. Twenty (77%) of the discomfort areas were categorized as occasional, four as often, and two as always. Seventy-seven percent of the time the discomfort level was rated a three or below (i.e. moderate to minimal). However, one participant rated his/her headache a five (severe). Two people rated the neck discomfort a level four (more than moderate but not quite severe). The wrist/hands and upper back each received one rating of four. See Table 1.

4 Discussion

The number of child smartphone owners continues to increase, as 17 of the participants in this study owned their own phone; 29 had daily access to a phone. A majority, 72.4%, had access to an Android phone. The top two choices of smartphone use by the participants was playing games (72%) and making phone calls (65.6%). Parents (83%) also listed those activities as the top choices for their children's cell phone use. Far more parents were of the impression that their child's phone was used to search the internet and for reading than was reported by the children, (75% vs. 56%) and (50% vs. 19%), respectively. Using a phone to watch movies was seen by parents as the fourth choice of phone activity. However, watching movies and television (47%) was below the reported activity of texting and listening to music; both reported as an activity which 18 (56.3%) of the participants engaged. No parent listed texting and listening to music as a smartphone activity for their child. Only one parent identified social media – Instagram and/or Snapchat – yet, 25% of the children identified social networking as a phone activity. In the comments from parents some expressed the desire to control the content and limit screen time for their children. Products have been invented that will give parents control over their children's devices [17, 18]. It is not known if any parents in this study owned such devices.

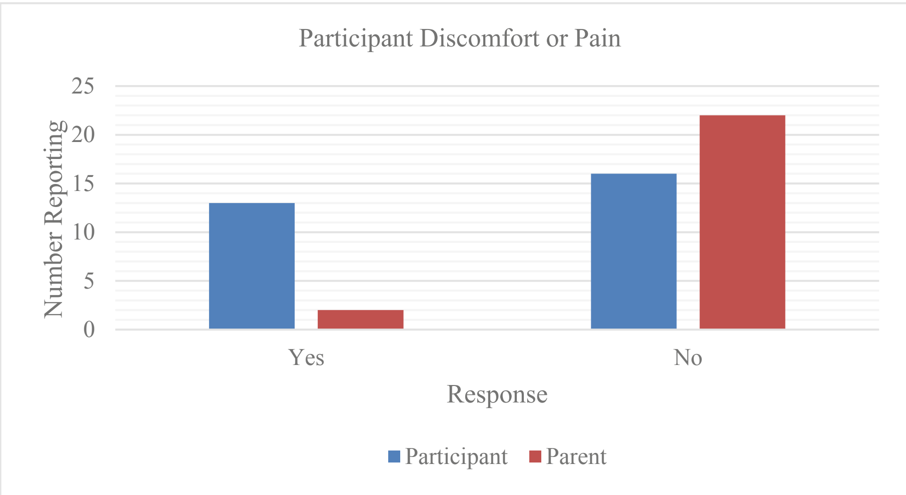

Fig. 6. Discomfort or pain attributed to phone use (n_1 = 29 participants, n_2 = 24 parents)

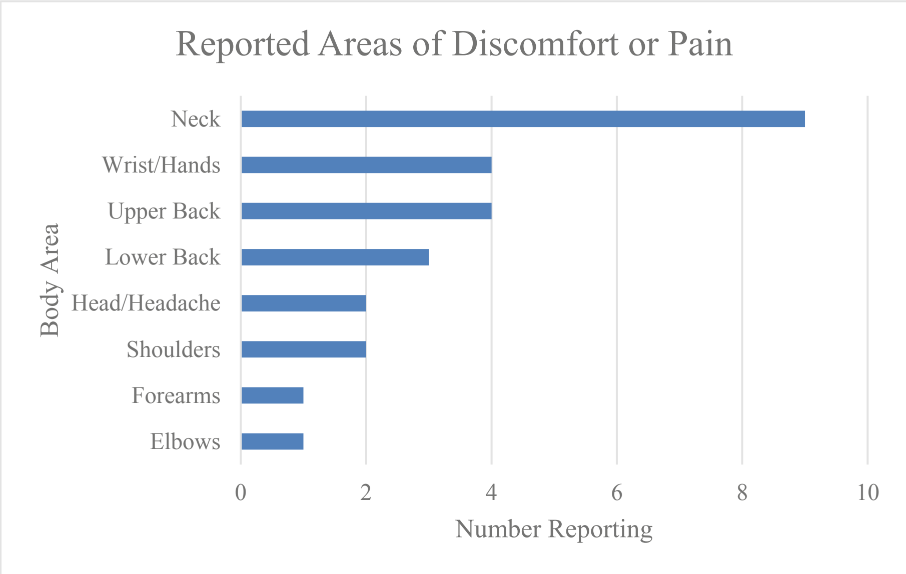

Fig. 7. Participant reported areas of discomfort and pain, (n = 13)

Table 1. Participant reported body areas of discomfort with frequency and level of severity

	Occasionally					Often					Always				
	Level of severity														
Body Region	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Elbows		1													
Forearms		1													
Shoulders		1	1												
Head/Headache			1		1										
Lower Back		3													
Upper Back	1		2						1						
Wrist/Hands		2	1											1	
Neck	1		3	1		1		2						1	
Total per severity	2	8	7	1	1	1		2	1					2	
Total per frequency of occurrence	20					4					2				

The study also revealed that not enough children were wearing an external device such as earbuds or head phones when using their phones. Parents confirmed the report given by participants. More than two out of three, 76%, wore an external device sometimes or not at all. The behavior of the children in this case mirrors the behavior of the parents. Only 22.5% wore an external ear device when using a cell phone. Children must be encouraged to wear an external hearing device when listening or talking on a smartphone as there are still concerns about the effects radiation from cell phones [14–16].

Thirteen of the parents who returned the questionnaire indicated they had phone use restrictions on their children. However, the exact time limits are not known. When comparing the data graphically, there was a noticeable skew to the right for parents who indicated restrictions in cell phone use, with 92% of the children's phone use being less than four hours per day. For those with no restrictions, there was a wider distribution of parent reported child phone use, ranging from <1 to ≥ 8 h. An additional point of interest regarding phone use was the difference in hours reported by participants and their parents. Approximately 63% of the parents reported their children used their phones <2 h per day. Only 41.4% of the participants stated this as true. Approximately 35% of the participants indicated they used their phones ≥ 2 but <4 h per day. Only 20.8% of the parents stated their children used their phones for this many hours per day.

A final point of interest was the number of areas of discomfort or pain, 26, stated by the participants; given their age. The 26 symptoms were reported by 13 of the 29 children who used a phone daily. All but two parents were unaware of any discomfort or pain. Nine participants reported discomfort or pain in the neck. This finding is verified by other cervical research with smartphones [19, 20]. While 77% of the children described their symptoms as minimal to moderate, another 23% described higher levels of discomfort and likely pain in the neck, wrist/hands, upper back and head. All participants and their parents indicated they were not at the time of the study nor had they been within the past 12 months under a doctor's care. This leads one to conclude that all symptoms were untreated and the children were at risk for developing one or more musculoskeletal disorders. Therefore, to decrease the risk of developing musculoskeletal disorders, the following ergonomic interventions would be 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 [21].
8. Minimize screen time.

5 Conclusion

The full effects of cell phones on the bodies of adolescents is not fully known, as no previous generation has been exposed to the technology at such a young age. These devices have been recognized as entertainment devices by both the parents and participants of this study. This entertainment appears to come with a price, as the 45% of the children in this study who used a smartphone reported discomfort and pain are at an increased risk of developing a musculoskeletal disorder. Not only do parents have to be vigilant in monitoring the programs on their children's phones, but they must ask questions about their health and make an effort to reduce the screen time.

This study was limited by the sample size of 32 participants. A follow up study of a much larger sample size with children in the same age group could help validate the findings. Additional questions could be asked about mobile device restriction limitations and any differences in the number of hours per day phones are used. Furthermore, the data should be analyzed to determine if there is a correlation between the discomfort symptoms and the number of hours per day phones are used. Child parent data can also be matched to compare responses.

Acknowledgments. This study was partially funded by the Bradley University Heuser Award and the Office of Sponsored Programs Special Emphasis Award.

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Development of Working at Height Management System Based on Legislation in Malaysia

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Abstract. Construction industry is one of the top dangerous industry in Malaysia because there is a high risk of accident occurrence. Amongst of the accidents happen in the construction site, the workers are likely to exposed to the accidents such as fall from height. Although Malaysian government has taken a lot of effort to reduce the number of accidents by legislations, but the construction-related accidents are still at high number especially working at height. Due to concern of this problem, a working at height management system is developed to help the construction especially small medium enterprise contractors to help them to manage the compliance of legal requirements FMA 1976 and OSHA 1994. The legal requirement taken from these two legislations for working at height activity only. The validity of the working at height management system, real case study was used by using a building construction project and interview was conducted with a safety practitioner to validate the working at height legal requirements. As a result, the working at height legal requirements and the prototype were used by a safety practitioner from construction industry to cross-check for compliance and to validate them as well. The developed working at height management system is proven systematically help the end users to store their documentations and check compliance with working at height legal requirements from their inspection checklists. The implementation of this system can contribute to the awareness of complying with the regulations and enhance their safety and health practices.

Keywords: Human factors · Safety management · Working at height

1 Introduction

Construction industry plays a big role in the development process of a country. The successful development would contribute towards the economic growth and generating additional demands for construction activities. Thus it also has a significant impact on the health and safety of workers which makes the construction industry is both economically and socially important [1]. In Malaysia, the construction industry also plays an important role in generating job opportunity and economic growth by improving the quality of nation lives [2]. However, this growing industry is one of the top dangerous industry due to the increasing in number of accidents and fatalities. Based on the

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 226–235, 2020.
https://doi.org/10.1007/978-3-030-20497-6_21

industrial fatality report by Department of Occupational Safety and Health (DOSH) Malaysia, from year 2016 to 2017, most of the fatality cases were related to working at height [3]. Until now, the trend is still the same. Due to that, it can be said any activity related to working at height is could contribute to a significant problem at construction site in Malaysia [4].

Although the workplace regulations in occupational safety and health (OSH) are comprehensively developed and efforts taken by DOSH Malaysia can be considered as excellent, unfortunately the working at height and the average incidence rate for fatalities in Malaysian construction industries are remaining at the top three highest compared to other industries such as mining, transportation and public services industry [5]. Five major factors that are contributing to construction fall accidents or working at height are due to unsafe tools and equipment, human (workers) factors, unsafe acts, unsafe conditions or environment and lack of management commitment to safety [6]. In fact, Samuel, Hamid and Misnan [4] also revealed that from the statistic of construction accidents, the first ranked accidents are as a result of non-compliance with safe work procedure. Due to the nature of work in every construction industry is well thought-out as continuously changing working environment which make it difficult to be managed, proper management procedure is warrant [7]. However, to ensure the effectiveness of the implemented procedure or safety management system is requiring a lot of efforts. Dealing with the system of work that involve with the complexity of human, it is important to ensure the implementing system is easy to follow at the same time can remove the hassle to comply with the legal requirements [8]. Therefore, it is very important to generate a management system namely Working at Height Management System (WAHMS) that can assist company to manage their working at height activities, at the same time can serve as a self-checking assistance on the compliance requirements and reduce human related errors.

2 Methodology

2.1 Deming Cycle: Plan – Do – Act – Check

In this study, the Deming Cycle is adopted to develop the WAHMS. The cycle starts from, Plan, Do, Check and Act. This cycle provides a structure for iterative testing of changes to improve quality of systems. The method is widely accepted and being applied in numerous related publications such as in Azmi and Aziz [9] and Hooi et al. [10]. The details implementation of Deming Cycle in WAHMS development is presented in Fig. 1.

Plan: Brainstorming the issues and elements related to working at height activity	**Do:** Development of WAHLR using Microsoft Words and then transform of the validated requirement into Microsoft Access
Act: Do improvement and corrective action based on input gathered in the validation process	**Check**: validate the developed prototype of WAHMS with experienced OSH practitioner and case study in construction site

Fig. 1. The Deming Cycle

2.2 Development of Working at Height Elements from Malaysia Legislation

Law of Malaysia for OSH, Factories and Machinery Act (FMA), 1967 [11] and Occupational Safety and Health Act (OSHA), 1994 [12] were analysed to identify the requirements for working at height activity. The extracted information was inserted in a table form in Microsoft Word software and named as Working at Height Legal Requirement (WAHLR). After complete information were gathered, Working at Height Management System (WAHMS) is developed by using Microsoft Access software. WAHLR and WAHMS system were validated by experienced OSH practitioner. Semi – structured interview and a case study in a construction project were performed to validate the WAHLR and WAHMS. Figure 2 shows the process how WAHMS was developed.

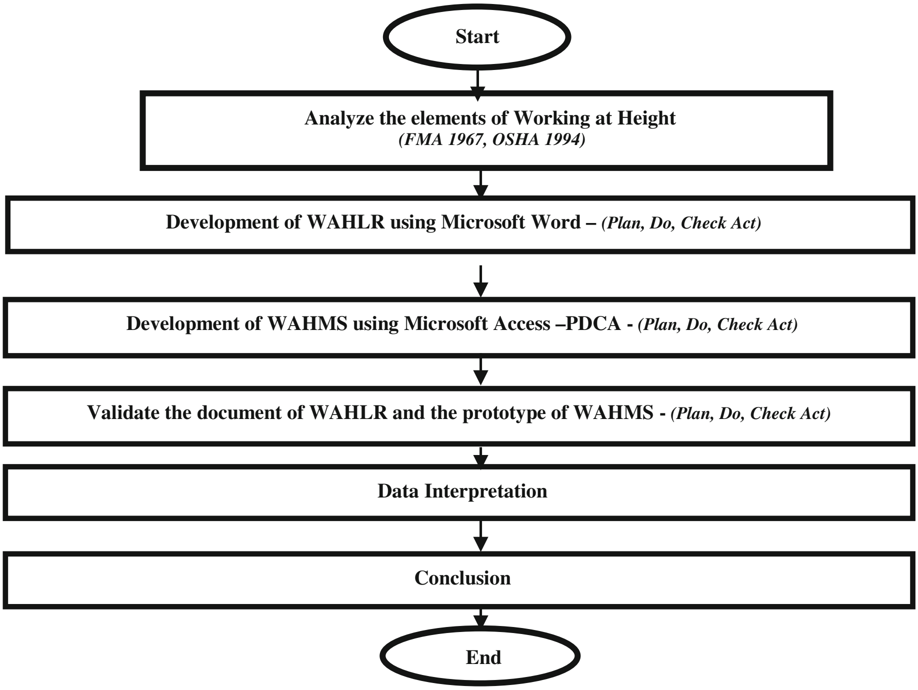

Fig. 2. The methodology of developing WAHMS

3 Results and Discussions

3.1 Identification and Validation of WAHLR Based on the Related Legislations

WAHMS was developed based on the extraction from various related legislations from OSHA 1994 and FMA 1967. In order to ensure the selected requirements under different legislations are valid, the identified WAHLR (before proceeding to develop the system) were validated through interviews with an experienced OSH practitioner from a construction industry. The finalized WAHLR consists of two groups. The first group is the requirements under OSHA 1994 that cover the requirements under Section 15, 16, 17, 20, 24, 32 and 33. This group also consist of 1 regulation (Regulation of Notification of Accident, Dangerous Occurrence, Poisoning and Occupational Diseases, NADOOPOD 2004). Meanwhile, for the second group is the requirements under FMA 1967. Two regulations that have many requirements for working at height activity; (1) Safety, Health and Welfare Regulation 1970 and (2) Building, Operations and Works of Engineering Construction Regulation 1986. Table 1 shows the validated of summarized WAHRL.

Table 1. WAHLR based on OSH Legislation in Malaysia

Law	No	Parts	Details of the requirement
Occupational Safety and Health Act, 1994 (OSHA 1994)	5 sections	Section 15	General duties of employers to their employees
		Section 16	Duty to formulate safety and health policy
		Section 17	General duties of employers to persons other than their employees
		Section 20	General duties of manufacturers
		Section 24	General duties of employees at work
		Section 32,33	Notification of incident
	1 regulation	NADOOPOD 2004	Incident Investigation
Factories and Machinery Act 1967 (FMA 1967)	2 regulations	Safety, Health and Welfare Regulations, 1970	Floors
			Fence the openings
			Catwalk, runway or gangway
			Working at Height
			General provision
		BOWEC (Safety) Regulation 1986	Concrete Work
			Cleaning, repairing and maintenance of roof
			Catch platform
			Chutes, Safety Belts and Nets
			Runways and Ramps
			Ladders and Step-Ladders
			Scaffolds
WAHMS	After endorsement of WAHLR, forms for WAHMS were developed using Microsoft Access 3 forms (OSH Policy ; HIRARC ;ERT); 1 form (Record of Incident Report);1 form (Working at Height Compliance attributes)		

NADOOPOD =Notification of Accident, Dangerous Occurrence, Poisoning and Occupational Disease
BOWEC = Building Operations and Works of Engineering Construction
WAHLR= Working at Height Legal Requirement
WAHMS = Working at Height Management System
OSH = Occupational safety and health
HIRARC = Hazard Recognition, Risk Assessment and Risk Control
ERP = Emergency Response Plan

3.2 Development of the WAHMS Using Microsoft Access

After the validation of the WAHLR, the finalized requirement was built into the system using Microsoft Access. The system interface was built into a format of forms so that the user can cross – check the compliance of OSH for working at height easily. The forms consist of 5 forms including form for working at height compliance, OSH policy, hazard identification, risk assessment and risk control (HIRARC), emergency response team (ERT), and record of incident report (see Table 1). Figure 3 shows the interface of WAHMS.

Fig. 3. Interface of WAHMS for 5 developed main forms

Major element for WAHMS is the form for managing of working at height compliance. Figure 4 shows the interface of Compliance Check form that consist of (1) roof works, (2) catch platform, (3) chutes, safety belts, nets, (4) runways, ramps, (5) ladders stepladders and (6) scaffolds.

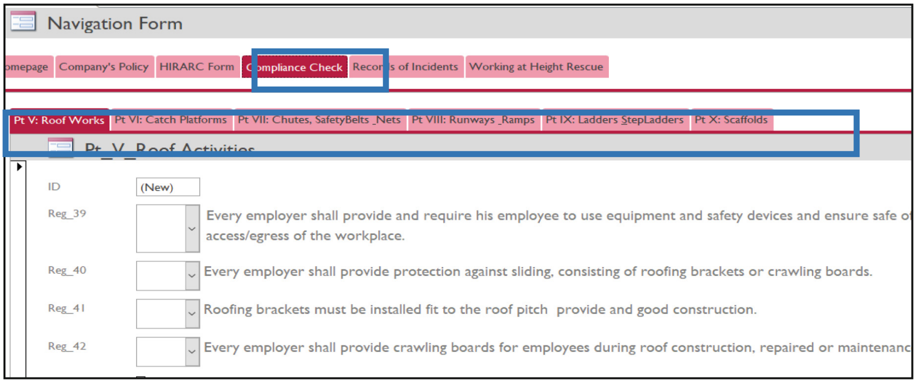

Fig. 4. Interface of compliance check for WAHMS

One of the forms under Compliance Check menu is to assess the legal requirements for working activity related to scaffold. Figure 5 shows one of the interfaces for scaffold related requirement and how the incompliance item is identified easily. The identification of the incompliance may serve as a lagging indicator for construction industry to prioritize their efforts and resources. In the form, there is a space to enable further information to be written.

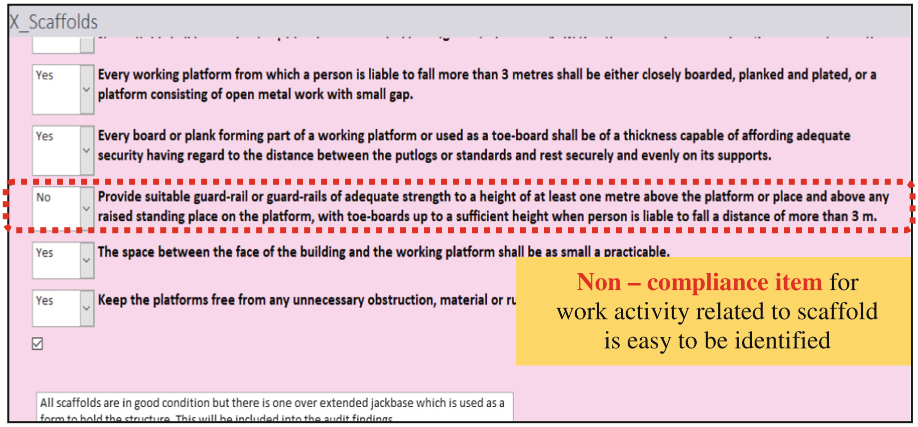

Fig. 5. The interface of scaffold related requirements and the incompliance item

3.3 Customisation of OSH Policy into WAHMS

The OSH policy shall state the organization's method and commitment to ensure safety and health regarding to working at height. Top management shall define, endorse and document its policy for working at height according to the size of the organization and capabilities [12]. The OSH Policy of the company need to be communicated to all workers. It need be revised from time to time. Using WAHMS, OSH policy can be customised into the system. So, the revision processes of OSH policy are also easy to be tracked. Figure 6 shows the modified OSH policy of visited construction industry. This system was proved the company is complying with Section 16 in OSHA 1994.

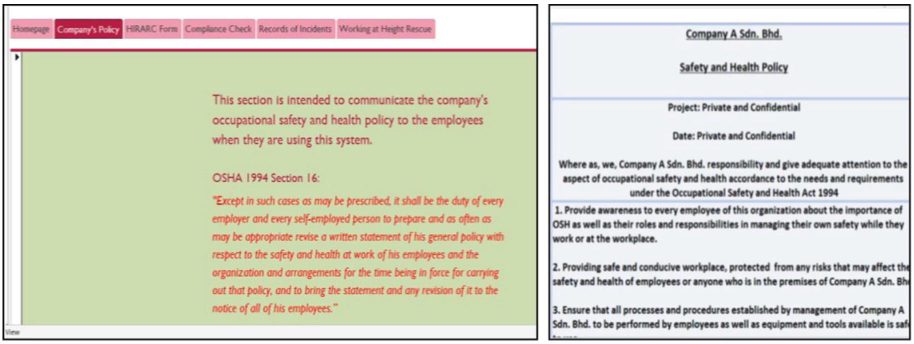

Fig. 6. The interface of OSH Policy in WAHMS

3.4 Customisation of HIRARC in WAHMS

A study was conducted by Bakri et al. [5] on the effectiveness of the implementation of Hazard Identification, Risk Assessment and Risk Control (HIRARC). The result showed that HIRARC is effective in identifying all potential hazards, assessing the risks of hazards, making adequate risk control and accident preventive measures. Another study found the organizations that have carried out risk assessment, had experienced numerous positive changes in their working practice as the hazards were recognized and necessary corrective action was put in place [13]. Therefore, an additional feature of storing the record of HIRARC related information is added into this compliance check system to help construction company to comply with Section 15 under OSHA 1994 [12] and improve their work practices. Simple HIRARC calculator also provided in the WAHMS. HIRARC report can be generated using the WAHMS system and the risk classification with three different colours indicating the risk level of Low (Green), Medium (Yellow) and High (Red) also can be performed as shown in the Fig. 7.

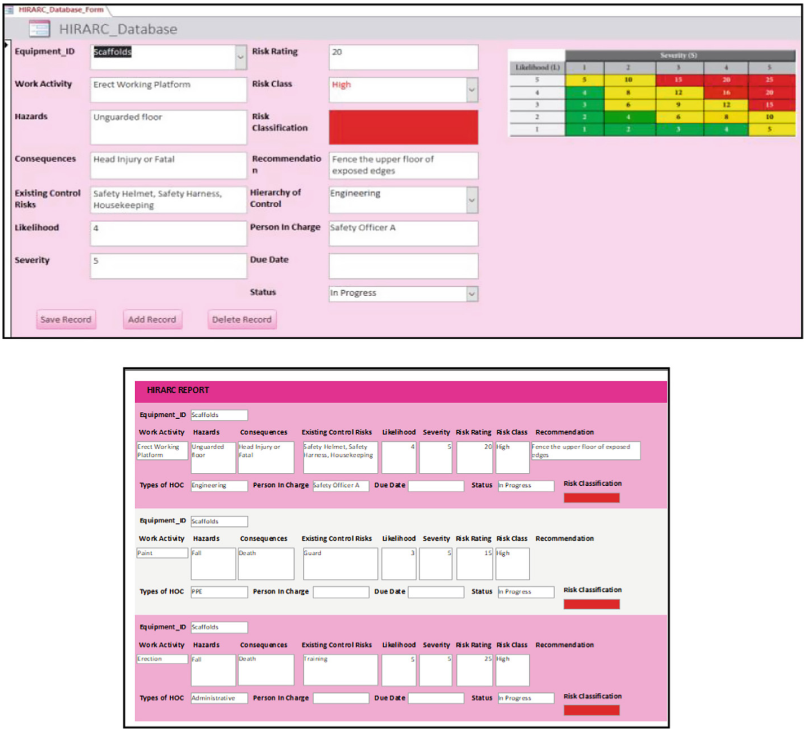

Fig. 7. The interface of HIRARC in WAHMS

3.5 Customisation of the Emergency Response Team in WAHMS

There is a requirement to every construction company to have emergency response team [12]. Due to that, document related to the emergency response team (ERT) of the company was customised into WAHMS as shown in the Fig. 8. During the site visit for conducting a case study, the company's ERT document was found pasted on the pillar of the building construction project and the noticeboard of the office building. In this

WAHMS the document is custom – made into the system. The original document also can be saved in the system using the "Insert Attachment feature" (see Fig. 8). This feature may help user to access to the file quickly if needed.

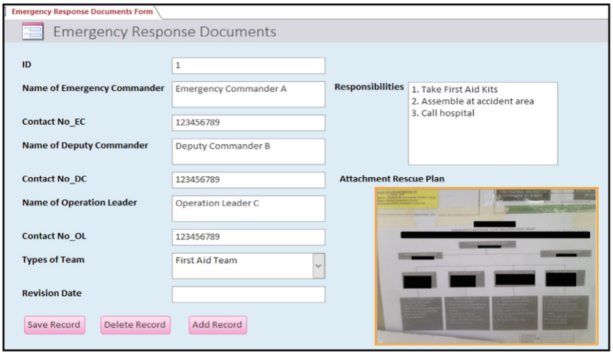

Fig. 8. The interface of emergency response form

3.6 Customisation of the Accident Reporting in WAHMS

Any accidents or incidents related to falls from height must be investigated to determine any underlying causes and implement the corrective or preventive actions for reoccurrence. The accident reporting flow chart of the company can be customised into the WAHMS as shown in the Fig. 9 and this proven that the company complies with Section 32(1) and NADOOPOD 1996 regulation under OSHA 1994 [12]. This customisation of setting up the accident reporting work flow may guide the workers on how to respond if there is an accident. It also can be the source of reference in the future.

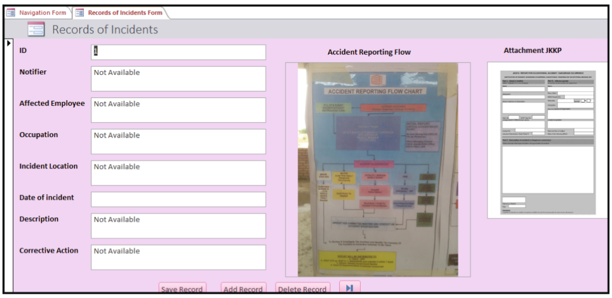

Fig. 9. The interface of reporting the incidents form

3.7 Feedback Based on the Validation Process of WAHMS

After completing the validation process for both WAHLR and WAHMS, the OSH practitioner stated that this system will be helpful for company that have working at height activity. WAHMS can store the documents into and print it out when needed. WAHMS able to help the user to self-check of compliance with the regulations. This system also provides a medium in helping user to keep in track with the data and reports at the same time. The idea of integrating safety into digital technology information would also enhance the safety value towards construction safety management. WAHMS would be able to help the contractor or other relevant parties of the building construction project to fulfil their duties on taking care of their employees' safety and health. Furthermore, their safety performance can be enhanced by increasing of compliance towards the regulations of OSH in Malaysia.

4 Conclusion

The development of WAHMS would provide an innovative safety management approach in construction projects and leaving the current practices of Malaysia construction industry that tedious with a lot of documentation. The idea of integrating safety into digital technology information would also enhance the safety value towards construction safety management. WAHMS is proven to be able to provide legislation related to working at height which will aid the contractor or other relevant parties of the building construction project to fulfil their duties on taking care their employees safety and health. Furthermore, their safety performance can be enhanced by increase the compliance towards the regulations of working at height. WAHMS is capable to help in doing self-check on the regulation, to store OSH documents such as OSH policy, HIRARC, ERT incidents records and generate the reports by simply pushing the 'Print' button. The authors believe this system will encourage the construction industry to comply with legislations and the objectives of this study are well achieved. In the future, it is recommended for developing a more advance system by using mobile application such as Android operating software (OS) or iOS development. It would be easier for OSH practitioner to conduct site inspection using a mobile phone which is quick and timely.

Acknowledgement. The authors would like to thank Universiti Malaysia Pahang (www.ump.edu.my) and Ministry of Education Malaysia for funding the project through grant (RDU181001 – Knowledge Transfer Program in Construction Industry) and making this study feasible.

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Safety Methods for Assessment and Evaluation

How Workplaces Actually Carry Out OSH-Related Risk Assessment and Management

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Abstract. The practices of risk management (RM) process are generally considered foundational and are commonly used for occupational health and safety (OSH) management at workplaces. However, some estimates propose that recent efforts to improve OSH have not had the desired effects. Previous research has recognized problems in the OSH-related RM in the workplace. A better understanding of how workplaces realize OSH-related RM is needed. This study examines the implementation of OSH-related RM based on the case studies of four companies. Interviews (n = 46) with personnel involved in RM, document analyses related to RM, and observations of risk assessments were carried out. The results show that the RM guidelines are mainly strictly applied. Nevertheless, the practices are also tailored. The elements of risk assessment are emphasized. More importance should be given to the risk treatment, monitoring, and review elements of the RM process to understand whether the planned controls are effective and efficient.

Keywords: Hazard recognition · Risk assessment · Risk management · Workplace safety · Current practices

1 Introduction

The European occupational safety and health (OSH) legislation, as well as practitioners, generally consider the practices of OSH risk management (RM) process to be the foundation and starting point for OSH management at workplaces. The European Directive 89/391/EEC [1] states that employers shall take the measures necessary for the safety and health protection of workers, including prevention of occupational risks. The risks should be avoided and, if not possible, evaluated and combated at their source. According to the Finnish Occupational Safety and Health Act [2], the employer shall, considering the nature of the work and activities, systematically and adequately investigate and identify the hazards and factors that can cause harm by the work, work premises, work environment, and working conditions, and if they cannot be eliminated, assess their consequences to the employees' safety and health.

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 239–251, 2020.
https://doi.org/10.1007/978-3-030-20497-6_22

RM practices are commonly used in workplaces. According to the survey by the European Agency for Safety and Health, 76% of companies in the EU-28 carry out risk assessments regularly. In addition, risk assessments are considered useful in OSH management [3]. A vast number of tools have been developed to help workplaces carry out OSH-related RM successfully. For example, in Finland, the *Risk Assessment in Workplaces Workbook* [4], published by the Ministry of Social Affairs and Health, is widely applied. The MSAH Workbook is intended to be used by companies' own personnel and provides a framework and guidelines for carrying out OSH-related RM, giving space for practical, company-specific implementation. In addition, the MSAH Workbook includes checklists that can be used to identify and analyze different risks.

However, several estimates propose that occupational accident prevention and OSH promotion have not had the desired effects in Finland or Europe. In Finland, for example, the overall trend in occupational accidents has remained more or less at the same level in the last decades despite the fluctuations related to economic and production factors [5–7]. In addition, regardless of some improvement in the working conditions, occupational risk factors have not uniformly reduced across worker categories, companies, sectors, and occupational accident types in Europe [8].

Moreover, previous research has recognized these problems and the need for further improvement in the practical implementation of OSH-related RM in the workplace. For example, difficulties in identifying hazards [9–11] and defining the magnitude of risks [e.g., 12] and the utilization of results [e.g., 13] have been reported. In addition, the RM efficiency is rarely estimated, or RM practices improved [13, 14]. Moreover, insufficient hazard identification and risk management has been mentioned as common causes of occupational accidents [e.g., 15, 16]. Nevertheless, it is not very well-known what companies' RM practices are like. To ensure the success of OSH-related RM, a better understanding of how workplaces actually carry out these practices is needed.

This paper examines the practical implementation of OSH-related RM based on the case studies of four Finnish companies. First, we use the MSAH Workbook as a framework to describe current company practices. Then, we compare the practices to find out whether they actually cover the fundamental elements of RM. In this study, we use the term RM to refer to the whole RM process as described in ISO 31000 standard [17]. The focus of the study is on risk assessment and treatment practices. The practices related to monitoring and review, recording and reporting, and communication and consultation are discussed where appropriate.

2 Materials and Methods

The objectives of this research are descriptive in nature. In addition, the phenomena of interest, the current implication of RM practices at companies, is contextual with limited researcher control over events. Hence, a qualitative approach [18] and case study strategy [19] was employed in this research. Four companies from the manufacturing industry and facility services participated in the study. In accordance with the qualitative approach, the data for this study were collected from the companies through interviews with personnel involved in RM, the analysis of documents related to RM, and observations of risk assessments (see summary in Table 1). Various materials were

Table 1. Summary of the participating companies and data.

Companies (n = 4)	Industry	Product manufacturing (3 companies), facility services (1 company)
	Revenue *	Between 70 and 420 million €
	Personnel *	Between 250 and 7,908 persons
Interviews (n = 46)	No. of interviews and interviewees	Company A (16, 19), Company B (10, 10), Company C (10, 16), Company D (10, 11)
	Role of the interviewees	Manager or supervisor (15), OHS representative (15), employee (12), HS or HR manager or specialist (9), occupational health service representative (5),
Document analysis	Type of documents	Records of RM forms and results (from all companies), process description and instructions (3 companies), training material (1 company)
Observations (n = 4)	No. of observations	Four observations at three different companies
	Type of risk assessment	The assessments were carried out due to changes in the work environment (new machine, product, work task)
	Duration	Assessments lasted from one and a half to six hours

* Revenue and number of the subjects' employees examined in the research project at the time of the research.

collected to obtain information on both the RM guidelines and practical implementation. The data were collected between spring 2017 and 2018.

The primary selection criteria for the case companies was a concrete need and desire to develop their RM practices. In addition, there were both similarities and differences in the RM practices between the companies. The companies include large-scale enterprises that operate in the manufacturing industry and facility services. All the companies were part of a larger group (three international corporations and one Finnish). However, the focus of the study was on their Finnish operations, and on the manufacturing companies, in one factory or production facility.

The interviews were directed at personnel who plan the RM guidelines and who carry out and participate in the companies' RM. The interviewees included OSH managers and experts, representatives of occupational health services, managers and supervisors, and employees from all the cooperation companies. Following a semistructured protocol, the interviews concentrated on the companies' current RM guidelines and practices. Nevertheless, some other themes, out of the scope of this study, were also included. The interviews were mainly individual face-to-face interviews. There were several group and phone interviews as well. Persons planning RM guidelines were mainly interviewed in groups. Interviews varied in length between 23 and 86 min for persons who participate in the RM and between 88 and 165 min for persons who plan the RM. The interviews were recorded and transcribed.

The interview data was supplemented with an analysis of RM-related documents and observations of risk assessments. The document analysis included various documents, such as instructions, training material, risk assessment databases, and the results of risk assessments. The researchers familiarized themselves with the documents, and notes were taken. A total of four observations were carried out on-site in the production facilities of three cooperation companies. The researchers followed the assessments but did not participate in them. Notes were taken according to a preprepared form.

Each dataset was first categorized separately according to the categories derived from the MSAH Workbook and the data. Then, a synthesis of the data in each category was compiled. The MSAH Workbook was used as a framework because the RM processes of the cooperation companies were largely based on it. The categorization was not completely identical with the MSAH Workbook, but similar categories suitable for the data were used. However, the main elements of the RM process were sought for inclusion into the categorization.

3 Results

3.1 Background Information of Companies' RM Processes and Tools

All the companies had defined some kind of process for RM and related practices. Three had also documented it. In one company, there were several different risk assessments for different purposes (e.g., general OSH risks at the company level and hazard identification carried out by employees before beginning the work). In other companies, one main RM process was used.

In all the companies, the process and tools used for RM were based on the MSAH Workbook. One of the companies quite precisely followed the MSAH Workbook. Two of the companies had included only company-specific relevant items and used more concise checklists in the hazard identification than in the MSAH Workbook. One company had supplemented the checklists with additional items, tailored the risk assessment process by supplementing it with the Hazscan method and the Fine and Kinney method [20].

None of the companies used external service providers' systems, or applications for RM. The results of the risk assessment were documented either on paper forms or directly in Excel or Word documents. The companies had other systems in which some of the risk assessment results were documented, but these systems could not be used in the actual risk assessment.

The following consecutive phases recurred in the companies' RM processes: planning and preparation, risk assessment including a selection of risk controls, and follow-up and feedback. The MSAH Workbook guidelines are summarized according to this categorization in the appendix. A summary of the MSAH Workbook guidelines and their comparison with the companies' practices according to this categorization is presented in the appendix. The companies' current practices are described in more detail as follows.

3.2 Planning and Preparation

Assessment Group. In all the companies, at least the industrial safety officer, the health and safety representative, the supervisor, and one employee of the assessment target participated in the assessment. In some of the companies, other managers, safety experts, and employees' health and safety representatives participated as well.

The participation of occupational healthcare varied between companies. Often, a representative of occupational healthcare and other experts were asked to join if needed. Employees' participation was usually organized so that employees working at the assessment target at the time of the assessment took part in it. The employees participated in the part of the assessment carried out on-site. Otherwise, the assessment group remained the same throughout the assessment. In some of the companies, a survey was used to more widely collect employee opinions about hazards and risk before the assessment.

The leader of the assessment and their role was not explicitly defined in the companies. Nevertheless, in practice, the leader was the safety expert or industrial safety officer and/or health and safety representative. The leader usually also documented the results of the assessment. In three of the companies, some responsibilities related to risk assessment were defined and documented, but not all, although practices existed. In one company, certain roles existed, but they were not documented.

In practice, carrying out the risk assessment was highly managed by some of the safety personnel. Although hazards, risks, and controls were discussed in the group, the group leader made the final conclusions and discussions and documented the results. The supervisors were usually responsible for implementing the controls, though this depended on the control. Nevertheless, it was the safety personnel who usually actively followed that the controls were effective.

Moreover, there seemed to be a contradiction between safety personnel and supervisors regarding the roles related to RM. The safety personnel wished a more active role from the supervisors in RM. However, overall supervisors and other than safety personnel were not very well aware of the RM responsibilities and related practices. Moreover, supervisors wished for more support from safety personnel in RM. Particularly, reminding of practices and responsibilities and help in selecting risk controls was hoped for.

Training. The general practice in the companies was that supervisors were introduced to risk assessments at the same time they first took part in it. Only one company had a training specifically focused on risk assessment directed at supervisors. In all the companies, safety issues were included in the supervisors' training, although often very superficially. However, there was a variation between companies and trainings as to whether the trainings were compulsory and whether the supervisors had participated in them. The safety experts had received a great deal of safety training. Employees were informed about safety-related issues particularly in their occupational instruction and orienteering. However, practices related to RM were not included, and some of the employees hoped they would be.

Initial Data. Before the actual assessment, the companies had either an official or a brief unofficial preparation meeting. The official meeting was held on a different day then the assessment and the unofficial meeting at the beginning of the assessment. In the preparation meeting, background information related to the risk assessment, including the initial data, were looked through, or it was discussed whether the initial data existed or was needed. The companies mainly used former risk assessment results, occupational accidents, safety observations, chemical information, noise and lightning measurements, ergonomic assessments, and questionnaires directed to employees as the initial data. Nevertheless, there were differences between assessments in how systematically these data were used.

3.3 Risk Assessment

Hazard Identification. The practices related to hazard identification were mainly well defined and realized as defined in the companies. In addition, mostly similar routines were applied in different companies. Like in the MSAH Workbook, hazard identification was carried out by using checklists, walking around in the assessment target, interviewing employees, and taking notes. Relevant work assignments were discussed to some extent. In some of the assessments, actual work was also observed, but this was not a general practice. In some of the assessments, hazards were identified on-site, and, in the rest of the assessments, they were initially identified in a meeting room and then supplemented on-site. Hazard locations, conditions and the workers exposed to them were addressed in the discussions related to hazard identification, although practices related to these issues were not separately defined. Other issues, such as previously realized hazards were discussed to some extent as needed. The focus was on normal situations, and exceptional situations were not actively paid attention to.

