Open University Cyprus **Hellenic *Open University***

Master's join degree/post graduate Programme
Enterprise Risk Management (ERM)

MASTER THESIS

Safety Culture in Industry 4.0

Evangelia Koudouni

Supervisor Professor
Antonios Targoutzidis

May 2020

Open University Cyprus **Hellenic *Open University***

Master's join degree/post graduate Programme
Enterprise Risk Management (ERM)

MASTER THESIS

Safety Culture in Industry 4.0

Evangelia Koudouni

Supervisor Professor
Antonios Targoutzidis

This thesis submitted for partial fulfilment of the requirements
Master's join degree/post graduate programme
«Enterprise Risk Management (ERM)»
Faculty of Economics and Management

Open University of Cyprus **Hellenic Open University**

May 2020

BLANK PAGE

Summary

The purpose of this Master Thesis is to identify the factors influencing, defining and shaping the safety culture of an organization and the way organization's leadership practices can influence safety attitude and behaviors. This research will be conducted via a literature review of safety culture models, tools and assessment survey case studies. Furthermore, an overview of the Industry 4.0 characteristics will be presented and a closer look to safety issues in the Industry 4.0 era. An attempt will be made to identify and analyze the Safety Culture 4.0 attributes in the context of Industry 4.0.

Acknowledgements

I would first like to express my gratitude and appreciation to my supervisor, Professor Antonios Targoutzidis, for his remarks, support, and encouragement. His calm and consistent guidance at each stage of this process was vital in completing this Master Thesis.

I would like to recognize the invaluable assistance of Ms. Konstantina Kapsali, from the ELINYAE – Hellenic Institute of Health and Safety in the Workplace.

I would also like to thank my loved ones for their infinite love support, patience and mostly faith in me, throughout the years of my studies. They kept me going.

to Christos, Niki

Table of Contents

1. Introduction

Safety culture is a notion very well researched and analyzed by scholars and safety experts, since almost three decades, from the early 80s'. Authors have undertaken the task to identify the operational, social and cultural aspects of safety culture. The concept of safety culture was the research field of sociologists and anthropologists who try to understand and describe it. Tools, models and programs were developed, in order to set a measurable and identifiable frame of the safety culture construct. It was furthermore attempted to measure organizations' safety culture through surveys with the use of questionnaires, interviews and relative statistical analysis. Authors have pointed out the connection with the holistic organizational culture and the interdependency of the term with the one of safety climate. Further research focused on the actual outcome of safety culture and whether this concept is indeed connected with safety performance and the reduction of injuries in the workplace. Safety culture was also connected with behavioral science and the term of human error[1]. All this researched was ultimately aiming to help not only academics, but also practitioners, engineers, regulators to summarize the aspects that could shape risk management and contribute to reducing accidents and injuries in the workplace.

The purpose of this Master Thesis is to identify the factors influencing, defining and shaping the safety culture of an organization and the way organization's leadership practices influence safety attitude and behaviors. The terms of safety culture and safety climate will be analyzed. In addition, models of assessing and identifying the levels and components of safety culture will be researched. Models that encompass the factors, persons, situations, perceptions, practices, resources and behaviors of

[1] Ταργουτζίδης Α. 2007

safety culture. In addition, tools that have been developed for measuring the maturity, or level of quantitative, or qualitative analysis of the safety culture construct in organizations will be described. The relationship between organizational attributes and safety climate is going to be addressed.

In the following parts of this Master thesis, safety culture will be also addressed through the context of the Industry 4.0 environment. New technologies, new working conditions, which emerge, create new aspects for workforce. This new era for manufacturing affects safety in the workplace and even more the aspects that define the notion of safety culture.

This research will be conducted via a literature review, a review of measurement analysis models, of tools and case studies, which are based on measurable indicators. Factors that shape an organization's culture are going to be assessed using a semi-systematic[2] literature review following a method defined in the next section.

2. Method

Literature for this review was retrieved from Open Athens Resource Database. Articles published up to now, the ones published mostly after 2000, were preferred. Additional search parameter of process/manufacturing industries was set, as well as geographical limitation for research on European industries. More specific search was focused on the aspect of safety culture also for Industry 4.0 era, although there is

[2] Snyder H., 2019: Semi-systematic: to review every single article that could be relevant to the topic is simply not possible. Besides the aim of overviewing a topic, a semi-systematic review often looks at how research within a selected field has progressed over time or how a topic has developed across research traditions. In general, the review seeks to identify and understand all potentially relevant research traditions that have implications for the studied topic and to synthesize these using meta-narratives instead of by measuring effect size

still little research from the perspective of Health & Safety, or even less in safety culture in this field.

Publications are selected from Health and Safety at Work, Safety Science, International Journal of Industrial Ergonomics and Safety Research (Elsevier), Wiley Online Library, Journal of Organizational Behavior, Journal of Safety Research, Journal of Occupational Health Psychology, Journal of Applied Psychology, Journal of Loss Prevention in the Process Industries, Springer. Moreover, reports and publications from ILO and EU-OSHA, are included in this review, as well as papers from congresses and conferences.

The basic search topic is the term "Safety Culture". Keywords and search terms, which might be in the title, body, or abstract of the publication, are safety culture, safety climate, safety attitudes, occupational safety, safety performance, management commitment, operational safety, safety perceptions, behaviors, safety compliance, safety participation, training, trust, communication, survey, questionnaire, model, industry 4.0, industry four, fourth industrial revolution, security, digitalization, smart manufacturing, privacy. These keywords were used in the databases research fields individually, or in combination.

Safety culture measuring tools and models, such as questionnaires applied in case studies were also retrieved, in order to investigate which attributes are considered significant, through the performed statistical analysis.

3. Terms – Definitions

3.1 Organizational Culture/Climate

Schein[3] defines organizational culture as a pattern of shared basic assumptions that the group learned as it solved its problems of external adaptation and internal

[3] Schein E.H. 2010

integration that has worked well enough to be considered valid and, therefore, to be taught to new members as the correct way to perceive, think and feel in relation to those problems.

Culture (of an organization, of which safety culture is a part) is shared values (what is important) and beliefs (how things work) which interact with an organization's structure and control systems to produce behavioral norms (the way we do things around here)[4].

Culture is a descriptive, value-free concept, a nominal variable.[5] From an academic, interpretative point of view a culture can be neither "good" nor "bad," that is, cultures develop when people interact and have to accomplish something together.

An organizational culture exists and is evaluated in the context of the organization itself and compared to a general norm, or standard. Therefore, organizational cultures have significance and meaning in relation to their history and initial composition. An organizational culture could be considered dysfunctional regarding its future, for instance, when compared with expressed ambitions or goals[6].

According to Schein, there could be at least three subcultures in an organization: 1) an operator culture, who works involving interconnected systems and co-operation among people, 2) an engineering subculture that values technical, error-free solutions and 3) an executive subculture that focuses on the financial aspects[7].

Schein indicates that there are three levels in groups' culture, the level of its artifacts, the level of its espoused beliefs and values and the level of its basic underlying assumptions[8]. These aspects are going to be further analyzed in this Master Thesis

The perceptions regarding procedures, practices and behaviors that are rewarded and promoted, in regard with the strategic planning, especially of high-risk

[4] Uttal, B. 1983, in Attwood D. et al. 2006
[5] Guldenmund F.W, 2016
[6] Guldenmund F.W, 2016
[7] Zwetsloot G. I.J.M et al, 2013
[8] Schein E.H. 2010

operations, define the organizational climate. In addition, safety climate is also defined, as it involves employee perceptions regarding selected characteristics or features of their organizational environment[9].

Guldemund describes organizational culture as a multilevel phenomenon, having an ambiguous character. Culture is expressed through different kind of manifestations, such as ceremonies, artifacts, slogans, or change programs and the meaning these aspects have to the members of the organizations. Different actors are participating in the culture, such as top management, change agents, employees of different professions, with different ideas of what culture means, different ways of relating to it and may be more or less prone to change.[10]

3.2 Safety Culture

The notion of Safety Culture has now been for almost three decades a highly researched, investigated, advocated, debated and has a level of contentiousness between scholars[11]. The phrase 'safety culture' first appeared in the International Nuclear Safety Advisory Group (INSAG) report following the 1986 disaster at the Chernobyl Nuclear Power Plant, as a causal factor, amongst others, of the accident. The following definition was given:

''Safety Culture is that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance''[12].

[9] Zohar D., 2010
[10] Guldenmund F.W, 2016
[11] Le Coze J. C., 2019
[12] INSAG-4, 1991

Safety culture is a complex construct. It is part of the aspects, or parts of the organizational culture. These aspects influence attitudes and behaviors and have an impact on the level of safety in the organization[13].

Rollenhagen suggests that ‘‘culture” concerns what and how people believe, feel, think and behave over time and how this is reflected in collective habits, rules, norms, symbols and artefacts. He continues by wondering how, whether and which of these patterns of cognition, behavior and associated norms are actually helpful and influence safety[14].

Safety culture corresponds to a set of beliefs, perceptions and attitudes that reflect the importance that people in the organization put on safety, for them and for others[15]. Safety culture is born, cultivated and ingrained via unconscious socialization processes. It is often regarded as a social construction. Safety culture is a set of ways of doing and thinking that is widely shared by the employees of an organization when it comes to controlling the most significant risks associated with its activities.

These definitions tend to reflect the view that safety culture is something an organization ‘is’ rather than something an organization ‘has’.

Cooper and Hale provide enlightening definitions of the safety culture concept. Cooper describes culture as ‘the product of multiple goal-directed interactions between people (psychological), jobs (behavioral) and the organization (situational); while safety culture is ‘that observable degree of effort by which all organizational members directs their attention and actions toward improving safety on a daily basis.

Hale refers to safety culture as the attitudes, beliefs and perceptions shared by natural groups as defining norms and values, which determine how they act and react in relation to risks and risk control systems[16].

[13] Nielsen K.J., 2014
[14] Rollenhagen C. 2010
[15] Zwetsloot G. I.J.M et al, 2013
[16] Choudhry R.M., Fang. D., Mohamed S., 2007

Many authors have adopted a layered concept in their understanding of the safety culture notion. They sometimes use, as a metaphor, the shape of an onion with its multiple levels. Others compare safety culture with the obvious and observable, but also the hidden but still crucial surfaces of an iceberg. In the onion, whereas the core is something deeply hidden, the culture projects itself gradually through and onto the outer layers. The more remotely a layer is located from the core, the more easily it can be observed but also the more indirect, or interpretive, its relation with the core becomes[17].

Another metaphoric description of safety culture is that of a helicopter vision achieved by an integrative concept and mention six levels: national culture, corporate culture, organizational culture, departmental culture, group culture and psychological climate[18].

The safety culture of an organization is the product of individual and group values, attitudes, perceptions, competencies, and patterns of behavior that determine the commitment, the style and proficiency of the organization's health and safety management[19]. Safety culture is functional, holistic, multidimensional, mutual and reciprocal, shared by groups of people[20].

3.3 Characteristics of safety culture

According ICSI[21], there are the following categories of safety culture, as indicated in Figure 1.

[17] Guldenmund F.W, 2016
[18] Guldenmund F.W, 2000
[19] Guldenmund F.W, 2000, HSE 2005
[20] Guldenmund F.W, 2000
[21] Besnard D., Boissières I. ,Daniellou F., Villena J., 2017

In a **fatalistic** safety culture, people are convinced that it not possible to prevent accidents, as they are considered inevitable, bad luck, or acts of god.

A **shop-floor** safety culture occurs when shop-floor employees have developed their own work practices, passed down from one generation to the next, to protect themselves against the risks. The management's role of in this category of safety culture is not so strong.