Magnitude of Risks. Two of the companies defined the magnitudes of risks. In one company, risks were analyzed in some of the assessments. One company no longer determined the magnitudes, although, in former assessments, they were defined. In the risk assessment observations, it was discovered that factors similar to those used in analyzing risks were discussed to some extent even in those assessments that did not define the magnitudes.

When the magnitude of risks was determined, objectivity and an estimate reflecting the current situation was strived for. The factors affecting the severity and probability of consequences were discussed to some extent in the group, though not systematically in the case of every risk. In the end, it was the group leader who made the decision about the magnitude. No particular practices were defined for these issues. In addition, it was mentioned that correctly defining the magnitude of risks is difficult.

Consequences and their probability were used to define the magnitudes. In two companies, a matrix from the MSAH Workbook or a similar matrix with more categories was used. In one company, the risk was defined as a product of consequence, probability, and time of exposure, each with ten different categories. It was not clear whether the consequences were defined before the probability. There were no clear instructions for this in the documents. The practices and awareness of this issue varied in the interviews and observations. The consequences were not systematically recorded, although some of the hazard descriptions contained consequence details as well. Companies did not define several different consequences because it was seen as too complicated. Outside the recommendations in the MSAH Workbook, the existing risk controls are, to some extent, considered. Moreover, the different consequence and probability categories had been literally described before the assessments.

Significance of Risks. In three companies, practices related to determining the significance of risks were defined and applied. In one company, the procedure for defining the significance of risks was not determined. In this company, the practice was based on free discussion for which risks controls were planned. No particular development needs in defining the significance of risks were mentioned.

In the companies with a procedure for the significance, the magnitude of risk was used to define whether risk controls were required. However, in one of these companies, risk controls were defined to all identified hazards regardless of the magnitude of the risk. Additionally, in two of these companies, the magnitude of risk established the basis for scheduling the risk controls as well. In one of these companies, it was not explicitly defined how the schedule for the risk controls should be determined. In this company, there were also other risk assessment practices, and whether there were practices related to the significance of risk and what they were like varied considerably.

Selection of Risk Controls. No particular protocol or practices were defined for the selection of risk controls in any of the companies or assessments. Nevertheless, risk controls were selected and implemented in all of them. The selection was based on free discussion, in which several different viewpoints like the MSAH guidelines emerged, depending on the risk in question. For example, compliance, personnel satisfaction, impact on risk magnitude, and resources required were discussed. The primary selection criteria were, however, the following: the control is efficient in the target in question (e.g., which hoisting aid is suitable for the target), and the implementation of the control in practice is possible. The company's predefined policy (e.g., concerning personal protective equipment) could also have an impact on decisions. The companies did not mention particular development needs with regards to the practices related to the selection and implementation of risk controls. However, it was mentioned that, for some risks, it is difficult to find solutions (e.g., risks due to close quarters).

3.4 Follow-Up and Feedback

Utilization of Results. The instructions related to the utilization of risk assessment results were rather scarce and imprecise and varied between companies. Nevertheless, as required in the MSAH Workbook, all companies had practices related to giving feedback on the assessment results. The assessment results were sent by e-mail to the assessment group. The supervisor of the assessment target presented the results in a meeting for the employees. Nevertheless, there were variations between supervisors in how and how well this practice took place. Sometimes, supervisors were too busy to do this or did not remember it was their duty. Sometimes, the supervisor was unsure of how to present the results. The results of the assessment were stored so that they were available for the whole company personnel, for example, on the intranet. It turned out, however, that not everyone was aware of this, and it was difficult to find the results.

Otherwise, the results were mainly utilized in implementing and monitoring risk controls. Variedly, the results were used similarly to the MSAH recommendations, for example, in meetings, training, audits, surveys of the workplace, planning further assessments and measurements, safety discussions with employees, work instructions, occupational instruction, and orienteering. However, these utilization purposes were mainly unspecified in the processes and instructions related to RM, and they were not actively considered as part of RM. Moreover, the companies believed the results could be more widely utilized.

Updating Risk Assessment. The companies had accurately defined when risk assessments should be updated and reassessments were carried out, although sometimes with a delay. Like the MSAH Workbook, in three of the companies, risk assessment was updated both regularly and as required if changes occurred in the work or work environment. In one company, risk assessment was updated only on an ad hoc basis. Risk assessments were updated, for example, when new chemicals or machines were taken into use. In addition to the reasons for ad hoc assessments mentioned in the MSAH Workbook, the companies updated their risk assessments if accidents, safety observations, projects, or surveys of the workplace required.

All companies followed that planned risk controls are effective and kept a record of them. Primarily safety specialists followed the realization of controls, although this was defined as the supervisors' duties as well. Companies' RM documents contained a place where the person responsible for the control in question signed for the realized controls. However, in practice, there was often a delay, or people did not remember to sign for the controls, even when they were realized. Therefore, the record was not up to date, and it was not accurately known which controls were effective. The companies did not currently have a system that would automatically remind of the realization and recording of controls, and that was desired. New controls were introduced if the former ones turned out to be inefficient or inappropriate. Nevertheless, the companies did not have a systematic process for following the efficiency of controls, nor was this information available in the RM documents.

Two of the companies also analyzed the magnitude of remaining risks. One company analyzed them in some of the assessments, and one did not analyze them. However, this information was not actively used. Moreover, possible new risks due to risk controls were not actively identified, or this was not visible to researchers. The companies did not mention any development needs with regard to new risks arising from controls.

4 Discussion

In all companies, the RM process included at least practices related to the use of preliminary data, hazard identification, the selection and implementation of risk controls, the utilization of results to some extent, and the follow-up of the effectiveness of the planned risk controls. In addition, all companies updated their risk assessments. Training related to RM practices was not organized in all companies, nor was the magnitude and significance of risks determined in all companies and assessments. Some of the practices were quite similar between the companies, e.g., issues and practices related to the assessment group, hazard identification, selection of risk controls, and utilization of results were more or less similar. However, differences between companies were identified particularly in the training related to RM and the use of initial data. There were also some differences in how the magnitude and significance of risks were determined and when risk assessments were updated.

Differences also occurred in how well the companies had defined different practices and how effectively they were used. Compared to the MSAH Workbook (see the appendix), the companies had defined accurately practices related to assessment group, training, initial data, significance of risks, utilization of results, and updating risk assessment. Practices related to hazard identification and magnitude of risks were partly well defined and partly not defined. In addition, the process related to the selection of risk controls was not defined. Therefore, it could be assumed there were problems and the need for development with regard to these practices. However, in practice, almost all the categories considered in this research were realized, at least to some extent. Hence, it can be concluded that the companies follow the MSAH guidelines quite well. Nevertheless, the practices were not realized as well as they should have been.

Further development needs were identified during the research principally related to the roles and responsibilities of the assessment group, utilization of results, and updating the assessment. The roles and responsibilities of the assessment group could be better defined and communicated. The results of the assessment could be utilized more widely and effectively for different purposes. A good dissemination of the results to the employees of the assessment target should be ensured. Moreover, the efficiency of risk controls should be followed better, and risk assessments and related documents could be more up to date.

It should be noted, though, that this study did not cover all the MSAH Workbook guidelines or the activities of the companies' RM practices. For example, the research was able to gather only limited knowledge related to the implementation of controls. Some of the companies' practices exceed the recommendations of the MSAH Workbook, for example, due to the application of standards. As an example, the current risk controls are considered in risk magnitude, although they are not mentioned in the MSAH Workbook. However, these issues are not highlighted in this research because of the focus on the MSAH guidelines.

During the research, it was noticed that the MSAH Workbook contains more detailed guidelines concerning some of the RM areas than others. For example, detailed advice is provided concerning hazard identification and the definition of risk magnitude and significance, whereas less advice is available concerning the implementation of controls and the utilization of results. Since, the companies seem to follow the MSAH guidelines quite well, it could be useful to give more instructions concerning the areas less well defined or in use at these companies. It is noteworthy, that the MSAH Workbook is based on BS 8800 [21], which no longer is in force.

The results show that the companies' practical implementation of RM is mainly based on the MSAH Workbook, and they generally apply it in a strict manner. Nevertheless, the companies also tailor their practices; therefore, some differences are observed between the MSAH guidelines and the companies' practical implementation of the guidelines. Finally, we conclude that the MSAH Workbook and the companies' practices emphasize the elements of risk assessment in the RM process. On the other hand, significantly less attention was paid to the implementation of risk controls, particularly to the monitoring and review elements of the RM process. In the future, more emphasis should be given to these elements to understand whether the planned risk controls are effective and efficient.

Acknowledgments. The authors would like to sincerely thank the Finnish Work Environment Fund for the funding of this study as well as this study's cooperation companies for their contribution.

Appendix: Comparison of the MSAH Workbook Guidelines with Companies' RM Practices

Category	MSAH Workbook guidelines	Companies' practices		
		A*	B*	C*
Assessment group	Group work including different personnel groups (decision-makers, experts, employees) is recommended. Everyone does not have to participate in the whole assessment. A good group size is from 3 to 5 persons	+	+	–
	A leader should be selected for the assessment group	~	+	+
	Employee participation is important, particularly in hazards identification. At least one employee representative and several employees should be involved in the assessment. Surveys can be used	+	+	+
	Specialists should be consulted concerning risks requiring expertise (e.g., occupational healthcare) in assessment, e.g., psychosocial and chemical issues	+	+	–
	The leader of the group is responsible for gathering the assessment group, obtaining required methods and materials, defining training needs, and organizing training	+	+	–
	The group responsibilities include planning and organizing the assessment, agreeing on responsibilities, guiding and assisting personnel, and making conclusions on results	~	~	+
Training	Training is not required, but the assessment group should be familiar with the general principles of risk assessment and effects of hazards. Group exercises can be used in training	~	~	+
Initial data	The existing data can be used in the assessment, e.g. - survey of the workplace - industrial safety inspections - chemical registers and operational safety bulletins - occupational accident statistics - safety observations	+	~	–
Hazard identification	Should be executed by - using a checklist or different analysis methods - finding out relevant work assignments - going around the assessment target on-site - interviewing employees - observing work assignments - making notes	+	+	–

(*continued*)

(*continued*)

Category	MSAH Workbook guidelines	Companies' practices		
		A*	B*	C*
	Hazards, their causes, locations, conditions consequences, and workers exposed (also external) should be examined.	–	~	–
	Previously realized, possible hazards, stress factors, and employees' personal abilities (e.g., disabled workers) should be considered (both in normal and exceptional situations)	–	~	–
Magnitude of risks	Magnitude should reflect the assessment situation and be as objective as possible, formed together with the assessment group, formed without under- or overestimation	–	+	+
	The magnitude of risk is analyzed by determining consequences and their probability	+	+	–
	Several factors affect the severity of consequences and their probability (e.g., the reversibility of consequences and the duration of the harmful event)	–	~	–
	Consequences are defined before the probability	~	~	–
	The consequences should be recorded	–	~	–
	If necessary, the magnitude of risk is defined separately for different consequences	–	–	–
	Several methods and ways can be used in analyzing risk. MSAH presents a matrix based on BS8800 as an example	+	+	–
Significance of risks	The objective is to eliminate or reduce all risks. However, risk criteria and boundaries should be considered to decide which risks need treatment and in which order. The MSAH Workbook lists examples of means that can be used in determining the significance, e.g., the magnitude of risk, narrative descriptions of the urgency of risk controls, risk profile compilations, interdependence of risks	~	~	–
Selection of risk controls	The following risk treatment options should be considered in selecting and implementing risk controls: avoiding the risk, removing the risk source, replacing the risk source with something less hazardous, implementing controls with a broad range of effect before those with a small range, using the latest technology and solutions available	–	~	–
	Alternative risk controls should be considered, e.g., according to the efficiency (e.g., compliance, cost-efficiency, impact on risk magnitude) and ease of implementation	–	~	–

(*continued*)

(*continued*)

Category	MSAH Workbook guidelines	Companies' practices		
		A*	B*	C*
Utilization of results	Feedback should be given to those involved in the assessment and whole personnel either on the level of workstation, department, or whole company	+	~	+
	Results can be utilized, e.g., in the work design and instructions, guidance, and orientation of employees, the planning of the activities of OSH and occupational healthcare, and further assessments or measurements	~	~	+
Updating risk assessment	Assessment should be maintained and updated regularly. Reassessments are needed when there are changes in the work or work environment (e.g., organization rearrangements, changes in the extent and nature of activities)	+	+	~
	Effectiveness and efficiency of planned risk controls should be followed	~	~	+
	A record of realized risk controls should be kept	+	~	+
	The magnitude of remaining risks should be assessed	+	~	+
	New risks due to effective risk controls should be identified and analyzed	–	–	–

A: Similar practices defined in all or most companies; B: Practices in use; C: Development need mentioned (+ Yes; ~ To some extent; - No)

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A Study on Exposure of Workers to the Risks Arising from Physical Agents in the Olive Sector in Andalusia (South Spain)

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Abstract. It is well established that workers being exposed to physical agents, such as vibration, noise and temperature can cause them different pathologies, such as musculoskeletal disorders, vascular and neurological problems, hearing loss, etc.

In this regard, there are many productive sectors in which workers are exposed to such physical agents, among them is the olive sector, mainly during the process of hand harvest of olives. In Spain, the number of workers employed in this sector is quite high, since one third of all the olive oil world production is generated there and particularly the region of Andalusia (South Spain) is the world's leading producer of olive oil. This paper presents the first phases of a study on the characterization of the physical agents to which the olive harvest Andalusian workers are exposed. In this study the exposure during the process of olive harvesting by hand-held machinery is analyzed.

Keywords: Physical agents · Vibration · Noise · Workers · Olive sector

1 Introduction

Exposure physical agents at work. i.e., vibration, noise and temperature, cause different pathologies in workers: musculoskeletal disorders, vascular problems and neurological disorders, hearing loss, etc. [1, 2]. These disorders reduces the quality of life of workers, both during his working life as in their retirement. In addition to the social cost, it poses a high economic cost for states and for entrepreneurs [3].

It is well known that high levels of noise cause health problems on workers [4]. According to the Sixth European survey on working conditions [5], 19% of workers in EU are exposed to such as high noise levels that they have to raise their voice to speak for more than a quarter of the workday. Noise exposure is also associated with other diseases, mainly cardiovascular problems, growing stress and an increasing risk of

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 252–264, 2020.
https://doi.org/10.1007/978-3-030-20497-6_23

accidents in several labour sectors. For example, Corrêa [6] Concludes that occupational noise-induced hearing loss and arterial hypertension among city bus drivers.

In addition, Punnett and Wegman state that exposure to vibrations is one of the ergonomic characteristics of the job that represents a risk factor with regard to work-related Musculoskeletal disorders (MSD) [7]. 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 [8].

Agriculture has been rapidly mechanizing throughout history, on the one hand, to facilitate the work and enhance the effectiveness, and on the other to reduce production times and costs [9]. Technology makes possible a sustainable mechanization in the sector [10] but at the same time, it makes workers to be exposed to different physical agents in many productive sectors [11]. Among these sectors is the olive sector and, particularly, the process of manual collection of olives.

In Spain the number of workers in this sector is high, since it generates a third of total world production of olive oil, 1.2 million tons a year [12]. Andalusia is the producing region par excellence of olive oil in the world, with an estimated production of 0.9 million tons[1].

The tasks that require the cultivation of the olive groves range from the planting of trees, the treatments with insecticides and fertilizers to planting, harvesting, transport to the storage silos and work in oil mills. In all processes there are different health risks, many of them associated with the machinery used [13–15].

This study focuses on the phase of fruit harvesting, where in addition to the noise and vibrations, workers are exposed to changing climatic conditions. Mechanically harvesting olive trees with vibrators increases the production of olives and facilitates the fruit detachment, increasing olive collecting rates, so increasing overall performance [16]. This makes the use of different vibratory machines has become widespread in recent years. These machines produce noise and vibration, and depending on the type of machine, they can cause whole body vibration (WBV) or hand-arm vibration (HAV).

There is a wide range of machinery, including many types or brands that cause the fall of the fruit easily. But it supposes a risk of high level of vibrations in the worker, which it demonstrates not only in dose levels [17], but also in high levels of crest factor [18], similar to those of the hand tools used in industry.

It should be noted that workers do not always show the same perception of the vibration effects. In this regard, in [19] a study performed with 11 different models of mechanical olive harvesters and a survey of 75 workers who use regularly these machinery, reports that a 66% perceived themselves symptoms related to exposure, although only a 12.1% shows a whitening of fingers during the working day.

In this context, few studies take into account measurement of the dose values combining both noise and vibration at the same time. Çakmak et al. [20] focus on the study of five flap type olive harvesters. Their results indicated that traumatic vasospastic disease appeared in 10% of the exposed population after 0.7–7.1 years for the left hand, 1.0–4.7 years for the right hand. On the other hand, the sound pressure values at the operator's ear level of harvesters were found below risk levels when

[1] World production values of oil for the 2017–2019 harvest.

compared with ILO standards. Similar results were obtained in another study on hook type olive harvesters [21].

Finally, it should be noted that in Europe, Directive 2006/42/EC [22] related to the machinery that affects manufacturers, suppliers and importers, establishes that machinery must be designed and constructed in such a way that risks resulting from the emission of airborne noise are reduced to the lowest level. In the same way, the machinery must be designed and constructed in such a way that risks resulting from vibrations produced by the machinery are reduced to the lowest level.

This study presents the first results of a comprehensive study on physical agents in the olive harvest. It has been taken measurements with the three types of mostly used handheld machines, measuring two different models of each one of them. There have been measured noise levels and HAV to compare with the values declared by the manufacturers.

This will allow us to define action protocol to the employer and even make recommendations on the selection of the machine. This selection should be done not only based on that it should minimize the possible damage on the olive tree, and so increasing performance, but also with the aim of reducing vibration and noise on worker.

2 Materials and Methods

2.1 Measured Machinery

The Table 1 shows the three types of machines analyzed and the two models measured. The data supplied by the manufacturer of noise and vibration levels in the instruction manual are indicated.

Directive 2006/42/EC [22] requires the manufacturer to declare the different values of noise emission of the machine, i.e. the A-weighted sound pressure emission level (LpA) when it exceeds 70 dB(A). In addition, specific conditions on the conducted trial or measurement should be indicated, citing the ISO used. In the specific cases used in this study, the manufacturer states that it has been used the ISO 11201:2010, which defines a procedure for determining the sound pressure level emitted by machinery and equipment in the workplace. Manufacturers must determine the A-weighted sound pressure level (dBA) produced by each source considering the different modes of machine operations. ISO 22868:2011 also establishes that values of the A-weighted sound pressure levels must be measured under different operating conditions (idle speed and full load).

Vibration values supplied by the manufacturer should be expressed according to the value of weighted equivalent acceleration $a_{hv,eq}$, on the hand-arm system, which correspond to the sum of the vibrations that are taking place in the various modes of operation of the machine (see Sect. 2.3). The above-mentioned Directive indicates that the values should be declared if they exceed the acceleration value of 2.5 m/s^2, and if this would not be the case, specific mention should be made.

Table 1 Machines studied and noise and vibration values declared by the manufacturers.

Machine	Model A	Model B
Flap type olive harvesters 	**Noise[2]:** -LpA = 84 dB(A). -Lw = 95 dB(A) **Vibration[3]:** ahv,eq: -Guide handle: 2.5 m/s^2. -Bow handle: 2.5 m/s^2.	**Noise**: No information **Vibration:** No information
Hook type olive harvesters 	**Noise:** No information **Vibration:** No information	**Noise:** -Leq[4] = 102 dB(A) -Lw[5] = 113 dB(A) **Vibration[6]:** -ahv,eq left=5.7 m/s^2 -ahv,eq right= 5.7 m/s^2
Leaf blowers 	**Noise[2]:** Lpeq = 100 dB(A) **Vibration[7]:** ahv,eq = 1.8 m/s^2	**Noise[2]:** Lpeq = 90 dB(A) **Vibration[7]:** ahv,eq = 1.4 m/s^2

[2] ISO 22868:2011. Forestry and gardening machinery - Noise test code for portable hand-held machines with internal combustion engine - Engineering method.
[3] ISO 60745-1. Hand-held motor-operated electric tools -Safety - Part 1: General requirements.
[4] ISO 11201:2010 Acoustics - Noise emitted by machinery and equipment -- Determination of emission sound pressure levels at a work station.
[5] ISO 3744:2010 Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure.
[6] ISO 20643:2005 Mechanical vibration - Hand-held and hand-guided machinery.
[7] ISO 22867:2011. Forestry and gardening machinery -- Vibration test code for port-able hand-held machines with internal combustion engine - Vibration at the handles.

2.2 Equipment Used

A sound level meter (Model 2260 Investigator, Brüel & Kjaer) was used to measure the different equipment. The sound levels were recorded and storaged of 1/3 and 1/1 band filters at each location. Simultaneously, a Squadriga I analyzer was used to made binaural recordings at the worker position. Sound level measurements was analysis with Artemis software.

The equipment chosen to measure vibrations exposure was a human vibration meter (SVAN 106 equipment, SVANTEK). The vibrations transmitted to the hand–arm system was measured with a triaxial accelerometer (SV 105, Svantek). Accelerations were measured for both right and left hands. However, in the case of the blower, only the accelerations transmitted to the right hand were measured, since these machines are not held with the left hand. The accelerometer was placed on the handgrip.

2.3 Calculation of the Worker Exposure Level

The European Union has developed a detailed regulatory framework on safety and health of workers (H&S) at work to minimize these related costs. In this sense, Directive 89/391/EEC [23] on the introduction of measures to encourage improvements in the H&S of workers at work (Framework Directive) requires the employer to carry out a risk assessment to prevent their workers to suffer from accidents or occupational illnesses. In addition, there are a series of individual Directives framed by the Framework Directive. On the one hand, Directive 2003/10/EC [24] establishes the minimum H&S requirements regarding the exposure of workers to the risks arising from noise. On the other hand, Directive 2002/44/EC [25] establishes these requirements for vibrations. Both Directive 2002/44/CE and 2003/10/EC, define exposure limit values: the daily Exposure Limit Values (ELV) and the daily Exposure Action Value (EAV). It is noteworthy to be mentioned that Directive 89/654/EEC [26] concerning the minimum H&S requirements for the workplace includes temperature regulation, although it is not of application in open places.

The assessment of the exposure level to HAV is based on the calculation of daily exposure, which can be measured using the method of ISO 5349-1:2001 [27]. The Fig. 1 shoes the method of calculation defined by ISO 5349-1:2001 and the daily limit values. The ELV should not be exceeded during a workday. In the event of ELV limits were exceeded, a program of technical and organizational measures should be performed, in addition to a deeper monitoring of worker health.

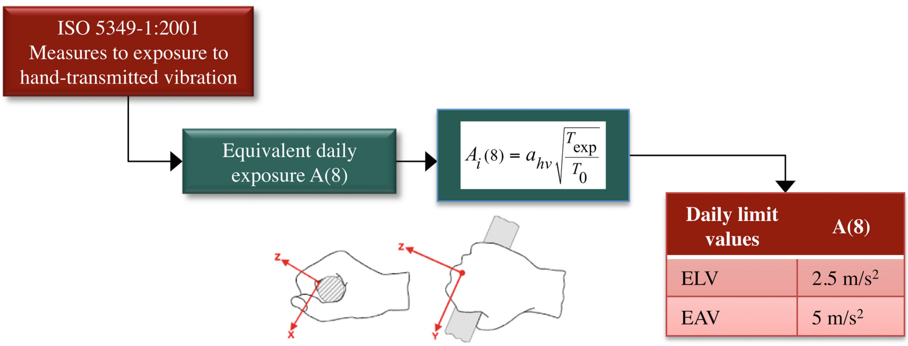

Fig. 1. The methods of calculation defined by ISO 5349-1:2001 [27]. EVL and EAV are defined by Directive 2002/44/CE [25].

In terms of magnitudes for vibration measurements (Fig. 1), the daily exposure A (8) is expressed as the equivalent continuous acceleration over an eight-hour period, calculated as an r.m.s. value. The value a_{hv} is calculated as the square root of the arithmetic sum of the squares of the weighted acceleration values a_{hw} measured in the three axes of a local coordinate system located on the handle (Eq. 1); T_{exp} is the exposure time; T_0 is the reference time of 8 h. The maximum of Ai calculated in the three directions becomes the value A(8).

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \quad (1)$$

On the other hand, a magnitude frequently supplied by the manufacturer is the equivalent vibration, $a_{hv,eq}$. D This value is calculated based on the acceleration values of vibration a_{hv} for each handle, as well as the mode of machine operation (Eq. 2).

$$a_{hv,eq} = \sqrt{\frac{1}{T}\sum_{i=1}^{n} a_{hwi}^2 \times t_i} \quad (2)$$

The Directive 2003/10/EC [24] measures noise exposure using two different methods, both defined in the ISO 1999:2003 standard [28] (see Fig. 2). Before the assessment and measurements were carried out, the length of exposure and ambient factors were considered in order to define the methods and the measuring device used.

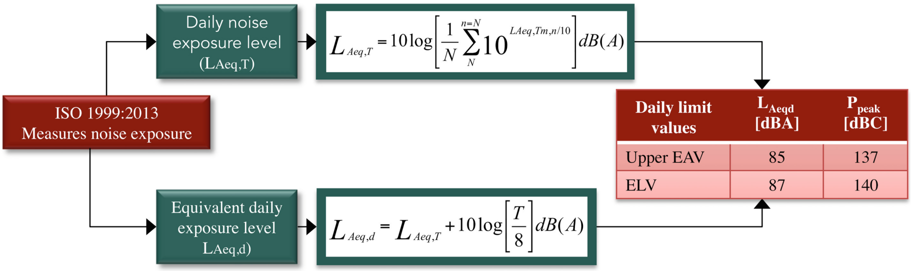

Fig. 2. The methods of calculation defined by ISO 1999:2013.

The Daily noise exposure level ($L_{Aeq,d}$) and the Peak sound pressure (P_{peak}) are the parameters used as risk predictors. The $L_{Aeq,d}$ is calculated as the time-weighted average of the noise exposure levels for a nominal eight-hour working day. The P_{peak} is calculated as the maximum value of the C-weighted instantaneous noise pressure.

The EVL and the EAV with respect to the $L_{Aeq,d}$ and P_{peak} are fixed in the Directive 2003/10/EC.

The vibration values of olive harvesters were measured and analyzed for both right and left hands, and the sound pressure level was measured at ear high of the operator. In addition, leaf blowers were only measured for the right hand, as only this hand is used to hold them.

For the calculations shown in Sect. 3, both the values of vibration and noise levels (magnitudes defined above) were calculated for a workday of 7 h.

2.4 Measurements

For vibration measurements, workers under study were equipped with the SVAN 106 m and analyzer and different receptors in hand and ears (see Fig. 3).

Fig. 3. Worker with measuring instruments

Measuring should last long enough to ensure a reasonable statistical accuracy and to assure a measurement value representative of the vibration exposure to be assessed. In the event that the exposure comprises periods with different characteristics, each one will be analyzed individually [29]. Given that there are no defined work cycles, vibrations should be measured up to a minimum of 3 min [29].

Before conducting a measurement, weather conditions were checked (wind speed, barometric pressure, temperature and relative humidity) to be sure that measurements are in the valid range. Considering that the measurements were carried out on the outside, we used a windproof ball to protect the microphone (the wind speed does not exceeded 3 m/s in any case). We studied the activity and the work procedure to ensure that the conditions of machine operation were representative of a standard working day. This allowed us to ensure that measurements with the sound-level meter were long enough so that the results obtained were representative.

The sound-level meter was placed on a tripod, 1.50 m high above the ground and keeping the same distance from any surface susceptible to generate reflections that might interfere the measurement. Once the worker was placed to perform his work, we identified four reference points relative to its location: behind the worker (P_{back} to the right of the worker (P_{right}); in front of the worker (P_{front}); to the left of the worker (P_{left}) (see Fig. 4). Durante la medición, la posición del sonómetro respecto del trabajador siempre se encontraba alineada, de forma que el micrófono apuntara a la fuente de ruido. During the measurement, the position of the sound-level meter relative to the worker was always kept aligned, so that the microphone always pointed to the source of noise. The sound-level meter was set up with a fast response (F) and A frequency-weighting filter.

In addition, a background noise measurement was carried out (with the same conditions as before) to ensure that the measured sound pressure level of the sound source was not affected by any other potential sources of noise.

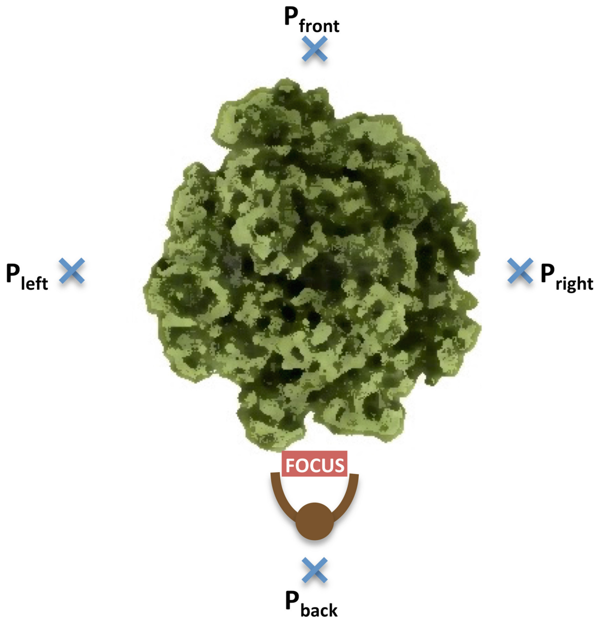

Fig. 4. Four measurement points of sound level meter allocation.

3 Results

After the fieldwork and measurements described in previous section, the values of vibration and noise indicators were calculated in accordance to the methodology described in paragraph 2.3.

Figure 5 shows the values A(8) for each machine. It can be observed how, except for the leaf blowers, the studied machines emit levels above ELV values in both hands. Measurements obtained from Leaf blowers of the model A are very close to the ELV limits, but far away from the EAV values.

It is noted that for the Flap type machine, A(8) measured values are all above EAV. In the case of the Model A, HAV value received by the left hand (15.522 m/s^2) doubles that value obtained in the right hand (7.734 m/s^2). This difference does not appear in the Model B, where the values are very close in both hands (Left hand 15.024 m/s^2 and Right hand 13.911 m/s^2).

On the other hand, to proceed with the data supplied by the manufacturer used for comparison to measured values, we have calculated the value A(8) in accordance with the methodology described in Fig. 1. For the Model A, it has been obtained a value of 2.339 m/s^2 for both hands, much lower than the value obtained in the measurements. The manufacturer of the Model B does not provide this data, so the Directive 2006/42/EC [22] is not observed, since even in the case that the value were lower than the ELV, this fact should be indicated.

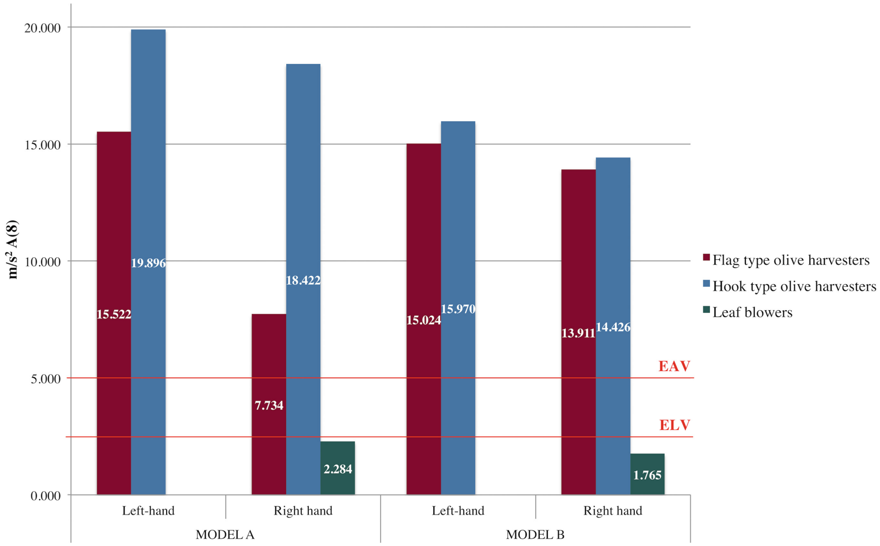

Fig. 5. HAV A(8) received by worker in a 7 h daywork.

In the two studied models of Hook type machinery, it is observed that there is lesser difference in HAV for both hands compare to the other models, although all values stands above the EAV. It should be noted that the values HAV are greater in the model A than in the Model B. Similarly, in the case of the data values supplied by the manufacturer, we found that this compulsory values do not appear (Model A), or they are far from the values obtained in the measurement −15.970 m/s^2 in the left hand and 14,426 m/s^2 in the right hand compared to the supplied A(8) value of 5.332 m/s^2.

These measured values of HAV should conduct to the employer to take corrective measures; the most common would be to limit the daily use of the machine by means of rotation of workers to other tasks.

Furthermore, it is observed that the noise values obtained by the Squadriga (Fig. 6). The two Flag type models have values below the ELV. In the case of Hook type and the Leaf Blowers, the noise values obtained are even higher than the EAV.

In reference to the values supplied by the manufacturers in terms of the weighted sound pressure level transmitted by the machinery, only the Flap type model A, Hook type model B and both models of Leaf blowers provide these data in their reference guides. After calculating $L_{Aeq,d}$ from these values, we found differences between the obtained values and in situ measured experimental values. In the case of the flap type model A, the value obtained experimentally is less than that published by the manufacturer ($L_{Aeq,d}$ manufacturer = 93.4 dBA, $L_{Aeq,d}$ measured = 82.7 dBA). The situation is similar for the Hook type model B ($L_{Aeq,d}$ manufacturer = 101.4 dBA, $L_{Aeq,d}$ measured = 94.0 dBA).

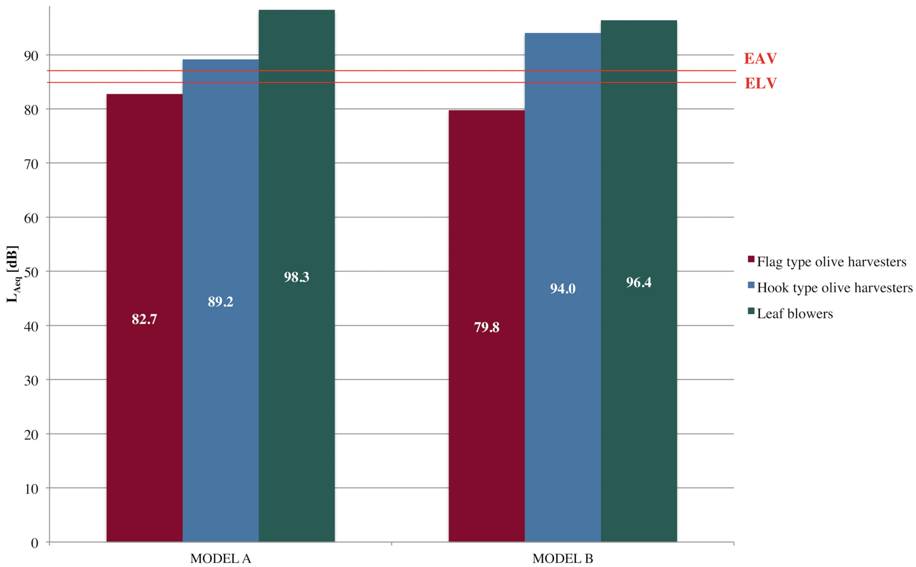

Fig. 6. Noise values obtained from in situ measurements.

With regard to the Leaf blowers, the emission value provided by the manufacturer of the model A is nearly identical to that measured in situ ($L_{Aeq,d}$ manufacturer = 99.4 dBA, $L_{Aeq,d}$ measured = 98.3 dBA). While for the model B the value is greater than that published by the manufacturer ($L_{Aeq,d}$ manufacturer = 89.4 dBA, $L_{Aeq,d}$ measured = 97.4 dBA). In this regard, it should be noted that our measurements were made on full load operations and we do not consider idle speed.

Finally, Fig. 7 shows the values of environmental noise obtained in the four points measured as indicated in Fig. 4 using the sound level meter. It is observed that the lowest values are obtained in the measurement point P_{front}, where the noise is damped by the branches of the tree. It can be seen that the noise produced by the flap type and the Hook type is less than that noise received by the worker and below the ELV and the EAV values. In contrast, in the case of Leaf blowers, almost all of the values are above EAV values, and even above the EAV values, except those measurements obtained in P_{front} for both models.

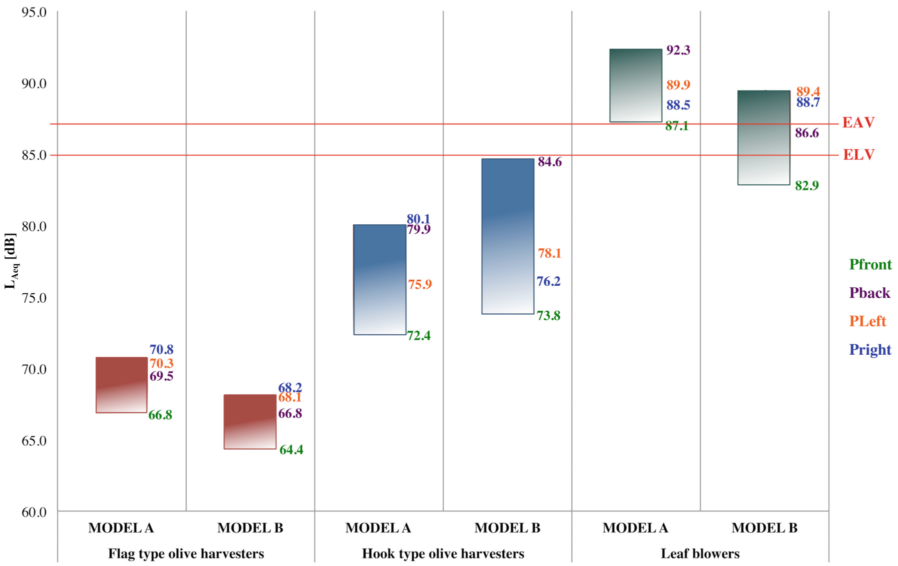

Fig. 7. Environmental noise levels.

4 Conclusions

Given the large number of workers employed in the olive harvest in Andalusia, as well as the increasing use of machines that emit HAV and noise, it becomes necessary to analyze and measure the exposure of those workers to these physical agents.

Within the portable machine used for harvesting, there are the Flap type and Hook type olive harvesters, in addition to the Leaf blowers.

In the first results obtained in this study, it is obtained that the two models of Flap and Hook type olive harvesters do expose workers to HAV values above the ELV and EAV values defined by Directive 2002/44/EC. The Hook type transmits higher values of HAV that the flag type ones.

The Models A and B of the Hook type provide exposure values quite similar in the left hand, although always lower than in the right hand.

In the case of the Flap type olive harvesters, the left hand also receives highest vibrations that the right hand. It should be noted that in the case of the Model A, the HAV received value is double than that of the right hand.

The levels of noise exposure transmitted by the Hook type machines are lower than the limits established by the regulations; in the case of the Hook type machines, these noise levels are above the ELV and even of the EAV values.

With regard to the Leaf blowers, these are the ones that transmit less exposure to HAV, without reaching ELV. However, in relation to exposure to noise, this type of machines significantly exceed the EAV values of noise exposition level.

With these results, we conclude that all these values are clear enough to undertake a program of technical and organizational measures, including a health surveillance of the worker, in addition to helping the employer to select the best machinery in terms of minimizing exposition levels. Among these technical measures, the use of personal protective equipment should be also taken into account.

Finally, the instruction manuals for manufacturers should indicate the exposition values to noise and vibration according to the Directive 2003/10/EC, but it has been found that they include values much lower than those obtained in in-situ measurements, or even they do not declare the prescribed values. This makes it difficult for the employer to design appropriate prevention protocols since important information is missing.

Acknowledgments. The research group wishes to thank those employers and workers that allowing us to obtain field data.

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Risk Assessment of Upper Limb Musculoskeletal Disorders in a Poultry Slaughterhouse

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Abstract. This paper aimed to assess the risks related to upper limbs repetitive movements in work tasks in a poultry slaughterhouse. The study was carried out in a poultry abattoir in which 180,000 chickens were slaughtered daily, with 2,000 workers distributed in three shifts. To evaluate the risks related to upper limbs repetitive movements, 10% of the workers were evaluated using the OCRA checklist. The workers performed 79.8 ± 21.7 technical actions per minute (10 points on the OCRA checklist). The overall mean OCRA checklist score was 18.9 ± 4.2 (medium risk). The right upper limb score (18.5 ± 4.5 - medium risk) was not significantly different (p = 0.128) from the left upper limb (17.8 ± 4.5 - medium risk). Among the 35 tasks analyzed, two were classified as high risk (6%) and 33 presented medium risk (94%).

Keywords: Repetitive movements · Risk assessment · Musculoskeletal disorders · Ergonomics

1 Introduction

Many factors have led Brazil to a leading international position in the production and export of chicken meat, especially: fertile soil, abundant lands, favorable weather, and innovativeness of the enterprises to overcome challenges [1]. Most of the chicken meat exported by Brazil is in the form of cuts (63%) [2], which are processed manually (knives) or by cutting machines (chainsaws). Yet, economic growth is not accompanied by improved working conditions in this sector [3]. Thus, slaughterhouse workers are at high risk of work-related musculoskeletal disorders (WMSDs) due to exposure to high physical work demands and cyclic repetitive muscular actions of the upper limbs [4]. According to the United States Occupational Safety and Health Administration (OSHA) [5], the risk factors often associated with WMSDs in slaughterhouses include repetitive and/or prolonged tasks, harmful postures, forceful exertions, vibration, permanent contact of the arms with the workstation edges, inappropriate hand tools and cold temperatures.

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 265–272, 2020.
https://doi.org/10.1007/978-3-030-20497-6_24

In this context, the OCRA Checklist was designed to measure the risk of biomechanical overload of the upper limbs through the evaluation of several risk factors (lack of recovery time, movement frequency, force, awkward postures with stereotyped movements, and others defined as "additional") related to performed tasks [6, 7]. This method was based on a consensus document of the technical committee on musculoskeletal disorders of the International Ergonomics Association (IEA) ratified by the International Commission on Occupational Health (ICOH) [6, 7].

Although several recent papers have assessed the risks inherent in repetitive upper limb movements in poultry slaughterhouses [8–12], this study is justified because each slaughterhouse has particularities such as the production of different types of products/cuts. Therefore, the importance of surveying different slaughterhouses is evident.

Hence, this paper aimed to assess the risks related to upper limbs repetitive movements in work tasks in a poultry slaughterhouse, as well as to verify the effects of reducing the work rate on the risk levels.

2 Method

The procedures performed in this study followed ethical precepts and were approved by the Human Research Ethics Committee of the Federal University of Santa Catarina.

The study was carried out in a Brazilian slaughterhouse with 2,000 workers, divided into three shifts, in which 180,000 chickens were slaughtered daily. The OCRA checklist (Table 1) was used to assess the risks related to upper limbs repetitive movements in approximately 10% of the workforce while performing their tasks [13]. For the analyzes the tasks were considered individually, independently if they were part of job rotation schedules. A 10-cycle sampling of each task analyzed was recorded with a digital camcorder.

Table 1. Criteria for classifying the results of the OCRA Checklist according to the level of exposure and corresponding expected prevalence (%) of workers with UL-WMSDs [13].

Risk level	OCRA checklist score	Predicted worker population with UL-WMSDs (%)
Acceptable	<7.5	<5.26
Borderline or very low	7.6–11.0	5.27–8.35
Low	11.1–14.0	8.36–10.75
Medium	14.1–22.5	10.76–21.51
High	>22.5	>21.51

The statistical treatment consisted of descriptive analysis (mean, standard deviation and percentage), and the Student t-test was used to compare the risk between the sides of the body (SPSS 17.0; $p \leq 0.05$).

3 Results and Discussion

Work tasks (35) that were performed in the following sectors were analyzed: cutting (19); packing (7); chiller (1); reception (4) and evisceration (4) (Table 2).

Bearing in mind that the total duration of the work shift was 07 h 20 min with five rest breaks of 10 min each, the net duration of the repetitive work was classified in the range of 361 to 420 min (multiplier factor 0.95). For the risk factor "Recovery" no points were assigned (on a scale of 0 to 10). The scores of the other risk factors evaluated by the OCRA method (movement frequency, force, awkward postures with stereotyped movements, and additional factors) were assigned according to the particularities of each task and the operative mode of each worker.

The workers performed 79.8 ± 21.7 technical actions per minute (10 points on the OCRA checklist) (Table 2). Similar results were reported in several studies in other poultry slaughterhouses, with averages of technical actions between 59.1 and 64.7 [9–12, 14]. Kilbom [15] recommends that workers movement rates of 25–33 actions/min. should not be exceeded for tendon disorders to be prevented, since higher rates provide insufficient pauses for the recovery of fatigue between contractions (micropauses).

Slaughtering and processing of chickens include repetitive and strenuous work, exposing workers to overuse injuries. Live chickens arrive at the factory and are then inserted into a production line, where workers hang, slaughter, pluck, clean, eviscerate, cut and pack the bird parts at an intense rhythm. Moreover, workers also assemble boxes, clean and repair equipment and carry pallets of packaged chicken meat. As a result, each of these occupational duties contributes to a potential risk of musculoskeletal disorders [16].

The overall mean OCRA checklist score was 18.9 ± 4.2 (medium risk), and the right upper limb score (18.5 ± 4.5 - medium risk) was not significantly different ($p = 0.128$) from the left upper limb (17.8 ± 4.5 - medium risk). Corroborating these results, Tirloni et al. [17] interviewed 312 workers at a poultry slaughterhouse and found that 71.2% reported body discomfort in at least one of the 14 regions cited, and the right side of the body was the most cited. In a poultry slaughtering industry, Colombini, Occhipinti and Fanti [13] found that 22.4% of workers exposed to medium risk tasks (on average of 20 points in the OCRA checklist) were affected by UL-WMSDs (confirmed by clinical evaluation and complementary medical examinations). Medium risk was also observed in several other Brazilian poultry slaughterhouses [8–12].

Among the 35 tasks analyzed, two were classified as high risk (6%) and 33 presented medium risk (94%). A few previous studies have indicated that high-risk tasks were prevalent in poultry slaughterhouses in Italy (90%) [14], Iran (67%) [18], and Brazil (56.5%) [8]. However, recent studies indicate that there is predominance of medium risk tasks in Brazilian poultry slaughterhouses [9–12]. It is believed that recent studies have presented a lower number of high-risk tasks due to the implementation of the Brazilian Regulatory Standard 36 (NR-36) [19].

Table 2. Risk assessment by the OCRA checklist and simulations to reduce risk by reducing the pace of work.

Tasks – sector	Current situation				Simulations for risk reduction			
	Units/min	TA/min	OCRA score	Risk level	Units/min	TA/min	OCRA score	Risk level
Meat transfer – bowl to box – secondary packaging	18.2	72.7	40.9	5	**			
Closing boxes – secondary packaging	12.0	36.0	25.7	5	**			
Interfold wing – packaging	*	103.0	20.9	4	-	35.0	11.0	2
Remove carcass fat – cuts	40.0	80.0	20.0	4	17.6	35.0	11.0	2
Chicken heart screening – evisceration	*	82.0	20.0	4	-	35.0	11.0	2
Stack empty cages – reception	2.7	81.8	20.0	4	1.2	35.0	11.0	2
Trimming boneless leg – cuts	7.2	72.3	19.0	4	4.0	40.0	11.0	2
Secondary packaging (single) – Secondary packaging	5.0	95.0	19.0	4	1.9	35.0	11.0	2
Breast carcass screening – cuts	*	70.0	19.0	4	-	40.0	11.0	2
Trimming breast – cuts	6.7	80.0	19.0	4	3.0	35.0	11.0	2
Breast screening – cuts	*	70.0	19.0	4	-	35.0	11.0	2
Gizzard screening – evisceration	*	81.0	19.0	4	-	35.0	11.0	2
Kakugiri screening – cuts	*	100.0	18.1	4	-	40.0	11.0	2
Repositioning sassami on the mat – cuts	*	74.0	18.1	4	-	40.0	11.0	2
Breast screening (x-ray entrance) – cuts	*	110.0	18.1	4	-	40.0	11.0	2

(*continued*)

Table 2. (*continued*)

Tasks – sector	Current situation				Simulations for risk reduction			
	Units/min	TA/min	OCRA score	Risk level	Units/min	TA/min	OCRA score	Risk level
Primary packaging – deboning leg	5.5	76.4	18.1	4	2.9	40.0	11.0	2
Breast screening (x-ray output) – cuts	*	129.0	18.1	4	-	40.0	11.0	2
Placing wings at portioning machine – cuts	40.0	80.0	18.1	4	20.0	40.0	11.0	2
Fueling Kakugiri conveyor belt – cuts	60.0	120.0	18.1	4	20.0	40.0	11.0	2
Repositioning Kakugiri on the conveyor belt (talisca) – cuts	*	97.0	18.1	4	-	40.0	11.0	2
Repositioning Kakugiri on the conveyor belt – cuts	*	100.0	18.1	4	-	40.0	11.0	2
Chicken paws screening – evisceration	*	80.0	18.1	4	-	40.0	11.0	2
Re-hanging chicken – chiller	31.6	63.2	18.1	4	17.6	35.0	11.0	2
Salted sassami – cuts	2.4	73.5	18.1	4	1.1	40.0	11.0	2
Halal slaughter – reception	60.0	120.0	18.1	4	20.0	40.0	11.0	2
Liver screening – evisceration	*	100.0	18.1	4	-	40.0	11.0	2
Weighing and packing breast	5.5	70.9	17.6	4	3.0	40.0	11.0	2
Unloading cages – reception	0.9	49.1	17.1	4	0.65	35.0	11.0	2
Skin screening – cuts	*	82.0	17.1	4	-	45.0	11.0	2
Sassami screening – cuts	*	60.0	17.1	4	-	35.0	11.0	2
Sealing packages – cuts	3.5	60.0	17.1	4	2.0	35.0	11.0	2

(*continued*)

Table 2. (*continued*)

Tasks – sector	Current situation				Simulations for risk reduction			
	Units/min	TA/min	OCRA score	Risk level	Units/min	TA/min	OCRA score	Risk level
Fueling horizontal cone line – cuts	31.6	63.2	17.1	4	20.0	40.0	11.0	2
Kakugiri classification by weight – cuts	35.3	70.6	16.2	4	22.2	45.0	11.0	2
Secondary packaging (double) – Secondary packaging	3.3	50.0	15.2	4	2.3	35.0	11.0	2
Hanging chicken – reception	14.0	41.9	14.3	4	12.0	35.0	11.0	2
Average	12.1	79.8	18.9	4	9.5	38.2	11.0	2
Standard-deviation	17.4	21.7	4.2		8.7	3.0	0.0	

Risks: 5-high; 4-medium; 3-low; 2-very low; 1-acceptable; TA-technical actions; * Task with variable work rate; ** The task needs to be restructured due to the high force requirement.

The NR-36 defines parameters for assessing, controlling and monitoring risks in work tasks of meat processing industries [19]. Among the parameters defined by NR-36, the minimum duration of the psychophysiological recovery periods directly influences the results of the OCRA checklist. The rest breaks should be adopted (20, 45 or 60 min) according to the length of the work shift (6 h, 7 h 20 min or 8 h 48 min, respectively). Besides that, each break should last 10 to 20 min, and should be distributed in the workday except for the first hour of work, following the meal interval and at the end of the shift. By applying these parameters, the time for exposure to repetitive tasks and the "recovery" score of the OCRA checklist are reduced.

Precursors of the OCRA method [13] were based on epidemiological data and used statistical procedures (regression analysis) to develop expected disease prevalence hypotheses in a specific occupational environment. Specific percentages were defined for each level of UL-WMSDs incidence, as described in Table 1. Colombini et al. [13] found an incidence of 47.7% of UL-WMSDs in meat boning workers, who were classified with 28 points (high risk) in the OCRA checklist. Thus, the workers analyzed in the present study had a probability of developing UL-WMSDs between 10.76 and 21.51% for medium-risk tasks, and >21.51% for high-risk tasks.

Considering that poultry slaughterhouses predominate the highly repetitive movements of the upper limbs [20], and previous studies suggest a reduced work pace to prevent UL-WMSDs [8–12], simulations were performed to reduce the work rhythm to reach lower risk levels, using the OCRA Checklist. By only reducing the work rate ($-38.8 \pm 4.8\%$) with these simulations, it was possible to reduce the risk of developing UL-WMSDs to very low levels in 33 of the 35 tasks analyzed. Very low risk levels were not reached in tasks “turn the boxes” and “cover the boxes” due to the high force requirement. In the same sense, several previous studies [9–12] also carried out simulations to reduce the risk by reducing the rate of work ($-42.1 \pm 14.5\%$; $-38.8 \pm 13.3\%$; $-44.9 \pm 13.7\%$ and $48.5 \pm 11.8\%$) and were successful in the majority of the tasks (24/26, 20/22, 28/30 and 15/15, respectively), except those with excessive demand of force.

4 Conclusion

Taking into account the results of this study, it is possible to conclude the following:

- In the abattoir analyzed there was a predominance of medium risk tasks, so the workers were two to four times more likely to have UL-WMSDs compared to workers who were not exposed;
- There was no difference between the risk of UL-WMSDs between the sides of the body;
- Reducing the pace of work proved to be an effective organizational measure to reduce the risk of UL-WMSDs.

To verify if the results of the present study can be generalized to other slaughterhouses, studies in other plants are necessary.

To reduce the risk of UL-WMSDs in chicken slaughterhouses, it is recommended to adopt a series of organizational measures: reduce the work rhythm, perform efficient job rotations (between tasks with different biomechanical demands), perform rest breaks well hourly, increase the number of workers in each task, keep cutting tools sharp, and use objective tools such as the OCRA checklist to constantly monitor the risk levels of tasks.

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An Ergonomic Assessment of Lighting Conditions of the Pedestrian Overpasses in Commonwealth Avenue, Quezon City: Commuter's Perception of Safety

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Abstract. The pedestrian overpasses in Metro Manila, Philippines are often taken by commuters especially during rush hours to go to places. However, concerns about design, safety, and security of these overpasses are being raised. These problems become more prevalent at night because of the poor lighting conditions experienced in these overpasses. For these reasons, it was necessary to address the concerns of the pedestrians, to come up with an appropriate lighting standard, and to make design recommendations.

Adequate lighting in pedestrian facilities are important for they give a sense of safety and security to the people traversing them. Moreover, good visibility prevents accidents in these areas especially at night. The Philippines, particularly Metro Manila, is not the safest place to experience commuting for various crimes related to theft and robbery are not uncommon. Moreover, pedestrian facilities such as pedestrian overpasses are deemed to have poor lighting at night - making these places unsafe to the eyes of the commuters.

To address these issues, surveys regarding their perception and lighting preferences were gathered both online and on-site. The overpasses that were put into focus for the evaluation and data gathering for the on-site survey were three (3) of those in Commonwealth Avenue, Quezon City. These overpasses are frequented by commuters for they are surrounded by different establishments and institutions such as hospitals, churches, malls, and universities. From the data gathered, the results showed that these overpasses did not have proper lighting causing the commuters to lack visibility, security, and confidence.

Within the parameters set by the researchers, a bulb with a luminous flux of 1,300 lx (measured 11 in. away from the light source) gave the best results in terms of security, visibility, and confidence. Moreover, even a relatively little increase in lighting intensity was acknowledged and felt by the commuters since these overpasses did not have any proper light source especially at the middle. Nonetheless, the need for lighting standardisation was addressed and possible steps for improvement of these vital facilities were recommended.

Keywords: Pedestrian overpasses · Lighting conditions · Perception of security and safety

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 273–279, 2020.
https://doi.org/10.1007/978-3-030-20497-6_25

1 Introduction

Transportation is one of the vital keys for the development of a country. More than just the mobilization of people, it involves movement of services, products, information, and knowledge in which time is a significant factor. Aside from having an efficient transportation system, safety of commuters and drivers must also be prioritized. It can be attained by ensuring that there are sufficient facilities and services provided by the government to its citizens.

It is no secret that in the National Capital Region of the Philippines transportation has always been a problem. This becomes more pressing for every driver and commuter during the rush hours. In 2015, according to the Philippine Statistics Authority, the total population in the Philippines was 100, 543, 973 [1]. Of this number, 12,786, 611 people live in the National Capital Region. With this number of people, the city must be able to provide adequate facility for transportation. In fact, with just the MRT3 alone, an average of 260,000 passengers daily was recorded during the month of February 2018 [2]. MRT3 is just one of the four train systems in the region.

A regular commuter in Metro Manila always has a negative comment to say about his/her experience. An article posted by Renee Karunungan in Rappler.com entitled: *"Commuter woes"* highlighted the frustrations of the Filipino commuters [3]. Moreover, she cited a post in Facebook which stated that the youth of Filipinos will be wasted on traffic - a hyperbole she used to emphasize the traffic situation in Metro Manila. The author further discussed that the commuting experience does not give dignity to its constituents. Traffic is just a speck of a huge problem in commuting in Metro Manila. In fact, another pressing concern of commuters is their safety.

Safety is not just limited to having freedom from injury, death, and other illnesses brought by natural and physical disasters - it encompasses crime prevention as well. From the April 16 to May 20, 2018, the National Capital Regional Police Office (NCPRO) recorded 1,255 crimes in Metro Manila which was a 29.29% drop in comparison with the same period of the previous year [4]. This was the lowest the region has experienced since the term of President Rodrigo Duterte. Although there was a good decrease, people still find no reason to be complacent about their safety with the possibility of crimes.

According to Fotios, Unwin, and Farrall, people tend to feel unsafe in areas that crimes can be easily carried out [5]. The common perception is that areas without proper lighting give opportunities for criminals to easily hide their mischievous deeds while the possible victims are left without anywhere to run. This is also true for the situation in Metro Manila such that people tend to avoid taking the overpasses because of design and safety factors.

Despite the presence of overpasses and other facilities intended for pedestrians, according World Health Organization as cited by Tribdino, 1,970 pedestrian deaths happened during the year 2015 that was 19% of the total road fatalities [6]. Drivers testified that the roads were *plagued* by jaywalkers. Furthermore, a good number of pedestrians claimed that they were discouraged from taking the overpasses because of their *laziness* and their fear of being victims of crime especially during dark.

Darkness is a huge factor to consider as one of the primary causes of the people's fear in taking overpasses. Ramsay claimed that these people were right to be afraid because in his study, the data gathered from the thieves that carried out their crime at night showed that they considered good surveillance as a risk to the success of their goal [7]. On the other hand, the primary consideration of pedestrians was to have adequate lighting in the path they were taking in order to have enough time to prepare for a response in case of an approaching danger by having the ability to see it from a distance.

Having pedestrian lighting standards in the Philippines is vital for the citizens, especially to the commuters for it is established that visibility is one of the major factors people rely for safety. These lighting standards must provide enough visibility for the people passing by. There are road lighting standards in the Philippines, but there is none for pedestrian overpasses. More specifically, in Commonwealth avenue, the overpasses are lacking in uniformity in terms of lighting systems. In fact, it is one of the busiest avenues in Metro Manila that commuters regularly take since located in it are universities, schools, government offices, transportation terminals, religious places, and business establishments. For this reason, twenty-two (22) pedestrian overpasses are built along the avenue [8]. Despite this, people are still seen jaywalking while the others are still apprehensive about taking these overpasses.

2 Methods

In determining the intensity of lighting in overpasses that commuters are most comfortable with, it is fitting to conduct a test in the likeliest scenario. Portable light bulbs operated by batteries will be brought to three (3) overpasses in Commonwealth, Quezon City. The kind of lights that will be used are LED with varying intensities and wattages. These wattages will be 5, 12, and 15 since they will exhibit varying luminous fluxes that will be comparable with incandescent lights of higher wattages which will not be energy efficient to consider. These lights will be placed on the existing handrails at the center of the overpasses to be examined. Since the height of the handrails may vary, the average height of these handrails taken from preliminary assessment will be used as the height for the on-site survey. Since the intensity of light varies with the distance from the source, the respondents are asked to stand one (1) meter away from the light. The primary goal of conducting this experiment will be to determine if increasing the wattages at the level of existing handrails will increase the feeling of safety and assurance of the commuters.

Another mode in gathering data will be through Google surveys to be distributed online. With this, respondents will be limited to commuters in Metro Manila that regularly take the overpass. Various questions regarding their commuting experience, safety issues, and lighting preferences will be asked. This survey will particularly include photographs of different lighting scenarios of overpasses from which the respondents will rate and evaluate their confidence in case they will take those paths.

The number of respondents that will be interviewed in the overpasses will be 30 to test the relationship between the varying intensity of light and level of safety. To avoid sampling bias, these respondents will be taken from the people that are currently traversing the overpass during the date of visit. The lights will be also be shown at a random order to avoid the noticeable increase and decrease in brightness. On the other hand, for the survey that will be distributed through Google survey, a number of 50 respondents will be needed.

To determine if there is an ordered scale from which respondents choose one option that measures their opinions and perceptions, Likert Scale will be used. Specifically, the Likert scale will be utilised in taking the rating of the commuters regarding different lighting scenarios for pedestrian overpasses. The measure scales that will be used is agreement (strongly disagree to strongly agree).

The study finds it necessary to use nonparametric tests for it is a more test fitting for data that are ranked. It comes with the assumption that the groups are measured in different conditions, sampled randomly, and gathered data are in ordinal form. Since the study will make use of Likert scale then compare the ratings of different samples or respondents for different wattages, Friedman Test and Wilcoxon Signed Rank Test will be appropriate. Most importantly, the study meets all the assumptions of the test.

3 Results and Discussion

3.1 Demographics

For the online survey conducted, a total of 53 respondents were gathered. These were pedestrians that regularly took the pedestrian overpasses. Fifty-one percent of the respondents were females while 49% are males. Fifty-three percent of these respondents were students while the remaining was composed of professionals. On the other hand, a total of 30 commuters were interviewed in the overpasses along Commonwealth Avenue to help evaluate the lighting conditions.

3.2 Results of Friedman Statistical Test

Preference is an essential aspect that we considered since the commuters, especially the younger ones, often uses the overpass at night. With the recorded accidents happening on the road with nearby overpasses, people seemed to lack the encouragement to take these overpasses. Thus, knowing in which brightness made the respondents most confident was a necessity for the study. By that, Friedman statistical test was used in order to measure the correlation of the unlike illumination intensities to the reassurance of people in passing the overpass at night. For the results of the data gathered, the chi-square table was used for the test statistic. The result showed that there was enough evidence to prove the relationship between varying brightness and level of preference.

Confidence is an aspect to consider in building up an overpass. Additional lighting together with the current design of an overpass helps the people gain confidence especially in dark areas since these places are prone to incidents. The Friedman statistical test was used to evaluate the relationship of the different lighting intensities to the confidence of the people in passing the overpass. It was confirmed using the Friedman test that setting up lights on a path increases the confidence of the people.

Visibility is a vital factor to consider in setting up lights on a path. People do not take paths that have poor visibility for the perceived dangers that might happen. Friedman statistical test was used to analyze the overall relevance of different lighting intensities in the bridge. Using the Friedman Test, it was proven that there was sufficient evidence that increasing the lighting intensity affects the visibility of the pedestrian. It was safe to say that as the lighting intensity increases, the visibility in the perspective of the pedestrian improves as well.

3.3 Results of Wilcoxon Signed-Rank Test

In order to identify specific changes and significant pieces of evidence between groups of varying lighting intensities to the level of preference, Wilcoxon Signed-Rank Test was used. By doing so, this can aid in setting up a fitting lighting intensity standard once pedestrians' encouragement is considered. Based on test results, there are enough evidences that the change in lighting intensities affect the motivation of people to take the overpass. Moreover, it is safe to say the there is a positive relationship between the lighting intensity and the level of preference of the commuter. Hence, as the illumination of the area increased, the level of confidence of the pedestrians increased as well. A further interpretation of the data is that the biggest differences were experienced with 12 W, which had the highest luminous flux, in comparison with all the other level of lighting intensities (Tables 1, 2 and 3).

Table 1. Significance between lighting intensities from different light bulbs in terms of commuter's confidence

	0 (No artificial light)	5 W (200 lx)	15 W (500 lx)	12 W (1500 lx)
0		✓	✓	✓
5 W	✓		✓	✓
15 W	✓	✓		✓
12 W	✓	✓	✓	

Table 2. Significance between lighting intensities from different light bulbs in terms of commuter's preference

	0 (No artificial light)	5 W (200 lx)	15 W (500 lx)	12 W (1500 lx)
0		✓	✓	✓
5 W	✓		✓	✓
15 W	✓	✓		✓
12 W	✓	✓	✓	

Table 3. Significance between lighting intensities from different light bulbs in terms of commuter's visibility

	0 (No artificial light)	5 W (200 lx)	15 W (500 lx)	12 W (1500 lx)
0		✓	✓	✓
5 W	✓		✓	✓
15 W	✓	✓		✓
12 W	✓	✓	✓	

In the case of confidence, this statistical tool is vital in computing the differences between the evaluations of different observed statistical values or sample from different wattages. After gathering and analyzing the data, the results suggested that there were significant differences between the treatments (different levels of brightness). Therefore, there is sufficient proof that the intensity of the lights has a big factor to the commuter. For the illuminance of the area, there was an increased level of confidence since the commuters, especially the younger ones, felt a big difference while taking the overpass at night. As the data gathered, the interpretation of the data is that there is prime differences when they experienced 12 W in which it had the maximum illumination in comparing with all the other wattages.

Wilcoxon Signed-Rank Test was also used to interpret the statistical significance between the treatments which are the different lighting intensities. In the case of visibility, the difference between all lighting intensities are significant. Hence, there is enough evidence that the increase in brightness is greatly felt and observed by the pedestrians in the overpass. Specifically, the biggest differences were observed from the test between the pairs 5 W and 12 W, and 0 W and 12 W. The 12-W bulb was observed to exhibit the highest luminous flux. Moreover, even if the bulbs are positioned on top of the handrails, the improvement was adequate enough for people to notice the difference the motivated them to rate the visibility as much as *highly agree* that corresponds to a rating of 5.

There were enough evidences to prove the significance in the relationship between varying brightness. The significant aspects that were considered on the basis of the necessary characteristics of an effective pedestrian overpass are confidence, visibility, and preference. The results showed that there were significant differences in the ratings of the respondents in relation to the significant factors that were considered. This was consistent with the study of Boyce, Eklund, Hamilton, and Bruno (2000) in which it was concluded that the increase in wattages had a significant contribution to the pedestrians' perception of safety. These supported the data gathered from the online survey which indicated that commuters give importance to every improvement and increase in the lighting scenario of the pedestrian overpasses. Even with a little increase from 200 lx (5 W) to 500 lx (15 W), significant differences were seen upon evaluating the three significant factors. It must be noted that these data can only be consistent with the given parameters set by the study stated in the methodology.

4 Conclusion and Recommendations

After gathering and analyzing data, the researchers were able to conclude that there was a lack of lighting standardization in the pedestrian overpasses in Commonwealth Avenue, Quezon City, Philippines. Moreover, there was an obvious lack of lighting uniformity in these overpasses after it was observed that lights were usually placed at both ends of the facility while the darkest point was found in the middle. Due to this, Filipino commuters tend to feel unsafe, but were left with no choice for the is a lack of alternative route other than taking the overpasses. The results of the experiment supported the need for better lighting. On these overpasses, different lighting intensities induced different levels of confidence, security, and visibility from the commuters. As the lighting intensity increased, so did their level of confidence, security, and visibility. Of all the bulbs tested, the one that produces 1,300 luminous flux was found to be the most effective in terms of the three perceptions evaluated. Despite the findings, the research can still be improved by performing the experiment in an isolated environment to prevent variations in the data by having a more controlled setup.

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Risk Assessment of Compressor Gold Mining at Camarines Norte, Philippines

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Abstract. There is a growing concern on mining related safety and health issues and disabling accidents especially in areas still practicing compressor mining even if the law does not allow this type of mining activity. In areas where small-scale mining entities practice unregulated compressor mining, there is insufficient data on the number of deaths and accidents that occurred mainly attributed to under reporting. Compressor mining requires a diver staying inside the hole for at least four hours and depends only on a compressor for his supply of oxygen. The harvested mud with gold ores goes through sluicing and use of mercury to obtain gold. Findings from the assessment showed that the miners do not follow safety measures in mining. Likewise, miners lack the motivation to comply with safety standards mainly due to financial challenges as well as their attitude. The Government plays an important role in providing interventions needed to address these concerns.

Keywords: Compressor mining · Safety management and human factors · Small Scale Mining · Safety · Risk assessment

1 Introduction

The Mines and Geosciences Bureau (MGB) indicated that the small-scale gold mining sector in the Philippines gained momentum at the time large scale operations declined. This sector has an average percent contribution of 28.7% in the total gross production value from 1998–2002 [1]. However, there is a growing concern on mining related safety and health issues and disabling accidents especially in areas still practicing compressor mining even if the law does not allow this type of mining activity. There is insufficient data on the number of deaths and accidents that occurred in areas where unregulated compressor mining is practiced by small-scale mining entities, which may be attributed to under reporting.

Compressor gold mining is unique in some areas in the province of Camarines Norte, Philippines. The site observed in this study is formerly known as Mambulao, taken from the word "mambulawan" meaning "bountiful in gold". Compressor gold mining is the process of making a sinking hole in a swamp wherein mud laden with gold ores are harvested. The process requires a diver who is assisted by around four persons. The diver stays inside the hole for four hours or more and depends on a

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 280–285, 2020.
https://doi.org/10.1007/978-3-030-20497-6_26

compressor for his supply of oxygen. The harvested mud with gold ores goes through sluicing and use of mercury to obtain the gold. Finally, it will be refined using a torch. In Fig. 1 below, the processes in compressor mining is briefly described. According to Executive Order 79, this activity is prohibited due to its dangerous nature.

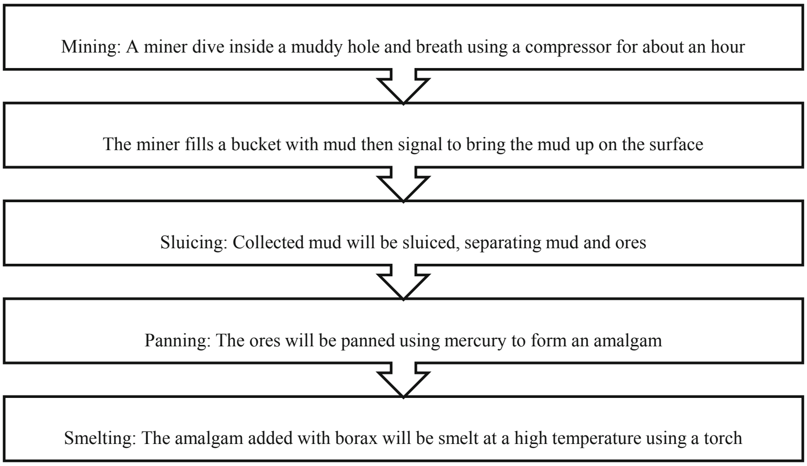

Fig. 1. Compressor mining process

In Fig. 2, miners are shown sluicing all the mud to separate gold form dirt. The hole with water next to them is an old sink hole dove by miners to get the mud laden with ores of gold. With its illegal nature, entities involved in compressor gold small-scale mining normally ignore the risk and hazards associated with it. There is the high chance of events that will have a negative impact on the health or safety of miners and people around them.

This study aimed at using a risk assessment tool to evaluate the key hazards and degree of risks in compressor gold mining operations. According to OSHA of United States Department of Labor, six main hazards are required to be observed and evaluated in any working environment including safety, chemical and dust, physical, biological, ergonomic and work organization hazards [2].

2 Methodology

The six hazards were observed if present in the site, namely, safety hazards, biological hazards, physical hazards, chemical hazards, ergonomic hazards, and work organizational hazards [2]. Then the risk level was computed by multiplying the severity and the likelihood of a hazard as shown in the equation below.

$$Severity \times Likelihood = Risk\,Level \tag{1}$$

Fig. 2. Compressor mining process showing miners sluicing the mud to separate gold from dirt

The risk level that ranges between 1 to 25 were averaged and then ranked. The variance was then computed in case there is a big difference between the risk levels made by the assessors. High risks are defined with risk level of 25-15. Moderate risks are defined with risk level 14-6. Low Risks are defined with risk level 5-1. With the potential risk identified, the next step is to check for compliance with the standards written in Department of Environment and Natural Resources Administrative Order for Small Scale Mining No. 97-30 (DAO 97-30) [3] and Philippine Occupational Health and Safety 1989 (OSH87) [4]. Figure 3 shows the summary of the risk assessment methodology.

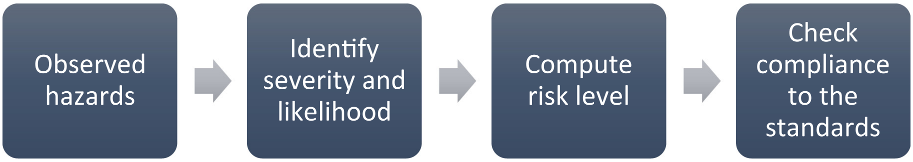

Fig. 3. Risk assessment methodology

3 Results and Discussion

3.1 Assessor Individual View

In Camarines Norte, two participants from the Department of Environment and Natural Resources at the municipal (MENRO) level. Though they are well educated with Department of Environment and Natural Resources Administrative Order for Small Scale Mining No. 97-30 (DAO 97-30) compared to miners, the MENROs have low mine exposure than miners with an approximately 17% mine exposure. This means, local government officials do not regularly visit mining sites.

3.2 Top Hazards

The results of the risk assessment show that the top hazards for compressor gold mining are safety and chemical hazards.

Safety Hazard

- The unsafe ways of using compressors were observed. Two Municipal Environment and Natural Resource Officers noted that miners do not follow any safety standards like using handling compressors. According to Executive Order 79 compressor mining is banned due to a high risk of death.
- Where compressor mining is used in the mine sites, there are stopes inside the holes full of water and mud. Stopes are not stable and can not be monitored. If miners are trapped inside it will surely lead to death.
- Abandoned holes are often left without refilling and no signage placed as a warning to others. This exposes passerby to accidents.
- The ropes used for the miners are not safe since the required 10 to 16 mm diameter ropes were not used.
- Personal Protective Equipment (PPE) are not used and not available (mostly due to financial constraints).

Chemical Hazard

- For chemical hazard, that is for using mercury to capture gold and unsafe disposal of mercury. Mercury is considered as a hazardous waste. If mercury vapor is inhaled, it is absorbed by the body, that can cause nerve poison, sleep disorders, agitation, and paralysis (Table 1).

3.3 Compliance to Law

For compliance purposes, the assessment tool can be used as an inspection tool for the government to monitor DOLE 57-04. Since only one of the MENROs is familiar with DAO97-30, the data for compliance was extracted from his answers. The MENROs noted that 40% do not comply to the given standards in the tool. 23% complied and the rest are not applicable to answer. The approximated 47.5% of all the DAO97-30 did not comply which means only 52.5% complied. One of the reasons for this result is that compressor mining is prohibited by law so there are no specific or proper safety laws and implementing guidelines indicated for this type of mining. Therefore, only forty (40) DAO safety standards are applicable and the rest are not covered by DAO97-30.

Table 1. Top hazards in compressor mining

Hazard Type	Risk Level	MINERS	MENRO
Safety Hazard (unsafe way of using compressor)	High Risk	Search for alternative way of getting gold.	2 MENROs noted that they do not follow any safety standards in handling compressors. Ban compressor mining as stated at EO-79
Safety Hazard (No monitoring of stopes condition & stability)	High Risk	Amazingly, there are stopes inside the holes full of water, monitoring would be impossible since only divers can get inside, and holes are covered by water	The two other MENROs did not know that there are stopes inside the holes, knowledge about this matter.
Safety Hazard (Accidents due to no ample warning)	Medium Risk	It is common in Jose Panganiban that they just abandon holes without refilling, means it impose danger to others	Did not comply to any controls related to warning signs. Must impose immediately
Safety Hazard (Proper ropes)	Medium Risk	Did not follow right diameter of ropes	Check ropes if followed the right diameter (10-16mm)
Safety Hazard (No PPE)	Medium Risk	Diving in the hole full of water and mud with additional PPE would make the miner feel heavier, it might impose more danger	Alternative way of getting gold if cannot be regulated
Chemical Hazard	High Risk	Safe way to use of Mercury	Alternative chemicals

4 Conclusion and Recommendations

The study determined the nature of existing risk controls and their effectiveness. With this, the hazards with the highest probability of occurring and with the greatest severity must be addressed to minimize worker's exposure to potential risk and ensure their workplace safety. Findings from the assessment showed that the miners do not follow safety measures in mining. Likewise, miners lack the motivation to comply with safety standards mainly due to financial challenges as well as their attitude. There should be a government initiative to conduct Information and Education Campaign (IEC) about alternative ways of getting gold in muddy areas, as well as processes without using mercury at the mining community in Camarines Norte, Philippines.

Acknowledgments. The authors acknowledge the support provided by the Engineering Research and Development for Technology (ERDT) program of the Department of Science and Technology and spearheaded by the UP College of Engineering. The data requirements gathered for this study was made possible through the ERDT Mineral Extraction with Responsibility and Sustainability (MINERS) Program, Project G, entitled: "The Gold and Copper Chase (Life Cycle Analysis of Sustainable Small-Scale Production Systems)".

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An Assessment of the Potential Risk of Hearing Loss from Earphones Based on the Type of Earphones and External Noise

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Abstract. The prevalence of personal sound equipment (i.e. earphones) are undeniable, due to the convenience it provides in certain conditions. However, in certain environments earphones could subject users to unintended consequences like hearing loss. In this experiment, the researchers sought to identify the effect of external noise level and the type of earphones on the perceived satisfactory volume level and sound quality of a user. These were assessed through a three-phase methodology namely; benchmarking, data collection, and data analysis. From a pool of 22 respondents, the results show that people do tend to increase their perceived satisfactory volume level depending on the noise level in the environment and on the type of earphones they were using.

Keywords: Hearing loss · Earphones · External noise level

1 Introduction

1.1 Background of the Study

People, especially those enthused by music, like to hear and listen to every detail of every song in their playlist. Consequently, songs are not the only thing that has to be heard; audio signals, and communication from different places are necessary as well. This is where earphones come in. Earphones are like speakers, the difference is that the user is the only one hearing the audio signals, or the sounds coming from the device to which the earphones are connected, because it is worn in or around the user's ears.

Furthermore, many people, especially the youth, use earphones for leisure purposes, whether they are at a cafe, or walking around the streets, going wherever. Despite the multiple uses of earphones, according to Ahmed, M.A., out of 100 people, 65 of them use earphones to listen to music [1]. However, in spite of all these technological improvements towards creating new ways of perceiving sound in a more private manner, risks are still paired with listening to high volume settings, particularly in the hair cells in the cochlea of the inner ear of humans.

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 286–297, 2020.
https://doi.org/10.1007/978-3-030-20497-6_27

One of those risks is the Noise-induced hearing loss (NIHL) which occurs to an individual when being exposed to sounds that are too loud, for a period of time, or even frequently for a short period of time [2]. Reddy [6] stated that roughly 60% of young individuals, particularly college students, listen to earphones for over 2 h; however, the different volume settings of the earphones used by this proportion of individuals are yet to be known.

Listening to music using earphones can be done for an extended period. However, this can be dangerous to an individual since there is a risk of permanent hearing loss. Several people, most especially those at the young age, are experiencing hearing loss because of the exposure to music from portable devices. This hearing loss problem can also be caused by boomboxes and car stereo speakers, but the most damaging are headphones or earphones. These devices are also a cause of permanent bilateral sensorineural hearing loss for it is the result of a combination of loudness and duration of exposure [3].

1.2 Significance of the Study

There are imbalances in the sounds that an individual can hear when wearing different designs of earphones. These types of earphones are: In-Ear and Canal earphones, also known as earbud type earphones. Each type has its own advantages regarding the balance between the environment sounds and the sounds produced by the earphones. A short study of Naik and Pai in 2014 tackling hearing loss in using earphone music showed that roughly 2 in 10 individuals experience hearing loss due to listening to loud music for long periods of time [7]. Thus, the results of this study will contribute to the improvement of product design by analyzing the type of earphones and the optimal volume setting in environments where individuals are usually exposed to. Furthermore, this study will contribute by assessing the risk of having a noise-induced hearing loss due to high volume setting of earphones and external noise.

1.3 Scope and Limitations

This study only focused on two types of earphones: the in-ear and the earbud type, and only one brand for each pair of earphones represented two earphone types. For the preference of the users, only the subjective sound quality based on individual preferences was considered since this study relates the user's subjective experience and the risk of hearing loss associated with it. Furthermore, this study was focused on gathering data from individuals within the age range of 18 years old to 25 years old, for a total of 22 respondents. Lastly, the study considered 3 environments to collect data from and create a simulation of; a coffee shop, a busy street, and a waiting shed – places that are presumably common environments where people usually stayed at or walked around.

2 Problem Statement

Individuals tend to listen to music using earphones at their preferred volume for a prolonged time in varied locations. Because of this, the user might be putting himself/herself at risk of hearing loss, depending on the associated response to the factors at hand. Thus, it is necessary to determine the behavior of users when utilizing earphones in certain environments. The identification of which can provide insight on the optimal earphone type and the maximum environmental sound level that a person can use earphones during a set period, so not to be at risk of NIHL.