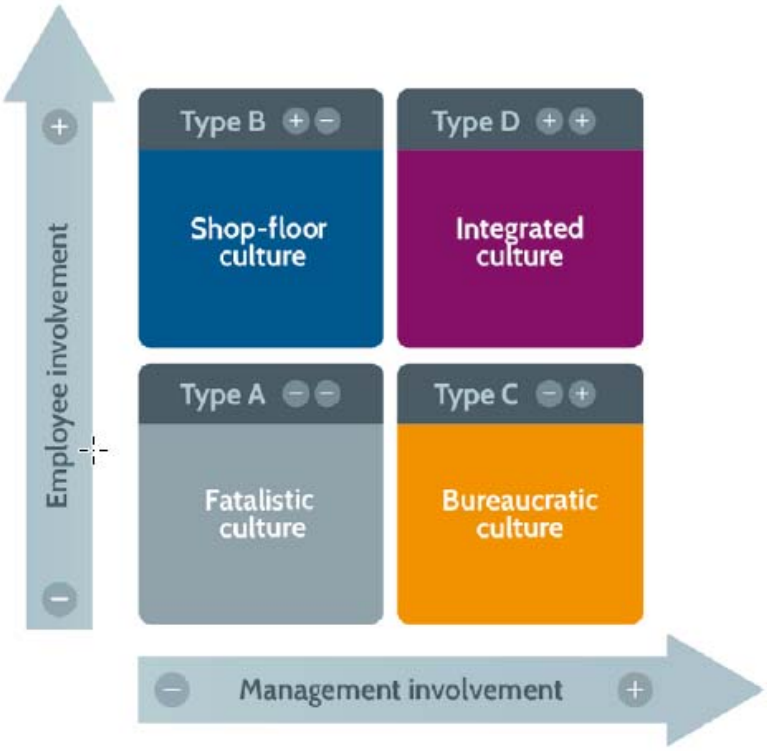


Figure 1 The categories of safety culture according to Marcel Simard

A **bureaucratic** safety culture is developed, when there is a formal safety system. Management becomes involved in safety, by ensuring necessary resources and defining procedures, which have to be followed by the employees. The implementation of rules and safety procedures though, may meet reluctance by the workers, as they are not used to follow them.

An **integrated** safety culture is developed when there is both commitment from the company's top management and employees' involvement is valued. All managers are mobilized in achieving a high level of safety and all functions contribute to this effort.

3.4 Safety Climate

Since the 1990s, research on safety at work has often centered on the term of safety climate, as an antecedent of safety performance, but also as a proxy of safety culture, the overt manifestation of culture within an organization. Safety Climate is viewed as a surface-level image of the state of safety culture, as safety attitudes, at a given point in time[22].

Safety culture and safety climate are notions inseparable, interdependent. Safety climate denotes attitudes to safety within an organization. Safety culture being the strong convictions or dogmas underlying safety attitudes. These beliefs do not have to be specifically about safety, but underlie all organization's attitudes[23].

Safety climate perceptions focus on the nature of relationships between safety policies, procedures and practices. Moreover, rules and procedures which are associated with safety often depend and influence, sometimes even compete with those applied in other sectors of the organization. One such example could be safety versus productivity or efficiency[24]. According to Zohar, when the strategic focus involves performance of high-risk operations, the resultant shared perceptions define safety climate[25]. Therefore, safety climate is naturally resulted from culture relatively, organizational culture expresses itself through organizational climate[26].

[22] Aburumman M., Newnam S., Fildes B., 2019
[23] Guldenmund F.W, 2000
[24] Zohar D., 2000
[25] Zohar D., 2010
[26] Brondino M., Silva S.A., Pasini M. 2012

Overall, as Nielsen vividly points out, climate can be seen as an entrance door to work with culture, as it is a visible and measurable concept that is tied to the creation of culture[27].

3.5 Operationalization of safety climate

The operationalization of safety climate should require from employees to evaluate the relative priority of safety, in such way that the overall level of safety climate represents the shared perceptions of the priority of safety compared to other competing priorities. Safety climate should be operationalized in the context of other competing task domains. [28]

i) Alignment between espoused and enacted priorities- leaders' words and actions

   Espoused priorities regarding safety, for example, might be compromised for certain customer types, such as high-volume customers who emphasize on-time delivery, certain product categories, or when safety changes cost more than expected.[29]

ii) Potential inconsistencies nested among organizational policies, procedures and practices. Employees will perceive signals both from senior management regarding policies and their local supervisor [30]. Using a sample of more than 40 manufacturing companies, Zohar and Luria[31] found significant within-company variation between departments, accompanied by an overall alignment between the average departmental climate and the company's global safety climate.

[27] Nielsen K.J., 2014
[28] Zohar D., 2000
[29] Zohar D., 2000
[30] Zohar D., 2000
[31] Zohar, D., Luria, G., 2005

iii) The formation of shared climate perceptions is motivated by the need to interpret the complex pattern of signals existing within the organizational context regarding what issues are of high priority and what behaviors are likely to be rewarded and supported. Social verification process that motivates the formation or emergence of organizational safety climate[32]. The perception of how the organization values safety is formed in part by work practices and operates as a process mechanism explaining why work practices influence perceived system safety effectiveness. Furthermore, the perception of how the organization values safety, which is the perceived safety climate, operates in conjunction or conflict with a second signal, which might be the perception of how co-workers are committed to safety practices in the organization[33].

Furthermore, when these perceptions are shared among individuals in a particular work environment, a group-level climate emerges. Group-level safety climate is shared perceptions of work environment characteristics as they pertain to safety matters that affect a group of individuals. In this way, the group's safety climate is differentiated from the individual's perception. Psychological safety climate is individual perceptions of safety-related policies, practices and procedures pertaining to safety matters that affect personal well-being at work[34].

Despite the differences and the struggle in defining these concepts, many studies have shown that both safety culture and safety climate play a key role in predicting workplace accidents[35].

The fuzziness of the culture concept and the unconscious nature of the basic assumptions make it difficult to influence culture directly. One way to approach culture change could be by looking at the related concept of climate, which describes

[32] Zohar D., 2000
[33] Stackhouse M. Turner N., 2019
[34] Christian, M.S., et al., 2009
[35] Aburumman M., Newnam S., Fildes B., 2019

the shared perceptions of organizational policies, practices, and procedures, both formal and informal[36].

4. Models of Safety Culture

4.1 Guldemund's Levels Model

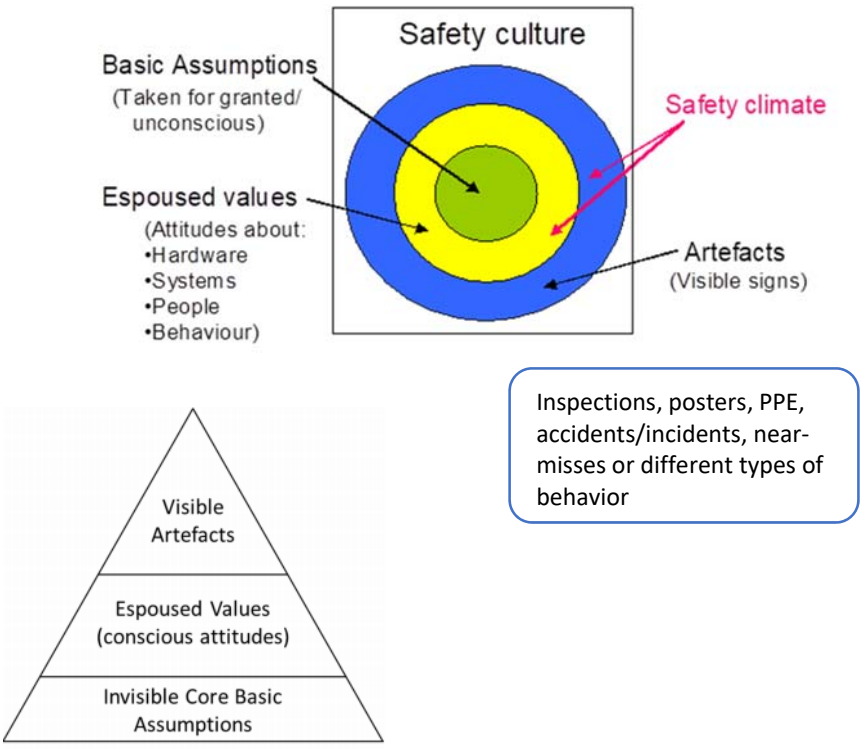


Figure 2, 3 Visualization of Guldemund's, Model according to PRISM, 2005 and Cooper M.D., 2016[37]

[36] Nielsen K.J., 2014
[37] Cooper M.D., 2016

Guldenmund proposed[38] that safety culture consists of three levels, similar to the layers of an onion, based on Schein's and Hofstede's model[39]. Hofstede's onion is however based on national cultures research, locating norms and values at the central core, rituals and heroes in the next layer and finally symbols in the outer layer (Figure 2, 3 and also Figure 14 later on). Guldemund suggests that:

1. The core consists of 'basic assumptions' that are mainly implicit, obvious for the members, invisible, pre-conscious. These values are shared in the entire organization. It is not necessary that these assumptions are specific only to safety, but they are more general. For example, if written rules are regarded as critical, then safety rules will also be considered as critical.
2. The next layer is labelled 'espoused values'. It is relatively explicit and conscious and refers to the attitudes of organizational members. In this layer, attitudes are specific to safety, as opposed to previous layer's general organizational factors. There are four broad groups of attitudes:
    - Hardware, the physical environment, which could be the plant design
    - Software, which might be rules and procedures, legislation, safety management and policy
    - People, which is the "liveware", all level of employees, workers, supervisors, senior management, safety committees, specialists, authorities, unions and
    - Behavior, attitudes towards risk taking.
3. The outer layer consists of artefacts or the outward expression of the safety culture. It is visible, but hard to comprehend in terms of the underlying culture These would include statements, equipment, such as personal protective equipment, behaviors, using appropriate safety equipment or managers conducting safety tours, posters, physical signs, posting number of days since last accident publicly and safety performance, number of incidents.[40]

[38] Guldenmund F.W, 2000
[39] PRISM, 2005
[40] PRISM, 2005

This model distinguishes between safety climate and safety culture, with safety climate consisting of the two outer layers of safety culture. Safety climate is a subset of safety culture and consists of espoused values and artefacts, which are specific to safety.

4.2 Model based on 'Fitness-to-operate" (FTO)

Based on the previous model, enabling capitals that include technologies, structures, processes and, more importantly, social aspects are added in the outer layers of this "onion"-like schema[41]. This model is developed in conjunction with the National Offshore Petroleum and Environmental Management Authority (NOPSEMA).

The central layer (Figure 4) represents the foundations upon which each capital is built. In the center of the figure, core inner layers are considered less tangible and distal in terms of their influence over behavior than successive outer layers. The outer layer represents the factors that directly influence safety.

[41] Casey et al., 2017

Figure 4 FTO and enabling capitals

Human capital refers to individual competences such as the knowledge, skills, abilities, dispositions, beliefs, attitudes, experiences, values and motives of employees within the organization. The outer layer includes the expertise, motivation, and energy of people.

Organizational capital includes human resource management, such as high performance work systems, and risk management procedures, structure, technology and resources. In the outer layer, there are safety information systems, policies, procedures, and practices.

Social capital refers to capacities embedded in social relationships, such as culture and teamwork, the shared understanding across members of the network, and the norms and trust that enable exchange relationships to work effectively. The outer layer includes leadership and teamwork.

4.3 Guldemund's Culture-Structure Flow Model

Guldemund[42] combined the model of Berger and Luckmann[43], with the model of Boudreau and Newman[44], creating the following schema, which depicts the culture flow, either organizational, either safety (Figure 5).

1. **Sense making enacting**: a member of a group develops his/her own perceptions that make sense in the organization and therefore this stage determines the personal understanding of what is risky or safe behavior. The result of this process is an individual's understanding of reality.
2. **Interacting, exchanging**: in this stage, there is interaction between the members of a group. They exchange meanings through formal and informal dialogue, which result to mutual adjustments, agreements and expectations with regard to each other's behaviors. There is significant iteration between stages one and two as subjective and intersubjective understandings influence and are influenced by each other. This stage results in partly shared understandings, both as meanings (of risk, of safety) and as rules; such as standards for behavior (procedures and rules), roles and responsibilities and norms.