3 Objectives

This study generally aims to determine the optimal earphone type in terms of the subjective quality of sound produced and the potential NIHL involved. The specific objectives of the study are as follows:

(1) Determine the correlation between earphone volume level and noise level of the environment for both the earbud and in-ear type earphone based on the user's preference;
(2) Determine the perceived sound quality of users for every specific earphone type; and
(3) Provide recommendations within the two-month duration of the study, to reduce the risk of earphone users to hearing disorders.

4 Materials and Methods

4.1 Materials

The materials to be used in this study are summarized in Table 1.

Table 1. Materials and their uses in the study.

Material/Equipment	Description
Survey Sheets	• Used for obtaining qualitative metrics such as perceived sound quality, and preference of the users
Silicone Ear Canal Models	• Represent the ear for acquiring the sound level of earphones • Only includes the ear canal • Molded with fire to ensure a perfect fit for both types of earphones
Earphones	• Earbud type earphones • In-ear earphones
Sound Meter with Data Logger	• Used to measure the sound level (in dB) of the earphones and noise level of the different environments
Mobile Phone (Apple Iphone 4S)	• Used for playing the sound and where the earphones will be connected
Laptop, Speakers, and Wires	• Used in playing the sound of the simulated environments

As shown in Table 1, this study will make use of two types of earphones, namely the earbud type and the in-ear earphones, which are shown in Fig. 1. In identifying the proper material that could mimic the ear canals of humans, Dabrowska et al. (2015) indicated several materials that assumes several properties of human skin. Some of those materials are liquid suspensions, gelatinous substances, elastomers, epoxy resin, metals, and textiles. Each of those replicated properties of the human skin, from its physical properties to its chemical properties. Silicone in particular replicates the surface property of skin along with optical properties. Some of the common uses of silicon skin models are optical imaging, absorption rate measurement, needle penetration, tactile assessment, friction, indentation, acoustics, and photoacoustics [4].

Fig. 1. Illustration of the earbud type earphones (left) and the in-ear/canal type earphones (right) [4].

4.2 Key Performance Indices

4.2.1 Perceived Sound Quality

A qualitative measure that captures a user's impression of sound quality is a post-experiment survey questionnaire that logs a user's subjective preference. The participant shall answer the *Perceived Sound Quality* Questionnaire in reference to both the in-ear earphones and the canal earphones after using each type.

4.2.2 Personal Sound Equipment

The Personal Sound Equipment (PSE) Hearing Loss Index is a quantitative metric that shall uniquely be found in this research, in an attempt to accurately identify the risk of hearing loss when using earphones while exposed to certain external environments. This metric aims to identify the likelihood of hearing loss when using earphones in a certain environment by relating the selected satisfactory volume level of playing music to the noise in the simulated environment.

4.3 Methods

The general procedure undertaken in this study followed three phases. The first of the three phases focused on benchmarking the necessary sound levels needed in the next two phases. The second phase was the actual experimentation where raw data were gathered from 22 respondents. The final phase processed the collected data, which in turn was used to draw final conclusions. Figure 2 summarizes the phases of this study's methodology.

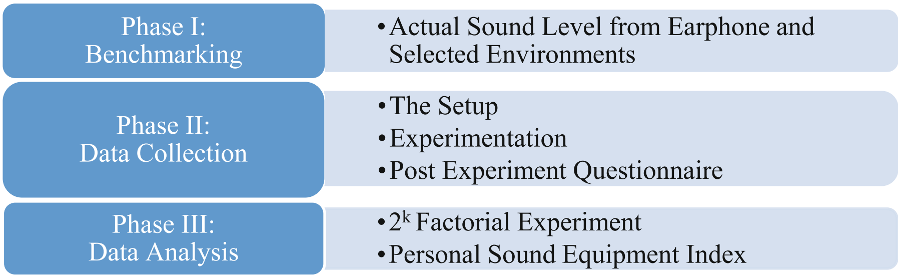


Fig. 2. The general procedure of the study from Phase 1 to Phase 3.

4.3.1 Phase I: Benchmarking

Using the sound meter and ear canal models, as shown in Figs. 3 and 4, the actual sound level produced by the earphones were measured for each incremental change on the music player (i.e. mobile phone). The earphones were placed at one side of the model, and the sound meter at the opposite end. One song was used in measuring the 180-s sound level average and the data collection. In this case the selected song was *Closer* by Chainsmokers since that was the top played song of 2017 on Spotify, a music streaming application.

Fig. 3. Ear canal models used to benchmark the sound derived from the earphones

Three kinds of environments were simulated in this study: a coffee shop, a busy street, and a waiting shed. The sound level per environment were measured at different times of the day. For the three selected environments, the sound levels were randomly collected between 9:00 AM to 6:00 PM, with one 60-s sample being collected with each hour of the day. The day's average values were then calculated and were used in the simulated environment.

Fig. 4. Image of an earphone attached to the ear canal model

4.3.2 Phase II: Data Collection

The different environments were simulated in a room, and the volume was adjusted according to the measured range of sound level of the three environments. The initial setting up of the appropriate sound level was measured and adjusted from the same spot as where the participant stayed during the experiment. Figure 5 provides a visual representation of the setup in the simulated environment.

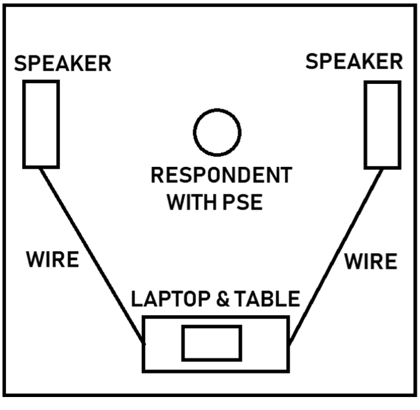


Fig. 5. Top-view of the set-up for the simulated environments

Before proceeding with the experiment, a waiver (see Appendix B) was filled out by each participant. Then, respondents were exposed to the sound played in the simulated room, and while using the earphones, were asked to adjust the volume from the mobile phone until they were satisfied. To minimize any potential negative impact, the participants were given a maximum of one minute to adjust the volume. Also, the task was done blindly without knowing the sound level indicated on the phone. This was done for all three environments. After the experiment, respondents answered a survey centered around their perceived sound quality and listening habits (see Appendix A).

4.3.3 Phase III: Data Analysis

In order to assess the significance of the three variables; namely, environmental noise level, satisfactory sound level, and type of earphones. The collected data were assessed with the help of design expert. For this experiment, there were 22 respondents which accounted for 22 replicates with 22 blocking indicated in each designed experiment. In this case, the two 2^k factorial experiments were preferred in order to obtain a quantitative formulation of the environmental sound level, as compared to having one designed multi categoric experiment that contained purely categorical factors that are qualitative in nature. Upon analysis of the data, the significance of each factor on one another and on the expected satisfactory sound level were quantified.

With the goal the assessing the potential risk of using earphones in an external environment, the following is the formula for the unitless PSE index:

$$\frac{Satisfactory\ Earphones\ Sound\ Level}{Maximum\ Allowable\ Sound\ Level}. \tag{1}$$

The range of this metric was from zero onwards, with one being the supposed maximum allowable value for the index. A value greater than one denotes that the perceived satisfactory sound level is beyond the safe hearing sound level. Hence, such sound level is detrimental and may result into hearing loss.

5 Results and Discussion

5.1 Phase I: Benchmarking

In getting the needed volume of the simulated environment, the researchers were able to derive the average sound level in the selected areas. The summary of those results can be seen in Table 3.

Table 3. Grand Mean Noise Level computed for each location.

	Coffee shop	Busy street	Waiting shed
Grand Mean Noise Level (dBA)	70.967	72.610	72.160

Meanwhile, for the sound level produced by the each of the two types of earphone pairs, the 180-s average for each of the 16-volume increment on the mobile phone used were taken. Table 4 summarizes the sound level, dBA, for each type of earphone for each volume increment.

Table 4. Sound Level per volume increment for each earphone.

Trial	Earbuds	In-Ear
1	46.2	42.6
2	49.4	43.6
3	54.5	45.2
4	59.9	45.6
5	64.7	46
6	69.3	47.6
7	73.9	50.9
8	77.8	54.3
9	81.7	58.4
10	85.7	62.2
11	89.8	66
12	92.7	68.5
13	96.7	73
14	99.3	76
15	103.2	80.1
16	106.4	86

5.2 Phase II: Experimentation

The second phase of the experiment was composed of two main parts: the testing of the earphones in each of the specified environments and the post-experiment survey. Based on the survey, 10 out of 22 people and 9 out of 22 people use their earphones at a coffee shop and at a busy street, respectively. The latter most frequently listen to music while at a waiting shed. Meanwhile when at a coffee shop or busy street, 81.8% and 77.3% respectively, of the respondents listen with earphones for under 2 h. As for the length time that people spend listening to music at a waiting shed, all respondents stated that they listened to music for 0–2 h. Furthermore, majority of the respondents prefer earbuds over in-ear earphones. The said earphone types differ in the sound quality produced, which means that the volume setting by the person will depend on the sound quality produced by the corresponding earphone type.

5.3 Phase III: Data Analysis

Using Design Expert, the significance of the factors (Environment Sound Level and Type of Earphones) were assessed. The responses of the participants were analyzed using two 2^k factorial experiments in order to get a numerical model.

For the first designed experiment, the coffee shop and the waiting shed were considered in a 2^k factorial experiment. Based on *ratio of max to min* the model is adequate at 2.28319, with the ratio being less than 10. The half-normal plot on the other hand shows that the significant factors that contribute the sound level are the environment and the type earphones. The interaction between the two factors are not significant. The second designed experiment was also a 2^k factorial experiment between the coffee chop and the busy street. The second designed experiment is also adequate with a ratio of max to min of 2.1969. Figure 6 shows the half normal plots of the two factorial experiments.

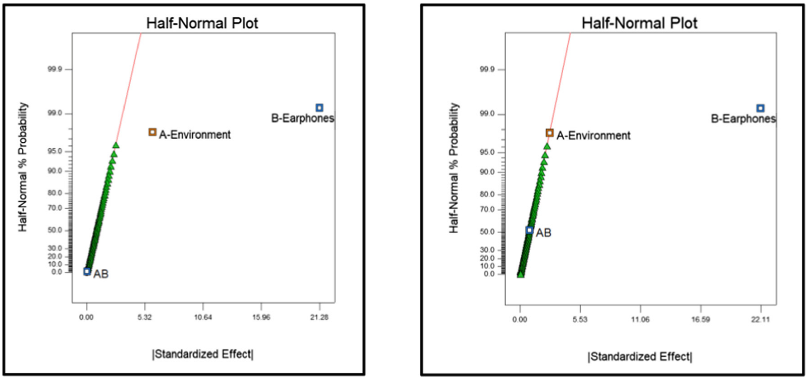


Fig. 6. The half-normal plot of the first designed experiment (left) and the second designed experiment (right)

For the first factorial experiment, in order to further verify the significance of the environment and the type of earphones on the resulting satisfactory sound level, the Analysis of the Variance (ANOVA) table was viewed. On the ANOVA table, it can be seen that the p-values for the environment and the type of earphone are <0.0001, which is smaller than 0.05. Hence, both factors are significant in a quantitative standpoint. Meanwhile, the interaction of those factors is 0.9816, a value much higher than 0.05; further suggesting that the interaction of other factors are not significant. Generally, the entire model's p-value is <0.0001 so the despite the interaction being insignificant, the model itself is a viable model. As for the second model, similar to the first experiment, both the type of earphone and environment are significant. The p-values associated with the significance of the environment and the type of earphones are 0.0238 and <0.0001, respectively. The p-value corresponding to the insignificance of the interaction of either factors is 0.4660, which is larger than the allowable p-value of 0.05 to be considered significant.

Lastly from the Fig. 7, it can be clearly seen that the pair of in-ear earphones gave results that were lower than the earbud type earphones. Purely basing on the created model, in-ear earphones are more ideal in ensuring that sound levels do not reach dangerous levels. The external sound level also plays a part as seen on the graph, where a slight jump in satisfactory sound level can be seen with an in increase in the environmental sound level. Moreover, the following equations model satisfactory sound level based on the collected data. With Eq. 2 being the model for the satisfactory sound level when using the earbud type earphones and Eq. 3 being the model for the in-ear type of earphones.

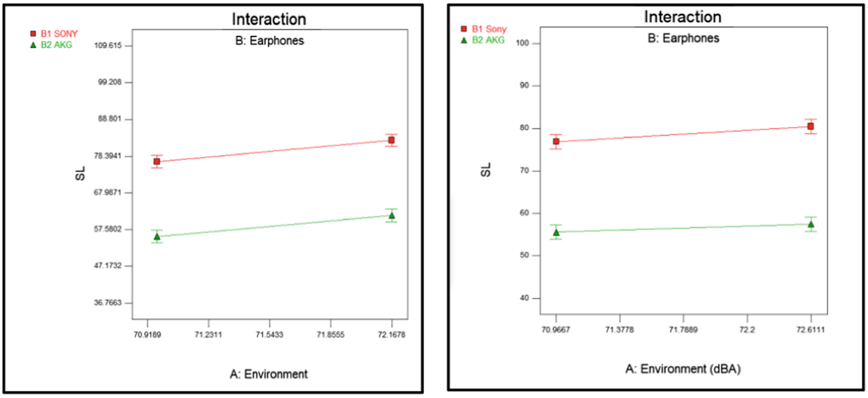


Fig. 7. The graph of results of the first designed experiment (left) and the second designed experiment (right)

$$SL = -281.46898 + (5.04924 \times \text{Environment}). \quad (2)$$

$$SL = -299.21986 + (5.00 \times \text{Environment}). \quad (3)$$

As for the PSE index, the PSE index formula was used to derive scatter plots to visually represent the indices based on the listening habits of the respondents and their resulting satisfactory sound level. Using earbud type earphones, an average PSE index of 0.7866 for all the environments was computed and none of the 66 data points exceeded the value of one. Thus, in this experiment no one is at risk of a hearing loss when exposed to environments with a maximum of 72.16. Consequently, with the in-ear earphones, the average PSE index for all three environments using the in-ear earphones is 0.5868. Also, none of the 66 data points for exceed one; hence, the in-ear earphones do not put listeners at a risk of hearing loss at a maximum external sound level of 72.16. Moreover, with the average PSE index of in-ear earphones being less than that of canal phones, in-ear earphones are safer to use than canal earphones.

6 Conclusion and Data Analysis

The analysis from the data gathered shows that the environment and the type of earphones are significant factors to the sound level. However, there is no significant interaction between the two factors. Further analysis shows that users of in-ear earphones are at less risk of NIHL since both the factorial experiments and the PSE indices manifests such.

Meanwhile basing on the outcome, none of the respondents are at risk of hearing loss given their current listening habits. Generally, earbud earphones users should not use earphones in an environment that exceeds 75.5 dBA for around two hours to avoid NIHL. While, in-ear earphones users are not at all at risk since the maximum sound level it produces is less than the prescribed limit. Therefore, regular earphones users should utilize in-ear earphones despite the preference of earbud type earphones. Users of earbud type earphones should also be cautious of the sound level that they choose since the maximum sound level produced by the earphones exceed the acceptable level.

Appendix

Appendix A

An Assessment of the Potential Risk of Hearing Loss from Earphones Based on Type of Earphones and External Noise

Personal Information

Name: ______________________

Age: ______________________

Student Number: ______________________

Music Preference (Title of Song): ______________________

____

Music Preference (Genre): ______________________

For the following questions, please write your answers on the space provided.

Introductory Questions

1. How much do you like listening to music? Encircle one, 5 being the highest:

1	2	3	4	5

2. Do you own a pair of earphones? (Encircle one: Yes/No)
3. Do you think earphones could be, in any way, harmful or detrimental to your health? (Encircle one: Yes/No)
4. Would you recommend using earphones to your friends or your relatives? Why?

____

____

____

Volume Setting Questions

1. Do you prefer hearing environmental sounds while you are using your earphones? (Encircle one: Yes/No)

Time Questions

1. How often, in general, do you listen to music on a day-to-day basis?
   a. 0-2 hrs per day
   b. 3-4 hrs per day
   c. 4-6 hrs per day
   d. 6-8 hrs per day
   e. 8 hours or more
2. How long have you been using earphones in your life (in Years)? ______________________

Place Questions

1. Among the three options, where do you usually use your earphones? (Coffee Shop / Busy Street / Waiting Shed)
2. How long do you listen to music when you are at a coffee shop?
   a. 0-2 hrs per day
   b. 3-4 hrs per day
   c. 4-6 hrs per day
   d. 6-8 hrs per day
   e. More than 8 hours
3. How long do you listen to music when you are at a busy street?
   a. 0-2 hrs per day
   b. 3-4 hrs per day
   c. 4-6 hrs per day
   d. 6-8 hrs per day
   e. More than 8 hours
4. How long do you listen to music when you are at a waiting shed?
   a. 0-2 hrs per day
   b. 3-4 hrs per day
   c. 4-6 hrs per day
   d. 6-8 hrs per day
   e. More than 8 hours
5. Why do you use earphones at these locations?

____

____

____

6. Please cite other environments where you use earphones.

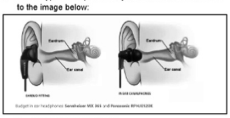
____

____

____

Post-Experiment Questions

1. Which type of earphone do you often use? Please refer to the image below:



   a. Earbuds / Canalphones
   b. In-ear earphones
2. In general, which type of earphone do you prefer? Why?(Earbuds, Canalphones/In-ear Earphones)
   a. Earbuds / Canalphones
   b. In-ear earphones
3. Which earphone do you prefer in terms of sound quality? (Earbuds, Canalphones/In-ear Earphones)
4. Which type of earphone would you prefer using:
   a. At a coffee shop? ______________________
   b. At a busy street? ______________________
   c. At a waiting shed? ______________________

Appendix B

CONSENT FORM OF RESEARCH PARTICIPATION

Study Title

An Assessment of the Potential Risk of Hearing Loss from Earphones Based on Type of Earphones and External Noise

Researchers

Chanco, Manuel Vincent P.
Gayahan, Ysabel Neena R.
Reyes, Jeriko Merlo E.
Villa, Alethea Diana P.

Date and Time of Study

November 22 and 23, 2018 at 10 AM – 6 PM

Procedures

The participant shall be asked to test two types of earphones, namely canal type and in-ear type. The participant will be exposed to the simulated environment and will then be asked to adjust the volume level produced by the earphones until the participant is satisfied with the volume and the sound quality.

This procedure will be done in three different simulated environments, and three trials each.

Possible Risks or Discomforts

The researchers assure that this study will bring no discomfort to its participants. The researchers also assure no threshold shift in the hearing of the participants since the procedure will only be exposed nine (9) times to the sound, and each trial will take no more than one (1) minute. There will also be breaks between each trial.

CONSENT

Please check all that apply:

- ☐ *The study and its procedures have been explained to me.*
- ☐ *I have been given the opportunity to ask questions and my questions have been answered.*
- ☐ *I agree to take part of this research study mentioned above and I will receive a copy of this consent form.*
- ☐ *If I have further questions, I have been given the contact number of a group representative*

_______________________________ _______________
Name (optional) and Signature of Participant *Date*

_______________________________ _______________
Name and Signature of Group Representative *Date*

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The Gap in the Safety Knowledge Between the Small-Scale Miners and Local Mining Monitoring Body in the Philippines

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Abstract. Small-scale mining is one of the most unsafe human activities in the Philippines. This paper aims to measure the gap between the concept of safety among miners and the local government mining monitoring body. This study checked the difference in percentage of exposure of miners on hazards in mining sites based on their perception and the perception of officials of local government mining monitoring body specifically the Department of Environment and Natural Resources at the provincial (PENRO) and municipal (MENRO) levels and the local level disaster risk management (LLDRM). An assessment tool was developed and used in three mining sites. To compare their agreement on safety, the study used Cohen's kappa, a statistical tool for assessing inter-rater reliability when observing categorical variables. There was a big difference in the knowledge of safety and safety standards for miners and monitoring officials.

Keywords: Human factors · Safety management and human factors · Small scale mining

1 Introduction

Small-scale mining is one of the most unsafe human activities in the Philippines. According to the study by J. Lu on occupational health and safety in small scale mining, the Philippine miners lack proper education and training on safe work practices and awareness of the hazards posed by the chemicals they handle, hence, there is a need for surveillance and regulation by both national and local governments on this type of economic activity [1]. In another study, R. Eisler concluded that in order to protect the health of underground workers, authorities recommend the continued intensive monitoring of atmospheric dust levels in order to conform to recognized safe occupational levels, the implementation of more frequent medical examinations with emphasis on early detection and treatment of disease states, and the continuation of educational programs on the hazards of risky behaviors outside of the mine environment; these recommendations can be implemented satisfactorily through mine management [2].

The Alternate Forum for Research in Mindanao found that miners and plant workers are faced with health problems as a consequence of exposure to the use of

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 298–304, 2020.
https://doi.org/10.1007/978-3-030-20497-6_28

hazardous chemicals in gold extraction and refining processes. Workers do not use protective gears while working on mines and processing plants. The establishment of gold processing plants in residential areas poses health threats to the public [3]. In another study entitled Occupational Health and Safety (OHS) in Mining, M.A. Hermanus stated that there is a need for resources and guidance to address the needs of contract workers, junior, small and artisanal miners. There is a need for training and consistency in risk management practices. Hence, holistic approaches to addressing risks by properly considering OHS risks to humans, human factors and ergonomics; and improving the quality of engagement between managers, workers, and supervisors [4].

According to the aforementioned studies by Lu [1], Eisler [2] and Hermanus [4], when it comes to mining policies, there is a need for proper education and training on safe work practices. While there is a perceived gap in the safety knowledge among miners, another concern is the proper monitoring of compliance to mining policies by the monitoring bodies responsible for this role. In view of this, there is a perceived gap in the safety knowledge for proper implementation of policies by the Philippine local government monitoring body to miners.

2 Methodology

This paper aims to measure the gap between the concept of safety among miners and the local government mining monitoring body. This study checked the difference in percentage of exposure of miners on hazards in mining sites based on their perception and the perception of officials of local government mining monitoring body specifically the Department of Environment and Natural Resources at the provincial (PENRO) and municipal (MENRO) levels and the local level disaster risk management (LLDRM). An assessment tool was developed and used in three mining sites. To compare their agreement on safety, the study used Cohen's kappa, a statistical tool for assessing inter-rater reliability when observing categorical variables.

2.1 Participants

A questionnaire was used to check the initial differences of the miners and local government mining monitoring body. The participants were asked if they have ever used an assessment tool, are they familiar with DAO 97-30 (Small Scale Mining Law) [6], and how many times are they exposed to mining sites.

2.2 Risk Evaluation

The hazards identified in small scale mining sites was assessed using the risk level score. Risk level can be determined by multiplying severity and likelihood points. The severity, likelihood, and risk level determination came from Risk Assessment Workbook for Mines for metalliferous, extractive and opal mines, and quarries [5]. This reference was chosen because it is relevant to mining.

Severity point system shows the consequences a hazard can affect the miners. The higher the points, the more severe it is. Five points is given to maximum consequence, that causes fatality or death which is very critical (e.g. tunnel collapse, falling for more than specific feet, or suffocation). Four points is given to a consequence of permanent disability that would make miners incapable of working in mines or part of their body will not be able to work properly, which is very serious (e.g. fall from specific feet, broken arms or legs, deafened, or blindness). For an activity that needs to be hospitalized or with lost time, means leaving from work for a certain number of days to recover, will have a severity points of three, which is defined as serious (e.g. exposure to borax, headaches, or stomach aches). Activity with no lost time consequences or only needs first aid will be given two points as marginal severity (e.g. scratches). Activities that cause no physical injuries are defined as negligible with one point severity level (e.g. *Kulipaw* and threatening).

The likelihood point system is for the occurrence or exposure of specific hazard in the area. The higher the points the higher the chances that hazard occurs. Likelihood differs on the geographical location of the site, the experience of miners (the older the more aware) and other factors. Five points refer to almost certain that it will occur every time they operate or common occurrence (e.g. stumbling, no PPE, exposure chemicals). Four points refer to likely, known to have occurred or often occur (e.g. rock fall, the collapse of tunnel, instability). Three points refer to possible or heard it occur but have not witnessed its occurrence in that site (e.g. drowning, falling in abandoned tunnels, suffocation). Two points refer to unlikely to happen and almost never. One point refers to rare cases that are sometimes practically impossible (e.g. blasting from sites that do not use explosive).

Risk level is computed as the product of the likelihood points and severity. The points have corresponding risk level.

$$Severity \times Likelihood = RiskLevel \tag{1}$$

For a score ranging 15–25, it is a high risk that needs urgent actions. It has also the 1st priority to be addressed by the management. For 5–12, it is a moderate risk that could be mitigated after some time and considered the 2nd priority. For 1–4, it refers to low risk, mean that controls should be maintained, no actions, or can be addressed later. Risk level actions and priority summary are shown at Table 1 below.

Table 1. Risk level determination for small scale mining

Risk level Determination *RISK LEVEL= SEVERITY X LIKELIHOOD*		SEVERITY				
		Critical (5)	Very Serious (4)	Serious (3)	Marginal (2)	Negligible (1)
	Almost Certain (5)	25 High Risk	20 High Risk	15 High Risk	10 Medium Risk	5 Medium Risk
	Likely (4)	20 High Risk	16 High Risk	12 Medium Risk	8 Medium Risk	4 Low Risk
	Possible (3)	15 High Risk	12 Medium Risk	9 Medium Risk	6 Medium Risk	3 Low Risk
	Unlikely (2)	10 Medium Risk	8 Medium Risk	6 Medium Risk	4 Low Risk	2 Low Risk
	Rare (1)	5 Medium Risk	4 Low Risk	3 Low Risk	2 Low Risk	1 Low Risk

2.3 Comparing Using Cohen's Kappa

Cohen's Kappa was then used to check the agreement of assessors to show the clear existence of individual biases. It is a statistical tool used to assess inter-rater reliability when observing categorical variables. Kappa has a range from 0.00–1.00, with larger values indicating better reliability.

$$Kappa = \frac{(observed\,percentage\,of\,agreement) - (the\,Expected\,percentage\,of\,agreement)}{1 - (Expected\,percentage\,of\,agreement)} \tag{2}$$

The participants' risk assessment were compared to know the agreement of a certain hazard is perceived or computed as low risk, medium risk, or high risk.

3 Results and Discussion

3.1 Site A

In Site A, none have used risk assessment tool before. Like other sites, PENROS and miners have mine exposure of approximately 1% compared to miners. For the safety standards, miners said they have complied to 129 standards while the PENROs ranges from 79–69 only.

Cohen's Kappa was used to know if the PENRO1 vs. PENRO2, PENRO1 vs. MINER, and PENRO2 vs. MINER, agreed if the safety controls are in place, no safety controls, or not applicable in the site. The two PENROs agreed well with k = 0.889, but the PENRO and miners have a fair agreement that ranges from k equal to 0.23 to 0.26. This implies that the miners view that they have compiled on the standards, while the PENROs think that they complied on the few. Table 2 below shows the k values of agreement on controls and risk.

Table 2. Site A k values for agreement on the availability of controls and level of risk

	Almost Perfect	Substantial	Moderate	Fair	Slight	Poor
	>0.81	0.61-0.8	0.41-0.60	0.21-0.40	0-0.20	<0
Summary of agreement of controls						
PENRO1 vs. PENRO2	0.889					
MINER vs. PENRO1				0.266		
MINER vs. PENRO2				0.239		
Summary of agreement in level of risk						
PENRO1 vs. PENRO2		0.619				
MINER vs. PENRO1					0.091	
MINER vs. PENRO2					0.040	

3.2 Site B

In Site B, MENROs have low mine exposure, here it is approximately 17% compared to miners. In Cohen's Kappa computation, it was that the miners have moderate to a fair agreement on the availability of controls with the MENROs and LLDRM. Miners perceive 30–40 available of controls and the rest are not available while LGUs have 9–28 identified available, and the rest are not available or not applicable. Miner vs. Miner shows almost perfect agreement.

Table 3. Site B k values for agreement on the availability of controls

	Miner1	Miner2	MENRO-DR	MENRO-GS	LLDRM EGJ
Miner1		0.959229	0.529733	0.331474	0.242581
Miner2			0.494254	0.316079	0.232943
MENRO-DR				0.486202	0.302523
MENRO-GS					0.618722
LLDRM EGJ					

To compare the degree of risk, the miners both agreed with k = 0.88 which means, almost perfect. The LLDRM vs. Miner1 shows a very poor agreement of k = −0.039 which means they do not agree at all. The table below shows the summary of their agreement on risk levels.

Table 4. Site B k values for agreement on the risk level

	Miner1	Miner2	MENRO-DR	MENRO-GS	LLDRM EGJ
Miner1		0.88501027	0.13253012	0.18122977	-0.03962264
Miner2			0.05882353	0.26517572	0.02658487
MENRO-DR				0.0942623	0.06235012
MENRO-GS					0.71317073
LLDRM EGJ					

3.3 Site C

It was checked if the standard or other controls are present or not. It resulted in a score of 0.165 which means that the PENRO and miner had weak strength of agreement. On the agreement on the degree of risk, the total score is 0.098 which show weak agreement on the degree of risk. This implies that the PENRO feels that a hazard has a different degree compared to the miners.

Table 5. Site C k values for agreement on the availability of controls and level of risk

	Almost Perfect	Substantial	Moderate	Fair	Slight	Poor
	>0.81	0.61-0.8	0.41-0.60	0.21-0.40	0-0.20	<0
Agreement on the availability/ compliance of controls					0.165	
Agreement on the risk level					0.098	

Hence, almost all local government monitoring body (PENRO, MENRO and LLDRM) do not substantially agree with small scale miners the concept of safety.

4 Conclusion and Recommendations

In conclusion, there is a big difference in the knowledge of safety and safety standards for miners and monitoring officials. The government should take initiative to conduct training/seminars to narrow this gap. However, a major hindrance is the unregulated nature of mining operations. Thus, the government needs to declare more areas as "Minahang Bayan" for which small-scale mining operations are permitted. Consequently, the miners can avail of needed assistance from the government.

Acknowledgments. The authors acknowledge the support provided by the Engineering Research and Development for Technology (ERDT) program of the Department of Science and Technology and spearheaded by the UP College of Engineering. The data requirements gathered for this study was made possible through the ERDT Mineral Extraction with Responsibility and Sustainability (MINERS) Program, Project G, entitled: "The Gold and Copper Chase (Life Cycle Analysis of Sustainable Small Scale Production Systems)".

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Safety Perception and Behaviour Analysis

Gender Differences in Risk-Taking-Related Personality Traits and Risk Perception: Implications for Safety Training and Awareness Programs

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Abstract. This study aims to examine gender differences among engineering students in terms of risk-taking-related personality traits and risk perception. Thirteen scenarios based on actual fatality cases in the construction industry were used in the analysis. A total of 100 engineering undergraduates (male: 63, female: 37) were interviewed to identify their risk-taking-related personality traits and risk perception. Among ten personality traits, results show that being adventurous was the only personality trait positively correlated with risk-taking behaviour among female respondents. Two personality traits, namely, being adventurous and arrogant, were positively correlated with risk-taking behaviour among male respondents. The personality trait of calm was negatively correlated with risk-taking behaviour among male respondents. In terms of risk perception, females were slightly lower than males. These findings can be used as a reference for designing different safety training and awareness programs for male and female engineers and workers in the construction industry.

Keywords: Risk-taking-related personality traits · Risk perception · Construction industry · Risk-taking behaviour · Gender differences

1 Introduction

The female labour force participation in the construction industry has an increasing rate [1]. Gender differences may contribute to a dissimilarity on risk-taking behaviour between males and females. Thus, a spectrum of practices is required to be implemented to adapt to the influx of female workers. Personality traits and risk perception are important elements influencing risk-taking behaviour [2]. Males and females have different personality traits [3], potentially resulting in different risk perceptions and risk-taking behaviours [4]. Risk perception is a subjective evaluation on the consequences of events [5]. Thus, individual risk perception influences the possibility of taking certain behaviours [5]. Such perception is constructed based on personal beliefs, individual values and experiences [6]. Therefore, acknowledging the differences

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 307–316, 2020.
https://doi.org/10.1007/978-3-030-20497-6_29

between males and females in terms of risk-taking-related personality traits, risk perception and risk-taking behaviour is important in designing an appropriate training program to accommodate both genders. This study aims to identify gender differences in risk perception and its related personality traits. An additional objective is to quantify the correlation between relevant personality traits and risk perception.

2 Methodology

A questionnaire survey approach was used to evaluate the risk perception and risk-taking-related personality traits of the respondents. The results were analysed using the Statistical Package for the Social Sciences (SPSS).

2.1 Questionnaire Respondents

A total of 100 engineering students (63 males, 37 females) from the City University of Hong Kong participated in the survey, all with informed consent and under the university's ethical guidelines.

2.2 Design of the Questionnaire

The questionnaire was divided into two sections: (1) 13 risk perception scenarios based on actual fatality cases in the construction industry and (2) risk-taking-related personality traits and types of risk takers. In the first section, 13 scenarios were used to identify the risk perception of the respondents. Table 1 shows the types of risks in the 13 scenarios. In the second section, 10 personality traits, namely, adventurous, emotional, instinctive, calm, impatient, inflexible, irresponsible, nervous, arrogant and thoughtless. Males and females potentially differ in these specific traits and these traits are likely to affect risk perception in construction context. These traits were discussed by a group of engineering students. The 10 personality traits were used to evaluate the intention level of risk-taking behaviour among the respondents. Table 2 shows the questions for the 10 personality traits.

Table 1. Types of risks in the 13 scenarios based on construction risk perception.

Scenarios	Types of risks
1	Contact with electricity or electric discharge
2	Contact with a moving machinery or object being machined
3	Fall of person from height
4	Injury while lifting or carrying
5	Strike against a fixed or stationary object
6	Strike against or struck by a moving object
7	Strike by a falling object (metal)
8	Strike by a falling object (cotton bale)
9	Strike by a moving vehicle

(*continued*)

Table 1. (*continued*)

Scenarios	Types of risks
10	Slip, trip or fall on the same level
11	Trap by collapsing or overturning object
12	Weather (heat)
13	Weather (typhoons, hurricanes, and cyclones)

Table 2. Questions for the 10 personality traits.

Personality traits	Questions
Adventurous	If I have a chance, I would like to try skydiving The planned country trail is my only choice for excursion
Emotional	I emotionally react when my friend speaks carelessly I easily wear a poker face
Instinctive	I think reading the instruction of electronic device is not important. It is more practical to immediately use the device I trust map more than my intuition if I get lost
Calm	When there is a car accident, I would like to help the others even if I suffer from small injures I do not know what to do when someone faints in front of me
Impatient	Waiting for someone or something is annoying I do not mind waiting for a few hours if the restaurant is recommended by friends
Inflexible	I think it is important to follow the rules even though it is wrong I believe things can be done in various ways
Irresponsible	I seriously take the assignment even though I am not responsible in fixing it when it turns wrong I will do my best if I accept the task, however, it is not my concern if it cannot be done
Nervous	I act unusually like sweaty hand when I have to publicly perform No matter how difficult things can be, I believe it is going to be fine
Arrogant	The others must follow my instruction If I have the right to choose, I hope I am not the leader in any groups
Thoughtless	I always forget to bring my belongings when I leave It is important to carefully read each question during the examination

2.3 Measures

In the first section, the risk perception was measured on a seven-point scale (7 = the highest possibility of working and 1 = the lowest possibility of working). In the second section, the risk-taking preference was measured using the seven levels of parameters. The parameters on the possibility of risk-taking preference were categorised into five types. Table 3 demonstrates the five types of risk takers classified by a seven-point scale (7 = extreme risk taker, 6–5 = high risk taker, 4 = moderate risk taker, 3–2 = low risk taker and 1 = minimum risk taker).

Table 3. Five types of risk takers based on risk parameter.

Risk parameter	Type of risk taker
7	Extreme risk taker
6–5	High risk taker
4	Moderate risk taker
3–2	Low risk taker
1	Minimum risk taker

2.4 Reliability Test

The reliability of the measure was tested by Cronbach's alpha in SPSS (version 21). When Cronbach's alpha was lower than 0.7, internal consistency was considered unacceptable [7]. Two items were eliminated in the second section as the values of Cronbach's alpha were less than 0.7. The two eliminated items were 'emotional' and 'irresponsible' (Table 4).

Table 4. Results of the reliability test.

	Cronbach's alpha (Male)	Cronbach's alpha (Female)
Adventurous	0.841*	0.830*
Emotional	0.524	0.901*
Instinctive	0.899*	0.830*
Calm	0.750*	0.766*
Impatient	0.832*	0.837*
Inflexible	0.919*	0.859*
Irresponsible	0.745*	0.648
Nervous	0.703*	0.808*
Arrogant	0.860*	0.850*
Thoughtless	0.909*	0.814*

*Cronbach's alpha > 0.7

3 Results and Analysis

3.1 Risk Perception in the Construction Industry

3.1.1 Case Analysis

A total of 13 cases based on actual fatality cases in the construction industry were used in this study (Table 5). The maximum mean values for males and females among the 13 cases were 3.70 and 3.65, respectively. The minimum mean values for males and females among the 13 cases were 2.33 and 2.51, respectively. The range of the standard deviation for males was between 1.45 and 1.94. The range of the standard deviation for females was between 1.62 and 1.88. Both male and female respondents constituted the greatest mean value in case 12 (heat weather) and the smallest mean value in case 7 (strike by a falling metal). Across all scenarios, females mean response (3.14) was slightly higher than that of the males (2.98). The results indicated that males and females had a relatively low risk perception on working in high temperature and a relatively high-risk perception on striking by a falling metal.

Table 5. Risk perception analysis of male (N = 63) and female (N = 37) respondents.

	Male				Female			
	Min	Max	Mean	STD	Min	Max	Mean	STD
Case 1	1.00	6.00	2.84	1.71	1.00	7.00	3.24	1.89
Case 2	1.00	7.00	2.35	1.65	1.00	7.00	2.97	1.88
Case 3	1.00	7.00	3.37	1.75	1.00	7.00	3.54	1.86
Case 4	1.00	7.00	3.40	1.73	1.00	6.00	3.51	1.79
Case 5	1.00	6.00	3.06	1.73	1.00	7.00	3.16	1.79
Case 6	1.00	7.00	2.62	1.63	1.00	7.00	2.78	1.73
Case 7	1.00	7.00	2.33	1.63	1.00	6.00	2.51	1.84
Case 8	1.00	7.00	3.14	1.45	1.00	7.00	3.62	1.83
Case 9	1.00	7.00	3.02	1.73	1.00	7.00	3.32	1.78
Case 10	1.00	6.00	3.11	1.70	1.00	7.00	3.00	1.86
Case 11	1.00	7.00	3.14	1.86	1.00	6.00	2.89	1.71
Case 12	1.00	7.00	3.70	1.94	1.00	7.00	3.65	1.87
Case 13	1.00	7.00	2.70	1.60	1.00	6.00	2.65	1.62

Note: Min = minimum value; Max = maximum value; STD = standard deviation

3.1.2 Proportion of Risk Perception

The lower the level of risk perception, the higher the possibility of risk taking, and vice versa. Table 6 shows the percentages of the types of risk takers among the male and female respondents. For male respondents, the percentages of extreme, high, moderate, low and minimum risk takers were 0%, 22%, 24%, 51% and 3%, respectively. For female respondents, the percentages of extreme, high, moderate, low and minimum risk takers were 3%, 27%, 16%, 51% and 3%, respectively. The findings indicated that majority of the respondents were low risk takers.

Table 6. Percentages of the types of risk takers among the male (N = 63) and female (N = 37) respondents.

	Extreme risk taker	High risk taker	Moderate risk taker	Low risk taker	Minimum risk taker
Male	0	22	24	51	3
Female	3	27	16	51	3

3.2 Risk-Taking-Related Personality Trait Analysis

3.2.1 Proportion of Inclination on Personality Traits

Table 7 shows the percentages of inclination on the eight personality traits for male and female respondents based on a seven-point scale. The respondents giving 7, 6, and 5 points were counted as those having that personality trait. For male respondents, the personality trait with the greatest percentage was being adventurous with 84% and that with the smallest percentage was being thoughtless with 24%. For female respondents, the personality trait with the greatest percentage was being nervous with 91% and that with the smallest percentage was being arrogant with 27%. Such results revealed that majority of the male respondents were adventurous, and majority of the female respondents were nervous.

Table 7. Percentages of inclination on the 8 personality traits for the male (N = 63) and female (N = 37) respondents on the seven-level risk parameter.

		7	6	5	4	3	2	1
Adventurous	Male	22	51	11	3	3	8	2
	Female	25	21	18	14	11	7	4
Instinctive	Male	8	40	21	9	14	5	3
	Female	3	27	22	8	21	16	3
Calm	Male	14	27	24	11	21	3	0
	Female	8	43	30	16	3	0	0
Impatient	Male	18	35	24	6	6	11	0
	Female	3	16	35	24	14	8	0
Inflexible	Male	10	21	9	6	29	18	6
	Female	3	22	13	16	24	11	11
Nervous	Male	14	33	16	7	22	8	0
	Female	16	48	27	3	3	3	0
Arrogant	Male	3	11	16	25	21	21	3
	Female	3	13	11	22	40	11	0
Thoughtless	Male	3	13	8	5	32	30	9
	Female	16	24	3	5	38	11	3

3.3 Relationship Between Risk-Taking-Related Personality Traits and Construction Risk Perception

3.3.1 Personality Traits of Risk Takers

Of the five types of risk takers, namely, extreme, high, moderate, low and minimum risk takers, extreme risk takers had the lowest risk perception, whereas minimum risk takers had the highest risk perception. Table 8 shows the percentages of the type of risk taker in each risk-taking-related personality traits for the male and female respondents. No male respondents with the eight personality traits were extreme risk takers. For high risk taker in the male respondents, the personality trait of being inflexible had the highest percentage of 33%, whereas that of being impatient had the smallest percentage of 18%. For low and minimum risk takers in the male respondents, the personality trait of being calm and arrogant had the highest percentage of 63% and that of being thoughtless had the smallest percentage of 28%. For extreme and high-risk takers among the female respondents, the personality trait of being adventurous had the highest percentage of 100% and that of being inflexible had the smallest percentage of 13%. For low and minimum risk takers among the female respondents, the personality trait of being instinctive had the highest percentage of 42% and that of being adventurous had the smallest percentage of 0%. The results revealed that the male respondents with the personality trait of being thoughtless tended to take higher risk than male respondents with the personality traits of being adventurous, instinctive, calm, impatient, inflexible, nervous and arrogant. Female respondents with the personality traits of being adventurous, instinctive, calm, impatient, arrogant and thoughtless were also found to take higher risk than female respondents with the personality traits of being inflexible and nervous. Comparing the percentages of extreme and high-risk takers with the eight personality traits between male and female respondents, female respondents showed higher percentages than male respondents except for the personality trait of being inflexible.

Table 8. Percentages of the risk taker type in each risk-taking-related personality traits for male (N = 63) and female (N = 37) respondents.

		Extreme risk taker	High risk taker	Moderate risk taker	Low risk taker	Minimum risk taker
Adventurous	Male	0	27	25	21	27
	Female	50	50	0	0	0
Instinctive	Male	0	31	29	21	19
	Female	27	22	9	15	27
Calm	Male	0	23	14	27	36
	Female	22	18	22	16	22
Impatient	Male	0	18	26	24	32
	Female	25	20	17	12	26
Inflexible	Male	0	33	16	22	29
	Female	0	13	41	16	0
Nervous	Male	0	20	21	24	35
	Female	21	17	21	20	21
Arrogant	Male	0	19	18	10	53
	Female	0	43	35	22	0
Thoughtless	Male	0	32	40	28	0
	Female	25	13	25	12	25

3.3.2 Bivariate Correlation Analysis

Table 9 shows the bivariate correlation between risk-taking-related personality traits and risk-taking behaviour based on the seven-point scale. For male respondents, the risk-taking-related personality traits of being adventurous, arrogant and calm had statistically significant correlation (p value < 0.05). The personality traits of being adventurous and arrogant were positively correlated with risk-taking behaviour and being calm was negatively correlated with risk-taking behaviour. For female respondents, the risk-taking-related personality trait of being adventurous had a statistically significant correlation (p value = 0.000) and was positively correlated with risk-taking behaviour.

Table 9. Bivariate correlation between risk-taking-related personality traits and risk-taking behaviour for male (N = 63) and female (N = 37) respondents.

		Correlation	2-tailed p value
Adventurous	Male	0.258	0.041*
	Female	0.984	0.000**
Instinctive	Male	0.226	0.075
	Female	0.235	0.161
Calm	Male	−0.288	0.022*
	Female	0.134	0.430
Impatient	Male	0.009	0.947
	Female	0.41	0.811
Inflexible	Male	0.229	0.071
	Female	0.135	0.425
Nervous	Male	−0.229	0.071
	Female	−0.124	0.464
Arrogant	Male	0.275	0.029*
	Female	0.284	0.088
Thoughtless	Male	0.214	0.093
	Female	0.129	0.446

*2-tailed p-value < 0.05
**2-tailed p-value < 0.01

4 Discussion

Working under heat and extremely hot weather was found to be the most underestimated situation as male and female respondents showed low risk perception for such condition. Among other control mechanisms to reduce risk from the increased temperature, there are administrative controls (e.g., water and electrolyte intake and resting in cool area). Our finding here is of critical importance because adhering to such controls might be dependent on the worker's risk perception. High temperature while working can adversely affect the health of construction workers and may also lower productivity and increase occupational injuries [8]. Such situation is due to the increased physical workload of construction workers [9]. For instance, workers' protective clothing potentially generates thermal load. This situation may be worsened due to the inadequate attention by the government and organisations. Alshebani and Wedawatta [10] argued that safety systems should be established by organisations, and sufficient information and training should be provided by supervisors or contractors. Regulations on the arrangement of extreme weathers have to be implemented to ensure the safety and health of workers [8, 11].

For risk-taking-related personality traits and risk-taking behaviour, being adventurous was positively correlated with risk-taking behaviour for both genders. This result supports the previous findings of Lee and Tseng [12]. They stated that risk-taking attitude is positively correlated with the adventurous personality type. However, our study highlighted that the strength of this correlation might depend on gender (see Table 9). A negative relationship between being calm among male respondents and risk-taking behaviour and a positive relationship between being arrogant among male respondents and risk-taking behaviour were demonstrated. Female respondents were found to have higher proportions of extreme and high-risk takers than male respondents among the seven personality traits (i.e. adventurous, instinctive, calm, impatient, nervous, arrogant and thoughtless). Such findings imply that females had lower risk perception. However, according to the study of Reniers et al. [13], males have lower risk perception and take more risks than females. In addition, males are less anxious and sensitive to negative consequences. The inconsistent findings reveal that gender differences on risk perception are still ambiguous. The relationship among personality traits, risk perception and risk-taking behaviours is interdependent. Thus, a distinct finding on gender differences in these elements may assist in the enhancement of safety awareness and consciousness through safety training and awareness programs. In addition, to identity the influences of personality traits on risk perception and risk-taking behaviours, further studies on the influences of other personality traits on risk-taking behaviour are needed.

There were several limitations in this study. First, since results were generated using student sample, it is unknown if same pattern of results would occur when recruiting experienced workers. Students were selected because of the ease-of-access in larger quantities. Second, it is true that statistical power might have differed for each gender given the different sample sizes. However, the study attempted to represent common gender distribution in construction sector. Last, this study examined only the linear relationship between traits and risk perception. Future work should also explore the non-linear correlation.

5 Conclusion

Most respondents were low risk takers and both genders had a low risk perception on working in extreme weather. Most of the male respondents were adventurous and impatient, whereas most of the female respondents were nervous and calm. The personality trait of being adventurous for both genders and being arrogant for males were positively correlated with risk-taking behaviour. The personality trait of being calm for males was negatively correlated with risk-taking behaviour. For male respondents, only those with the personality trait of being thoughtless had higher inclination to take high risk compared with those with the personality traits of being adventurous, instinctive, calm, impatient, inflexible, nervous and arrogant. For female respondents, those with the personality traits of being adventurous, instinctive, calm, impatient, arrogant and thoughtless had a higher inclination to take high risk than those with the personality traits of being inflexible and nervous. The results provide an understanding of the gender differences in risk-taking-related personality traits and risk perception among engineering students. Current safety training and awareness programs have inadequate information on the gender differences in terms of risk perception and risk-taking-related personality traits. Accordingly, the results of this study can be utilised as a reference for designing various safety training and awareness programs for male and female engineers and workers in the construction industry. Thus, further analysis on the influence of different types of personality traits on risk-taking behaviour should be conducted.

Funding. The authors extend their appreciation to the International Scientific Partnership Program ISPP at King Saud University for funding this research work through ISPP-136.

Conflicts of Interest. The author declares no conflict of interest.

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Socially Oriented Design of Technical Systems and Objects: Safety and Accident Prevention

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Abstract. The main purpose of the article is to study the human factor in the technical systems and objects development, to develop a method of socio-economic design that ensures the safety of systems and objects and reduces the probability of accidents on them.

The essence of the article lies in the fact that, according to the authors, the conditions for the safe operation of technical systems and objects should be created in the early stages of designing. At the same time, the safety function should be considered as the main function of the system/object being created, which determines their economic and structural characteristics. This position is proved in the article by analyzing the factors influencing the technical systems and objects creation. The proposed method of socio-economic design of technical systems and objects implies that determining their cost characteristics on the conceive step of their lifecycle is the most efficient if it is based on probabilistic approach. On the next steps of design process, such as concept design and detailed design, a designed construction's price should be estimated basing on its informational (parametric) complexity indexes.

Keywords: Socially oriented design · Human-oriented manufacturing · Production system · Design · Reindustrialization

1 Introduction

Reindustrialization has become a modern trend in the development of production around the world. It changed the deindustrialization of the late twentieth century in industrialized countries. Deindustrialization was mainly caused by the commercial interests of corporations that transferred material production to countries with low labor costs and other social and economic conditions favorable to running a business (primarily to the countries of Southeast Asia). This trend was theoretically substantiated by the socio-economic concept of a post-industrial society, the fallacy of which was shown by the further development of the economy and society. This is now recognized by many researchers. It can be argued that deindustrialization was one of the stages of production development in the period of information economy.

Awareness of the destructiveness of deindustrialization, leading to the building up of Asian producers and, accordingly, the emergence of new competitors. As well as the development of technologies that reduce costs to the level of production profitability in

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 317–326, 2020.
https://doi.org/10.1007/978-3-030-20497-6_30

their territories, led to the beginning of reindustrialization (third or new industrial revolution) in developed countries at the beginning of the XXI century.

Production systems at all stages of development (gun, machine, information) have their own specific features. This fully applies to periods of deindustrialization and reindustrialization.

One of the characteristic features of these periods was the emergence of a human-oriented manufacturing system. The emergence of this term in the seventies - early eighties of the last century coincided with the beginning of deindustrialization period. Research in the field of creation human-oriented manufacturing intensified in the first and second decades of the 21st century - in the period of reindustrialization.

Human-oriented manufacturing systems are traditionally understood as systems, which interaction with a person is analogous to his interaction with another person with their own perception model. Some researchers believe that human-oriented manufacturing systems can be created based on the concept of ergo design. The works and others are widely known.

The declared goal of ergo design is to ensure the success and well-being of a person in many areas of his activity, which is achieved by ensuring the unity of the three aspects of design-convenience, comfort and aesthetic perfection of the means and conditions of human activity. Obviously, in this case we are not talking about the social aspects of the human person. Therefore, in our opinion, ergo design cannot be considered as a fully human-oriented design. Even despite the fact that its modern adherents began to consider the axiological aspects of ergo design.

It is obvious that genuine human-oriented design is possible if social criteria and norms are used as the basis for the formation of the constructive look of the technical system/object being created, and the design process itself is socially oriented.

2 The Essence and Content of Socially Oriented Design

The goal of a socially oriented design of technical systems is, firstly, to ensure their safe and environmentally sound use, and secondly, to build up human and social capital in the process of creating and using it.

The influence of the design features of technical systems on the social results of their functioning has been studied previously. Known work Trist and Emery [1], research done at the Tavistock Institute of Human Relations (TIHR) in London. In these studies, the concept of sociotechnical systems was proposed, which include any system in which the components of fixed capital (primarily technological machines) and people participate. Based on the provisions of the theory of sociotechnical systems, a scientific approach to the design of the labor process in the aspect of human interaction and technical-technological factors of labor can be formed. Obviously, any production system is a sociotechnical one. This concept becomes especially relevant in the context of reindustrialization and NBIC convergence.

The concept of sociotechnical systems as opposed to theories of technological determinism, which asserted the unilateral impact of technology on a person in the process of performing labor operations, is based on the idea of the interaction between man and machine. The design of technical and social conditions should be carried out in such a way that technological efficiency and humanitarian aspects do not contradict each other.

Development of the concept of socio-technical systems can be considered, in particular, the study of Arai [2], which describes the structure of the production enterprise, focused on the person, and proposed management methods in it. The proposed structure includes two technologies: a factory communication network using the active database system and a dynamic scheduling method to guarantee the workers' satisfaction.

As mentioned above, the social-oriented design of technical systems and facilities should be aimed at increasing human and social capital. This requires the creation of appropriate methods and tools, some of which are described in well-known studies [3–7].

For the practical solution of the task of increasing social capital in the socially oriented design of technical systems and objects (in particular, in the design of systems and objects based on NBIC technologies), it is necessary to ensure a high level of trust between the people involved in this, and to minimize the likelihood of opportunistic behavior. This can be done guided by the ideas Hirshleifer [8] on the need to use in the evaluation of NBIC-technologies of good-quality tools that allow quantifying the qualitative characteristics of a particular technical system or object. At the same time, an integrated assessment is important, allowing to compare the variants of the created technical systems/objects with various private parameters. This can be done by referring the analyzed development to a specific technological structure [9, 10]. Moreover, such an approach may provide an answer about the compliance of a project. Convergence criteria. In this case, an improved model proposed in our earlier works [11] can be used, which takes into account the degree of materialization of information, the size scale of shaping, the degree of closeness of the technology used to the extremely efficient technology and some other parameters.

Addressing the problem is, building human capital as a result of socio-oriented design of engineering systems and facilities requires an assessment of its value. In this case, it is advisable to apply the ideas of the information theory of value Valtukh [12]. In this case, personnel engaged in socially oriented design and operation of the technical systems and objects created as a result of it are considered as a set of thesaurus information carriers. In this case, the amount of information that workers possess (their professional thesaurus) should be determined taking into account the fact that this resource has a hierarchy of qualification complexity. This is expressed through the qualification categories g, $g \in L$, where L - is the sum of the economic resources associated with human activities in the created technical system.

In accordance with the concept of qualification hierarchy, in determining single information embodied in workers of a certain category g, the cumulative probability of the set of workers in this category should be used: each such group includes everyone who is able to do the work of this qualification, including those who can also perform work of higher qualification. If we denote the value of the cumulative probability symbol q_g^L, $q_g^L > 0$ then the ratio q_g^L of each other (i.e., the ratios of these values for different g) are determined by the ratios of the cumulative number of the respective groups of workers (the number of such groups can be determined based on the concept of technocenoses [13].

The hierarchy of labor, as described here, corresponds to the Shannon model (each state *g* has one systemically preceding state $g - 1$). When this occurs not disintegration systemically previous states for the next and subsequent selection of the foregoing:

$$q_1^L > q_2^L > \ldots > q_G^L; \quad (1)$$

Taking into account the above, it is possible to determine a single amount of information embodied in the employee of group *g*:

$$I_g^L = \sum_{\tau=1}^{T} r_\tau, \quad (2)$$

where $\tau = 1 \ldots T$ is the number of types of work stipulated by the standards for the qualification group *g*; r_τ is the number of elements of the labor process required to complete the work τ.

Our analysis of the average labor processes in different industries showed that when designing technical systems and objects as socially oriented average value I_g^L exceeds the corresponding parameters in the general mechanical engineering by 4.4 times, in the energy sector - by 4.7 times, in the chemical industry - by 3.9 times.

On this basis, a generalized criterion can be proposed for assessing the level of human capital, the increase of which is associated with the creation and operation of a new technical system/object.

3 Ensuring the Safety of Technical Systems in the Process of Their Socially Oriented Design

The safety of a technical system/object as a condition of its social significance and focus on the person includes two aspects: the failure-free operation (since any accident is more or less likely to cause harm to health and a threat to human life) and environmental well-being, assuming no harm to human health with stable operation of the technical system/object.

A number of works are known where aspects of the safe operation of technical systems are considered. For example, Gorobets [14] considered this situation for the construction of locomotives. The occurrence of man-made disasters on railways is probabilistic in nature, although there are no representative statistics on such disasters due to their comparatively small number. A similar approach was used Liderman in assessing the safety of mining equipment [15].

Another example of a probabilistic description of the safety conditions of technical systems is given in the study [16], where the functioning of irrigation and drainage systems is considered. Hydro-amelioration systems in agricultural production prevents situations when in dry years food expenditures are required that are many times greater than the costs of creating such systems. It is obvious that the onset of dry years is probabilistic, but, unlike the previous example, it is very well described statistically.

Designing technical systems/objects with a specific purpose, related to the prevention of emergencies is not the only case of applying the probabilistic approach. The termination of the operation of any object or system with utility potential leads to crises of different scale and duration.

When evaluating the performance of the designed objects or systems by the degree of risk reduction, the essence of the processes associated with their operation can be described using insurance models, and the corresponding cost parameters can be determined using actuarial models [17]. At the same time, the variant of mass risk insurance is considered as an analogue (alternative) of the designed facility/system activity, and the situation in which the economic result of the designed facility/system operation is considered identical to the creation of a special insurance fund that allows for emergency response measures is considered as a working model.

Analogue insurance tariff (tariff of insurance premiums), here is an economically viable size of the functioning costs of the technical system or object. It is assumed that annually an amount equal to the insurance payments that must be made to compensate for the damage caused by the cessation of the existence of the designed object/system is required for its maintenance.

In the process of justifying the cost of maintaining the designed facility/system, the following indicators are calculated: an accident frequency; accumulation risk index; loss ratio; average sum insured; severity of the risk; unprofitableness of the sum insured; rate of loss; frequency of damage; severity of the damage.

An accident frequency's F_a basic characteristic is a number of accidents and crises in the analyzed period:

$$F_a = L/n \tag{3}$$

F_a is an accident frequency index; L is a number of crises; n is a period duration.

Where L is the number of crises; n - the duration of the period under review.

Rate of loss, or the insurance payout ratio R_1 is a percentage ratio of the indemnity paid to the amount of insurance premiums:

$$R_1 = (B/p) \cdot 100\% \tag{4}$$

R_1 is rate of loss; P is the amount of insurance premiums (rubles).

In the analyzed example, a calculation may be based on the idea that P amount is similar to a designed object's total service cost in analyzed period, and B is similar to a cost paid to eliminate the consequences of crisis.

When predicting the hazard level of projected objects belonging to product groups for which there is no representative statistical information about emergency situations arising during their operation (as in the example described above with locomotive safety [13]), the theory of solutions can be applied, which is complemented by the formula Bayes [18].

In this situation a possibility $P(H_1)$ of object's trouble-free functioning may be determined in the following way:

$$P(H_1) = (1-K) \tag{5}$$

H_1 here is a hypothesis about designed object's trouble-free functioning during the whole lifecycle; K is an estimated probability of the accident, based on the expert knowledge.

The following formula is to be used to determine a probability of the accident in this situation:

$$P(H_2) = K \tag{6}$$

H_2 here is a hypothesis that the accident matters during the object's functioning.

Based on the reasonable costs of the function of ensuring safe operation calculated by the method described above using the cost design method [19], the cost of operating the created technical system/object can be calculated and its price justified. These parameters, after consultation with the customer, become fundamental in the development of the design of the technical system/object.

The same parameters are used in the concept design and detailed design stages, during which the parameters of the technical system/object are determined on the basis of its functional model. It should be born in mind that virtually any machine parameter is determined by a set of particular indicators and at the same time acts as a component of a more general indicator. There is a hierarchical structure of indicators in which the significance of an indicator can be determined on the basis of their weighting factors.

As our studies have shown, operational safety indicators should not be included in any generalized indicator due to their special significance. The system of weight coefficients does not sufficiently reflect their significance. Therefore, they must form a parallel hierarchical structure.

In terms of concept design and detailed design, it is necessary to estimate the cost based on preliminary design parameters, since the exact cost of production will be known only after the development of the technology for manufacturing its parts.

In the well-known studies [20, 21] describes some methods for determining the cost of technical systems (mainly machines) by the parameters of their design at the design stages of concept design and detailed design. In our opinion, the most expedient is the method of calculating the cost based on the value of the parametric value of the structure [22].

4 Organization of Design Work in the Socially Oriented Design of Technical Systems

The development of any technical system is a process of increasing information about it and, accordingly, reducing the entropy of the structure [22].

The degree of approximation of the structure to the optimal state can be characterized by the level of its entropy, and a decrease in the entropy index indicates the approximation of the structure to it (the optimal state). This results from the fact that in process of formation and the analysis of various variants of a design (each of which represents a step to achievement of an optimality) the number of potential variants of a structure from which the optimum can be chosen is reduced.

Entropy estimation is a rather complicated independent task. In the conditions of socially oriented design of technical systems, consideration of the conditional entropy index proposed by Rényi [23] is most expedient. The essence of this approach is to consider a variant of the construction V, chosen randomly with a positive probability, and ξ is a random variable taking the values x_1, x_2, …, x_n. Denote by A_k the construction version derived from V, for which $\xi = x_k$ ($k = 1, 2, \ldots, N$). Then by the definition of conditional entropy value of ξ under the condition V is the entropy of the random variable ξ, calculated from the distribution of conditional probabilities under the assumption that version V of the construct is created, that is,

$$H_V(\xi) = \sum P(A_k|V)\log_2 \frac{1}{P(A_k|V)} \quad (7)$$

where $P(A_k|V)$ - conditional probability embodiment A_k provided (original version) V.

The use of the approach described here is most effective under conditions of CAx systems (first of all, MCAD and EDA). It can be carried out within the framework of an invariant subsystem of technical and economic indicators as part of CAE (CAA) [24] automation tools for calculation and process simulation based on the AGILE design ideology. This will allow to quickly respond to changes in design conditions (both external and internal), to take into account new knowledge emerging in the design process. However, following this ideology requires coordinated work of developers (first of all, designers) and representatives of customers, who control the progress of the project at each step of its implementation.

The methods described above were applied in the design of locomotives and other railway equipment, mining equipment, equipment for land reclamation and water management.

Table 1 provides information on some of these projects and the methods used in them. Table 2 presents some parameters of the products, in the design of which the considered methods of socially oriented design were used.

The obtained results allow us to outline areas for further research and development for the development of socially oriented design of technical systems. Justification of the cost of ensuring safety based on actuarial calculations requires the study of statistical data on the probability of man-made and other accidents in various technical systems. For more reliable use of the Bayes' method, it is necessary to work out the algorithm for conducting an expert assessment. The use of indicators of the parametric complexity of structures for calculating their cost requires the formation of a regulatory framework that allows expanding the range of evaluated structures (the current method allows only parts and assembly units of the general engineering design to be assessed. Solving these problems will create a complete system engineering social-oriented design of technical systems and objects.

Table 1. Projects and project sets, realized in SRSPU (NPI) and based on presented methodology

Worked out objects	Years	Used methods and instruments				
		Actuarial approach	Bayes's method	Parametrical complexity	Construction's entropy	Agile
Electric locomotives	2004–2010	–	+	+	–	–
Material mining equipment	2006–2011	+	+	+	–	–
Waterside structures	2004–2015	+	–	+	+	–
Fish protectors for the weirs and water intakes	2004–2015	+	–	+	+	–
Power installations for the melioration systems	2017–2018	+	–	+	+	+

Table 2. Parameters of some products worked out with the help of presented methodology.

Product	Determined safety costs, thousand rubles	Accident prevention costs function	Product's estimated value on the level of draft proposal, thousand rubles
Electric locomotive (for passenger service, AC)	11611	0,251	46258
Electric locomotive (for cargo transportation, AC, two sections)	18764	0,185	101432
Electric locomotive (for passenger service, dual standard, AC and DC)	31320	0,294	106534
Electro pulse fish protector	13,6	0,017	798

5 Conclusion

The conditions under which modern Advanced Manufacturing is created are determined by the beginning of the process of re-industrialization and NBIC-convergence, the emergence of a new technological order. When creating technical systems and objects, it is necessary to minimize their possible negative impact on a person.

This allows to create human-oriented systems capable of ensuring the harmony of the techno sphere and man. At the same time, it is important that the design process be socially oriented. The formation of the cost characteristics of the designed technical system at the conceive stage should be carried out with the probabilistic approach. In this case, the probability of trouble-free operation of the designed technical system is estimated (by the actuarial method or based on the Bayes formula). Taking into account this probability, the costs of eliminating the consequences of possible accidents are calculated and, on their basis, (using the technique of value engineering), the costs of operation and the price of the designed machine are determined.

At the subsequent stages of design, design and detailed design, it is necessary to estimate the cost of the design being developed on the basis of the information (parametric) complexity indicator.

The most effective use in the framework of social-oriented design of CAx-systems (primarily MCAD and EDA). They can play the role of invariant subsystems technical and economic indicators as part of calculations of means of automation and simulation processes CAE (the CAA) based on AGILE–ideology.

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Safety Management and Digital Transformation

Driving Risk Assessment Under the Effect of Alcohol Through an Eye Tracking System in Virtual Reality

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Abstract. The issue of driving under the effect of alcohol is a matter of several studies in the field of road safety because today alcohol is widely diffused especially among very young people (age ranging between 18 and 25). Each year data provided by authorities are worrying, more than a third of the accidents registered in European countries are caused by alcohol. Italy is aligned with this trend; the ISS – National Institute of Health estimates that alcohol-related road accidents are equal to 30–35% of the total road accidents. Medical researches confirm that alcohol generates negative effects on driving, impairs the ability of perception, attention, processing and evaluation and it has negative effects on cognitive and motor skills. Therefore, the present research is developed in the field of a wider project research with the purpose to investigate and estimate the impact of alcohol on road safety to support awareness campaigns "Drink or Drive". As demonstrated by findings of the previous study, alcohol has a significant impact on driving performances in terms of geometric, kinematic and dynamic measures. Trajectory, stopping and overtaking maneuvers were studied and a significant delay in reflexes, especially in stopping and overtaking maneuvers, that exposes drivers to high risk level, was calculated. In this research, the focus is on the drivers' eye-movements that are recorded in the virtual reality driving experiment. To understand how much alcohol impairs attention and concentration in relation to the driving performances, these data are processed and two eye blinking measures (i.e. % blinking and blink rate) are analyzed A sample of 20 drivers were requested to drive the virtual reality-driving simulator situated in the LASS3 Virtual Reality Laboratory of University Research Centre for Road Safety. The route runs in extra-urban and urban areas, in order to study drivers' behavior in different cases and subjecting drivers to different stimuli (i.e. pedestrian crossing, overtaking maneuver, sudden braking, etc.). The results are a comparison between the results of two conditions drunken and sober. Results show that alcohol affects attention and concentration increasing the absolute value of blinking and its rate. During the stopping and the overtaking maneuvers where driving measures show higher risk levels in drunkenness condition respect the to the sober one, eye measures show a reduction in blinking and frequency (in both conditions) on behalf of a more attention to the road.

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 329–341, 2020.
https://doi.org/10.1007/978-3-030-20497-6_31

Keywords: Driver behaviour · Alcohol effect · Driving simulator · Human · Factor

1 Introduction

Alcohol affects different brain functions and impairs the capabilities of perception, attention, processing and evaluation. It is identified as the most important human factor altering risk perception with consequences on road safety [1]. Alcohol involve every year many people in driving accidents, especially young people. Data provided by European Commission [2] show that 96% of people involved in accidents are men, of which 33% young with an age between 15 and 24 years. Young people are the most affected by this custom and often, for the unconsciousness due to age, they reach higher values of Blood Alcohol Concentration (BAC) level are the most involved in alcohol-related accidents [3].

The statement of the problem seems very worrying; hence, there are many awareness campaigns promoting a consciousness of drink and drive, as in this French case of study [4]. To date, in Italy, the legal BAC limit is 0.5% (0.0% for novice drivers), over this value, the suspension of the license is expected for the offenders, over 0.8% there is the detention up to six months [5].

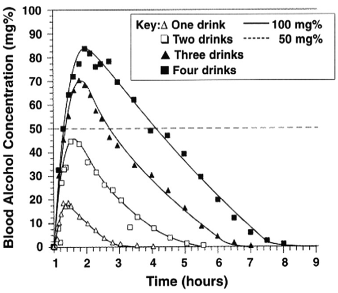

Fig. 1. Curve of BAC (Blood Alcohol Concentration %)

The achievement of these values is subjective and depends on the diffusion of alcohol in the body (Fig. 1.), that is related to bodily and biological parameter (e.g. weigh, gender, age), to the amount of alcohol drunken and to the time elapsed since the assumption. The first negative effects appear already with a value of 0.2 BAC in terms of the ability to divide the attention between two or more sources of information, at a value of 0.5 BAC the peripheral view is compromised, reaction times increase, and psychomotor coordination begin to be compromised. Reaching 0.8 BAC, the previous symptoms get worse until with 1 BAC when the peripheral view is strongly compromised, as well as the perception of the distances and the speed [6, 7, 8].

Therefore, it is clear how these effects have a significant impact on the driving skills and several studies have studied this issue. In detail, alcohol assumption represents a hazard for road safety not only because impairs the driving risk perception, but also because it reduces the perceived negative consequences of risk-taking [9] and alters decision-making while driving. Then, who drives under the effect of alcohol is not aware of exposing himself and the other users of the road to high risk [10, 11].

As literature review shows, effects of alcohol on driving skills involve different cognitive and motor impairments (e.g. eye and body) could be examined and calculated in a variety of ways by means of different kinds of measures on driving performance [12] or on psychophysiological effects. This study is a part of a project research that aims to investigate the effects of alcohol on driving by monitoring different parameters of driving behaviour. The first study developed by the authors [13] has investigated the kinematic and dynamic measures to estimate the decay in driving performance in impaired psychophysiological condition. In the same virtual reality driving experiment, the present paper aims to analyze the eye-movements, recorded by an eye tracking system, in order to estimate the blinking measures to correlate them with the results of the previous study.

As mentioned in the literature review, blinking is a semi-automatic action of the eyelid necessary just to keep the eye lubricated. Blinking measures both cognitive and visual distraction and it depends on the cognitive workload [14]. Results of a study aims to investigate eye-movements during a lane changing task [15] show that with the increasing of workload, increases the blinking value in comparison with the track where there is low cognitive workload. Blinking is also related to the psychophysiological condition of the driver. In fact, it is a reliable indicator of drowsiness and fatigue [16] and, in this regard, it allows to understand how much the effect of alcohol affect the drivers' behaviour in terms of drowsiness and lassitude during a driving task.

Blinking is a bodily function that involve the eyelid in a rapid close of the eye to lubricate the eye. Medical researchers [17] have found that the duration of blink and its rate are related to attention and concentration and are reliable indicators of tiredness, drowsiness and lassitude. Therefore, the research question could be: is it possible to correlate the eye measures with the driving performances measures to understand the alcohol-related accidents phenomenon?

2 Aim of Study

In the field of this literature review, the present research is developed with the purpose to assess the effect of alcohol on the driving capabilities using an eye tracking system in a virtual reality driving environment. Therefore, the results of the eye-movements will be compared with the previous results of the driving performance in order to understand how much are different the driving performance and the eye-movements of drivers in drunken condition.

3 Method

3.1 Eye Tracking System

The eye tracker is the tool to study the eye-movements and the position of the gaze. The eye tracking system of the LASS3 - Virtual Reality Laboratory of University Research Centre for Road Safety - is made up of a camera, fixed on the dashboard of the vehicle that records the face of the driver during the virtual reality driving test. Therefore, the outcome is a recording of the driver face during the driving task.

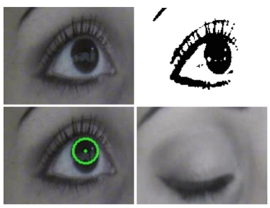

Fig. 2. Processing of the image analysis algorithm

Image Analysis Algorithm

Video is processed with an ad hoc image analysis algorithm (Fig. 2.) in order to carry out the outcome measures of blinking and frequency. The proposed algorithm detects the eye-movements starting from a sequence of images of the driver face, converted in binary images by means of a RGB threshold. For each frame the code scans the face of the driver to find the search-space around the eyes. During the tracking, the search-space decreases to the area corresponding to the eye-envelopes. When an area with a percentage of black pixels over a fixed threshold (i.e. pupil) is found, it recognizes the eye as opened, otherwise the eye is considered closed. The algorithm records the percentage of opened and closed frames weighted on the total of the images and the frequency of closed frame in time.

The reliability of the algorithm is highly dependent on the quality of the image in terms of lighting condition. In fact, the light contrast of the raw image is the main variable that may affect the RGB threshold and consequently the black pixels recognition. During a driving test, the light of the room is switched off and the lighting condition of the pictures depends on the light of the simulated scenario. Therefore, the RGB threshold during the tracking must be checked in order to set the most suitable value for the current light condition.

3.2 Driving Simulator

The driving simulator of LASS3 is a Toyota Auris (Fig. 3), converted in a driving simulator by removing all unnecessary parts and integrating with the components that will communicate with the workstation computer, equipped with the software STISIM DRIVE®. With three high-tech projectors, a wide image in front of the car and sideways is projected in order to cover a visual angle of 180°. In addition, the sound speakers are located in the hood of the car in order to emulate the acoustic road environment at the best. The outcome measures of the simulation tests are 45 parameters recorded with a frequency equal to 0.25 s.

Fig. 3. STISIM DRIVE® driving simulator of LASS3

Driving Scenario

The same scenario of the previous study is implemented and tested by a sample of drivers. The two different environments: urban and extra-urban are characterized as described in Table 1.

Table 1. Characterization of two road environment

Area	Analysis	Lanes	Shoulder	Speed limit	Description
Urban	Baseline Stopping maneuver	3.50 m	–	50 km/h	Intersections, pedestrian crossing, parking vehicle on the roadside, overtaking maneuvers is not allowed
Extra-urban	Baseline Overtaking maneuver	3.50 m	1.00 m	90 km/h	No intersection, no pedestrian crossing, no parking vehicle, overtaking maneuvers allowed

Baseline measures are recorded in the tracks of the ride at rest without event (in both areas) could affect the physiological parameters. In the urban area, many sudden events are built to induce the stopping maneuver, as well in the extra-urban area slow vehicle lead drivers to overtake.

In addition, to increase the accuracy of the virtual reality environment, a value of Level of Service (LOS) is determined. This value corresponds to a travel speed defined as a percentage of base Free-Flow Speed (FFS). According to Highway Capacity Manual (HCM), with a travel speed of 35–40 km/h in an urban area characterized as described above and a FFS of 50 km/h, the corresponding LOS value is B. In the extra-urban area with the same LOS a traffic density equal to 7 vehicle/km is defined.

3.3 Participants

To twenty participants (10 women and 10 men, 35 years old on average ranging from 26 to 50 years) of the driving sample of the previous study, the eye-movements are recorded. The sample is recruited via advertisings as volunteers from the Department of Engineering at the University Roma Tre and is tested is in LASS3. All subjects were required to have a driving license for at least 1 year.

At the beginning, after the reception in the laboratory, they are informed about the procedure of the test in terms of duration, use of drivers control and knowledge of the tool. They have also completed a questionnaire with personal information and then they are requested to complete a training scenario for at least 10 min in order to get confident with the tool. In order to assure to select a homogenous sample of drivers to avoid biasing of the results induced by driver attitude, experience, age and gender out other neuro-cognitive factors [13], a statistical criterion is applied. Chauvenet criterion [18] allow to assess if the sample, in terms of number of subjects, is significant from a statistical point of view, so assuring a correct interpretation of the results. According to Chauvenet criterion one driver is excluded to the analysis due to anomalous behaviours in terms of speed (data are considered outliers if the speed values were strongly higher or lower than the mean), therefore the data processing is based on 19 drivers.

3.4 Procedure

After the training test, the drivers were requested to perform the scenario in sober condition to record the baseline ride to compare it with the results of the drunken condition. Afterwards, a very careful procedure of a virtual reality driving experiment was required to administer alcohol to the participants. Subjects were instructed to abstain from food and smoke (for 4 h before), caffeine and alcohol (for 36 h before) to avoid biasing the effects of the alcohol administration [1].

The threshold of alcohol, calculated in BAC, we chose to test is equal to 1. For each participants the amount of alcohol to reach 1 BAC was calculated in function to different body parameter (e.g female, male, weigh, height, etc.) with the Widmark formula (1) described as follow and in Table 2.

$$BAC = \frac{A \times Sw_{blood}}{r \times W} - \xi \times t \tag{1}$$

Table 2. Parameter of Widmark formula

Parameter	Description
A	Weight of the amount of alcohol (grams)
S_w	Specific weight of the blood that is fixed equal to 1.055 (N/m^3)
W	Weight of the driver (Kg)
r	Widmark factor that allow to convert W to liters of blood that the body contains and it depends on gender (equal to 0.73 for men and 0.66 for women)
ξ	Decay ratio of the drunkenness equal to 0.015 (1/minutes)

The amount of alcohol in grams (A) comes out easily from the inverse of the formula.

The alcohol level is monitored by a breath analyzer, that measures the alcohol concentration in the air emitted with the breath. BAC is measured for the first time 10 min after the end of administration and then at regular intervals to monitoring the alcohol absorption and built the alcohol curve for each participant. In this way, it was possible to understand when each subject had reached a BAC level equal to 1 to start the driving test and assure that this level is constant for all the time of the test drive. After the test, subjects are seated in the laboratory waiting area until the end of the session, where some drinks and snacks were offered. During this period the level of BAC is measured at 30 min intervals until the end of the session (e.g. BAC < 0.5 g/L).

3.5 Indicators

Eye-Movements Measures

As mentioned in the literature review, blinking is a semi-automatic action of the eyelid necessary just to keep the eye lubricated. Blinking measures both cognitive and visual distraction and it depends on the cognitive workload [14]. Results of a study aims to investigate eye-movements during a lane changing task [13] show that with the increasing of workload, increases the blinking value in comparison with the track where there is low cognitive workload. Blinking is also related to the psychophysiological condition of the driver. In fact, it is a reliable indicator of drowsiness and fatigue [16] and, in this regard, it allows to understand how much the effect of alcohol affect the drivers' behaviour in terms of drowsiness and lassitude during a driving task. From a numerical point of view (2), the algorithm calculates blinking values as the ratio between the closed frames on the total frames. It means the percentage of the closed frames that result in the time that the driver spent with closed eyes during the driving task with consequently affection on road safety.

$$Blinking = \frac{N^{\circ}\, closed\, frames}{N^{\circ}\, total\, frames} \times 100 \qquad (2)$$

The blink frequency, instead, is the blink rates in time; it means how many times the driver closes the eyes in the period referred to the simulated scenario. The combination of these two indicators could be useful to understand how much alcohol affects the driving behaviour in terms of drowsiness, fatigue and lower risk perception, than in sober condition.

3.6 Anova Test

A statistical validation of the outcome measures of the processing data is required in order to generalize the results. According to findings in literature [19] the analysis of variance test (ANOVA) is applied in order to highlight that the values differences into two groups (sober and drunken) for each indicator depend on the two psychophysiological condition and not on the chance. Starting from the postulate that the average of the dependent variable (i.e. eye-movements indicators) is the same for the two sample (null hypothesis), rejecting the null hypothesis would mean that the independent variable (i.e. sober or drunken condition) influences the dependent variable and the results are reliable. For each parameter, two analyses are performed: the first to evaluate the effects due to the psychophysiological condition and the second to investigate the effects of different scenario, namely type of analyzed maneuver. The results of ANOVA test will be show in the following section Results and Discussion.

4 Results and Discussion

The data analysis of the eye-movements aims to study the differences in blinking and its frequency between sober and drunken conditions in order to estimate how much alcohol affect the drivers' behaviour in terms of risk perception during the driving task. Data analysis is processed before to find the baseline values of blinking and frequency for each driver and then focusing on stopping and overtaking maneuvers to compare it with the previous results of driving performances [13]. The baseline is estimated considering the tracks of the ride at rest without event could affect the physiological parameters, while in the other two situations the length of maneuvers is determined. For the stopping maneuver, the length of analysis is from the point of release to the point with speed value equal to zero; instead, for the overtaking maneuver from the point when the driver crosses the centerline to perform a lane changing to the specular point at the end of the same maneuver.

4.1 Statistical Analysis

As mentioned before, for each parameter (blinking and frequency), two analyses are performed: the first to evaluate the effects due to the psychophysiological condition (sober and drunkenness) and the second to investigate the effects of different scenario, namely type of maneuver.

As statistical results show (Table 3), blinking values depend both on psychophysiological condition and on type of maneuver with high values of likelihood. On the contrary, frequency values depend more on type of maneuver (likelihood around 98/99%) then psychophysiological condition.

Table 3. ANOVA results

Indicators	On psychophysiological condition			On type of maneuver	
	Baseline	Stopping maneuvers	Overtaking maneuvers	Sober Condition	Drunken Condition
Blinking	$F_{(1,37)} = 7.7$ $P < 0.01$	$F_{(1,37)} = 2.6$ $P = 0.12$	$F_{(1,37)} = 1.8$ $P = 0.2$	$F_{(2,56)} = 9.3$ $P < 0.01$	$F_{(2,56)} = 14.3$ $P < 0.01$
Frequency	$F_{(1,37)} = 0.03$ $P = 0.88$	$F_{(1,37)} = 0.13$ $P = 0.75$	$F_{(1,37)} = 0.25$ $P = 0.62$	$F_{(2,56)} = 5.1$ $P < 0.01$	$F_{(2,56)} = 4.8$ $P = 0.015$

4.2 Baseline Values

Analyses of blinking indicate a significant increase in blinking values (Fig. 4) under the effect of alcohol. From a numerical point of view, average values are 9% in sober condition and 13% in drunkenness. The average of values is a reliable indicator because of two reason: the standard deviation into two groups (3.6 in sobriety and 4.4 in drunkenness) and the trend for all couples of values that is never decreasing from sobriety to drunkenness.