[42] Guldenmund F.W, 2016
[43] Berger, P. L., Luckmann, T., 1966
[44] Boudreau, F. A., Newman, W. M. 1993

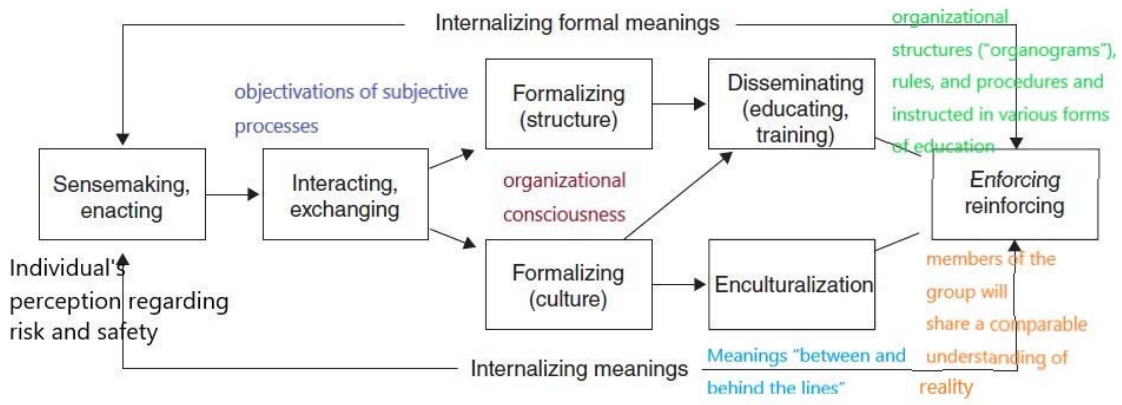


Figure 5 The development of organizational (safety) culture consists of the following stages

Stage two eventually results in partly shared understandings, both as meanings of risk, of safety and as rules, which accompany those meanings.

3. **Formal structure: organizational consciousness:** The next stage, split in two steps, regards structure formalization, in terms of organograms, rules procedures and culture development. It contains the (formal) establishment of norms and meanings and the institutionalization of behavior and expectations. At this stage the organization's shared representations and actions become explicit, official and formal so that, among other things, they can be taught to newcomers. The organization thus is reaching its "organizational consciousness"
4. **Disseminating- enculturating:** the formal structure, created in the third previous stage is institutionalized and instructed through training. The **enculturalization** takes place in the classroom as well as on the shop floor, by disseminating the spoken and written common language acquired through various socialization processes.
5. **Enforcing, reinforcing**: Members of the group share a comparable understanding of reality, meanings, standards and expectations. Structures and meanings are enforced and reinforced through various organizational processes and should be woven into existing processes and actions. Lack of

common understanding could be the cause for differentiation and, ultimately, the formation of sub-cultures.

4.4 Zohar and Luria Model

Zohar and Luria' s model[45], examine whether the relationship between organization-level safety climate and safety behavior is mediated by group level climate. It also analyses whether routinization moderates the relationship between organization climate levels and group climate levels. An example could be stronger positive relationship under high routinization.

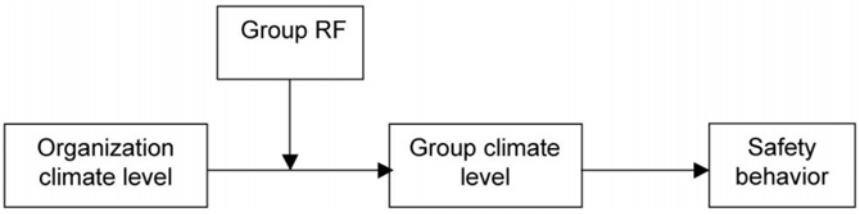


Figure 6 A multi-level model of Safety climate

According to Zohar and Luria' s model depicted in the scema above (Figure 6), the organization climate level is promarily set by the company policies and procedures. Organizational climate strength, which results from these procedural coherence defines group climate strength, by setting priorities at the workplace. Organizational

[45] Zohar, D., Luria, G., 2005

climate is considered a social – cognitive construct emanating from effortful sense-making activities.

High routinization-formalization (RF), which is developed by implementing formal procedures, ensures that more possible contingencies are covered and that the procedures themselves are more specific and rigid. High formalization also helps build stronger relationships between organization and group climate and results in minimizing supervisory interventions. In addition, policies and procedures are the sources of organization level climate perceptions and stregthen the boundaries for permissible variation in implementing these procedures by the supervisors. Group climate level is mainly defined by the supervisory practices in the organizations' subunits. Both organization and group level climate play a crucial role in determining safety behavior in the workplace.

4.5 Zohar's integrated model- safety climate and safety pyramid models

The following conceptual model is linking the occupational safety and organizational climate literatures. In this model safety climate was included, creating a framework of climate perceptions attributes. Zohar's[46] model is a modified version of Reasons'[47] Safety Pyramid model:

The bottom or deep layer represents organization's policies, focusing on the distinction between espoused and enacted policies. These policies function as indicators of priorities to the members of an organization. In the middle layer departmental or group's priorities are depicted. These priorities occasionally

[46] Zohar D., 2010
[47] Reason, J.T., 1997

compete with operational demands, focusing on safety versus speed, or productivity. The wrong focus may lead to unsafe behaviors, which may be explained latent factors in the upper or surface layer. This layer refers to the climate perceptions that increase the likelihood of injury, to workers' practices while performing high-risk operations, focusing on the prevalence or likelihood of unsafe acts among relevant employees.

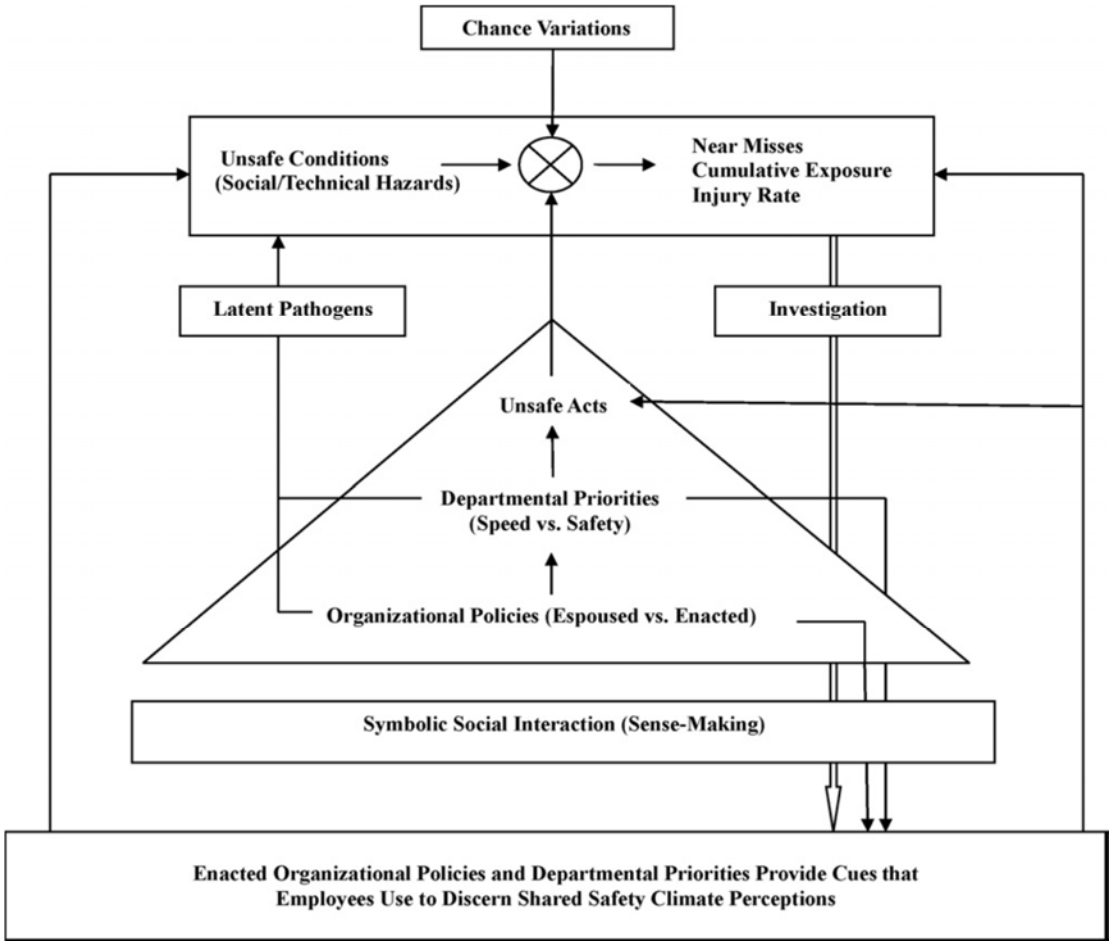


Figure 7 Zohar's integrated model

4.6 DeJoy's integrative approach to safety management.

Dejoy describes the integrative approach to safety management as an organizational learning effort with culture change as the ultimate endpoint[48].

His approach consists of a multi-level problem-solving process and depicts the inputs at each level of analysis.

At the top layer, there is the basic safety management sequence, which consists of exogenous factors, such as social-cultural, economic and other external aspects. At the organizational culture level, there are policies and practices, official and unofficial, related to safety and human resources, which can be considered as the most indicative manifestation of this culture.

Inputs for management system are operational priorities and personnel motivating rewarding system. Finally, inputs for exposure level are working conditions, job demands and work practices. Therefore, these upper level inputs define which problems are identified, leading to the next level, the one of problem-solving process. This level is based on two basic pillars, workers involvement, as they are familiar with the operations, risks, hazards and practices. Their contribution, if any, depends on the management support, demonstrated through attributes and actions of the management system. This problem-solving process provides a set of activities, which can actually lean to a shift in culture.

The lower level of this schema, the culture change, which is based on dissemination and diffusion of safety issues and possible solutions. It contains the auxiliary processes, which are key attributes to safety culture change. An open problem-solving process related to safety should be built upon the feeling of affective commitment and trust among team members, but also towards management.

[48] DeJoy D.M., 2005

On the other side of this level, there are the attributions, which include conclusions regarding causality and responsibilities. In a positive safety culture, all members of an organization should have balanced attributions, which is safety perceptions regarding the causes and responsibilities of safety results. The other aspect on this side is reciprocity. High reciprocity is achieved when employees and employers consider that each side is making its best efforts on safety. That could be considered as a psychological contract.