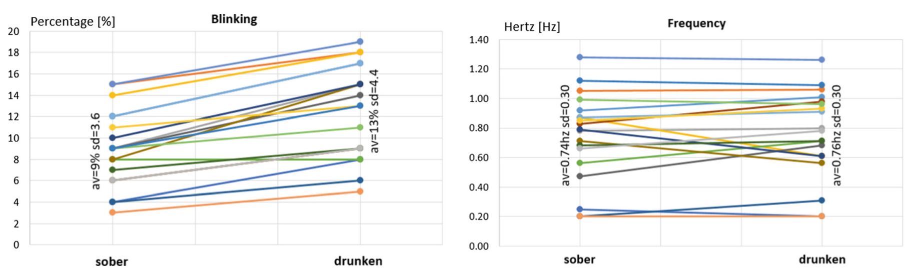

Fig. 4. Baseline values of blinking (left) and frequency (right)

It means that under the effect of alcohol the percentage of closed eyes frames is 4 percentage points more than sober condition. In terms of time or space, it represents a significant problem for road safety. In fact, in urban area (speed 50 km/h) considering 1 h the driver loses 2 km of the road due to alcohol drowsiness respect to sober condition; in extra-urban area (90 km/h), the same computation returns a value equal to 3.6 km.

Frequency values are almost constant between two groups in terms of average values, a little bit higher in the drunken sample: 0.74 Hz in sober condition and 0.76 Hz in drunkenness with standard deviation equal to 0.30 in both cases. If a value of blinking increases, keeping constant the rate, it means that the number of blinks is the same, but the driver takes more time to close and open eyes each times. For this reason, it is not possible to know how this difference (delta of 4%) is distributed for each blink, but it could be assume that it is divided in each blink homogeneously.

4.3 Stopping and Overtaking Measures

According to previous findings [13], in drunken condition during a stopping maneuver, the driver performs braking with high values of deceleration that lead to a high percentage of braking over the safety threshold of 8 m/s^2 (Fig. 5). In particular, this percentage in sobriety is around 25–30% of all braking performed and in drunkenness it exceeds 40%. It suggests, as mentioned by [20], a low risk perception of the potential risks of the road environment that lead drivers to brake with high value of deceleration and consequently with high value of brake pedal pressure.

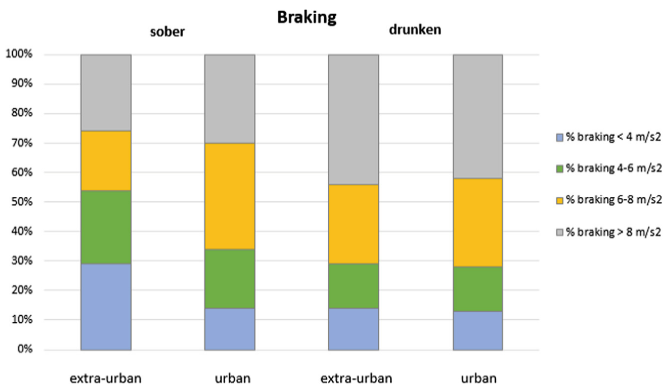

Fig. 5. Percentage of braking divided in classes [13]

In addition, the results of the overtaking maneuvers [13] confirm high risk under the alcohol effect levels in terms of number of performed overtaking in the ride: 31.8% more than in sober condition.

The eye-movements analysis, in this regard, show that in performing maneuvers, both stopping and overtaking, the driver's behaviour is more careful to the road environmental risks with a lower value of blinking and its rate.

As shown in Fig. 6 lower values of blinking respect to the baseline are recorded in both psychopsysiological conditions and in both maneuvers. It means that during a maneuver the percentage of closed eye frames is lower respect to baseline condition. This behaviour, with direct consequences on attention and concentration, careful and consciousness in performing a maneuver, is found in both psychopsysiological condition. From a numerical point of view, in stopping maneuver blinking is 5% in sober condition and 6% in drunkenness (respect each baseline there are 4 and 7 points of percentage of reduction). Instead, in overtaking maneuver blinking is 7% in sobriety and 8% in drunkenness (2 and 5 points of percentage of reduction).

The results of blinking, that are very reliable (both with a variance of psychophysiological condition and of type of maneuver) as ANOVA test established, show a greater reduction of blinking values respect to its baseline in drunkenness condition than in sobriety.

Furthermore, it is right to notice that the values of the percentage of blinking in drunkenness condition during a stopping or an overtaking maneuver is very close to the sober baseline (both less than the sober baseline, 9%). Therefore, the effect of a risky maneuver on drunken drivers' behaviour acts in terms of alert, lead the driver to pay attention to the road and restoring a blinking value similar to the baseline one (it must be specified that this result is referred to the BAC value analyzed in the present research, equal to 1).

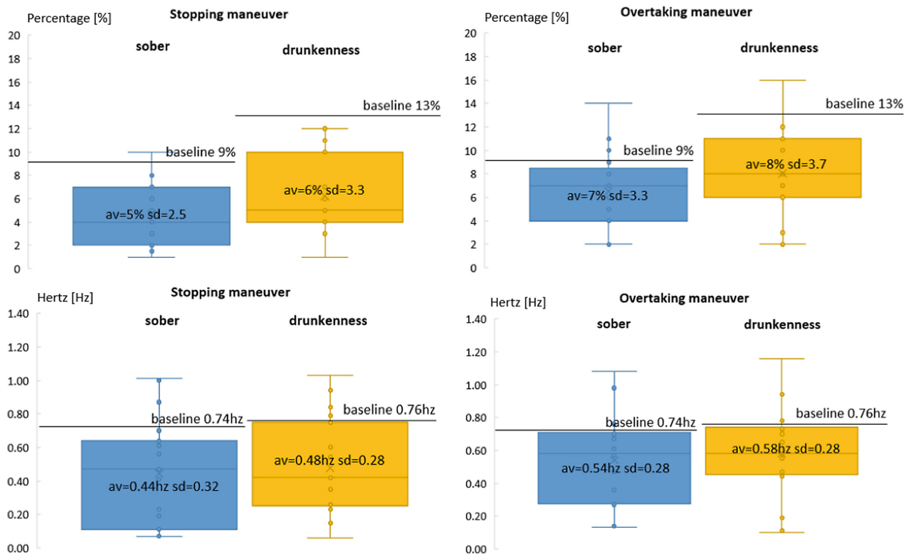

Fig. 6. Blinking and frequency in stopping and overtaking maneuver

The same behaviour of a reduction of values is found in terms of frequency. It could be due to a more attention to the road while the driver is performing the maneuver and a greater consciousness to the risk-taking. Lower value of blinking and its rate means lower closing time and a smaller number of blinks, on behalf of caution to the road risks. During a stopping maneuver there is a reduction of 0.30 and 0.28 Hz respectively in sober and drunkenness condition with a standard deviation around 0.30. In an overtaking maneuver the reduction is 0.20 Hz in sobriety and 0.18 Hz in drunkenness, with same standard deviation 0.28. As well in this case, the reduction is greater in stopping maneuver than in overtaking. Drivers pay more attention in stopping maneuver than in overtaking; it could be due to the environment where the maneuvers are performed, overtaking in extraurban are and stopping in urban area. This latter requires the ability to scan the road environment to predict the potential road risks.

Summarizing results point out two main findings: alcohol leads to a behaviour close to the drowsiness and tiredness, as shown by the drunken baseline values of blinking and its rate respect to sober condition. In performing a risky maneuver, there is an attitude to pay more attention to the road that result in lower value of blinking and frequency (lower time with closed eyes and lower number of blinks). This attitude is verified both in sober and in drunkenness condition, so that the values of blinking in drunken condition during a maneuver are close to sober blinking baseline.

5 Conclusion and Future Prospective

The present paper aims to investigate the driving behaviour under the effect of alcohol, by means of eye-movements. In particular, blinking measures during a virtual reality driving experiment are recorded thanks to an eye tracker camera and processed with an image analysis algorithm. The output measures are the blinking, expressed as the percentage of closed eyes referred to all the frames recorded during a simulation and its rate (frequency of blinks). This research is developed in the field of a project research aims to analyze the impact of alcohol on road safety to promote awareness campaigns “Drink or Drive”. In a previous research, developed by the authors [13], in the same virtual reality driving experiment the driving performances are recorded and analyzed to understand how much the alcohol affect the driving task ability.

Previous findings demonstrate that alcohol have a significant impact on reaction time and on the ability to risk-taking that lead drivers to do more risky maneuvers (as stopping and overtaking maneuvers). In this regard the present paper aims to answer to a research question: is it possible to correlate the eye measures with the driving performances measures to understand the alcohol-related accidents phenomenon?

The comparison between the blinking measures and the driving performances allow to understand more in deep the psychophysiological condition of the driver and how this latter affect the driving task. In this instance, the two kinds of measures support a wider knowledge of the “Drink and Drive” phenomenon in order to promote an awareness of the risk-taking under the effect of alcohol and to restrict the number of alcohol-related accidents.

Results show a reduction in attention and concentration after the alcohol assumption demonstrated by an increasing value of blinking in drunkenness condition respect to the sober one and a constant value of frequency. In performing risky maneuver, a reduction of blinking and its rate is observed compared to the baseline recorded for both sober and drunkenness. It could be imputed to a more attention to the road on behalf of a better scan to the potential road risk in both analyzed maneuver, more in stopping maneuver (higher delta values between blinking and its rate average and the corresponding baseline).

Considering a comparison with the driving performances results, the reduction in blinking values could be explain in terms of a lower risk perception of the driver maneuver performance in drunkenness (as high percentage of braking with value more than 8 m/s^2 and a higher number of overtaking show).

Concluding, it is important to emphasize on the innovation of the proposed approach in terms of integration between the blinking measures and the driving performances, both recorded in a virtual reality driving experiment, as driving risk perception assessment.

Hereafter, the authors will be involved in other studies in order to expand knowledge on the subject to promote and advance awareness campaigns. The project research could be extended by studying driving performance and eye-movements depending on different levels of BAC and integrating the analysis with another outcome measure (i.e. steering wheel, lane position, etc.).

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The Impact of Autonomous Vehicles' Active Feedback on Trust

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Abstract. The successful introduction of self-driving technology may depend on the ability of the vehicles' human-machine interface to convey trust to the vehicle occupants. Using a driving simulator, in this experiment we aimed to evaluate drivers' trust on an autonomous system, depending on the feedback the vehicle provided by an assistive cluster's interface. Forty participants were divided into three groups regarding levels of feedback: (a) cluster without feedback (N = 13); (b) cluster with feedback regarding the surrounding vehicles (N = 14); (c) cluster with feedback regarding the surrounding vehicles and the vehicle's own decisions (N = 13). For all groups, a visual search task was introduced as an indirect indicator of trust in the autonomous system. Results showed an inverse relation between available feedback and correct answers. The system was evaluated as trustable and safe by all groups. Overall, the results may contribute to design requirements for future vehicle HMIs, as they indicate that more information does not necessarily convey more trust.

Keywords: Autonomous driving · Trust · Cluster's feedback · Visual search task

1 Introduction

The introduction of autonomous driving technology may fundamentally change the role of the driver. Freed from driving responsibilities, he/she may be allowed to engage in leisure or working related tasks that were previously deemed as incompatible with driving. However, for this to happen vehicle occupants must trust that the autonomous system is aware of surrounding events and is deciding its course of action accordingly.

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 342–352, 2020.
https://doi.org/10.1007/978-3-030-20497-6_32

A seemingly obvious way of conveying such information is through the Human-Machine Interfaces (HMIs), but deciding on exactly what type and amount of information and vehicle performance/decision feedback should be presented is a leading question in autonomous driving (AD) transportation research. More specifically, which information concerning the vehicle's current state should be presented to facilitate trust in the system?

Several studies have shown that informing users about the capabilities and limitations of the autonomous system, as well as continuously communicating its current state promotes a safer and more appropriate use of the system (Hoffman et al. 2013). One of the first experiments that aimed to study whether communicating automation uncertainty improves driver–automation interaction was developed by Beller et al. (2013). They showed a face-like icon expressing uncertainty whenever the autonomous system had ambiguous or incomplete sensory information. They concluded that, compared with a group that had no uncertainty information, (a) the time to collision increased in case of a system failure, (b) situation awareness increased, and (c) trust and acceptance in the system increased.

The results from Beller et al. (2013), suggest that presenting information regarding the uncertainty of the system may be useful. However, in their study, there were only two levels of uncertainty under testing: uncertainty and no uncertainty. Helldin et al. (2013), also addressed the display of uncertainty by the vehicle but investigated the effect of communicating it as a continuous variable. The experimental group saw a figure in the cluster indicating, on a scale from 1 to 7, how certain the car was that it could handle the situation autonomously. When the confidence level was 2 or less, automation could not be guaranteed. The control group had no information regarding the current status of the car. The results showed that the drivers of the experimental group were quicker to take-over, looked more often away from the road, and even though the difference was small, had less trust in the system. In this case, the behavior of the experimental group (trusting less) revealed to be more appropriate as the vehicle sometimes asked for manual take-over. Moreover, participants in this group were more efficient in responding to take-over requests.

Even if the results from the previous studies might indicate that presenting status information could be useful, it is not clear whether it is enough to inform about the status of the vehicle, or it is better to also inform *why* the vehicle is doing what it is doing. Regarding this question, Koo et al. (2015), investigated whether the content of verbal messages stating the vehicle's autonomous actions affected the driver's trust in the system. For that, they conducted a driving simulator experiment where a semi-autonomous system prevented frontal collisions by activation of an automated brake function. They were asked to drive, and whenever an unexpected risk situation appeared on the course, a voice warning and/or auto braking was activated. There were four conditions concerning the message content: (1) 'how' the car is acting (e.g., "Car is braking"); (2) 'why' it is acting the way it is (e.g., "Obstacle ahead"); (3) 'how + why' message (e.g., "Car is braking due to obstacle ahead"); and (4) no message. The 'how' condition yielded the poorest results on driving performance, and the 'why' was the most preferred by the drivers. Combining the 'how' and 'why' messages resulted in the safest driving performance measured by number of road edge excursions, but also led to more negative emotional states (these were inferred by asking the participants how much they felt “anxious”, “annoyed”, and “frustrated” while driving). Overall, drivers who received some type of information about the driving environment expressed higher system trust and acceptance when compared with those who received no message.

In sum, informing users regarding the system’s status seems to be beneficial, both in terms of trust and performance. One way to convey that information is by means of displays. However, it is yet not clear which type of information users need and find useful. The present study aimed to explore the role of visual feedback cues that may affect trust in the interaction process between the user and the autonomous vehicle’s interface. Trust was measured by objective and subjective metrics. Many physiological methods are already used as indirect indications of a driver’s trust in the vehicle, and in this study, heart rate was measured. In addition, a study by Llaneras and Green (2013) found that increased trust could lead drivers to allocate less visual attention to the road ahead. Therefore, a visual search task was introduced without previous notice, and prompted on a display inside the vehicle away from the typical central area of the road gaze. Task performance was analyzed as an indicator of trust in the autonomous system. Finally, a trust questionnaire was used.

2 Method

2.1 Participants

Forty participants with a driver’s license were recruited to take part on this experiment, ten of which were female, with a mean age of 29 years old (SD = 9.11). The mean years of driving experience was 10 years (SD = 8.41).

2.2 Apparatus, Materials and Setup

The experiment was conducted in a fixed-base Driving Simulator Mockup (DSM), composed of two seats, a steering wheel, two pedals, and three monitors for rear view projection. The DSM is connected with the simulation software (SILAB v.5.0, WIVW 2018) which controls the simulation environment. The frontal visualization was displayed in a curved screen with 5-m width by 2-m height, mounted in a metal structure. Along this curved surface three projectors (1920 × 1080 pixels each) displayed the simulation environment in the curved surface. A Head-Up Display (HUD) was installed and the Assistive Cluster (AC) was mounted on the right side of the steering wheel, at approximately 75 cm from the drivers’ head. A touchscreen display on the lower dashboard was placed within reach to prompt the visual search task (Fig. 1).

Heart Rate (HR) was measured using BIOPAC’s MP160 data acquisition system that can record data at a frequency of 2000 Hz and is coupled with the AcqKnowledge 5.0 data analysis software. Three pre-gelled electrodes were applied to the skin, on the participant’s right clavicle (negative electrode), left clavicle (positive electrode) and left lowest rib (ground electrode).

Fig. 1. DSM: (a) Head-up display (orange dashed outline); (b) Assistive cluster interface (blue solid outline); (c) Touchscreen display (green dotted outline).

3 Procedure

The participants were invited to an autonomous driving experience, and upon arrival, they read and signed an informed consent form. Then, they were randomly assigned to one of three groups: the group without feedback (*No Feedback Group*, N = 13), the group with feedback regarding the surrounding vehicles (*Sensors Group*, N = 14), and the group with feedback regarding the surrounding vehicles and the vehicle's own decisions (*Decision group*, N = 13). The No Feedback group had a cluster with no information (Fig. 2a); the Sensors Group had information regarding the proximity of surrounding vehicles: lateral and longitudinal control lines turned yellow as other objects got closer - e.g., while in a queue or during an overtake (Fig. 2b); and the Decision group had full feedback: the same sensor information as the Sensors group and also arrows that informed the driver of the vehicle's immediate future behaviour regarding lane changes (Fig. 2c).

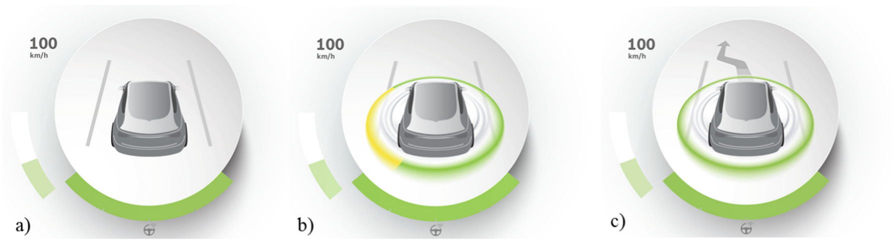

Fig. 2. Cluster's level of feedback: (a) No feedback; (b) Sensors feedback; (c) Sensors and Decision feedback.

All clusters had an illustration of the vehicle at the centre, and an automation bar below that represented the driving mode within four possible autonomy levels. For the purpose of this study, the AD mode – level 4 – represented by a full green automation bar, was presented to all participants during the experiment. The HUD (see Fig. 1a) had a speedometer at the centre and an AD icon, as shown in Fig. 3.

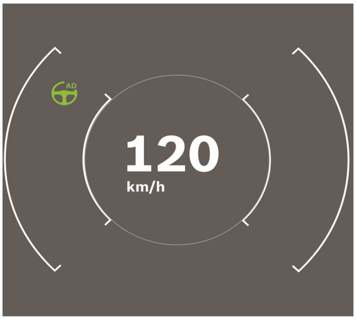

Fig. 3. Example of the centre of the Head-Up Display (HUD) with AD mode engaged.

3.1 Route Description

For an overview of the experiment see Fig. 4. The scenario was composed of a 12-min drive in a highway during which several events occurred such as a free traffic segment, an overtaking and a traffic queue that required the system to brake. While on AD mode, a visual search task was prompted twice, 3 and 6 min after the beginning of the experiment (t1 and t2), with no previous notice. Finally, the car stopped at a gas station for recharge and the experimenter asked the participant to fill a trust questionnaire.

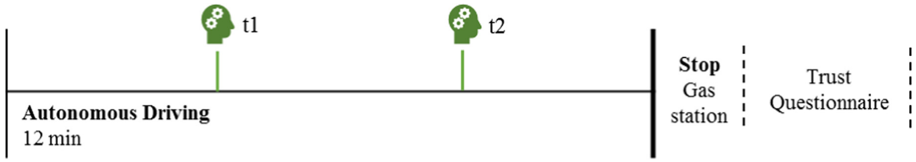

Fig. 4. Scheme of the experiment.

4 Measures

4.1 Visual Search Task

In the search arrows task (e.g., Engström et al. 2005), the participant had to search for an upward facing arrow in a grid of equal but differently oriented arrows by pressing a "Yes" button (if present) or "No" (if absent). Figure 5 shows an example of an arrow grid, with a "Yes" as a correct response for this trial.

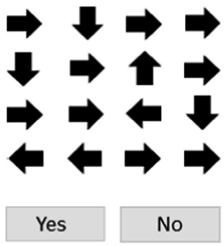

Fig. 5. Example of an image for the visual search task.

While the car was on AD, this task was presented twice (visual search task t1 and t2). Each time the task was presented, it was composed of three trials/images, forcing the participants to deviate their attention from the road or the environment. Each trial started with a fixation cross displayed for 500 ms, followed by the arrows grid and ended either with the driver's response or after a 6-s presentation without response. After the third trial, the touchscreen was turned off until the second evaluation. The participant's performance was measured based on the percentage of correct/incorrect and/or missing answers. As higher levels of trust are associated with lower monitoring frequencies (Hergeth et al. 2016), the best performance was expected from the *Decision* group. As this group has been given more information regarding the vehicle's behaviour, it was hypothesized a higher level of trust in the system and a better performance on the visual search task.

4.2 Heart Rate

It was expected that the more the cluster's feedback, the higher the trust, and consequently, the lower the heart rate. It has been shown that the use of a simulated autonomous vehicle can increase stress (Morris et al. 2017), and heart rate is a frequently used physiological variable that reflects cognitive stress of subjects (e.g., Reimer and Mehler 2011). Therefore, it was hypothesized that the *No Feedback* group, due to the lack of information which is a factor that triggers an anxiety state (Lee et al. 2016), showed the highest heart rate.

4.3 Trust Questionnaire

To evaluate trust, a custom-made questionnaire was presented at the end of the experiment. The participant was asked to classify each sentence on a scale from 0 (totally disagree) to 5 (completely agree):

- The autonomous driving system is trustable;
- The autonomous driving system is safe;
- I understood the intentions of the autonomous driving system;
- I understood the actions of the autonomous driving system.

It was expected that, as the cluster's feedback increased, the reported trust in the system also increased.

5 Results and Discussion

5.1 Heart Rate

For each participant, the mean heart rate was calculated in the 5 s immediately before the presentation of the visual search task and in the 5 s immediately after the visual search task has ended. To test whether heart rate increased when the visual task was introduced, the heart rate values before the first and the second visual task presentation were averaged (M = 78.48 beats/min), and the same was done for the values after the tasks (M = 85.96 beats/min). Reimer and Mehler (2011) found that heart rate and skin conductance levels were lower in a driving simulator than under actual on-road driving, but that the relative increases in these measures across cognitive tasks of increasing difficulty were equivalent.

A mixed Analysis of Variance (ANOVA) with the amount of information (3 levels: no feedback, sensors feedback, and decision feedback) as the between-subject factor and the moment relative to the visual search task (2 levels: before and after) as the within-subject factor was conducted. The increase in heart rate with the occurrence of a visual search task was statistically significant, $F(1, 36) = 19.09$, $p = .0001$, $\eta_p^2 = 0.35$. However, no significant differences were found between the three levels of information, $F(2, 36) = 0.06$, $p = .94$, $\eta_p^2 = 0.004$, meaning that heart rate was similar across the different levels of information.

5.2 Visual Search Task

Figure 6 shows the percentage of missing answers to the visual search tasks according to the amount of available information in the assistive cluster, in the first moment (t1, left panel) and in the second moment (t2, right panel).

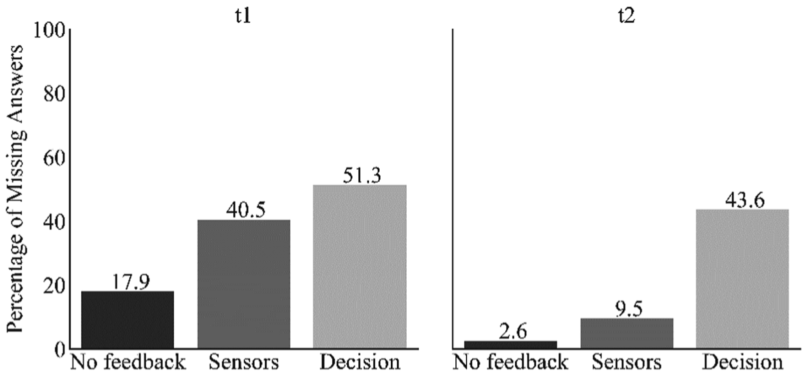

Fig. 6. Average percentage of missing answers to the visual search tasks according to the amount of available information in the assistive cluster in each moment of presentation (t1, t2).

Both in t1 and in t2 the percentage of missing answers was lowest for the No Feedback group, intermediate for the Sensors group and highest for the Decision group.

A mixed ANOVA with amount of information (3 levels) and the instance of the visual search task (2 levels: t1 and t2), in the number of missing answers to the visual search task was conducted. Significant differences were found for the information level, $F(2, 37) = 8.18$, $p = .001$, $\eta_p^2 = 0.31$, and for the instance of the visual search task, $F(1, 37) = 9.70$, $p < .01$, $\eta_p^2 = 0.21$. A post-hoc analysis of the information level using least-squares means with Bonferroni corrections, revealed that the Decision group had significantly more missing answers than the No Feedback group, $t = 4.01$, $p < .01$, and then the Sensors group, $t = 2.47$, $p = .05$. These results could indicate that a more complex cluster may be more distracting. The cause for that distraction is not clear: participants may be looking at the information cluster (because it was showing almost continuous information) or the environment (e.g., to compare their knowledge of the environment with the cluster's information) instead of looking to the visual search task. Concerning the instance of the visual search task, there were fewer missing answers in the second presentation of the task, which was expected since the element of surprise was removed with the first task presentation, so participants were more aware that the visual search task could be shown at any time.

It seems that having more information on the cluster has an influence on the missing answers to the visual task. However, when participants do answer the task, does the percentage of correct answers differ across groups? Figure 7 shows the percentage of correct/incorrect answers to the visual search task, calculated after excluding the missing answers. In this analysis, 6 participants were eliminated because they either failed to respond to all three trials in the first task (N = 2, all from Sensors group), to all three trials in the second task (N = 1, from Decision group), or to all trials, in both tasks (N = 3, all from Decision group).

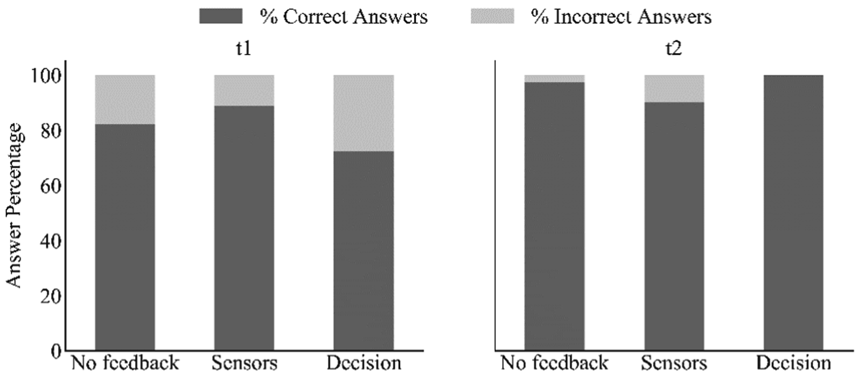

Fig. 7. Percentage of correct and incorrect answers to the visual search tasks according to the amount of available information in the assistive cluster in each moment of presentation (t1, t2).

From the results, it seems the percentage of correct and incorrect answers was very similar across groups. A mixed ANOVA with amount of information (3 levels) and the instance of the visual search task (2 levels: t1 and t2) was conducted regarding the percentage of correct answers (excluding missings). No significant differences were found for the information level, $F(2, 31) = 0.14$, $p = .87$, $\eta_p^2 = 0.009$. Conversely, a significant effect was found for the instance of the visual search task, $F(1, 31) = 6.10$, $p = .02$, $\eta_p^2 = 0.16$, with the percentage of correct answers increasing considerably in the second appearance of the task ($M_{t1} = 82.4\%$ vs. $M_{t2} = 93.1\%$). Although the number of trials was small, this increase in performance may reflect the effect of training.

5.3 Trust Questionnaire

Figure 8 shows the answers of the three groups to the four questions concerning the trust on the system. As depicted in Fig. 8, the overall system was perceived by all groups as trustable and safe.

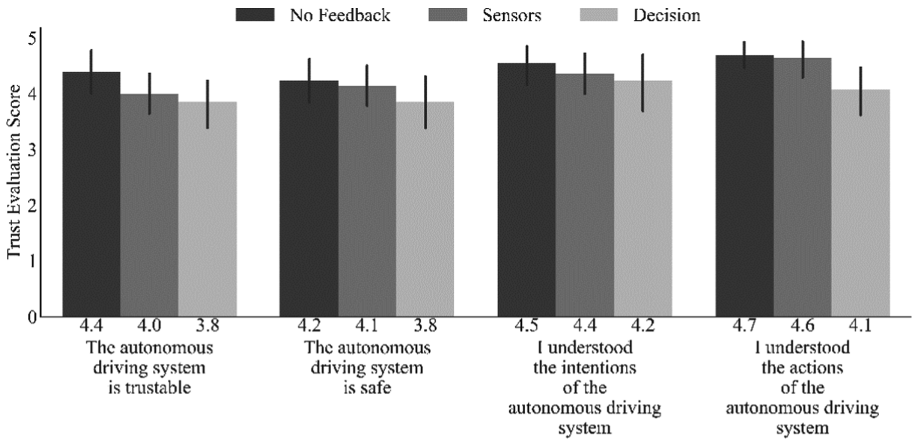

Fig. 8. Mean scores of the Trust questionnaire. The score 0 means "totally disagree" and score 5 means "completely agree" with the sentence.

Generally, participants agreed with all the questions. The lowest mean score was 3.8 and it was obtained for the Decision group in the questions regarding the autonomous system being trustable and safe (first two questions in Fig. 8). The intentions and actions of the autonomous driving system (last two questions in Fig. 8) were well understood, as the mean score rate for both items was higher than 4 for all groups. Although Young et al. (2015) argue that subjective measures, like self-reports, are rather complicated, Schmidt et al. (2017) report to have successfully used verbal assessment of drivers' condition regarding perceived sleepiness and cooling sensations.

Looking at Fig. 8, there seems to be a tendency for perceiving the system as more trustable and safe (first and second questions in Fig. 8) the less information it has. Also, the comprehension of system's intention and actions (third and fourth questions in Fig. 8) seem to be rated with lower scores as the cluster's feedback increases on complexity, with the worst scores in the Decision group.

One-way ANOVAs were conducted to analyse differences between the three information levels for each one of the questionnaire items. The differences were non-significant for all ANOVAs, except for the item "I understood the actions of the autonomous driving system", $F(2, 37) = 3.36$, $p = 0.05$, $\eta_p^2 = 0.15$, were the result was partially significant. Post hoc analysis indicate that the participants from the Decision group performed worse than the No Feedback group, $t = -2.321$, $p = 0.08$.

6 Conclusion

Self-driving technology has the potential to profoundly change how we use automobiles. However, generalized adoption will strongly depend on the perception of trust experienced by the users (Choi and Ji 2015). Given that the HMI is one of the main sources of information for the vehicle occupants, it may play a key role in increasing system transparency, a factor known to affect trust (Choi and Ji 2015), thus influencing acceptance.

In this study, we investigated how conveying feedback regarding perception of surrounding driving environment and from the autonomous systems decisions may affect trust. Results of our study do not point clearly to a direct relation between the available feedback information and the amount of trust assessed by the questionnaire. This may be due to the particular design of the interface, which provided only limited information regarding the location of surrounding vehicles and of the vehicle's own course of action. It may be that more explicit and complete information is required to affect trust. For instance, in a recent work by Haeuslschmid et al. (2017) which also compared different feedback visualizations a "world in miniature" concept (inspired on the one used in Tesla vehicles) was the most effective in conveying trust and sense of safety. Our results also showed an inverse relation between available feedback and performance on a visual search task. That may imply that the more complex assistive cluster created the greatest cognitive load, leading to the worst task performance.

In conclusion, more information does not necessarily lead to more trust and may in fact negatively affect cognitive load. These results point to the need of investigating which types of feedback are more appropriate and how the particular design choices for the visual HMI may affect trust and influence cognitive load. Other ways of conveying information to the user should also be studied. For instance, this experiment focused on visual feedback, but the use of other sensory modalities, either in combination with the visual cues or by themselves, should also be explored. Other approach to convey trust on autonomous vehicles may be by anthropomorphizing them, by for example providing it a voice and simulating intelligent conversation (Ruijten et al. 2018).

Despite a different cluster feedback design or other modalities that could be implemented to transmit a feeling of safety and trust to the user, this study calls for the need to test different approaches on active feedback of autonomous driving systems.

Acknowledgments. This work has been supported by FCT – Fundação para a Ciência e Tecnologia the scope of the Project: UID/CEC/00319/2019 and by: European Structural and Investment Funds in the FEDER component, through the Operational Competitiveness and Internationalization Programme (COMPETE 2020) [Project no. 039334; Funding Reference: POCI-01-0247-FEDER-039334].

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Revitalizing Safety Management and Practice

Collective Mindfulness as a Preventive Strategy Against Workplace Incidents: A Comparative Study of Australia and the United States

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Abstract. The workplace has become a second home to many workers as they spend most of the day working in their various work environment while performing their job roles. It is therefore imperative as a duty of care for employers to ensure they provide a safe workplace for both employees and visitors. In the quest to provide safer working conditions, organizations have continually sort for strategies and successful models from other industries which they can emulate. This has led many organizations to study High Reliability Organizations as an incident prevention strategy. High reliability organizations (HROs) which include air traffic control, nuclear power generation stations and US Navy air carriers, are known to perform their operations in an uncertain and hazardous environment filled with the possibility of failing, and even when they fail they are able to recover quickly. HROs are known to perform nearly incident-free, with high safety and production performance. Research has shown that HROs are able to perform exceptionally well because of their cognitive mindset and collective mindfulness. Collective mindfulness is made up of five aspects present in all HRO which are; preoccupation with failure, reluctance to simplify, sensitivity to operations, commitment to resilience, and deference to expertise. This paper compares workplace incidents in Australia and the United States, using 2016–2018, incident data, extracted from WorkSafe Victoria, SafeWork New South Wales, Workplace Health and Safety Queensland, WorkSafe Western Australia, and the United States Department of Labour, and Occupational Safety and Health Administration websites. We identify falls and being struck by moving object or equipment as the leading cause of workplace accidents, while lack of supervision, non-compliance, training, and the absence of appropriate safety procedures were identified as contributing factors to most workplace accidents. The paper further proposes CM as an incident prevention strategy that can be integrated into organizational safety management systems to mitigate accidents and provide safer working environment.

Keywords: High Reliability Organization · Construction safety · Reliability

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 355–366, 2020.
https://doi.org/10.1007/978-3-030-20497-6_33

1 Introduction

Workplace health and safety is a major concern for organizations because it is their legal responsibility to provide a safe and conducive working environment for employees and visitors as a duty of care. Despite efforts made by various organizations over the past decades to mitigate workplace accidents, it remains a major challenge. The International Labour Organization (ILO) reports that people die daily as a result of occupational accidents or work-related diseases, with more than 2.78 million deaths per year, and 374 million non-fatal workplace related injuries and illnesses each year. The human cost of the daily calamity is enormous with high economic burden as a result of poor workplace safety and health practices, which is estimated at 3.94% of global Gross Domestic Product (GDP) each year [1]. In 2018, 189 workers were killed at work in Australia, with work related injuries costing $61.8 billion to the economy [2]. While in the United States, 5147 workers were killed in their workplaces, and 2.8 million non-fatal workplace injuries and illnesses were reported in 2017 [3]. These statistics are worrisome and highlights the need for result oriented approaches, which will address hidden contributing factors of workplace accidents and injuries. Research suggest that the most influential precursor of workplace accident are organizational and management related [4, 5], and this cannot be over stressed, as frontline staff and middle management all depend on top management for implementation and approval of safety policies. This study proposes how CM can be applied to prevent workplace accidents by analysing 2016–2018 workplace accidents dataset obtained from Work-Safe Victoria, SafeWork New South Wales, WorkSafe Queensland, WorkSafe Western Australia [6–9] and United States Occupational Health and Safety Administration (OSHA) [10] websites. Using descriptive statistics, we present graphical representation of the results and the relationship between cause of accident, job role, and industry and accident outcome. Furthermore, we identify contributing factors from the accident narrative data and propose how CM can be applied to prevent such accidents from occurring. The subsequent sections provide an overview of theoretical background, data analysis, results, discussion, conclusion and recommendation for future research.

1.1 Theoretical Background

1.1.1 High Reliability Organization (HRO)

High reliability Organizations (HRO) are known to function in hazardous and uncertain environments where the probability of failing, or an accident occurring is very high, but rather than fail they perform their activities almost accident-free, achieving high safety and production performances [11]. HRO was conceptualised in the early 80s, when some group of researchers from Berkely University in order to counter Perrow's normal accident theory, that accidents in highly complex organizations are normal and unavoidable because such Organizations had become so complex and tightly coupled to the point that a little incident, might result in a sequence of cascading failure in different part of the system resulting in unavoidable disaster [12]. They agreed that some organizations were tightly coupled and complex, in regard to Perrrow's criteria but were able to achieve outstanding safety and production goals. Their HRO research focused on three industries; nuclear power generation stations, air traffic controls and aircraft carriers, because of their similarities as they operate in unforgiving social and political environments, with risky and complex technologies that present potential for error. To avoid failures they used complex processes to manage complex technologies [13]. Weick and Sutcliffe [14] took HRO further and proposed that HRO were able to consistently perform exceptionally well because of their cognitive mindset applied in the management of organizational risk. They invented the name "collective mindfulness" to represent cognitive mindset which are present in all HROs [14, 15].

1.1.2 Collective Mindfulness (CM)

Collective mindfulness is a team's ability to develop a comprehensive alertness of discriminatory details about internal and external processes and to regulate team behaviours accordingly [16–19]. It also involves an increased attention to internal and external present-activities and managing present activities with open and nonjudgmental attitude. CM consist of five aspects; (a) preoccupation with failure, (b) reluctance to simplify, (c) sensitivity to operations, (d) commitment to resilience, and (e) deference to expertise. CM is further classified into anticipation of unexpected problems which includes the first three aspects and deals with the ability for an organization to manage unforeseen problems, and containment of unexpected problems which includes the last two aspects, and deals with the ability for an organization to manage unexpected problems without allowing it go out of control.

Preoccupation with Failure

This involves proactive analysis, discussions and action reviews [13], by looking out for things that might possibly go wrong and affect the safety of a system, at the same time searching for errors and near misses. This is a practice in HRO used to capture warning sign because they believe if warning signs are captured and acted upon failures can be averted [20].

Reluctance to Simplify

This is the process of gathering information that can be used to monitor activities, identify warning signals, and analyse incidents and near misses in order to enhance safety performance. HROs create a clear and understandable picture of current situations, by simplifying less and seeing more [13, 21].

Sensitivity to Operations

Sensitivity to operations is the ability to obtain and maintain the 'bigger picture' of the functionality of a system's operations, which enables the effective anticipation of potential future failures [13]. Data on incidents are systematically collected, analysed and stored to capture the increasing sources of root causes [13].

Commitment to Resilience

This is the ability to successfully absorb, contain, and recover from failures, which is achieved by a real commitment to learning from past incidents both from within and outside of an Organization. HROs are of 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.

Deference to Expertise
This is the process of shifting decision making in the event of an emergency to the most experienced person or team, to manage the situation irrespective of organizational rank. 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 [15].

To fully understand how CM can be applied to prevent workplace accidents, we need to understand the leading causes of workplace accidents that are fatal and non-fatal, and how various industries and job roles influences accidents and their outcomes. Thus, we intend to answer the following questions:

1. Can Job role influence the likelihood of workplace accidents?
2. Are employees likely to be involved in workplace accidents based on the industry they work in?
3. How can CM be applied to mitigate workplace accidents?

2 Materials and Methods

Data Source
The data used for this study are 2016–2018 datasets obtained from WorkSafe Victoria, SafeWork New South Wales, WorkSafe Queensland, WorkSafe Western Australia [6–9], and United States OSHA [10] websites. The datasets are available for research and review purpose only. 100 incident narratives reports were extracted from WorkSafe Australia websites, and 1412 from United States OSHA website. After pre-processing and labelling the dataset, 72 (2018) cases were obtained from Australia, and 430 (2016–2017) from the United States which were coded and included for analysis. The original datasets were not labelled, some were presented as incident report narratives without titles, and others with just titles and narratives. We labelled the dataset as: industry, cause of accident, job role, accident outcome and year (Table 1).

Data Analysis
A total of 502 labelled cases were included for analysis, and descriptive statistics was applied to identify accident occurrences, and the most likely cause of fatal accidents in workplaces. Details of this are presented in the result section.

Table 1. Dataset labels

Industry (INDT)	Cause of accident (CA)	Job role (JR)	Accident outcome (AO)	Year
1. Construction	1. Falls	1. Construction worker	1. Fatality	2016
2. Contracting	2. Struck by moving object	2. Apprentice	2. Hospitalized	2017
3. Maintenance	3. Electrocution	3. Mobile machine operator		2018
4. Marine	4. Caught between object or machinery	4. Machinery operator		
5. Agriculture	5. Asphyxiation	5. Farm worker		
6. Manufacturing	6. Vehicle collision	6. Marine worker		
7. Oil and gas	7. Rollover off non road vehicles	7. Skilled worker		
8. Mining	8. Structure collapse	8. Technician		
	9. Exposure to extreme temperature	9. labourer		
	10. Slips and trips	10. Other		
	11. Falling object			
	12. Explosion			

3 Results

The results are presented in two sections, the first section presents results from Australia and the second section presents results from the United States.

3.1 Australia

The frequency for various causes of accident and outcomes are presented below for 72 cases from Australia (Tables 2, 3). Clustered bar charts were used to present workplace accident distributions between job role, cause of accident, accident outcome and industry (Figs. 1, 2).

Table 2. Frequency distribution of workplace accidents

Cause of accident	Frequency	Percent
Falls	30	41.7
Struck by moving object	12	16.7
Electrocution	2	2.8
Caught between stationary or moving object	4	5.6
Rollover off non-road vehicle	5	6.9
Falling object	4	5.6
Asphyxiation	3	4.2
Vehicle collision	1	1.4
Explosion	4	5.6
Structure collapse	7	9.7
Total	72	100.0

Table 3. Frequency distribution of accident outcome

Accident outcome	Frequency	Percent (%)
Fatality	31	43.1
Hospitalized	36	50.0
Days off work	5	6.9
Total	72	100.0

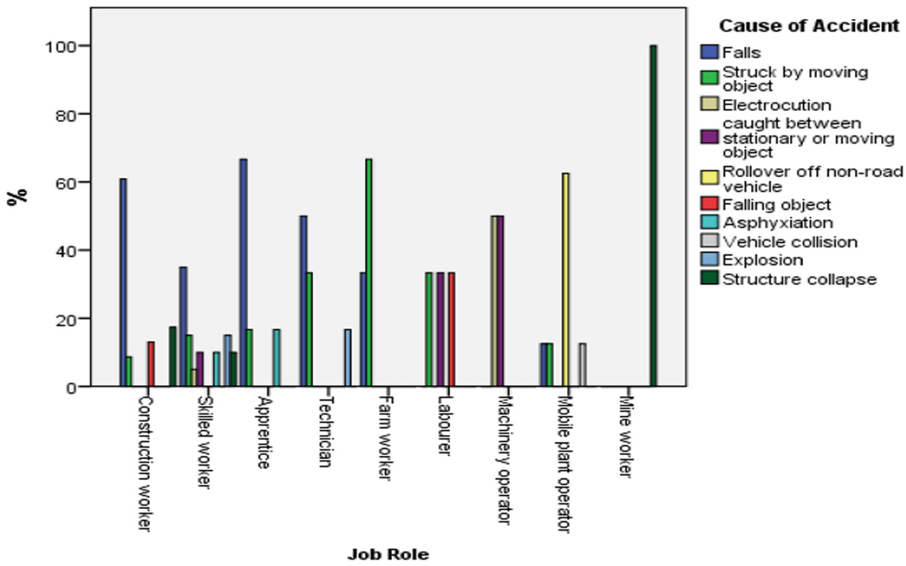

Fig. 1. Distribution of workplace accidents by Job Role and Cause of Accident

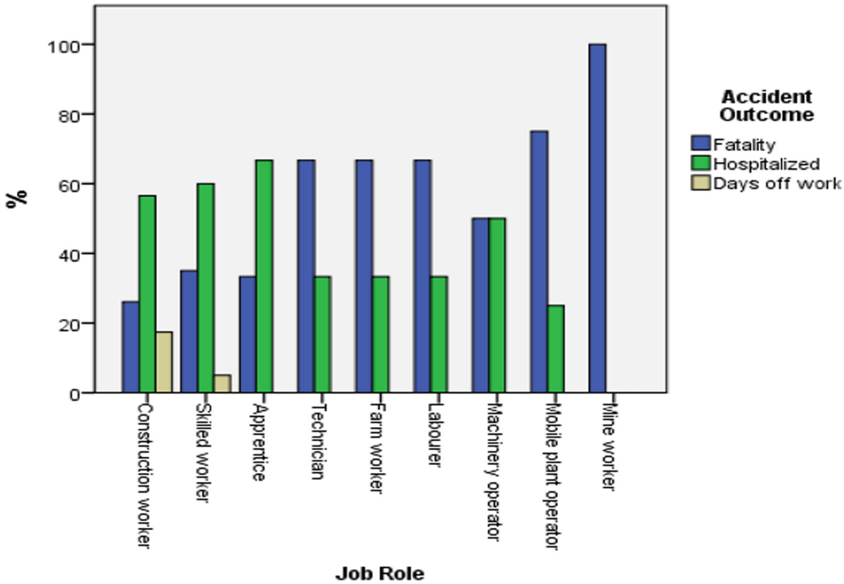

Fig. 2. Distribution of workplace accident by Job Role and Accident Outcome

3.2 United States

The frequency for various causes of accident and outcomes are presented below for 430 cases from the United States (Tables 4, 5). Clustered bar charts were used to present workplace accident distributions between job role, cause of accident, accident outcome and industry (Figs. 3, 4).

3.3 Result Summary

The results from Australia showed that in 2018, 41.7% of workplace accidents were caused by falls, and 16.7% by being struck by moving object or equipment, while electrocution and vehicle collision were the least cause of workplace accidents accounting for 2.8% and 1.4% of accidents. 43.1% of accident outcomes resulted in fatalities, with contracting and constructions industry accounting for 29.0% and 25.8% respectively. Apprentices, construction, and skilled workers were the most involved in workplace accidents.

Results from the United States revealed that from 2016–2017, falls accounted for 34.4% of workplaces accidents and being struck by moving object or equipment 20.9%. Slips and trips (0.5%), extreme temperature (1.2%), and vehicle collision (1.6%) were the least cause of accidents. Accidents with fatal outcomes accounted for 97.7% fatalities, with construction and contracting industry recording the highest, 39.3% and 33.1%. Construction workers, skilled workers and labourers were the most involved in workplace accidents.

Table 4. Frequency distribution of workplace accidents

Cause of accident	Frequency	Percent
Falls	148	34.4
Struck by moving object	90	20.9
Electrocution	37	8.6
Caught between stationary or moving object	42	9.8
Asphyxiation	11	2.6
Vehicle collision	7	1.6
Rollover off non-road vehicle	20	4.7
Structure collapse	21	4.9
Extreme temperature	5	1.2
Slips and trips	2	.5
Falling object or equipment	31	7.2
Explosion	16	3.7
Total	430	100.0

Table 5. Frequency distribution of workplace accidents outcome

Accident outcome	Frequency	Percent
Fatality	420	97.7
Hospitalized	10	2.3
Total	430	100.0

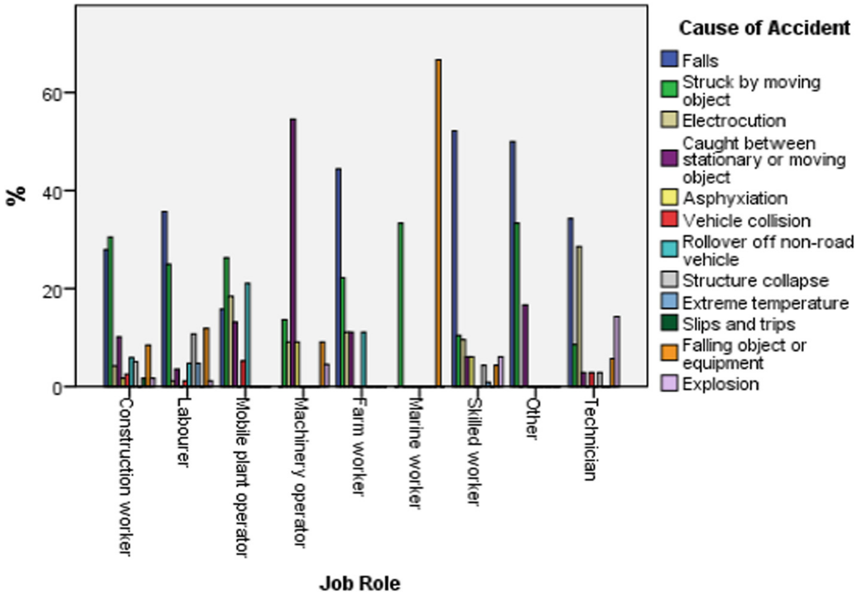

Fig. 3. Distribution of workplace accidents by Job Role and Cause of Accident

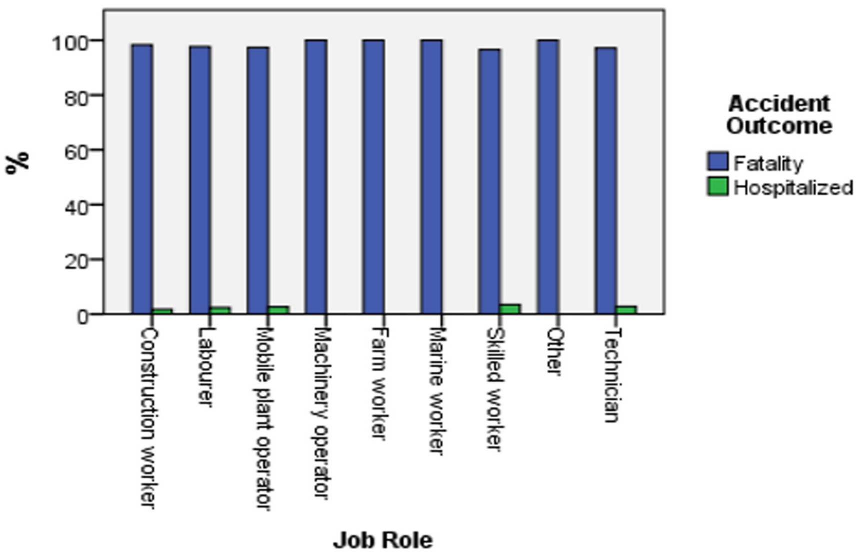

Fig. 4. Distribution of workplace accident by Job Role and Accident Outcome

4 Discussion

A number of factors influences workplace accidents, and we set out to identify those factors by analyzing accident narrative datasets from Australia and United States. This we did in order to propose the application of CM to mitigate workplace accidents. The results from our analysis has shown that workers are most likely to be involved in an accident depending on the industry sector they work in. As shown in Fig. 3, construction and contracting industries ranked the highest in workplace accidents accounting for 25.8%, and 29.0% in Australia, and 39.3%, and 33.1% in the United States.

From the dataset narratives, we identified lack of supervision, non-compliance, lack of training, and the absence of appropriate safety procedures as contributing factors to most workplace accidents. Safe work method statements (SWMS) were found to be absent in some cases and other times workers did not complete and sign them off. In one of the cases, an apprentice was unsupervised while installing new smoke alarms, and in the process electrocuted. The investigations revealed that, the company the apprentice worked for failed to provide a SWMS for the job. In other cases, most organizations failed to train workers on safety procedures for conducting high-risk task, such as working at height, mobile plant operation, and confined space. The results in this study has shown that falls are the leading cause of workplace accident, with fatal and non-fatal outcomes. For workplaces to be safer, it is imperative to implement practical approaches that will effectively mitigate accidents. CM has five aspects divided into anticipation of unexpected events, and containment of unexpected events, and can be applied to improve workplace safety management for various organizations.

4.1 Applying CM to Prevent Accidents

Anticipation of Unexpected Events
Organizations need to be prepared for unexpected events in order to safeguard against workplace accidents, as most accidents are catastrophic with huge social and financial impacts, which may be devastating to recover from [22]. Research has shown that the major causative factors of falls, are falls from frames, from or through roof and trusses, through open stair void, from ladders and scaffolding. These and other accident causative factors can be eliminated by picking up weak signals through regular workplace risk assessment, effective supervision, learning from experience, incident report logs, and near misses. The information gathered can be used to identify warning signals to enhance safety performance, and ensure problems are resolved from different perspectives.

Containment of Unexpected Events
In the event of a workplace accidents, most organizations find it very tasking to fully recover and resume normal operations, therefore, to contain unexpected events organizations need to improvise adaptable work routine strategies when such events occurs. Strategies such as updating SWMS as the job and workplace changes, effective communication of safety issues across all levels of the organization, regular training and refresher programs for workers, learning from small mistakes and surprises [23], can improve safety and productivity performance. Furthermore, decision making should be left for those with higher experience to make, during emergencies irrespective of rank, as this practice will eliminate trial and error approach of solving critical problems.

5 Conclusion

This study examines how workplace accidents can be prevented by applying CM, in doing so the following questions were addressed: Can Job role influence the likelihood of workplace accidents? Are employees likely to be involved in workplace accidents based on the industry they work in? How can CM be applied to mitigate workplace accidents? The result from our analysis lead us to conclude that job role has an influence on the likelihood of workplace accidents because construction and skilled workers were involved in more accidents, we also conclude that there is a likelihood of workers being involved in an accident if they work in certain industry sectors, with construction and contracting industries accounting for a greater percentage of workplace accidents with fatal outcomes. Finally, we conclude that CM can be applied to improve workplace safety management by anticipating unexpected problems and containing them. CM can help organizations attain error free operations and improve safety and productivity.

The limitation of this study is the small sample size obtained from Australia, which did not permit elaborate comparison because of the substantial difference in cases, however we identified common links between the variables, such as patterns and trends in workplace accidents in relation to job role, accident causation and various industries.

We recommend further research to focus on how mindfulness can be applied to prevent workplace accidents, as several organizations will benefit from such contribution to the body of knowledge.

Acknowledgments. The authors acknowledge funding provided by The University of Newcastle Australia [International Postgraduate Scholarship (UNIPRS) and University of Newcastle Research Scholarship Central 50:50 (UNRSC5050) scheme] for the first author.

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The Occupational Risk Assessment Method: A Tool to Improve Organizational Resilience in the Context of Occupational Health and Safety Management

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Abstract. The resilience engineering (RE) approach driven by Hollnagel, Woods and Leveson [1] focuses on the ability of organizations to cope with disturbances. The notion of "control of operations" is essential to the concept of resilience. Hollnagel [2, 3] proposes a regulatory model of the operational control function, broken down into four essential abilities: to anticipate, monitor, respond, and learn. Within the domain of occupational health and safety (OHS) management, the risk assessment method "DIARBENN" was developed through a French approach to contribute to the development of the four resilience abilities of an organization. This method places the analysis of operators' activity at the center of the risk assessment process. The aim of this paper is to present the DIARBENN method as a tool that contributes to the development of organizational resilience in the context of OHS management.

Keywords: Resilience engineering · Occupational health and safety management · Organization · Occupational risk assessment method

1 Introduction

The resilience engineering (RE) approach driven by Hollnagel, Woods and Leveson [1] focuses on the ability of organizations to cope with disturbances. The notion of "control of operations" is essential to the concept of resilience. Hollnagel [2, 3] proposes a regulatory model of the operational control function, broken down into four essential abilities: to anticipate, monitor, respond, and learn. These abilities enable an organization to be resilient, that is, able to *"adjust its functioning prior to, during, or following events (changes, disturbances, and opportunities), and thereby sustain required operations under both expected and unexpected conditions"*.

RE is often viewed from a macroscopic point of view (i.e. the blunt-end level). The sharp-end level, however, is highly relevant to RE issues [4]; it involves viewing the activity of the operators as a worthwhile object of study for resilience. Executing this

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 367–376, 2020.
https://doi.org/10.1007/978-3-030-20497-6_34

activity may, under certain conditions and/or when disturbances occur, lead to a loss of control of operations and consequently to the occurrence of occupational accidents, occupational diseases, and industrial disasters. This loss of operational control indicates the inability of operators to adapt, in specific circumstances, to the work activity constraints. In the RE domain, it is therefore worth examining the adaptation processes that enable operators to remain in a safe functioning space of operations [5, 6, 7, 8].

The French tradition of ergonomics research (e.g. [9–13]) is particularly involved in investigating the activity of operators in the context of industrial safety and occupational health and safety (OHS) concerns. Examining operators' activity provides a genuine opportunity to identify all the dangers they are exposed to in order to conduct an accurate assessment of their health- and safety-related risks. Analyzing operators' activity from the perspective of the assessment process of the risks they are exposed to also helps identify the room for maneuver available to them. This room for maneuver is essential to the adaptation process that enables them to keep control of the operations. Organizational resilience, from the sharp-end level, depends upon this capacity to adapt. Consequently, the links between the four resilience abilities (i.e. to anticipate, monitor, respond, and learn), operators' activity, and the risk assessment process are very close. In this context, as part of OHS management, the risk assessment method "DIARBENN" was developed through a French approach at the Health, Safety, and Environment Department of the Lorient University Institute of Technology (France). This method contributes to the development of the four resilience abilities of an organization at the sharp-end level and places the analysis of operators' activity at the center of the risk assessment process.

This paper is divided into three sections. The first section presents the regulatory context of OHS in France and more specifically that of occupational risk assessment. The second one presents the DIARBENN method developed to assess occupational risks and improve organizational resilience at the sharp-end level. The last section is the discussion/conclusion.

2 The Regulatory Context of OHS in France

From a legislative perspective, Directive n°89/391/CEE of June 12, 1989, gave momentum to a common framework within the European Union regarding the prevention of health and safety risks for workers. The directive placed occupational risk assessment at the top of the hierarchy of the general principles concerning prevention. Law n°91-1414 transposed the provisions that the framework directive added into French law. With reference to risk assessment, Articles L4121-1/2/3 of the labor code incorporate the community legislation under three requirements: 1. Employers are required to ensure their workers' health and safety; 2. The general principles of occupational risk prevention must be implemented; 3. Risk assessment must be conducted. Decree n°2001-1016 of November 5, 2001, makes it mandatory to produce a document relating to the assessment of the risk's workers are exposed to in an organization. Failure to comply with this requirement results in subjecting managers to the criminal penalties provided for in Article R4741-1 of the labor code.

The regulatory framework specifies neither the method nor the tools to be used for the occupational risk assessment. It is the managers who must assume the responsibility for the task by implementing an occupational risk assessment process that is adapted to their situation.

The Health, Safety, and Environment (HSE) Department at the Lorient University Institute of Technology has developed a risk assessment method called "DIARBENN", which is taught to the future occupational health and safety professionals. It has been deployed in many companies for a number of years.

3 The Diarbenn Method

The Diarbenn method is implemented as part of the occupational risk assessment process that represents the backbone of any OHS management system. The Diarbenn method includes four main phases, presented in detail in the following sections. It is implemented by the OHS specialist in a company.

3.1 Phase 1. Breaking the Company Down into Elementary Operational Units

The first phase of the Diarbenn method involves breaking the company down into elementary operational units (e.g. administration, production, logistics, export, maintenance). Next, the job posts in these units are classified into homogeneous exposure groups. Once the breakdown has been set out formally within a dedicated document, Phase 2 of the preliminary risk analysis may start.

3.2 Phase 2. Preliminary Risk Analysis

The goal of the preliminary risk analysis (PRA) is to identify all the dangers operators are exposed to and the risks arising from the exposure. An exhaustive identification of the dangers and risks is conducted for all homogeneous exposure groups within the various operational units. Deeply embedded in mainstream French ergonomics, the PRA first requires analyzing operators' activity in the different job posts. Hence, all the on-site preliminary observations the OHS specialists carry out help describe all the operators' activities and view them in the light of the corresponding dangers, risks, and damages. The analysis of activity also helps the OHS specialists determine the room for maneuver available to operators to enable them to keep operational control.

To carry out the PRA, OHS specialists need to fill in the grid shown in Table 1.

Table 1. The preliminary risk analysis grid

PRELIMINARY RISK ANALYSIS							
Work Situation	Operators' activity	Hazard	Risk	Type of risk (Chronic or Accidental)	Type of injury	Location of injury	Penibility factors ? (Yes or No)

To help them avoid potential errors, OHS specialists are given a predefined list of risks (Table 2). The Diarbenn method distinguishes between two main risk categories: 1. Quantitative risks that may be assessed through metrology, hence by using specific quantitative assessment methods usually related to regulatory thresholds not to be exceeded; 2. Qualitative risks that may only be assessed subjectively (or differently but with great difficulty). For this risk category, a single general assessment method has been proposed (see Sect. 3.3).

Table 2. Quantitative and qualitative risks

Quantitative risks related to:	Qualitative risks related to:
Noise	Occupational slips, trips and falls and other movement disturbances.
Vibrations *(hands-arm and whole body)*	Falls from height
Thermal environments (Heat & Cold)	Car travel
Physical workload	Physical activity, including musculoskeletal disorders
Manual handling of loads	Biological agents
Repetitive work activities	Mechanical handling
Chemical hazards	Work equipment
Fire	Collapsing and falling objects
Explosion	Electricity
	Ionizing radiations
	Psychosocial risks

The PRA represents the most important phase of the Diarbenn method as it enables OHS specialists to understand operators' activity together with activity-related constraints and resulting risks.

3.3 Phase 3. Occupational Risk Assessment

When all the risks have been identified and entered into the PRA grid, the OHS specialists may proceed with the assessment of the criticality level of each risk. Two criticality levels are taken into account, which leads to two distinct assessments: 1. The level of "raw" criticality, which is assessed first. This first assessment does not take into account any aggravating factors, the means of controlling the human, organizational, and technical (HOT) resources, and the available room for maneuver. As mentioned in the preceding section, risks are assessed through different methods. Quantitative risks are assessed using the results of the implementation of metrology techniques. In this particular case, the "raw" criticality level of any given risk depends upon the regulatory thresholds. Hence, the OHS specialists enter the corresponding "raw" criticality level in their assessment grid. For qualitative risks, the "raw" criticality level is assessed through a generic method shown in Appendix 1 (see Tables 5 and 6) based upon the failure mode, effects, and criticality analysis (FMECA) method. 2. The level of "residual" criticality that is assessed second, which takes into account all aggravating factors, the HOT dimension, and the available room for maneuver. To assess this second level of criticality, OHS specialists use a second matrix (see Appendix 1, Table 7). The results of this second assessment (i.e. of the residual criticality level) are used to determine the needed remedial actions. The OHS specialists' understanding of the operators' activity is essential for them to be able to assess accurately this level of residual criticality.

The Diarbenn method involves conducting the assessment of two criticality levels, whereas many other methods call for the examination of residual criticality only, which is problematic because a low level of residual criticality may hide a high level of raw criticality. In this case, it is the HOT dimension, the aggravating factors, and the available room for maneuver that induce a low level of residual criticality. Should these three parameters deteriorate gradually while the company is unaware of the changes, the result would be dissonance between the actual level of residual criticality and that recorded in the document presenting the occupational risk assessment results. Taking both criticality levels into account enables the company to monitor its risk control process but also the available room for maneuver.

Table 3 shows the risk assessment grid the OHS specialists fill in, which is matched with the PRA grid (see Table 1).

Table 3. The risk assessment grid

RISK ASSESSMENT PROCESS														
First Criticality Assessment				Aggravating factors					Risk control				Second Criticality Assessment	Comments
Severity	Probability	Exposure duration	Criticality level	Gender	Age	Nightwork	Shiftwork	Lighting conditions	Technical	Human	Organizational	Lack of room to maneuver		

3.4 Phase 4. Implementing and Monitoring the Action Plans

After assessing the second criticality level (i.e. residual criticality) in Phase 3, the OHS specialists are in a position to propose and prioritize a set of actions that need to be implemented within the framework of OHS management.

In addition to the two grids shown earlier, the OHS specialists fill in the following table (Table 4). Hence, they are able to coordinate and monitor the implementation progress of their action plan.

Table 4. The action planning grid

ACTION PLANNING		
Action type	Action manager	Deadline

The Diarbenn method has been implemented in a software program especially developed to facilitate the activities of the OHS specialists. Its user interface enables them to configure their risk assessment methods for Phase 3, to fill in all the grids in the same table, to monitor their action plan, and to produce a document showing all the occupational risk assessment results, namely the "Single Document" that is legally required. This document is then made available to all the company employees and represents a genuine prevention tool. It is dynamic, since it is updated regularly, in particular when changes are made to the various job posts. Hence, the OHS specialists can remain vigilant regarding the operating conditions in effect at the different job posts.

An excerpt from a risk assessment table produced with the Diarbenn program can be found in Appendix 2.

4 Discussion/Conclusion

The Diarbenn method was first created to meet the regulatory constraints in the domain of OHS management. As a second step, it was modified to contribute to the development of the four abilities of organizational resilience [2] at the sharp-end level, namely, to anticipate, monitor, respond, and learn.

The Ability to Anticipate. The risk assessment process implemented through the Diarbenn method is proactive by nature. It helps anticipate all the situations that may lead to loss of operational control. In this respect, it contributes significantly to the development of the ability to anticipate that characterizes any resilient organization.

The Ability to Monitor. The Diarbenn method is a means to support the occupational risk assessment process that constitutes the backbone of any risk management system. This method is based upon two main pillars: 1. The analysis of operators' activity; 2. The assessment of two levels of criticality. From the perspective of resilience engineering, these two pillars are crucial since they contribute directly to keeping operations within an operating space that is viewed as safe. Phases 2 (i.e. the preliminary risk analysis) and 3 (i.e. the risk assessment process) enable the OHS specialists to identify, within the various work situations examined, all the conditions that may lead to the loss of operational control and, in particular, the situation of the available room for maneuver. The operators' ability to adapt depends partly upon the room for maneuver that is available to them [14–16]. A significant step for resilience is the ability to determine the situation of the room for maneuver at the PRA stage and then to take that description into account when assessing the risks operators have to face. Similarly, assessing both criticality levels (i.e. raw and residual criticality) facilitates monitoring the organization from the perspective of its capacity to retain its available room for maneuver and HOT resources. It is essential to be able to identify the nature of the risk encountered in case the organization loses its room for maneuver and HOT resources. Hence, the Diarbenn method contributes to the accurate assessment of the operators' adaptability within their occupational activities, and it helps strengthen the monitoring capacity of the organization regarding the various items that may induce the loss of operational control. This monitoring capacity is essential to any resilient organization. The Single Document also fosters the development of this monitoring capacity because all the organization employees are expected to be aware of it; hence, they are in a position to know the nature of the dangers and risks present in their environment to which they are directly or indirectly exposed.

The Ability to Respond. Following the risk assessment phase, the action plans implemented to deal with the critical risks contribute to the development of the ability to respond of the organization. These actions are intended to contribute to maintaining the organization in an operational space viewed as safe through strengthening the operational control process. Furthermore, regular updating makes the Single Document a genuine prevention tool that also contributes to the development of the response capacity. Any deviation identified by the OHS specialists induces an update; hence, a response is given to a specific situation.

The Ability to Learn. When any accident, occupational disease, catastrophe, and/or incident occurs in an organization, fingers are often pointed at the risk assessment process. This type of event is indicative of the loss of operational control that has poorly, or not at all been anticipated in the Single Document. This type of situation leads the OHS specialists to analyze the causes of the event occurrence and take those into account in the risk assessment process. The workplace situation is once again analyzed following the Diarbenn method. The feedback thus obtained contributes to developing the ability to learn of the organization.

The Diarbenn method, embedded in mainstream French ergonomics, thus represents a tool that contributes to the development of the four resilience abilities of an organization. Implementing it is part of a grounded managerial approach focused upon the operators' activity and located at the sharp-end level. When presenting this approach, a comparison with the Australian approach will be conducted in order to identify the areas of convergence and divergence and the potential developments of the approach.

Appendix 1: The Generic Risk Assessment Method (Qualitative Risks)

Table 5. Probability and severity levels

	ACCIDENTAL RISK	
LEVEL	SEVERITY	PROBABILITY
L1	Accident without treatment	Has never occurred and improbable
L2	Accident with treatment but without work incapacity	Has never occurred but probable
L3	Accident with treatment and partial work incapacity	Has already occurred at least once in three years
L4	Fatal accident or total work incapacity	Occurs at least once a year

	CHRONIC RISK	
LEVEL	SEVERITY	EXPOSURE DURATION
L1	Short-term disability, without reduction of work capacity	Exceptional: 1 to 2 hours per quarter
L2	Chronic disability, without reduction of work capacity	Occasional: 1 to 2 hours per month
L3	Disabling impairment, with reduction of work capacity	Regular but discontinuous: 1 hour per week
L4	Fatal disability or severely disabling	Continuous: more than 1 hour per day

Table 6. Matrix for the first criticality assessment

		Severity			
	LEVEL	L1	L2	L3	L4
Probability OR Exposure Duration	L1	A (SL1)	A (SL2)	B (SL3)	B (SL4)
	L2	A (SL1)	A (SL2)	B (SL3)	C (SL4)
	L3	A (SL1)	B (SL2)	C (SL3)	C (SL4)
	L4	B (SL1)	B (SL2)	C (SL3)	C (SL4)

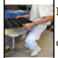
Table 7. Matrix for the second criticality assessment

	RISK CONTROL		
FIRST CRITICALITY ASSESSMENT RESULT	HIGH	INTERMEDIATE	LOW
Criticality LEVEL 1			
Criticality LEVEL 2			
Criticality LEVEL 3			
SECOND CRITICALITY ASSESSMENT			

Immediate action
Medium-term action
Level to maintain

Appendix 2: The Complete Risk Assessment Grid (Example)

Work Unit	UNIT 1	PRODUCTION

PRELIMINARY RISK ANALYSIS									RISK ASSESSMENT PROCESS																ACTION PLANNING		
									First Criticality Assessment				Aggravating factors					Risk control									
Work Situation	Operators' activity		Hazard	Risk	Type of risk (Chronic or Accidental)	Type of injury	Location of injury	Penibility factors ? (Yes or No)	Severity	Probability	Exposure duration	Criticality level	Gender	Age	Nightwork	Shiftwork	Lighting conditions	Technical	Human	Organizational	Lack of room to maneuver	Second Criticality Assessment	Comments	Action type	Action manager	Deadline
Making cakes		Making the dough	Machine	Risk related to work equipment	C	Crushing	Hands and arms	No	S2		D2	A(SL2)				x		Operational maintenance	Training	Turnover	x		Time pressure too important	Rearrange tasks + reduce time pressure	Andrew	30/03/2019
		Preparing the equipment	Weight of the hob	Risk related to physical activity, including musculoskeletal disorders	C	Musculoskeletal disorders	Upper limbs	Yes	S1		D3	A(SL1)	x	x				Adapted equipment	Training	Turnover			Need to remain vigilant	x	x	x
		Cook the cakes	Gas	Explosion & Fire	A	Deaths, burns	The whole body	No	S4	P2		C(SL4)						Operational maintenance + fire extinguishers	Training	Turnover			Intensify gas detection	Intensify gas detection	Nicholas from maintenance department	01/07/2019
		Check the cakes	Repetitiveness and gestures	Risk related to physical activity, including musculoskeletal disorders	C	Musculoskeletal disorders	Upper limbs	Yes	S2		D3	B(SL2)	x	x				Adapted equipment	Training	Turnover	x		Workstation not adapted	Modify the workplace	Andrew	01/07/2019
		Stock the cakes	Weight of the hob	Risk related to manual handling of loads	C	Musculoskeletal disorders	Upper limbs	Yes	S3		D2	B(SL3)	x	x				Adapted equipment	Training	Turnover			Need to remain vigilant	x	x	x
		Package the cakes	Machine	Risk related to work equipment	A	Cuts	Hands	No	S3	P2		B(SL3)				x		Individual protection equipment & Operational maintenance	Training	Turnover			Need to remain vigilant	x	x	x

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Study on Sleep Disorder in Gasoline Service Stations Workers

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Abstract. Study objectives: The main purpose of this research is to investigate the effects caused by the sleep disorder in workers of service stations with rotating shift. Method: One hundred and two workers of Forty-five service stations of Valparaiso city participated in this study. Informed consent was obtained from all subjects prior to their participation, in the Pittsburgh Sleep Quality Index (PSQI) to assess sleep. Results: From 102 participants, 52% were good sleepers. About 85% of the participants reported no history of sleep medication usage, almost 7% of the participants in this study report some degree of sleep problems. The mean sleep duration was 6.36 h and the mean score on the Pittsburgh Sleep Quality Index was 6,05. Conclusion: The vast majority of the workers evaluated in rotating shifts present easy to sleep.

Keywords: Sleep disorder · Sleep quality · Service station workers

1 Introduction

Sleep is essential for physical and mental health. Deep sleep for a particular number of hours is important for maintaining a normal human life. Interest in sleep is growing in today's world, as are the percentages of workers with sleep disorders those undergoing treatment for sleep disorders [2, 6]. Symptoms of sleep disorders include poor concentration, fatigue, anxiety, and disorientation. In particular, sleep disorders cause daytime sleepiness, reduce work efficiency, and increase the risk of accidents [7]. Poor sleep is associated with increased health care use, work absenteeism, and reduced work productivity [8, 9]. The health impact of night and shift work is widely felt even apart from performance decrements during work and accidents on and off the workplace site and has given rise to long-range health concerns [11, 12].

Several preliminary studies have suggested that insomniacs report more absenteeism at work than do persons who sleep well [13]. Insomnia has also been associated with an increased use of medical services, [14, 15] and with the development of somatic and psychologic disorders, [14, 16] such as alcoholism [17], depression [18], smoking [19] and morbidity in HIV patients [20].

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 377–382, 2020.
https://doi.org/10.1007/978-3-030-20497-6_35

It is commonly believed that sleep duration in the population has declined gradually [1, 2]. Insomnia is a highly prevalent disorder in the general population and in the clinical practice [3, 4]. There are different recommended interventions in the bibliography for the treatment of sleep problems, but the most widely applied to treat insomnia are the pharmacological treatments [5].

It is also important to consider that sleep itself is not a unitary construct but can be characterized by dimensions that include: duration, continuity, architecture, and quality [10].

1.1 Method

See (Fig. 1).

Fig. 1. Phases made with collaboration of a group of students

1.2 Setting and Participants

This was a cross-sectional study conducted during the Fall of 2018 on gasoline service station workers of the Viña del Mar in Valparaíso province, Chile. All questionnaires were administered and unnamed and the participants signed an informed consent. We interviewed a total of one hundred and two workers in forty-five gasoline stations.

1.3 Questionnaire PSQI

To evaluate sleep quality, Pittsburgh Sleep Quality Index (PSQI) was used. It consists of 19 rated questions which are scored to obtain a total score. The 19 items are grouped into seven components or scales of sleep, These are subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbance, use of sleep medications, and daytime dysfunction. Each component has a score that ranges from 0 to 3. All component scores are added to obtain a global score. A PSQI global score greater than 5 is indicative of significant sleep disturbance. This questionnaire were anonymous and written informed consent was obtained from all participants.

1.4 Data Analysis

Statistical analysis was performed using Minitab software version 17. The majority of the employees at the gasoline service stations were male (only one at the workshop was female).

2 Results

This study was conducted in 45 gasoline service stations located in Valparaiso Province, Chile from October to December 2018. They were 24–55 years old, and they spent about 8 h per day at gasoline service stations. All workers aged more than 18 years and had worked for more than three months. The scores of participants in the seven scales of sleep quality are shown in Table 1.

Table 1. Participants' scores for the seven scales of the Pittsburgh Sleep Quality Index (PSQI).

Scale	Number (%)			
	0	1	2	3
Subjective sleep quality	29 (28,1)	53 (52,0)	17 (17)	3 (2,9)
Sleep latency	24 (23,5)	38 (37,3)	25 (24,5)	15 (14,7)
Sleep duration	50 (49,0)	38 (37,3)	10 (9,8)	4 (3,9)
Habitual sleep efficiency	57 (56,0)	18 (17,6)	14 (13,7)	13 (12,7)
Sleep disturbance	3 (2,9)	69 (67,6)	26 (25,5)	4 (3,9)
Need for sleep medication	88 (86,3)	9 (8,8)	2 (1,9)	3 (2,9)
Daytime dysfunction	45 (44,1)	40 (39,2)	10 (9,8)	7 (6,9)

2.1 Daytime Dysfunction

Among the 102 participants who completed all of the questions in the PSQI questionnaire, 85 (44,1%) were good sleepers.

Need for sleep Medication

A score of 0 indicated the participant reported no problem. About 86% of the participants reported no history of sleep medication usage (Fig. 2).

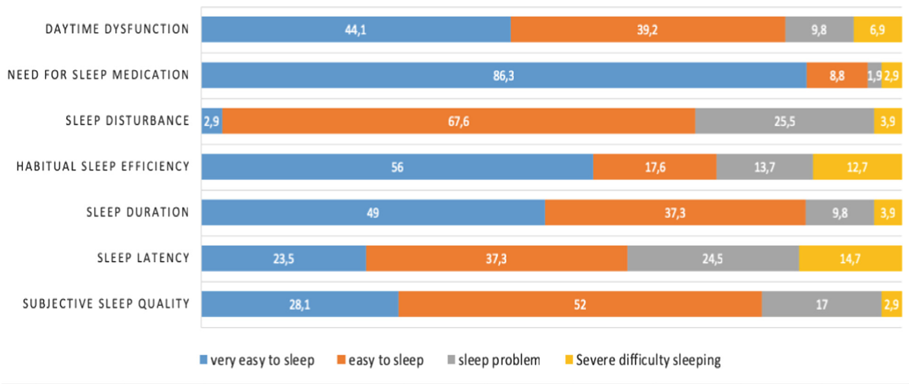

Fig. 2. Participants' scores for the seven scales and very easy to sleep to severe difficulty sleeping

2.2 Sleep Disturbance

The disturbance are defined as any physical, psychological and/or environmental condition (urgency to urinate, respiratory problems, cough, snoring, discomfort due to temperature, nightmares, pain, etc.) that postponed or interrupted the desired sleep.

2.3 Sleep Latency

In this study, 14,7% of workers reported severe difficulty sleeping (>1 h) and 24,5% of workers sleep problem (30 min to 60 min).

2.4 Discussion

Correlation was found between the PSQI score and the duration of sleep, however it is interesting to note that it is possible to find workers with difficulty to sleep even if they have slept less than 8 h, is shown in the Fig. 3.

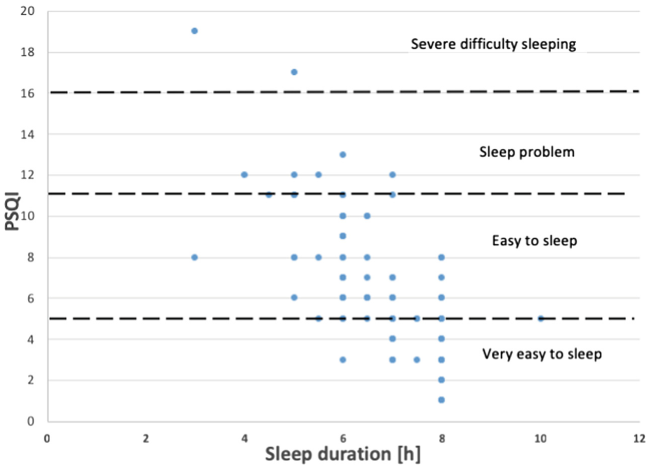

Fig. 3. Relation between PSQI score and Sleep duration

The Fig. 4 shows that participants with sleep problem or severe difficulty sleeping reported more sleep latency (31 min < SL < 60 min).

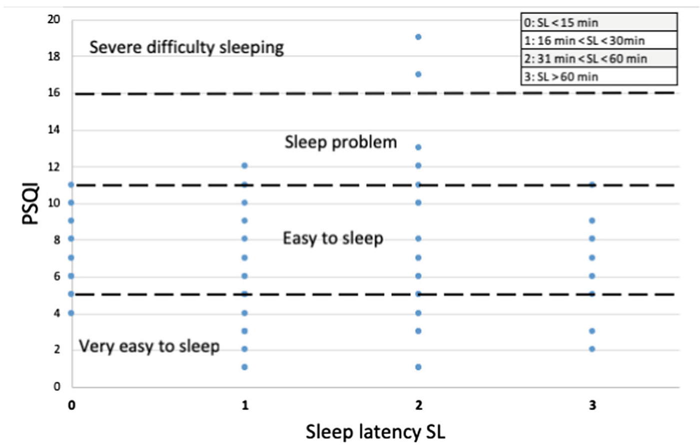

Fig. 4. Relation between PSQI score and Sleep latency (SL).

3 Conclusion

Almost 7% of the participants in this study report some degree of sleep problems. The current study provides important evidence for the association between good sleeper and rotating shift.