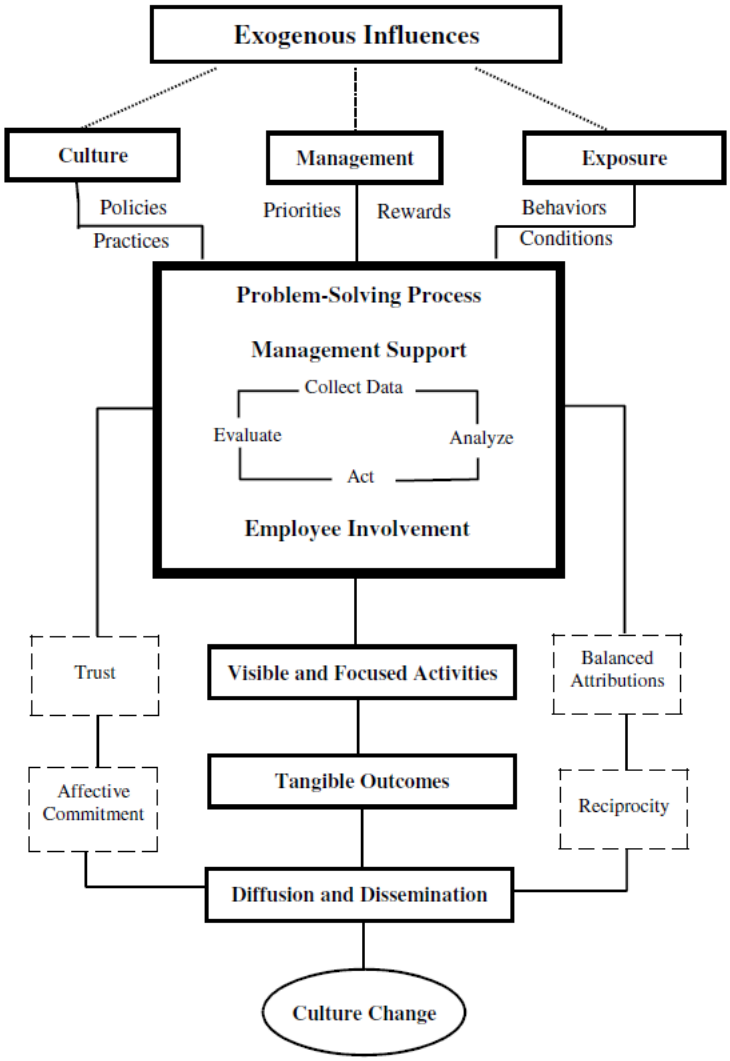


Figure 8 DeJoy's Key features of the integrative approach to safety management[49].

[49] DeJoy D.M., 2005

4.7 ICSI integrated safety culture

According to ICSI[50], safety culture attributes, which are depicted in the following schema (Figure 9), consist of the following:

1. **A shared awareness of the most important risks**, beyond severe accidents. Indicators make it possible to assess the organization's readiness to deal with these risks.
2. **An interrogative culture**: The conviction that risk management is never acquired is shared. Doubt is valued. Vigilance is shared by all operational actors at all times. Attention to detail of operations is important and the human cost of certain operations. Serious or high-potential events are the subject of a root cause search and lessons learned are learned. This is a learning culture.
3. **A culture of transparency**: Managerial practices aim to foster trust and freedom of speech. Management ensures consistent communication and actions. The circulation of information is favored. The risks of organizational silence are identified and addressed, including an explicit policy and shared recognition and sanctions incorporating the difference between error and violation. This is just culture. External communication, particularly towards local community is fair.
4. **An integrated culture**: Safety is the object of the commitment and mobilization of all parties, the management, the managers, the employees. Everyone's participation in safety passes both by the respect of the rules and by proactive contributions, which might be alerts and suggestions.
5. **Management leadership and employee involvement**: Safety is taken into account in all arbitrations. Management exercises directive-participatory

[50] Besnard D., et al., 2017

security leadership, promoting both compliance and safe and proactivity. The dialogue between management and employees on safety is promoted.

6. **Constant attention to the three pillars**: The technical barriers are defined in design to be compatible with all the operations of production and maintenance. They are regularly maintained and updated. The organization is reflecting on the essential rules, which must be observed at all times. The drafting of the rules is the subject of a participatory approach associating the teams concerned. The design of work situations includes consideration of organizational and human factors.

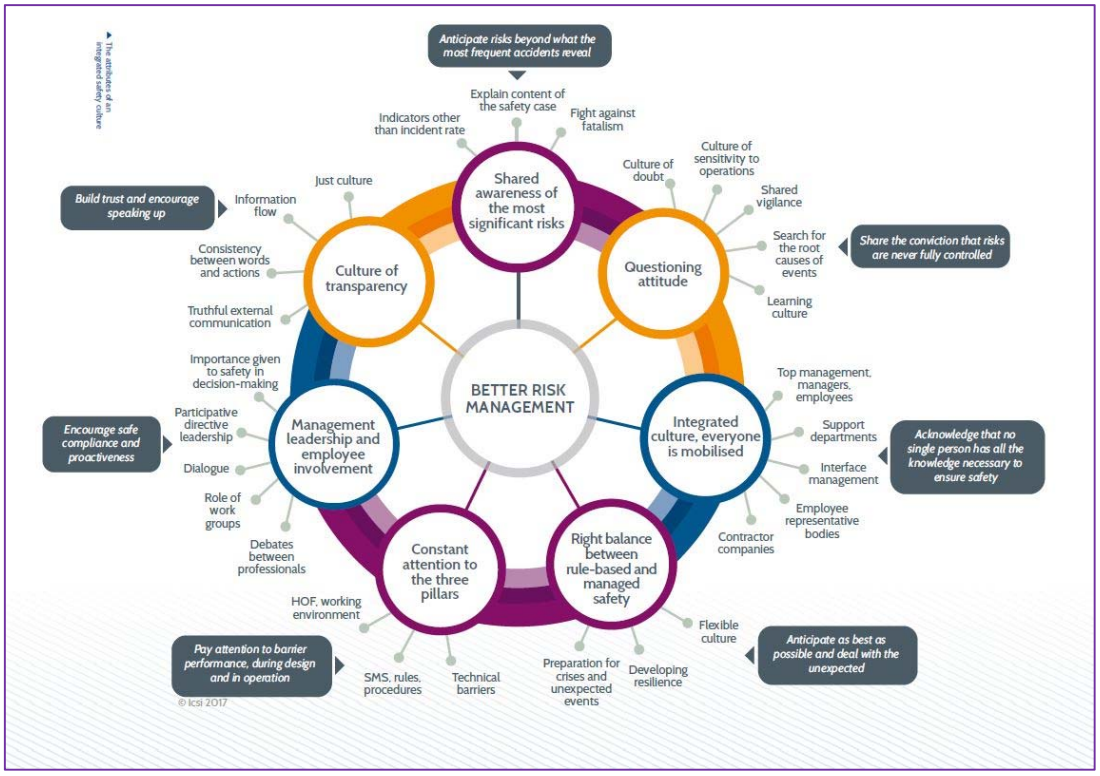


Figure 9 ICSI Integrated safety culture

7. **The balance between rule-based and the managed safety**: The organization prepares itself for both predictable and not. The foreseeable ones

are the subject of a collective reflection associating the operational teams and regular training. Resilience to unforeseen events is enhanced by support for individual skills and employees and managers. The crisis management procedures make it possible to adapt the command structures to the needs of events.

4.8 Cooper's reciprocal Safety Culture Integrated Model

This interactive safety culture model[51] encompasses the factors, persons, situations and behaviors. It focuses on three basic constituents, situational, which are safety management systems, perceptual, which is safety climate and behavioral, which is the goal-directed safety behavior. An organization's safety culture is based on the following pillars:

1. The interrelations between its members' perceptions and attitudes towards safety goals. This could be interpreted as the individual and group values and attitudes
2. Safety behavior, which are the behavior patterns and
3. The management systems to achieve and support these goals, integrated organizational mechanisms

There is a reciprocal connection among these elements. All these practices interact with each other providing an integrated safety culture in all departments.

[51] Cooper D., 2001

In the revised Safety Culture Integrated Model[52], which resulted from process safety research and results from inquiries into process safety disasters, there are again three basic pillars, Psychological, Situational, Behavioral and the six more often identified safety culture characteristics are pointed out:

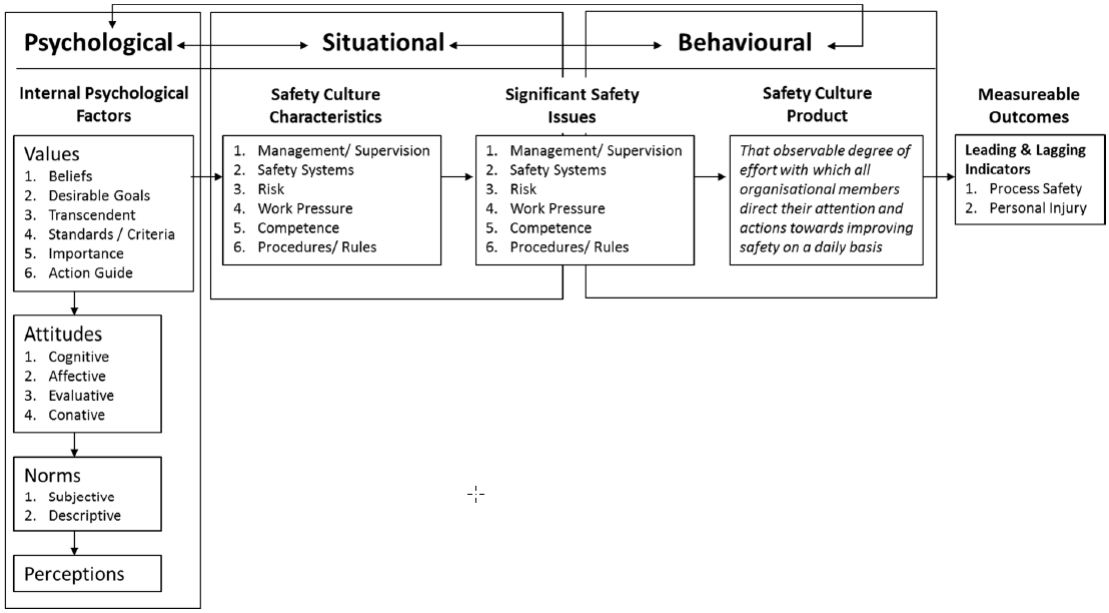


Figure 10 Cooper's reciprocal Safety Culture Integrated Model - revised[53]

1. Management and supervision. It is mostly concerned with people's visible safety leadership. Company's safety management systems and policies, leader's individual safety responsibilities and obligations authorities and accountabilities are factors which help build an effective safety leadership
2. Safety systems, via clear policies and procedures, include the formalized strategic system to control HSE. They ensure two-way safety communications processes, incident analyses and lessons learned processes, the design of plant, equipment, and processes so that safety is an integral element, asset

[52] Cooper M.D., 2018
[53] Cooper M.D., 2018

integrity and management of change processes related to risk assessment and analysis.

3. Risk includes the concepts of risk appraisal, risk assessment and risk control
4. Work pressure includes safety-production conflict which is caused by competing priorities, lack of resources or of a willingness to treat safe production as the number one priority
5. Competence includes knowledge, skills, and abilities people possess to do their job efficiently and effectively and
6. Procedures and rules are the codified behavioral guidelines. Their success depends on their availability to the workforce, or absence, presence, or lack of necessary updates.

The efficiency and successful implementation of those characteristics will shape the safety culture product.

4.9 Technology – Systems - Safety Culture

The concept depicted in Figure 11 shows schematically how the technology and the systems approaches each reach a certain level, in terms of incident rates[54]. The implementation of safety management systems seems to be effective, but not sufficient on its own. It seems that the contribution of People's parameter is necessary, apart from systems and technology. Safety culture is reached as a final "wave" following the implementation of Technology and Safety Management Systems.

[54] Hudson P., 2007

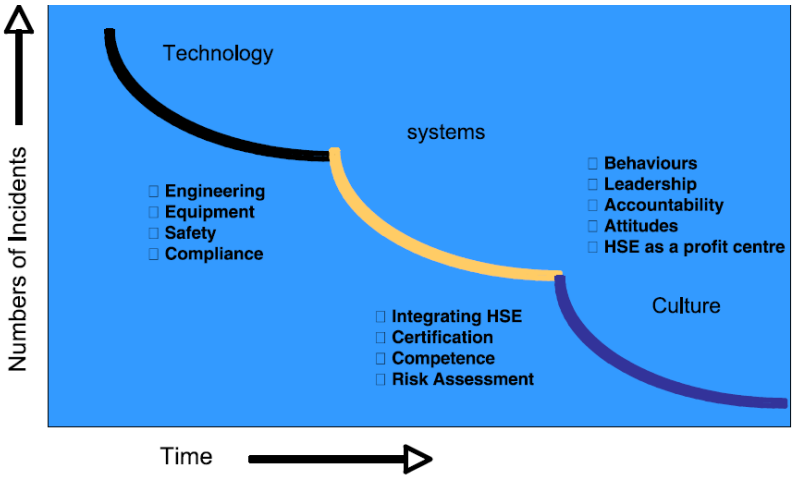


Figure 11 Technology, Systems, Culture in time

4.10 Reniers P2T-model

With P2T model[55], all safety and security culture and climate aspects can be integrated and covered, since all elements concerning a good safety and security culture and climate can be placed under one of these three dimensions. The three proposed dimensions of P2T-model are People, Procedures and Technology.

The technological dimension is indispensable, in order to ensure safety and security culture. In this model, even though, technology can be focused on physical safety measures, one other aspect of security can be the virtual, or cloud safety for systems protection. This kind of measures require socially accepted boundaries for the respect and protection of personal data and freedoms.

The second dimension Procedures, regards the Safety Management System or a Security Management Program, which contains the up to date procedures defining safely operations and processes, employees competences management, emergencies management.

[55] Reniers, G.L.L., 2011 based on Reniers, G.L.L., 2010

Figure 12 Safety and security culture and climate according to the P2T-model

The third dimension is People. Creating safety awareness among all employees through training, safety incentives, is essential.

4.11 The Egg Aggregated Model (TEAM)

The Egg Safety Culture Model[56] is an integrated, holistic conceptual approach, which incorporates several models[57]. It uses the shape and layers of an egg to explain the visibility of each layer, but also their relationships. The aspects that are placed in the yolk are the ones that are visible, whereas the ones that are found in the protein part of the egg represent the perceptual, psychosocial factors of safety. Beliefs, basic assumptions and values are in the air of the egg, as a metaphor for the invisible, but truly indispensable aspects of safety. The straight arrows from the air to the yolk

[56] Vierendeels G. et al., 2018
[57] Cooper M.D., 2016, Reniers, G.L.L., 2010, Schein E.H., 2010

indicate a causal influence of the beliefs, basic assumptions and values to all the functions of the egg. The lightning arrows, on the other side, indicate the sequential influence of the yolk to each domains of the domains. There are three domains, technological, human and organizational. Triple Venn diagrams further analyze each domain. In addition, each domain could and should have a measurable outcome

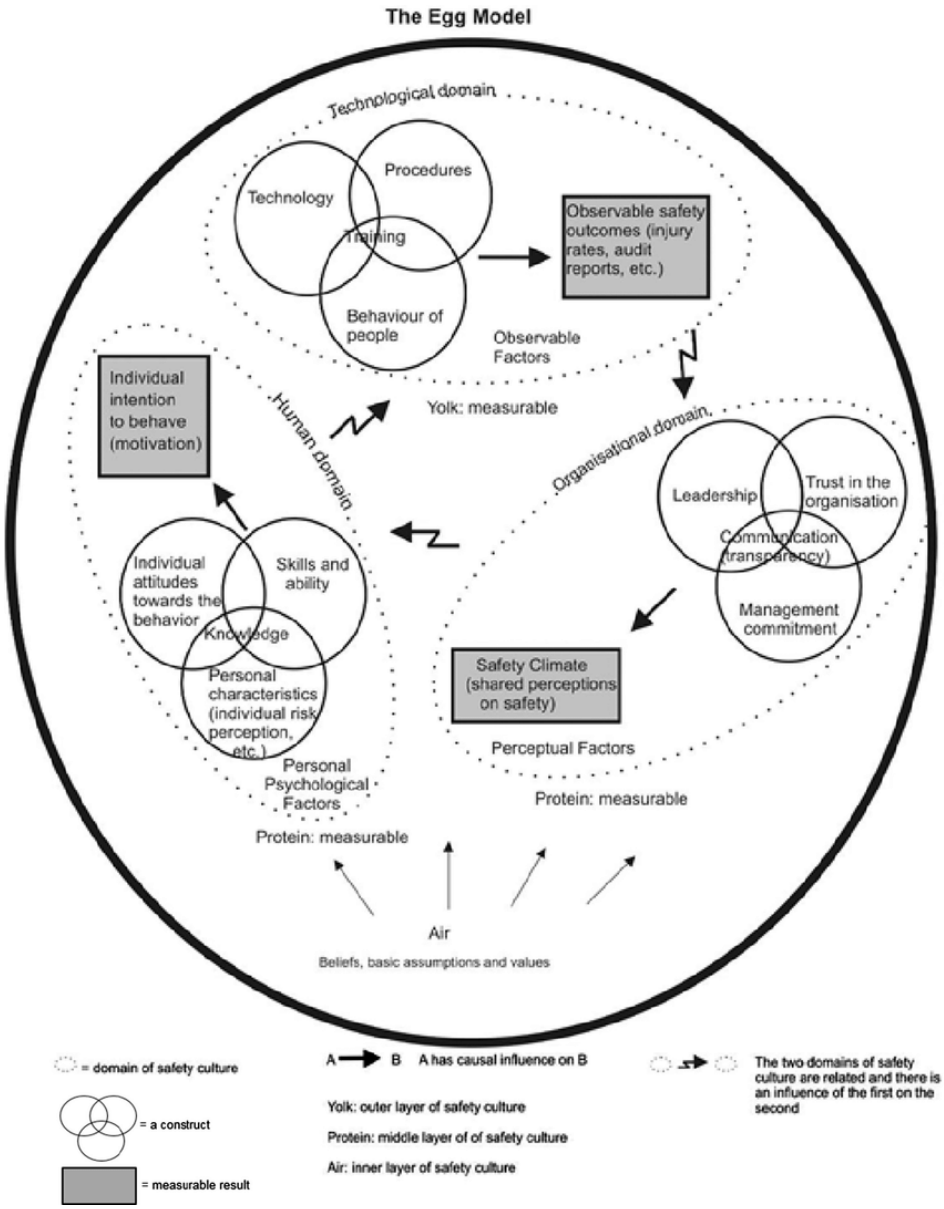


Figure 13 The Egg Model

5. Measuring Assessing Safety Culture

Prospective or leading safety performance evaluation methods reveal how well the company is performing, in relation to activities that prevent injuries. These measurable activities include safety management system activities, employee, supervisor, management activities, such as safety inspections/audits, behavioral observations, safety climate/culture surveys. However, these methods are often used separately or complementary and not in an integrated way[58].

Assessing organization and more specifically safety culture is an indirect or inferential process[59]. The purpose of performing a safety culture assessment would be to receive a diagnosis. Conclusions will be extracted when comparing the results with previous ones. The target might be to benchmark with peer organizations, to initiate a gap analysis, where the present status of culture is compared with an ideal or optimal one, resulting in recommendations to improve the status[60]

According Guldenmund's analysis, there are three most common approaches in safety culture research[61]:

1. Interpretative or anthropological approach

Qualitative in nature, narrative research, a phenomenological study, a study using grounded theory, an ethnography or case study, or various combinations. The result is "thick descriptions" a "theory" of the culture of an organization.

2. Analytical or psychological approach

[58] Sgourou E., Katsakiori P., Goutsos S., Manatakis Em., 2010
[59] DeJoy D.M., 2005
[60] Guldenmund F.W, 2016
[61] Guldenmund F.W, 2016

The analytical approach denominated safety climate, the more "measurable aspect of safety culture". This is a research methodology that can be applied in case studies or comparative surveys. The technique used is a standardized questionnaire that is self-administered. Indicators, such as accident and injury rates, self-reported accidents, incidents can be easily correlated with behavioral as they results have the form of frequencies or ratios and can be statistically tested. The analytical approach does not deliver evaluations of culture specifically but it is possible to conclude to an evaluation.

3. Pragmatic or experience-based approach

The pragmatic approach is normative. It is based on experience and expert judgment. In this approach, it is prescribed in detail in each activity what an organization should do to obtain an advanced or mature status. The pragmatic approach merges the concept of culture with that of safety.

Both safety culture and safety climate are measurable concepts. The individual, social and organizational aspects of safety culture can be measurable and assessed with different measurement methods and thus amenable to change. These assessments can vary from personal assessments to safety climate and culture surveys and system audit tools[62].

As it was previously mentioned regarding onion-layered concept of safety culture[63], safety climate consists of the two outer layers of the onion. Espoused values and artefacts can be measured quantitatively via structured questionnaires. Basic assumptions, which is the core element of safety culture, can be assessed by qualitative, non-numerical methods, as these notions are subconscious and therefore can only be inferred. To that end, Schein[64] has advocated ethnographic methods to measure organizational safety culture, in order to get at these basic assumptions[65].

[62] Casey et al 2017
[63] PRISM, 2005
[64] Schein E.H. 2010
[65] PRISM, 2005

5.1 Tools for assessing safety culture

5.1.1. "Hearts and Minds" online toolkit

Royal Dutch/Shell Group has developed the comprehensive toolkit[66], which provides an image of the level of maturity of an organization and what the next steps would be, in order to improve its "ladder" status and move to next level of maturity. This ladder, which is used in this tool to categorize safety cultures status, contains the following "stairs".

In **Pathological** organizations, people have no interest in HSE whatsoever.
In **Reactive** organizations, safety is important, but still not yet in a proactive way.

The **Calculative** organizations focus on systems, numbers and data analysis. Safety is managed on the basis of procedures, documentation and lagging indicators. Safety audits provide results, but effectiveness is still not achieved.

The **Proactive** organizations are using past experiences, in order to prevent incidents from reoccurring. Safety is managed with workforce involvement and leading indicators

In **Generative** organizations the following key features are developed:

- Planning of operations to every detail.
- Train of personnel to the planned procedures.
- Accountability and responsibilities are defined
- Superb safety performance
- Management and workforce relies on one another.
- Safety culture is maintained, even if there is a management's change

[66] Attwood D. et al 2006

- In case of failure, the key is to actively seek and learn from such events, identify errors and create opportunities for improvement.

5.1.2. Safety Culture Maturity® Model (SCMM)

The Keil Centre developed the Safety Culture Maturity Model SCMM®[67], which includes ten key elements of safety culture. These elements are derived from existing safety culture and human factors literature and industry experience.

- Visible management commitment
- Risk taking behavior
- Safety communication
- Trust between management and front-line staff
- Learning organization
- Industrial relations and job satisfaction
- Health and safety resources
- Competency
- Participation in safety Productivity versus safety

As safety culture improves and consistency is increased, the organization evolves from the Emerging Level 1 to Managing Level 2, where management commitment is developed. From Level 2 to Involving Level 3, the Organization realizes the importance of the frontline employees' involvement and develops personal responsibility. Moving on to Cooperating Level 4, it engages all personnel to develop cooperation and commitment to improve safety. Finally, reaching the top Level 5, continuous improvement is achieved, through consistency and avoidance of complacency[68].

[67] Attwood D. et al 2006
[68] Fleming M., 2001

5.2 Questionnaires – Surveys

A method used widely for measuring/assessing safety culture is surveys through questionnaires. Many different questionnaires have been constructed, for different kind of sectors and applications.

It will be useful to provide few characteristics about the elements and the design of questionnaires and question surveys[69]. There are many things to consider in a well-designed survey, such as:

Length and Time for response: If the survey takes too long to complete, people may lose interest in the process and choose not to participate. A good length for the survey's completion is 20–30 min, with 45 min being the maximum.

Target audience: management, office employees, workers craftsmen, contractors and others. It should be kept in mind that approximately 20–30% participation rate should be expected.

Participation reminders: plan to send periodic reminders to participants to boost participation

Method of delivery: electronically, printed, or both

How data are analyzed: The type of data analysis of the survey should be decided upon the survey's design. Descriptive statistics and graphical analysis. Inferential statistics should be used, in case of a demographic comparison. A six-sigma black belt should be consulted in survey design and for the data interpretation.