Acknowledgments. The research presented here was carried out within the framework of the research project “Method and research” from engineering occupational risk prevention career at Santa Maria University. The authors thank all volunteers for their participations in this study.

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Process Safety Competence of Vocational Students

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Abstract. Since safety demands are an integral part of the process industry, process safety competence should be developed accordingly. When developing this competence during the vocational education and training (VET) of process operators, close collaboration between the students, VET providers, and workplaces is essential. The aim of this study was to examine the current needs regarding process safety education in the process industry with respect to VET. Interviews (n = 46) and a workshop were carried out with participating process industry, VET, and expert organizations. Competence requirements were categorized into (1) knowledge and skills, (2) values and attitudes, and (3) abilities and traits needed to achieve the required level of performance in the process industry. Developing these competencies can be helpful to VET organizations, as they enable students to adapt to workplaces' process safety requirements. Moreover, the study results can be utilized in the development of the process safety competence of senior employees.

Keywords: Process safety · Safety competence · Vocational education and training

1 Introduction

In the process industry, work is typically done using dangerous materials, under extreme conditions, and with potential for major accidents. Although safety systems and regulations have evolved over the last few decades, major hazards still exist and accidents still happen [1]. Apparently, companies are still unable to recognize weak signals, and process deviations with potentially major effects [2]. Therefore, safety criticality needs to be emphasized in the process industry. At the same time, some high reliability organizations have achieved exemplary performance in safety and are extremely effective "learning organizations" [2, 3]. Their good safety performance comes from an emphasis on safety and continuous competence development.

To remain aligned with the dynamic needs of the business environment, industrial organizations must ensure that their competencies are up to date [4]. Competence is the ability to transform knowledge and skills into practice in a qualified way [5] and to achieve the required level of performance [6]. Hence, competence is a personal trait

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 383–392, 2020.
https://doi.org/10.1007/978-3-030-20497-6_36

that influences an individual's behavior and performance [7]. In the broadest sense, 'competence' refers to the specific knowledge, experience, abilities, skills, traits, values, attitudes, understanding, and behavior that are necessary for achieving the required level of performance [6, 8–10]. Competency starts with basic awareness, and it should be developed continuously throughout an employee's career to build expertise [11]. This development is critical to maintaining companies' competitiveness in the turbulent business world [4, 5, 12].

Since safety demands are an increasingly integral part of business [13], safety competence should be developed accordingly. The recent safety paradigm, Safety-II, describes humans as a necessary resource for successful safety performance [14, 15]. Many safety researchers similarly consider humans to be heroes in resolving system vulnerabilities [3, 15–17].

In the safety-critical process industry, process safety competence is essential to ensuring safe operations. Process safety focuses on preventing and mitigating major process accidents, such as fires, explosions, and toxic releases [18]. It concerns the strategies of hazard identification and analysis, risk assessment and evaluation, preventative measures, and safety-critical decision making [18].

As automation systems and technologies become more complicated, safety culture and competence are key performance determinants in the field of process safety [19]. Since the workforce is aging and future age groups are decreasing, new, skilled workers are needed in the process industry [20]. However, young and inexperienced workers typically encounter accidents more commonly than other employees [21, 22]. Therefore, new workers and students must be introduced to safe work practices from the very beginning of their careers [22].

Production workers, such as process operators, for process industry are educated in vocational education and training (VET) institutions. The aim of this education is to ensure that all students have sufficient process safety competence. In addition to technical skills, strong safety culture and appropriate valuation of process safety should be established during VET. If students learn to value process safety early in their studies, they will most likely take this attitude into the workplace [11].

When it comes to developing process operators' process safety competence during VET, workplace learning is essential. Theoretical and practical education in VET institutions provides students with basic knowledge of process safety. However, training for company-specific safety requirements, culture, and practices is provided at the workplace. Moreover, real-life situations provide a hands-on learning experience, which cannot be completely replicated by VET institutions. Close collaboration between students, VET providers, and workplaces has been found to be beneficial in improving students' learning in general [23]. Current good practices and development needs regarding guidance of workplace learning in the process industry were examined in a related study of Tappura et al. [24]. Further actions were suggested to help process industry companies and VET organizations to collaborate and adapt to process safety requirements.

In conclusion, basic process safety competence should be taught at VET institutions, as basic safety requirements are quite similar across all companies in the industry. Company-specific safety values and requirements, however, should be taught at the workplace, since they may vary between different organizations. The aim of this study was to examine the current content needs relating to the basic process safety education of process operator students at VET institutions.

2 Materials and Methods

The study employed a qualitative approach [25] due to its descriptive and contextual nature. Several process industry, VET, and expert organizations (see Table 1) participated in the study. The companies and VET providers were selected so that each company cooperated with at least one VET provider and vice versa. A concrete need and will to develop this type of cooperation were also part of the selection criteria. The VET providers represented different geographical areas in Finland. The role of the expert organizations was to provide broader insight into the process industry and its needs with respect to VET and process safety development.

Table 1. Participating organizations' background information.

Companies (n = 5)	Industry	Chemical and process industry
	Revenue	Between 63 million and 13.2 billion €
	Personnel	Between 194 and 5,297 persons
VET providers (n = 5)	No. of students*	Between 1,400 and 18,000
	No. of employees*	Between 236 and 1,200
Other expert organizations (n = 5)	Type of organization	Labor union, trade association, safety authority, safety service provider governed by labor market organizations

* Number of all students and employees, not only those within the process industry.

Congruent with the qualitative approach, the principal data for this study were collected through interviews (n = 46) with the participating companies. The interview results were then validated and complemented in a workshop. In addition to these companies, the workshop also included VET providers and other expert organizations, for a total of 18 participants.

For the study, semi-structured individual interviews (see Table 2) were carried out, primarily on-site at the companies' locations. However, some phone and group interviews were conducted as well. The interviews targeted people involved in workplace learning in different roles. The interviewees included supervisors, health and safety (HS) or human resources (HR) experts, VET students, work advisors or instructors, and workers. The interview questions concentrated on identifying current needs in the content of process safety education, both in the industry and in the VET of process operators. The interviews were recorded and transcribed.

The workshop participants were representatives of the organizations that agreed to take part in the study. The workshop was organized together with the study steering group meeting and focused on several themes in addition to the current content needs of process safety education. The one-day process began with an expert presentation concerning a general competence survey that had been conducted in the chemical industry. The interview results from this new study were also presented, then validated in and complemented through discussions, during which time notes were taken.

Table 2. Background information on the interviews and workshop.

No. of interviews and interviewees per company	Company A (9,10), Company B (10,11), Company C (6,6), Company D (9,9), Company E (12, 12)
Roles of the interviewees*	Supervisor (15), HS or HR manager or specialist (10), VET student (7), work advisor or instructor (6), employee (10)
Workshop participants	Company representatives (8), VET providers (4), expert organizations (6) HR managers, development managers, HS managers, education managers, and teachers
Duration	Interviews of 30 to 60 min One-day workshop

* Employees included process operators, advisors, and instructors. Some of the employees were also HS representatives.

The results of the interviews and workshop were categorized utilizing the classifications of competence presented in literature [6, 8–10], although those classifications were adjusted to reflect the unique content of the data. Thus, instead of sticking strictly to the categories of competence presented and highlighted in the literature, the data was coded according to similar themes of process safety competence.

3 Results

The interviews and workshop revealed three major components of process safety competence: (1) knowledge and skills, (2) values and attitudes, and (3) abilities and traits. These competencies are displayed through behavior [6]. Participants specifically emphasized the importance of knowledge and skills related to different aspects of process safety competence. Neither values and attitudes nor abilities and traits were highlighted as much, but several elements related to these competencies were still pointed out. The components of process safety competence that emerged in this study are presented in Table 3 and discussed as follows.

Table 3. Components of process safety competence and related competence requirements.

Knowledge and skills related to…	Values and attitudes	Abilities and traits
Processes	Serious attitude toward safety	Perceptual ability
Chemicals and chemistry	Prioritizing safety	Concentration
Special and high-risk work tasks	Zero vision mindset	Stress tolerance
Fault situations		Rationality
	Lifelong learning	Carefulness
Reading and following instructions	Grown-up attitude toward work	Humility
General practices in the workplace	Admitting own mistakes	Prudence
Operational environment		Vigilance
General view		Calmness
		Courage
Consequences of own actions		
Learning from experience		
Identification of own skills		
Proactive mindset		
Safety procedures		
Hazard identification		

3.1 Knowledge and Skills

Participants brought up several requirements for knowledge and skills regarding process safety. They noted that during VET, a student should gain not only relevant knowledge, but also the skills to apply that knowledge in practice. The requirements identified related to processes and work tasks, working and general practices, employees' actions, and safety performance.

Processes and Work Tasks. Participants highlighted process and work task-related knowledge and skill requirements concerning operation of the processes, chemicals and chemistry, special and high-risk work tasks, and fault situations. Among the most commonly noted requirements was students' knowledge and skills regarding operation of the processes. Participants indicated that a certain "process intelligence" is needed in order to succeed at everyday work tasks. A student should understand the operating principles of the process (*e.g.*, how the automation works, what energies are involved, and how to react to process alarms) and develop the corresponding skills. However, interviewees admitted that students would need to amass a huge vocational information bank in order to succeed.

Along with this process intelligence, participants emphasized the importance of understanding chemicals and basic chemistry (*e.g.*, knowing which chemicals are used in the company, how to use them, how to protect against their adverse effects, and how to read operational safety bulletins). Additional knowledge and skill requirements mentioned included knowledge of special and high-risk work tasks, such as those described by the following interviewee:

> *Soon [process industry students'] work tasks include everything from building and excavation tasks to working in confined spaces, equipment isolation practices, working at height... you name it. It may be quite difficult. Such competences could be invested in. – HS specialist*

Furthermore, the participants noted that knowledge and skills related to actions in normal procedures as well as fault situations are necessary.

Working and General Practices. Knowledge and skill requirements related to working and general practices can be divided into four categories: instructions, general practices, operational environment, and general view. The participants indicated that a student must be able to both read and follow all directions, from operational safety bulletins to work instructions and safety procedures. It was also considered essential that they understand the reasoning behind such requirements, as the following quotation shows:

> *The instructions have taken shape during the past decades according to the good practices of our own and whole industry as well as accidents that have occurred on our premises and elsewhere…. Certain things must be done a certain way so that nothing happens. – HS specialist*

Participants also considered knowledge of general practices in the workplace and the ability to act according to these to be an important competence. Such practices can include seemingly simple aspects that are not seen as self-evident by novice employees, as exemplified by one interviewee:

> *If we see an employee attached to his/her mobile phone all the time, then we start asking if it's really necessary to check the phone constantly… particularly with young people you need to remain off it once in a while. – Supervisor*

Participants also expected students to understand and be familiar with the operational environment (*e.g.*, what substances and machinery are used at the site, how they work, and how to interact with them). Another element that was highlighted was students' ability to understand the overall picture of all processes on-site, not only the parts relating to their own work.

Employees' Actions. The requirements participants emphasized relating to employee behavior dealt with understanding the consequences of actions, learning from experience, and identifying one's own skills. Participants stressed that it is extremely important that students understand the cause and effect relations of their own actions, both in general and within safety procedures, as the following quotation shows:

> *[A student needs] basic abilities to realize his/her own role, [grasp] the effect of his/her actions, and to understand his/her safety. We have a natural cultural problem [of assuming] someone else should take care of things. For example, if you do not wear protective equipment, [you might claim] it's the supervisor who did not tell you to wear it. – Supervisor*

In other words, a student should be able to take responsibility for his/her own actions and learn from experience. Participants also mentioned that students' ability to identify their own skills is important. This means that a student should be able to evaluate his/her own abilities and ask for help if some tasks are beyond his/her expertise, with the understanding that becoming a professional requires time and practice.

Safety Performance. Although the aforementioned competence requirements include safety aspects such as following safety procedures and understanding safety principles, participants also noted the importance of some particular safety competencies. These safety-related knowledge and skill requirements included a proactive mindset, an understanding of risk and safety procedures, and hazard identification.

The importance of possessing a proactive, safety-oriented mindset was discussed as follows:

You must have a safety-critical mindset. You need to think how to safety complete work tasks before you start the work... thus proactively looking ahead at safety aspects. – Supervisor

Understanding safety procedures and having an ability to identify risks were also seen as important competencies. Interviewees emphasized that a student should be able to act according to the safety instructions and procedures of the worksite. He or she must also take responsibility for identifying hazards and reporting them to supervisors or safety personnel. The importance of hazard reporting was described in the following way by one of the interviewees:

If you identify a shortcoming regarding safety, whatever it is, even a little matter, it must prick your conscience to do something about it so that nobody will not hurt him/herself. – HS specialist

3.2 Values and Attitudes

In addition to knowledge and skills competencies, participants indicated that a student participating in VET should have certain values and attitudes toward process safety and working in general.

Outlook on Safety. The values and attitudes required by the participants for safe performance in process industry environments included a serious attitude toward safety, an ability to prioritize safety, and a zero-vision mindset. Participants noted that a student must understand the significance of safety and view it seriously. In fact, a good attitude toward safety was perceived as the basis for safe performance. As one of the interviewees put it:

It all starts from attitude. If your attitude is to follow instructions and safety rules ... then it will be possible to work in a safe manner, because we have comprehensive instructions. - Supervisor

Prioritizing safety over production was also highlighted as crucial. The participants believed that students should consider themselves supervisors of their own safety, in the sense that they must remain interested in safety aspects and seek safety-related information by choice. Additionally, interviewees emphasized the importance of adopting the zero-vision mindset, since it is a necessity in the process industry.

General Attitudes and Values. As well as noting the need for a good attitude toward safety, participants mentioned several requirements related to students' attitudes toward working in general. Participants said that a student stepping into working life should understand that he/she is not a professional yet and that learning continues throughout one's career. They also indicated that students should be able to admit to any mistakes they make, as the following quotation illustrates:

The worst cases are those in which you don't know what you are doing, something happens, and you try to cover it up. ... Those are nasty cases, because if you try to hide it, then nobody can learn from it. – Supervisor

3.3 Abilities and Traits

Participants pointed out various abilities and traits that promote safe performance as well. They noted that it is important for a VET student to have good perceptual abilities so that he/she can observe important aspects of both workplace safety and the process he/she is working with. Concentration, vigilance, carefulness, calmness, rationality, and prudence were also seen as important traits for students working in high-risk environments like process industry workplaces.

Interviewees also mentioned that tolerance for stress is required in this fast-paced work environment, as is humility when learning and accepting new things and viewpoints. Another characteristic that was emphasized was courage, a trait that was looked at from multiple perspectives. Some participants stressed that it requires courage to work in hazardous work environment business, while others connected courage to the ability to ask for help if the task at hand is new or beyond one's own competencies. One noteworthy viewpoint defined courage as the confidence to act in a safe manner even under pressure. The following quotation gives an example of such a situation:

> *You join a team of several people, in which a certain safety culture has been established. You may have a very strong sense of safety, but social pressure steers you when you make choices. In such cases, it is pleasing that [students] still dare to bring up their own opinions and their safety knowledge – HS specialist*

4 Discussion

This paper presents the components of process safety competence based on an empirical study in the process industry. The objective of this study was to discuss the industry's basic process safety competence requirements with regard to the VET of process operator students. Based on 46 interviews and a workshop, three major components of process safety competence were revealed: (1) knowledge and skills, (2) values and attitudes, and (3) abilities and traits. The results of the current study add to previous study regarding the guidance of workplace learning in the process industry [24] by specifying process safety competence requirements and giving practical examples of the competence requirements in the industry.

Based on these results, one can conclude that companies expect VET students shifting from school to work to possess various competencies, including technical skills and process knowledge, sufficient abilities to achieve good safety performance, and a positive attitude toward both safety and work. Thus, the generic competencies expected from a VET student are already extensive. However, the ability to adapt one's skills and behavior to specific workplace requirements is also expected. This study showed that to help students reach these demanding competence requirements, VET providers should (1) emphasize the importance of safety through exemplary safety performance during in-class training, (2) take advantage of the benefits of new technology (*e.g.*, gamification), and (3) utilize examples from real-life cases.

The study provides a basis for competence development in the vocational education of process operators and process industry companies. During VET, its results can be used to discuss the safety competence requirements of the process industry and to prepare the students for working life. In the companies and during on-the-job learning, the results can be utilized in induction and process safety training to ensure the sufficient safety competence of students, other new employees entering the process industry, and senior staff.

Process safety competence requirements are extensive, and the competencies develop quite slowly from awareness to expertise [11]. Moreover, company-specific process safety requirements may vary significantly and should be emphasized during on-the-job learning. Hence, competence should be discussed repeatedly as an employee's career develops, and different issues should be emphasized in different phases of the career. In the future, further steps required to develop process safety competence could be studied.

This study has some limitations. It was descriptive in nature and exploited a limited number of organizations. The categorization of the results was subjective, although the typical components of competence were covered. It also revealed mainly general safety skills, attitudes, and traits, and little was said about technical competence, which is presumably clearer in the industry. Moreover, this study did not discuss company-specific safety values and requirements, since students may end up working at not only various process industry companies, but also organizations in other industrial sectors. Nevertheless, basic process safety competence is beneficial in all sectors.

The contribution of this study is to produce new information on process safety competence components, which can be developed during VET and on-the-job learning in the process industry. The results can guide VET providers and companies toward shaping process safety competence and safety culture among process operator students. Developing the process safety competence of VET students provides a qualified workforce for the process industry in the future. Moreover, it may support companies in competence development of their current workforce, as well as help them to entice, recruit, and engage new workers [24].

Acknowledgments. The authors acknowledge the research funding provided by the Finnish Work Environment Fund, participating process industry companies, and Tampere University.

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Occupational Exposure to Heat in Outdoor Activities in Building Constructions in Southeastern Brazil

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Abstract. In Brazil, conventional construction sites processes prevail, where the workers develop outdoor activities and are exposed to environment variables, which, along with the personal variables – metabolic rate and clothing – may cause heat stress. This article evaluates the heat exposure that workers with outside activities on concrete slabs during the construction of buildings in the city of Campinas, state of São Paulo, in Southeastern Brazil. For the data collection, the analysis and exposure evaluation it was used the norms ISO 7243, ISO 8996, ISO 9920 and the Norma Regulamentadora Brasileira (NR5) that foresees the tolerated limits of heat exposure. It was analyzed the Wet Bulb Globe Thermometer Index (WBGT) along with the metabolic rate estimated of 40 exposed construction workers. The results show that, in every season of the year there is the necessity of heat exposure monitoring to avoid health damage to the construction workers' health.

Keywords: Heat stress · Outdoor activity · Metabolic rate · Construction workers

1 Introduction

In tropical regions, it is necessary to monitor the exposure to heat of workers performing outdoor activities throughout the entire year, especially those in the agricultural, mining and construction sectors.

In the Brazilian construction industry, which employs about 1.8 million workers [1], it is prevails labor-intensive construction processes. Workers that perform outdoor activities and suffer from environmental variables, such as: temperature, solar radiation, humidity and air velocity. They also suffer the effects of individual variables, which can be expressed by the metabolic rate and the thermal resistance of clothing. All of these variables influence in heat exchanges and in human reaction towards the thermal environment [2, 3].

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 393–403, 2020.
https://doi.org/10.1007/978-3-030-20497-6_37

When the body's core temperature exceeds the normality, around 37 °C, the body reacts triggering some defense mechanisms, such as: activation of sweat glands, vasodilation, increased heart rate to allow loss of heat through the surface of the body. When these mechanisms are insufficient, hyperthermia and its effects can happen, such as: cramps, heat exhaustion and thermal shock or heat stroke that may lead to death [4–6]. Other negative impacts of the exposure to a hot weather are: concentration lags, fatigue and wrong decisions that can be causes of low production and work-related accidents [7, 8].

Among the main stages of the construction of a building stands out the execution of superstructures – structures made of reinforced concrete executed from the level of the ground floor and on the slabs. Mainly, in these steps, the exposure of workers to the heat coming from the external environment must be taken into account.

In this work, for the analysis of heat exposure, it was used the Wet Bulb Globe Thermometer Index (WBGT), which was adopted by the International Organization for Standardization (ISO), in ISO 7243 [2]. This index was also adopted by the Brazilian legislation through the Norma Regulamentadora NR15 – Insalubrious activities and operations of Portaria n. 3214, from Ministério do Trabalho [9]. This standard determines the tolerance limits and work breaks needed to avoid heat illnesses.

The heat exposure condition is determined by the calculation of the average WBGT, measured in the 60-min interval in the most critical condition in the working day and by the average metabolism calculated under the same critical conditions and period, according to ISO 7243 [2] and ISO 8996 [9].

Therefore, the main goal of this study is to present an estimate of the heat exposure of construction workers in outdoor activities on concrete slabs during the execution of a building structure in the city of Campinas, state of São Paulo, southeastern Brazil, considering the intensity of physical activity (metabolic rate) and the environmental conditions of work.

The study was registered in the Comitê de Ética em Pesquisa em Seres Humanos (Ethics Committee on Research in People) of the University of Campinas, Campinas City, state of São Paulo, Brazil (CAEE 64413717.7.00005404).

2 Methodology

The study was conducted in eight different open-pit concrete slabs from four construction sites from March to December of 2017, covering the four seasons of the year. The working sites are located in the city of Campinas, state of São Paulo, which has a tropical climate (Cwa type, Köppen, with rain in the Summer and dry in the Winter (22°53′14.0″ S; 47°03′31.5″ W; 671.3 m).

To obtain the WBGT, the environmental variables were measured: natural wet bulb temperature (Twb), dry bulb temperature (Tdb), globe temperature (Tg), using the QuesTemp 36™ equipment, with a data logger installed at a height of 1.20 m from the floor of the slab. The height of the slab varied from 4.80 m to 40.0 m.

Before the data collection and after calibration, the equipment went through gauging, according to the method described in previous research [11].

In the collection, the data were recorded every 60 s, from 9 a.m. to 4 p.m. (Brasilia standard time), during 2 to 6 consecutive days per month in each slab, totaling 25 days of measurement. The calculation of the WBGT was done by applying the Eq. 1, for environments with direct solar charge [2, 9].

$$WBGT = 0.7Twb + 0.2Tg + 0.1Tdb. \quad (1)$$

The evaluation of the exposure to heat was done accordingly to NR 15, which establishes the working/rest (W/R) regime, per hour of work, shown in Table 1 [9].

Table 1. Tolerance limits for exposure to heat, in intermittent work regime with rest periods at the workplace, according to NR 15 [9].

Intermittent Work Regime with rest at workplace (per hour)	WBGT (°C) by type of activity		
	Light	Moderate	Heavy/High
Continuous work	Until 30.0	Until 26.7	Until 25.0
45 min - work 15 min - rest	30.1 to 30.6	26.8 to 28.0	25.1 to 25.9
30 min - work 30 min rest	30.7 to 31.4	28.1 to 29.4	26.0 to 27.9
15 min - work 45 min - rest	31.5 to 32.2	29.5 to 31.1	28.0 to 30.0
Not allowed working without the adoption of adequate control measures	Above 32.2	Above 31.1	Above 30.0

Simultaneously with the measuring, information was obtained, through observation, about the exercised activities, cycle of work, clothing and Personal Protective Equipment (PPE) used by the workers at each work station. Other individual data were collected: gender, age, weight, height, function and time at the role. The clothing were classified accordingly to its characteristics and thermal isolation, contained in ISO 9920 [12].

The body surface area (ADu) was obtained by means of the Dubois Equation (Eq. 2) and the age of the workers were analyzed with respective reference values of a "standard man" (30 years old, weighing 70 kg and 1.75 m height, *body surface area* 1.8 m^2 of height) [10]. The sample values of the 40 workers were compared with the reference values using the Student t test (with bilateral hypothesis). The level of significance was 5%.

$$1.\ ADu = 0,202\ Wb^{0,425}.\ Hb^{0,725}. \quad (2)$$

Where: ADu is the body surface area, in m^2; Wb is corporal mass, in kg; and Hb is the height of the body, in meters.

For the estimation of the average metabolic rate of each work cycle, the method 2A proposed by ISO 8996 [10], better known as a method of decomposition of movements, was used for the respective calculation, Software Conforto 2.03 [13].

The tasks observed were the activity of execution of reinforced concrete structures – pillars and beams – and of the slab cleaning. The metabolic rate (M) of each task per work cycle is given by Eq. 3 [10].

$$M = \frac{1}{T}\sum_{i=1}^{n} M_i \,.\, ti \tag{3}$$

Where: Mi is the metabolic rate of the task in a work cycle, in W/m^2; ti is the duration of the task i, in minutes and T is the time of exposition or period for a work cycle (60 min).

3 Results and Discussion

The review of the profile of the 40 individuals that worked on the four concrete slabs during the studied period was made per age group, weight, height, function, time in role and body surface area.

3.1 Profile of Workers

Out of the 40 workers that worked on outdoor slabs, 21 (52%) were carpenters, 8 (20%) were rebar workers, 8 (20%) were general assistants and 3 (8%) were bricklayers. It stands out that the most part of the carpenters are 40 to 49 years old, followed by the age of 20 to 29 years old, with the time in function of 10 to 19 years. This can be attributed to the need of experience in this function. The most part of rebar workers are 50 to 59 years old and have 5 to 9 years in the role. The general assistants are the youngest, from 30 to 39 years old and with 1 to 4 years of experience.

Table 2 shows the descriptive measures and average comparison of body surface area and the age with the reference values.

Table 2. Descriptive measures and comparison of body surface area and age with the reference values of ISO 8996 [10].

Variable	Mean	Standard deviation	Minimum	Median	Maximum	Reference	p-value
ADu (m^2)	1.83	0.10	1.56	1.84	2.00	1.80	0.040
Age (years old)	42.5	11.3	21.0	43.0	62.0	30.0	<0.001

The average age of the participants (42.5 ± 11.3 years) was bigger than the reference value of the 30-year-old "standard man" (p-value < 0.001). The average body weight was 74.1 ± 7.4 kg, being 72.5% weighing 70 kg or more. The average height (168 ± 6 cm) was smaller than the standard of 1.75 m.

The body surface area (A_{Du}) presented an average of 1.83 ± 0.1 m^2 (p-value < 0.04), very close to the reference of 1.8 m^2.

The Fig. 1 presents the absolute frequency in each age group of all the 40 workers. In the Fig. 1 it is possible to see the predominance of the age group of 45 to 49 years old (8 workers), followed by the 50 to 54 years old (7 workers) and followed by 35 to 39 years old (6 workers).

In Fig. 1b it is observed that the frequency of body surface area the predominance of values from 1.75 to 1.95 m^2 (28 workers) in the total sample of 40 workers observed.

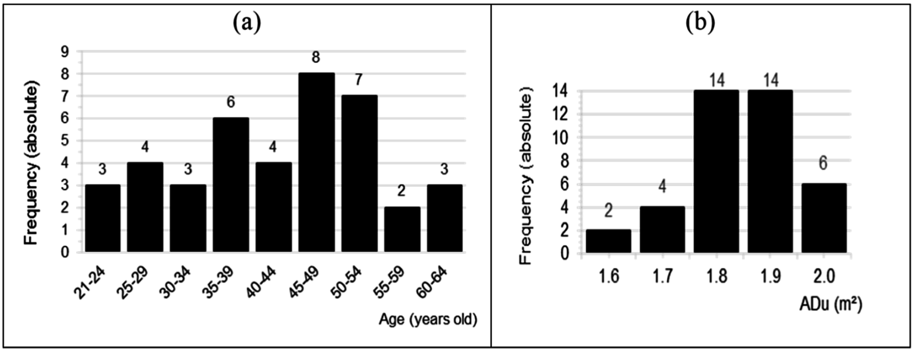

Fig. 1. Absolute frequency by age group in (a); and absolute frequency of body surface area (ADu), in (b).

A series of 14 more relevant tasks carried out by the carpenters were observed in the work of making wooden frames for the pillars (approximate dimensions of 25 × 35 × 345 cm), for a total time of 172 min, which is repeated (not always in the same sequence), during the journey of 8 h. The average metabolic rate was estimated at 2.24 met or 131.4 W/m^2, which can be classified as a moderate rate according to Table A.2 of ISO 8996. The estimate was also compared to the Table A.1 from the same standard, which was within the reference range (110–175 W/m^2) for the "carpenter" occupation.

A series of six more relevant tasks carried out by the rebar workers were observed for the construction of the steel rebar structures of the concrete pillars and beams were, for a total of 125 min, which resulted in an average metabolic rate of 2.63 met or 153.0 W/m^2 (275.4 W). In Wong [14] the average metabolic rate of rebar workers in the tasks of cutting, folding and fixing of steel bars presented values of 179 W, 158 W and 186 W, respectively.

General assistants perform different tasks on open-air slabs; there are many displacements, going up and down stairs for manual transport of materials. Only the most frequent activities were considered, that is, the six tasks with the most unfavorable metabolic rates, obtaining 4.15 met or 241.3 W/m^2, classified as "high" (200–260 W/m^2), according to Table A.2 of ISO 8996 [10].

Table 3 shows the estimated metabolic rates and respective rankings for carpenters, rebar workers and general assistants.

Table 3. Metabolic rates of the studied group of workers.

Function (n. workers)	Average metabolic rate (M)		Ranking of activity	
	met	W/m^2	ISO 8996 [10]	NR 15 [9]
Rebar worker (8)	2.63	153.0	Moderate	Moderate
Carpenter (21)	2.24	131.2	Moderate	Moderate
General assistant (8)	4.15	241.3	High	Heavy

In Slab 2 (Fig. 2a), the thermal resistance garment Iclu equal to 0.83 clo, calculated according to ISO 9920 [12] was composed of cotton and polyester long-sleeved shirt, light gray color, light gray jeans, thick stockings, underwear (light colored cotton sleeveless t-shirt and underwear). In Slab 3 (Fig. 2b), for the owners, the garment set (0.82 clo) was composed of medium blue color (neither light nor dark) cotton and polyester long-sleeved shirt, medium blue jeans, coarse stockings; underwear (light sleeveless shirt and underwear). Carpenters and general assistants wore long-sleeved shirt and medium-dark gray denim trousers, with a total of 0.83 clo (Fig. 2c). In Slab 4, the uniform similar to Slab 2 (0.76 clo) was observed, but the shirt was cotton and polyester with the company logo and without undershirt (Fig. 2d). The cap for sun protection was considered as a hood, for the calculation of thermal resistance of clothing.

Especially in construction, the cap, long sleeve shirt, pants and PPE, besides contributing to protection against solar radiation, eventually prevent bruises, cuts, scratches on the skin, among other injuries.

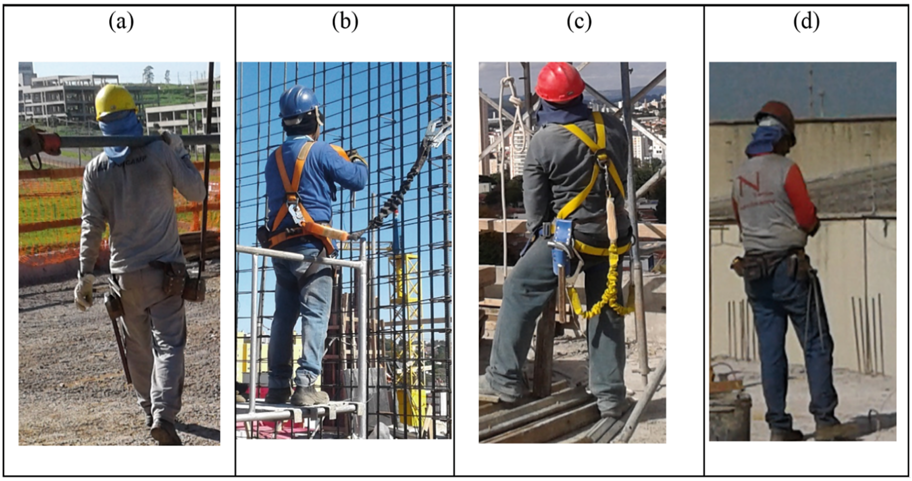

Fig. 2. Clothing and PPE, in (a): general assistant at Slab 2 (0.83 clo); in (b): rebar setter at Slab 3 (0.82 clo); in (c): carpenter at Slab (0.83 clo); in (d): rebar setter at Slab 6 (0.76 clo).

In this work, a pattern of thermal resistance clothing varying from 0.76 to 0.83 clo was observed, which are larger than those considered for more "comfortable" clothing, such as the male suit, for example (0.6 clo) [15], which hampers heat exchanges between man and the environment.

The use of Personal Protective Equipment (PPE) and the tools in the body implies additional weight (approximately 4.5 to 6.0 kg), contributing to a greater effort of the worker. The metabolic rate can be increased by the use of PPEs or by the restrictions; they impose on the user's movement. The British Standard-BS 7963 [16] provides the estimated increases in metabolic rate due to the use of PPE. However, with the exception of footwear, there are no values for observed PPE in literature.

3.2 Heat Exposure Assessment

The results of the heat exposure assessment of carpenters, rebar workers and general assistants were summarized in Tables 4 and 5. The average WBGT of each hour of the eight days of evaluation and the respective rest time for thermal recovery of carpenters, rebar workers and general assistants can be seen in these tables. Specifically, for mild activities of carpenters and rebar workers, Table 4 shows the 0, 15, 30 or 45 min pauses for thermal rest at each hour worked, with the last (darker column) interval indicating that the conditions of exposure to heat are the most severe ones, in such a way that, as a rule, it would be forbidden to carry out work activities without the special measures of prevention of heat diseases, according to the Brazilian norm NR15 [9].

Table 4. WBGT Index and respective rest time for moderate activity, by each concrete slab, from March to December of 2017.

Place (Slab) (Month/ Season)	WBGT (average time, in °C)								Rest Time (min)
	9a.m.	10a.m.	11a.m	12a.m	1p.m	2p.m	3p.m.	4p.m.	
Slab 1 (March/Summer)	26.7	27.0	27.8	28.7	29.1	29.8	29.4	28.1	195
Slab 2 (March/Autumn)	22.9	25.0	26.4	27.5	27.6	28.6	28.7	28.1	120
Slab 3 (May/ Autumn)	19.6	21.8	23.3	24.5	25.5	25.8	25.7	25.5	-
Slab 4 (August/Winter)	19.3	20.7	23.1	24.4	24.6	25.1	24.6	24.4	-
Slab 5 (September/Winter)	22.7	23.9	24.9	26.0	27.0	26.7	26.2	26.7	30
Slab 6 (October/Spring)	24.0	25.5	26.2	26.6	27.6	27.7	28.0	27.0	60
Slab 7 (November/Spring)	24.6	26.2	27.2	27.7	27.9	27.7	27.4	27.9	90
Slab 8 (December/Spring)	27.5	29.2	29.5	29.9	31.0	31.3	30.7	30.0	330
								Total:	825

Note: for Moderate Activity [9]

until 26.7°C W/R: continuous	26.8 to 28.0°C W/R: 45/15	28.1 to 29.4°C W/R: 30/30	29.5 to 31.1°C W/R:15/45	Above 31.1°C W/R:not allowed

In every month of the year, WBGT increased throughout the day, reaching maximum values between 2 p.m. and 3 p.m. During the months of March/2017 and December/2017, the WBGT was observed above the tolerance limits already at 9 a.m., and in November, from 11 a.m. In the months of May (Autumn) and August (Winter) the WBGT did not exceed the limits of tolerance for moderate activity.

From the month of September, the WBGT was observed above or near the tolerance limits in the hottest times of the day, at 1p.m and at 2 p.m.

Considering that the need for rest time, according to NR15 [9], occurs from WBGT values above 26.7 ºC in moderate type activities, it was noticed that in the 64 h of work of carpenters and rebar workers, there was a need to total of 13 h and 45 min. (825 min) of pause, representing 21.5% of the total period studied. In this same reasoning, applying these results being applied to the exposure of one year of work (12 months of 22 days and 8 h a day) that counts 2,112 h, would result in a total of 454 h, which corresponds to 58 (454/8) days of production in thermal rest.

In the Summer, the total hours of "stopped" of only one worker can reach 25 h per week (57%). Table 4 shows that in the evaluation of March 2017 (Summer) the workers needed, although they did not have it, an average daily pause time of 195 min.

The evaluation of the heat exposure of carpenters' and general assistants, whose activities were considered high (or heavy) were summarized in Table 5.

Table 5. WBGT Index and respective rest time for "heavy/high" activity, by each concrete slab, from March to December of 2017.

Place (Slab) (Month/ Season)	WBGT (average time, in °C)								Rest Time (min)
	9 a.m.	10a.m.	11a.m	12a.m	1p.m.	2p.m.	3p.m.	4p.m.	
Slab 1 (March/Summer)	26.7	27.0	27.8	28.7	29.1	29.8	29.4	28.1	315
Slab 2 (March/Autumn)	22.9	25.0	26.4	27.5	27.6	28.6	28.7	28.1	225
Slab 3 (May/ Autumn)	19.6	21.8	23.3	24.5	25.5	25.8	25.7	25.5	60
Slab 4 (August/Winter)	19.3	20.7	23.1	24.4	24.6	25.1	24.6	24.4	15
Slab 5 (September/Winter)	22.7	23.9	24.9	26.0	27.0	26.7	26.2	26.7	150
Slab 6 (October/Spring)	24.0	25.5	26.2	26.6	27.6	27.7	28.0	27.0	210
Slab 7 (November/Spring)	24.6	26.2	27.2	27.7	27.9	27.7	27.4	27.9	210
Slab 8 (December/Spring)	27.5	29.2	29.5	29.9	31.0	31.3	30.7	30.0	390
								Total:	1,575

Note: for High Activity [9]

until 25.0°C W/R: continuous	25.1 to 25.9°C W/R: 45/15	26.0 to 27.9°C W/R: 30/30	28.0 to 30.0°C W/R:15/45	Above 30.0 °C W/R: not allowed

Considering that the tolerance limit for continuous activity in a WBGT of 25 °C for heavy or high activity, the pause regime (15/30/45/60 min/hour of work) was necessary for all seasons of the year, although in fall and winter there was less need for them.

Of the total of 64 h observed, one has 26 h and 15 min (or 1575 min) of pause and 37 h and 45 min of continuous work, that is, 41% of rest at time “stopped production”. Applying the same rationale as that applied to carpenters and rebar workers; the general assistants, according to NR15, should enjoy a total annual thermal rest of 866 h, that is, more than 108 days of production.

As an example, considering the heat exposure assessment of the general assistants in March 2017 according to Table 5, which resulted in an average daily pause of 315 min (Table 5) which corresponds to another 5 h of daily production.

4 Conclusion

In the execution of open-air activities on concrete slabs of buildings, the most frequently exposed workers are the carpenters, rebar workers and their assistants.

The evaluation of the heat exposure of the general assistants, according to the Brazilian norm NR15 [9], showed that even the days with milder temperatures (months of May and August), in the period close to 2 p.m. there was a need for many thermal rests. On the other hand, the exposure to the heat of carpenters and rebar workers, in the Spring, from 11 a.m. and in the Summer, from 9 a.m., reached values equal to or greater than the tolerance limit of 26.7 ºC.

The daily time necessary for the thermal rest counted in one year was of 866 h, that is to say, more than 108 days of the general assistants’ production and, of 454 h (or 58 days) of carpenters and rebar workers’ production.

The parameters of weight, height and body surface area that influence the heat metabolic rate showed an average weight of 74.1 kg, body surface area of 1.83 m^2, close to the reference value of the “standard man” (1.8 m^2) and an average age of participants of 42.5 (± 11,3 years), higher than the standard age (30 years) of ISO 8996 [10], being able to consider statistically very close values, taking into account the requirements for use of the metabolic rate values of the tasks referenced by this standard.

The observation of the activities carried out by each worker revealed the predominance of a sequence of movements for the accomplishment of a task, and which are repeated throughout the workday, which allowed the estimation of the metabolic rate for the main functions. The estimated average metabolic rate was classified as moderate for carpenters (2.24 m or 131.4 m^2) and rebar workers (2.63 m or 153.0 W/m^2), and as high (heavy) for your general assistants (4.15 met or 241.3 W/m^2). The general assistants perform different tasks on open slabs, with constant displacements, in level and unevenness, which made it difficult to estimate their metabolic rate, which was finally estimated at 241.3 W/m^2.

In all the slabs, clothing (uniform), whose thermal resistance ranged from 0.76 to 0.83 clo, were observed.

Although PPE influences the thermal exchange between the body and the environment and can cause an increase in internal body heat, its simultaneous use with tools such as hammer, nail, nails, tape, etc. can not be counted in the estimate rate of metabolic heat, due to lack of data in the literature.

Finally, it is concluded that in the city of Campinas, located in the southeastern region of Brazil, in every season of the year there is a need for daily monitoring of exposure to heat to avoid damages to health and to ensure the safety of workers in building construction.

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Author Index

P. M. Arezes (Ed.): AHFE 2019, AISC 969, pp. 405–406, 2020.
https://doi.org/10.1007/978-3-030-20497-6