Anonymity of response: this should be clearly stated and ensured, as it will permit participants to answer freely and honestly and it will increase the rate of participation and the reliability of the results.

[69] Forest J.J., 2012

Likert scale questions can be designed with a five-point scale, such as strongly agree, agree, neither agree nor disagree, disagree, or strongly disagree.

Demographic data is obtained for final data analysis. Open-ended questions can be asked to empower respondents to voice their opinion.

There are several standardized questionnaires, developed by National Safety Organizations. The Danish Safety Culture Questionnaire incorporates leadership, organizational and worker factors. The Nordic Safety Climate Questionnaire (NOSACQ-50)[70] is developed by a Nordic network of occupational safety researchers and consists of 50 items across seven dimensions, which include shared perceptions of:

1) Management safety priority, commitment and competence

2) Management safety empowerment

3) Management safety justice

4) Workers' safety commitment

5) Workers' safety priority and risk non-acceptance

6) Safety communication, learning and trust in co-workers' safety competence and

7) Workers' trust in the efficacy of safety systems

The Zero Accident Vision- the PEROSH Zero Accident Vision (ZAV) Survey[71] focuses on the elements of the organization commitment, individual commitment, management communication, individual communication, climate priority, climate justice, empowerment, group safety climate, learning actions, learning conditions and safety resilience.

In the Annex Section of this Master Thesis, there are results from different kind of surveys. In these tables the design, sample and its description, industrial sector, the

[70] Kines et al., 2011
[71] Zwetsloot G. I.J.M et al., 2017

measurement method, level of analysis, indicators analysis, results, but also the limitations of the surveys are demonstrated. The ones that have been statistically validated and their quality is considered fair or good are presented[72]. All results from these surveys can be found in the Annex 1.

5.2.1. The use of questionnaires in safety culture research –An evaluation

The use of questionnaires in safety culture assessing surveys, has been sometimes criticized regarding the effectiveness, statistical reliability of their results, but also on the value of their contributions safety overall. Furthermore, the factors, which are needed to address the safety culture construct, have not yet been determined in a standardized method. There is neither a specific guidance on how to engender safety culture characteristics, nor the way to evaluate if the employees have actually embraced these traits[73].

According Zohar[74], a large number of industry-specific scales is necessary to offer a concrete variety of concrete climate indicators. In this way, it would be possible to discover underlying or tacit sense-making processes, which shape climate perceptions. It would be preferable to identify the core themes of concrete climate indicators in each industry, in order to obtain conclusions regarding processes, which define safety climate.

Climate measurement should be based on level-adjusted subscales offering separate measures for climates associated with respective organizational level[75].

[72] Aburumman M., Newnam S., Fildes B., 2019, Smith A. P, Wadsworth, E. J. K, 2009
[73] Strauch B, 2015
[74] Zohar D., 2000
[75] Zohar D., 2000

Moreover, if well-developed procedures for safety climate assessments are available, it is possible to perform an analysis of the perceived latent pathogens, allowing a comparison between departments in the same organization and between organizations in the same industry, using benchmarking as a means for meaningful comparisons. Validating safety climate as a robust leading indicator or predictor of safety outcomes is an enormous task[76].

The 2007 Safety Science's editorial mentions: ''While safety researchers have relied mainly on questionnaires, other assessment methods may be more illuminating.'' Suggested techniques include ''in-depth interviews, simulations and roleplaying''[77].

5.3 Influencing Safety Culture – Interventions

The effort of ingraining safety culture and avoid complacency is an ongoing one. Taking again into consideration the onion-layered approach for national culture by Hofstede, norms and values are in the central core of culture formation. As this layer is formed and learned during childhood by parental and school, it is something rather stable. The fact the culture in general, is something that can be learned and formed applies also for organizational and more specifically safety culture. Accordingly, basic assumptions influence espoused values, which in turn determine artefacts[78].

[76] Zohar D, 2010
[77] Strauch B, 2015
[78] PRISM, 2005

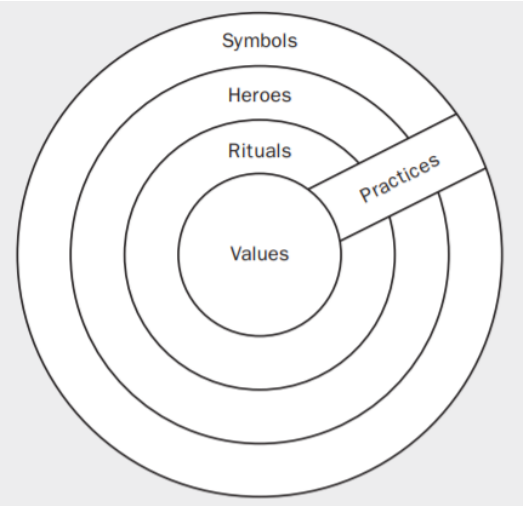


Figure 14 The "Onion": Manifestations of Culture at Different Levels of Depth[79]

As it has been already mentioned in the previous section of this Master Thesis, the purpose of assessing and measuring safety culture is to receive a diagnosis of the organization's status, in comparison with a benchmark, or previous results.

An attempt of changing the basic assumptions, or safety attitudes, which is a time consuming and ambitious plan for managers, might turn out to be very difficult to attain, if it is indeed feasible. Furthermore, changing safety attitudes might still take a few years, some mention five[80].

Culture change approaches to safety are "top down". In order to understand and change the fundamental values and beliefs of the organization, this almost always involves working with the leadership of the enterprise. Management agreement is indispensable to give spark priorities change, provide resources and personnel new initiatives and therefore, demonstrating the importance of safety within the organization[81].

[79] Hofstede, G., Hofstede, G. J. Minkov M., 2010
[80] Guldenmund F.W, 2000
[81] DeJoy D.M., 2005

Culture change, in the sense of changing basic assumptions, is difficult, time - consuming and highly anxiety - provoking — a point that is especially relevant for the leader who sets out to change the culture of an organization[82].

Interventions:

1. Harmonizing physical and social realities throughout the organization
2. Performing open dialogue
3. Developing norms, rules, and procedures based on consensus
4. Educating, training of shared rules
5. Reinforcing or correcting what is considered meaningful[83]

In recent years some researchers have used ethnographic measures to examine safety culture as well as techniques include ‘‘in depth interviews, simulations and role playing.

In the Table 2 of the Annex Section of this Master Thesis, the results of safety culture surveys are demonstrated. In these surveys, the purpose was not only to measure safety culture, but also improve company safety culture by implementing new procedures, or creating more and better safety-related interactions between the organization’s members. After the implementation of these interventions, the organizations repeated the assessment, in an attempt to identify changes in safety attitudes and perceptions. In the Table 2, these interventions applied, the type and the results are depicted.

[82] Schein E.H., 2010
[83] Guldenmund F.W, 2016

6. Safety for the Future – Safety Culture in the Industry 4.0 era

The fourth industrial revolution is an age of advanced technology based on information and communication. The new digital industrial wave brings the promise of increased flexibility in production, increased speed and competitiveness, better quality and improved productivity. Artificial intelligence, the Internet of Things, edge computing, Big Data analysis, Real-time communication, semantic technology, cloud computing/data and advanced analytics, Man–machine cooperation, remote sensing, monitoring and control, autonomous equipment, autonomous production or assembly and interconnectivity offer what can be described as an evolution, or more probable as a revolution in manufacturing.

Industry 4.0, therefore, describes the amalgamation of manufacturing with digitalization of data and information, collaborating to get maximum output with minimum resource utilization. Work is increasingly overseen and coordinated by algorithms and AI based on big data.

The industry 4.0 technologies connect the machines, tools, devices, components, products and logistics equipment ensuring real-time communications in such a way that system develops the potential to generate and feed information, adding value to the manufacturing process. This interconnection is made possible with a combination of software, sensor, processor and communication technologies. Interoperability,

decentralization, virtualization, real-time capability, modularity are terms that emerge in this new production and describe the process integration's industry 4.0 principles[84].

Many of Industry 4.0-related technologies nowadays have the advanced built-in safety measures for the safe and reliable operation of production machinery. Industry 4.0-compatible technologies for maintenance management that allow real-time and autonomous assets troubleshooting and problem solving reduce the safety concern of dynamic production environments significantly[85]. The data-driven End-to-End (E2E) visibility leads to the manufacturing risk reduction and stability improvement. Therefore, Industry 4.0 allows manufacturers to identify potential hazards in real-time and act upon them before they become real risks.

Furthermore, the development of industry 4.0 which is accompanied by changing tasks and demands for the employee in the factory that require new forms of skill and knowledge. There is a shift towards more complex jobs, which require new skills, continuous learning and education. Operators 4.0 need to adapt tasks and skills that are not part of their job description.

Traditional job profiles are expiring and estimations predict that medium-wage jobs are at highest risk of being replaced by intelligent machines[86]. These changes would have either positive results for employees, such as the machines assistance, either negative consequences, such as job loss[87]. The smart technologies will increase the mobility of workers, which will lead to a different concept of the workstation in a physical location.

It is more than clear that human resources management needs to set new strategies. Recent research suggests[88] that only 14% of EU jobs face a high risk of automation, with most related tasks substituted by machine learning algorithms. This includes

[84] Kamble S.S. et al., 2018
[85] Ghobakhloo M., 2020
[86] Digmayer C., Jakobs E.A., 2018
[87] Digmayer C., Jakobs E.A., 2018
[88] CEFEDOP, 2019

many positions on the shop floor, but also in the whole supporting supply chain. For approximately 18 million EU workers, 8% of jobs, the risk is severe, as the required training is not always provided.

The impact of automation is more intense for people with less digital skills, who are working in medium- or low-skill occupations. They are prone to a higher automation risk than their better educated peers. The same applies for workers in elementary occupations, such as plant and machine operators. In contrast, the automation risk is lower for managers and professionals and those employed in social and personal services, such as education, health or cultural industries. For lower-skilled workers the introduction of automating technologies at their work environment requires a long period of adaptation until they acquire new necessary skills to cope with new tasks or find a new job[89].

Organizations will have to consider new work models, rethink decision-making authorities, IT solutions and most of all recruiting processes. Employees' resourcing will focus on new capabilities for the needs of the new variety of tasks emerging from the industrial roles.

On the other hand, employees will have to be open to changes, ready to adopt new roles and flexible to continual interdisciplinary learning.

The implementation of industry 4.0 technologies will allow manufacturers to create new jobs to satisfy the new demands resulting from the growth of new markets and the reshaping of products and services. Although some jobs will be lost, through adoption of technological advancements and the increase of productivity, the level of cooperation between man and machine will increase significantly, by using robotic systems to assist workers[90].

As Industry 4.0 is a new paradigm of production that leads to a faster and more precise decision making, an entirely new approach to production, work organization

[89] CEFEDOP, 2019
[90] Lorenz M. et al. 2015

manner of work task performance will be needed[91], which may have a significant influence on the health and safety of workforce. It is important to enhance integration of occupational health and safety into manufacturing in the context of Industry 4.0[92]. Many risks as well as opportunities for occupational health and safety will occur from this new technology era.

New types of work emerge, such as teleworking, which can offer an improved work-life balance, reduction of stress associated with commuting, reduced need for work-related travel, increased worker control over work-life balance. Remote working could include potential challenges, such as perceived need to be 'available' at all time, isolation due to lack of social interaction, the feeling of constant performance monitoring, or of job insecurity[93].

There has been little research so far, besides the technological transformation, on the impact on Health and Safety and on establishing an Industry 4.0 safety culture.
To move on to the next era of safety management and culture, the industry 4.0 era, it is necessary to "think out of the box", as Reniers suggests[94].

The stability offered through the digital management of operations provides improved working conditions and a safe manufacturing environment to the workers[95].

The greatest challenge is to consider the role of the employee in transformation processes towards industry 4.0. It is important not to solely focus on the security and safety of objects, such as software, but also on processes in which the employee plays a key role. Security and safety concepts are therefore mostly examined from the aspect of technology and less from the human point of view[96].

[91] Polak-Sopinska A. et al., 2020
[92] Polak-Sopinska A. et al., 2020
[93] ILO 2019
[94] Reniers, G.L.L., 2017
[95] Kamble S.S. et al., 2018
[96] Digmayer C., Jakobs E.A., 2018

The new Industry 4.0 era, in the context of smart manufacturing, will create smart shop floors and the term of Operator 4.0 is making its appearance.

Until now, in order to increase workers' safety, systems and design of processes have separated human and machine interaction. In the industry 4.0 era, these barriers are eliminated and this collaboration between humans and robots is desirable. This human and robots collaboration is achieved with the use of cobots[97]. Unlike robots, which are working autonomously and have no contact with workers, cobots interact, respond and cooperate with humans on the shop floor. The replacement of physical work is the greatest advantage, as cobots can be used as assistants to support workers in tasks, which require great physical effort, and reduce the load imposed on the human body and thus reducing musculoskeletal difficulties[98].

Several technologies in the context of industry 4.0 aim at supporting employees in their daily work, with the help of robots. However, this transformation and the subsequent removal of the separation of workspaces between robots and employees will also mean changing the established safety procedures. Current research focuses on identifying and preventing employee-robot impacts by minimizing related risks[99].

Furthermore, the new technologies and the use of robots integrated into factories and warehouses are replacing monotonous, mundane and health aggravating tasks, which create stress, overwork and loss of interest, because of the repetitive work. One person's job, for example would be to detect product defects by visual inspection, sitting, immobile, in front of repeated images for several hours at a time, in order to identify quality issues. AI can fully replace these kind of tasks.[100]

In addition, tools such as intelligent cameras, smart sensors, smart safety wearables and Artificial Intelligence (AI) based location awareness systems can detect and

[97] https://en.wikipedia.org/wiki/Cobot
[98] Bragança S. et al., 2019
[99] Digmayer C., Jakobs E.A., 2018
[100] EU-OSHA, 2018b

report any human or machine behavior that might pose a risk to safety[101]. Two new aspects incur from these technological possibilities in the occupational Health and Safety. Identifying Environment hazards and personalizing individual risk assessments.

New technologies in the workplace can create safe **working environment**s by excluding humans from harmful activities in the workplaces, or even predict unsafe behaviors and thus prevent accidents in advance[102]. The wearable technical solutions, such as exoskeletons, body-sensors, mixed reality glasses, smart-watches, helmets, handsets, location trackers may foster detection of situations that involve potential occupational risks before they actually occur at smart shop floors.

They can monitor hazardous emergencies in their work environment and activate protective systems. Risks and hazards can be assessed in a continuous and real-time manner, reduced and maintained at a minimum acceptable level, by creating a sensing and social shop floor Therefore, real-time monitoring can protect workers in hazardous environments, ensure human-machine precise and safe interaction, tracking hazards via GPS monitoring, or ambient intelligence. Other applications use geographical localization of workers with regard to other, potentially dangerous objects or high-risk zones, detecting the end-of-service-life of Personal Protective Equipment (PPE) used by workers. Personal protective equipment may include items such as wearable electronic gloves, safety glasses and shoes, earplugs or muffs, hard hats, respiratory monitoring devices, high-visibility vests etc. Therefore, warnings are provided to workers in case of emergence of hazardous situations and activate protective systems after exceeding a high-risk threshold value[103].

The second aspect consists of the **personalization and individualization** of risk assessment for Operator 4.0 vital signs at any given time. In comparison with the traditional risk approach applicable until now for those who were working on similar

[101] Ghobakhloo M., 2020
[102] Min J. et al. 2019
[103] Podgórski D. et al., 2017

workstations[104], new sensor technologies can monitor worker's health state, by measuring key physiological parameters, such as body temperature, heart rate, breathing rate, or monitoring work comfort, underclothing temperature and humidity, work posture, stress indicators, micro-facial expressions and even tone and sentiment analysis[105]

On the other hand, negative results could emerge in workplace safety and workforce well-being from the use of new technologies. Automation, replacement of positions and tasks by robots, on demand economy, poor legal support and social security deficiencies can cause work insecurity.

Digitalization may result in some workers being more exposed to new OSH risks such as ergonomic and new kind of safety risks. Increased organizational and psychosocial risks, with an increase in work-related stress and poor mental health, could also be a consequence of increasing performance pressure and work complexity, irregular working hours, less social interaction and support at work, blurred boundaries between work and private life and new forms of work with unclear employment status. This may be the case for example for certain forms of work facilitated by online platforms or in situations where workers are managed by intelligent machines[106]. These new types of occupational risks could lead to mental illnesses.

Furthermore, interconnection of systems and machines, as well as remote access can compromise secure data exchange. Framework as security and privacy in an industry 4.0 environment is very critical. The data breaches and cyber-attacks through malicious software need to be controlled to improve the trustworthiness and acceptability of the system[107]. Organizations should be also focusing in the cloud computing, functional safety risks associated with cybersecurity, which can also have a significant effect on human physical, but also psychological. The dramatic increase of interconnected devices, wide exchange and processing of data, without proper risk

[104] Podgórski D. et al., 2017
[105] EU-OSHA, 2019a
[106] EU-OSHA, 2019a
[107] Kamble S.S. et al., 2018

awareness, hides a growing threat of potential cyber-attack. This risk is actually a Health and Safety risk for the employee.

The increase in the level of networking results in more and more IT systems being used in production. As a result, industrial control systems are increasingly being targeted by the same cyberattacks as those affecting conventional office IT systems. This is where the aspects of safety and security converge. A danger of either a coincidental malfunction, either an intentional cyber, or malware attack exists not only for infrastructures that are directly connected to the Internet, but also for those indirectly connected to it[108].

In addition, employees' well-being monitoring technologies, for example, can be perceived as an invasion of privacy and personal data safety and can be a stressful factor. Psychological hazards have been recognized considerable regarding OHS legislation and management systems

In this context, the new era organizations should also develop a new approach to safety culture that can support new workplace realities and adapt to the effects, positive, or negative, of these new developments. In order to achieve a Safety Culture 4.0, potential safety risks will need to be identified as well as the means to ingrain awareness to all stakeholders. New norms of interaction between employees and between leaders and employees, will be necessary.

Four aspects of Health & Safety could be the following:

1) **Organization of work**, in order to optimize utilization of resources, and to increase performance. Advancing or redesigning a process should include H&S consideration. Even more important is training of the existing, sometimes ageing personnel to the new technologies and applications.
2) **OHS legislative and regulatory framework**. The legal process should try to keep up with the technological progress and try to respond to the new situation.

[108] Bretschneider-Hagemes M., Korfmacher S., von Rymon Lipinski K., 2018

3) **OHS management systems**: Standards could be an initial point of application and re-evaluation
4) **Management of occupational risks**. One could suppose that with the increasing and probably complete atomization of processes, health & safety risks will be reduced. However, the concept of risk management in real time and most importantly delocalized, "smart" issues should also raise the awareness of organizations on cyber security.

   All the above parameters are depicted in the following schema[109].

Figure 15 Industry 4.0 technological categories and aspects of OHS.

Reniers P2T-model model, analyzed in section 4, could be considered as a first model leading to industry 4.0 safety culture models. The term of security culture is making

[109] Badri A., Boudreau-Trudelc B., Souissi A.S., 2018

its appearance and it corresponds to the new needs arising from the technological evolution of industry 4.0 era.

6.1 Model of a cyber-physical system in smart working environments

Podgórski proposes[110] that smart working environments are composed of two overlapping spheres:

The Manufacturing Sphere (Figure 16), where a network of sensors collect data from the manufacturing processes, identify potential failures and malfunctions and their probable relation of equipment with the workers.

On the other hand, the Worker Sphere contains a network of sensors, collecting data from the physiological status of the workers, the status of their PPE, parameters from their environment.

The software layer includes the context database, where all the data from Worker and Manufacturing sphere are collected. The reasoning engine is involved in data analysis and real-time risk assessment.

The risk manager analyses, selects and activates and monitors relevant preventive and protection measures.

[110] Podgórski D. et al., 2017

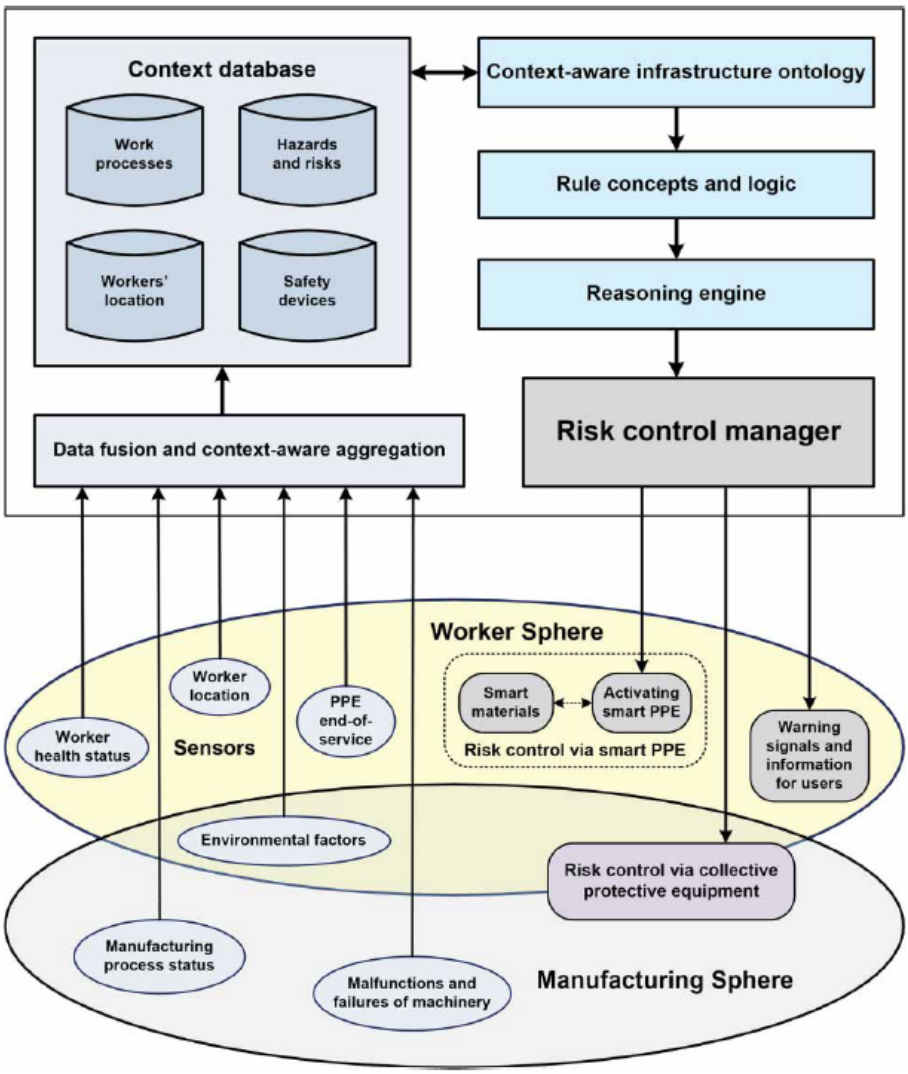


Figure 16 Cyber-physical system in smart working environments

6.2 'CHESS' tool

'CHESS' tool includes 5 very important fields where revolutionary progress is needed:

1) Cluster thinking and intensified cooperation

This would consist of the following:

- Create a multi-plant council or a cluster council
- Establish proactive strategic cooperation and improvement
- Creating a cluster safety funding budget
- Use risk assessment and internal audit cluster teams
- Establish a cluster emergency planning matrix
- Take into account various forms of risks such as domino effects (escalating accidents) in risk assessments.
- Establish a cluster safety management system upgrade approach.
- Establish a cluster safety culture on top of the individual plant safety cultures

2) High transparency and efficient inspection
    - establish a national reporting database
    - create “just a culture”
    - establish a learning dissemination system
    - establish an understanding between cluster safety council members and inspection services for efficient inspections
    - use drones for safety purposes
3) Education, training and learning
    - training sessions with both plant safety managers and safety inspection services
    - include risk management in primary schools education and process safety in the academic educational program
4) Security integration
    - security should be treated in an integrated way with safety by company safety management, in order to avoid and mitigate losses
5) Safety innovation and dynamic risk assessments

    In this field the use big data and the Internet of Things, new risk assessment techniques on real-time knowledge and decision-making is considered. Safety /security proactive performance indicators should be

used and alternative risk assessment techniques should be developed, whereas ethical and moral principles should be considered.

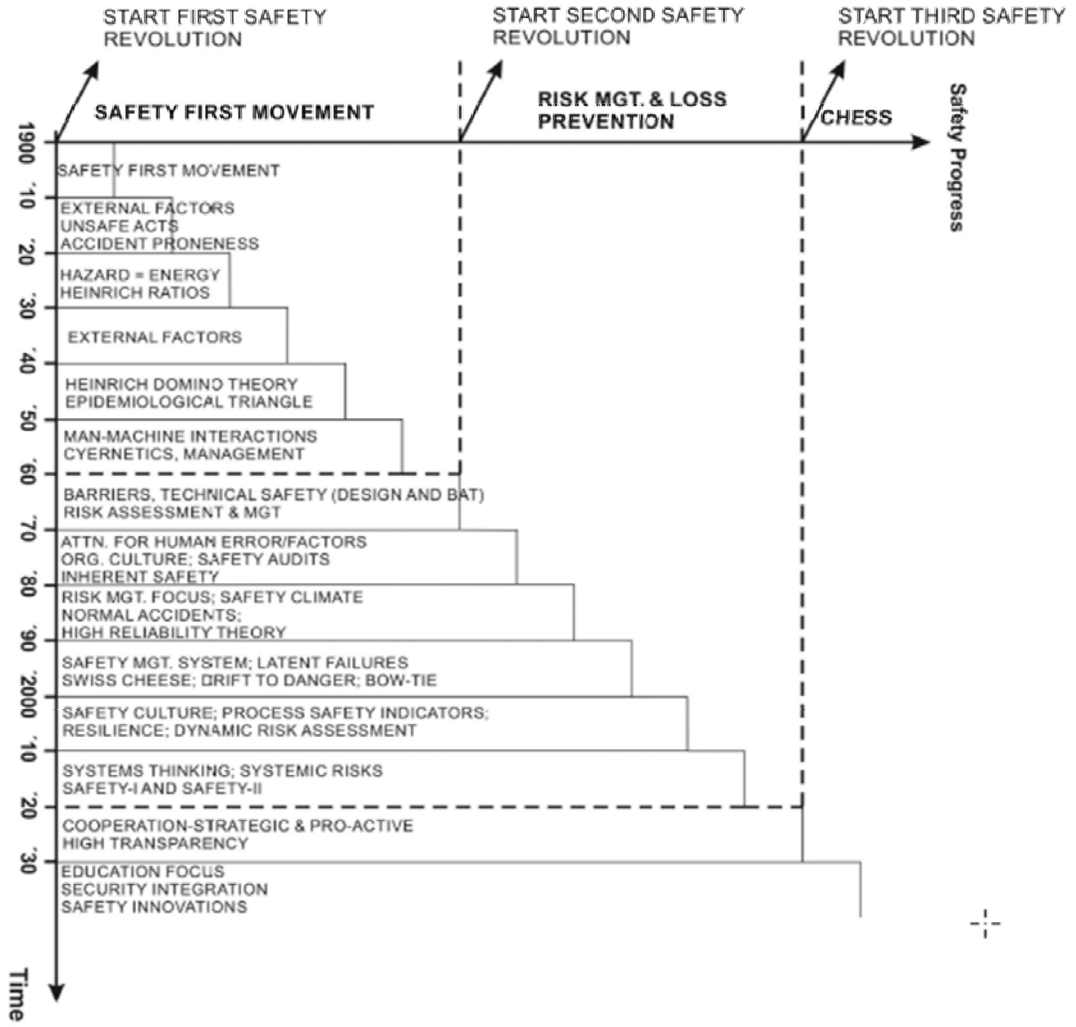


Figure 17 Safety progress and the three safety revolutions in the chemical industry (1900-2030 and future)[111].

[111] Reniers G., Khakzad N. 2017

6.3 SiTra4.0 project

The Sustainable Safety Culture Transformation Approach for Industry 4.0 project[112] aims at developing a transformation approach for the establishment of a preventive and participatively acquired safety culture concept as a decisive success factor for the implementation of industry 4.0 in SMEs.

Digmayer considers Guldemund's safety culture three- layer model (based on Schein 1992), in order to create an equivalent applicable Safety Culture 4.0.[113]

1) **Assumptions:** the nature of reality and truth, of time, of space, of human nature, of human activity, of human relationships
   That means that safety culture 4.0 should include a common understanding of new risks occurring from digitalization. The role of leadership is here again indispensable in setting the principles and strategies for the upcoming risks, but also the employees themselves should participate in developing solutions for their day-to-day life in their workplace.
2) **Values/Attitudes towards hardware, software, people/liveware (Geller 1994), risks**. This aspect requires a positive attitude towards the new technologies and the way they change the work context. There is also the need of internal rules and procedures, defining security measures, presented in a simple manner. People should be actively included in the transformation process by being trustingly allowed by management to contribute in improving their own processes. Finally, potential risks should be identified and adapted, through constant training, to the emerging threats.

[112] http://www.tl.rwth-aachen.de/index.php?p=sitra
[113] Digmayer C., Jakobs E.A., 2019a

3) **Artifacts: observable behavior**. Machining safety implementation requires clear visualization of the functionality and employees' training on the new safety measures. The point is also to protect operators form excessive information and task load.

6.4 The three Rs for a Culture of Responsibility

The following Deloitte model[114] for building a culture of responsibility can be also applicable for, organizational culture, or safety culture and responsibility. Three sides of the responsibility triangle—roles, rules, and relationships—that contribute toward building a culture of responsibility within an organization. These are the three pillars of responsibility, which help determine the level of motivation employees can show toward owning an outcome.

Role clarity is the extent to which individuals understand their areas of responsibility and the impact they can make to the organization

Rules encompass the explicitly communicated processes, as well as the implicit social norms, that govern the right thing to do in a particular context.

Relationships describe the strength of interpersonal trust, or connectedness, among the individuals involved and the feeling that team members are invested in each other's growth and development.

[114] Sniderman B., et al. 2018

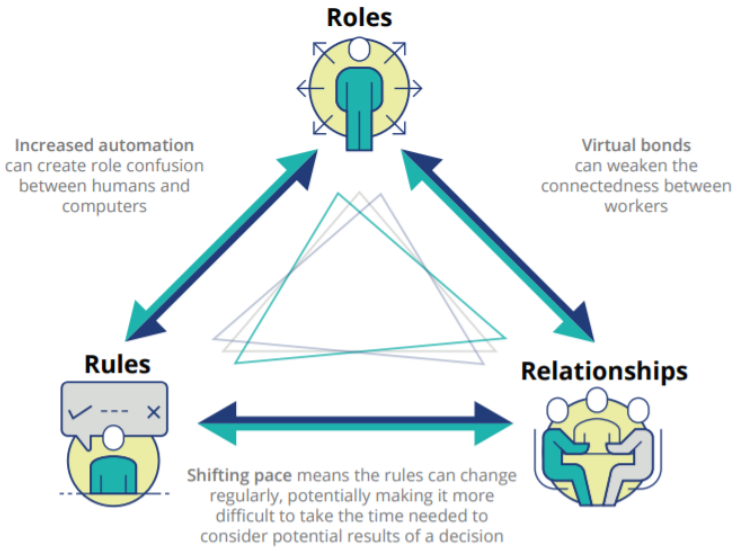


Figure 18 The 3 Rs of the Culture of Responsibility[115]

As remote work has increased in recent years and workforce models have changed, giving the opportunity for more alternative forms of work beyond the traditional full-time virtual teams are not only feasible but also productive. A side effect of this trend is that bonds based on experience and mutual trust, between workers and with their leaders can be weakened and give fewer opportunities to build bonds.

Reliance on automation may even lower barriers to error when, absent input from other humans, they consider the machine to be "in charge." This tendency is known as automation bias: Humans accept the machine's answer as correct, ignoring conflicting information or their own instincts.

The model proposes tree ways that leaders can help strengthen the pillars of responsibility for their teams.

- Promote intentional collaboration, by fostering trust and a sense of ownership. Leaders can create an environment in which their employees feel

[115] Sniderman B., et al. 2018 Adapted and modified from Barry R. Schlenker, Personal responsibility: Applications of the triangle model," *Research in Organizational Behavior* 19 (1997)

a sense of responsibility, not only to their work, but also to their peers and their team.

- Reinforce reciprocity among coworkers and practice digital leadership. Employees who perceive their organization as valuing their contributions and caring about their well-being are much more likely to assume a sense of responsibility for others. An employee who feels responsible often precedes and can even predict, prosocial behaviors in the workplace
- Practice digital leadership. A digital leader should communicate consistently with employees fostering a culture of knowledge-sharing, continuously sharing relevant content and stories to engage the team.

7. Factors -Attributes of Safety Culture–Safety Culture 4.0

Changes in technology without accompanying strategic and cultural changes can cause more problems than they solve. The effective industry 4.0 transformation should contain communication employee-initiated bottom-up and management-initiated top-down. There should be active employee involvement, all relevant parties, employees, supervisors and managers should understand their safety roles

and responsibilities, should have adequate information to fulfill their safety roles and responsibilities and be comfortable bringing safety problems to the attention of their supervisors.

Management tasks, such as monitoring performance, are increasingly performed by AI systems, but some tasks cannot yet be automated, for example embedding organizational culture[116].

To achieve the Safety Culture 4.0, an interdisciplinary approach needs to be adopted drawing on the expertise of a team comprising not only safety specialists, engineers, IT experts, but also legal scientists, psychologists, ergonomists, social and occupational scientists, medical practitioners and designers.

Results from studies on safety programs effectiveness have underscored the importance of management support and involvement and that positive safety performance occurs when safety is fully integrated into the management system of the organization. Communication has consistently been identified as a key element of safety program effectiveness[117]. Other attributes are safety training, systematic hazard control activities (hazard/risk perceptions), safety systems (safety policies, procedures, equipment).

By harnessing these new technologies, the following questions must be asked from the safety science perspective:

- To what extent will these new technologies alter the parameters of the safety culture construct?
- Are current safety management systems good enough to cope, or will they need to be adapted?
- Will the safety culture construct need specific tools and methodologies or will validated universal models still be applicable?

[116] EU-OSHA, 2018a
[117] DeJoy D.M., 2005

- What do the smart factories need to do to implement Safety Culture 4.0 in their workforce[118]?

OSH strategies propose the following methods that could help to mitigate the OSH challenges presented by digitalization:

- The development of an ethical framework for digitalization, codes of conduct and proper governance
- A strong 'prevention through design' approach that integrates human factors and worker centered design
- The involvement of workers in the design and implementation of any digitalization strategies
- Collaboration between academics, industry, social partners and governments on research and innovation in digital technologies to properly take account of the human aspect
- A regulatory framework to clarify OSH liabilities and responsibilities in relation to new systems and new ways of working
- An adapted education system and training for workers
- The provision of effective OSH services to all workers of the digital world of work[119].

More analytically, safety culture in general, but more specifically Safety Culture 4.0 needs the following factors to be developed:

[118] Cooper M.D., 2019
[119] EU-OSHA, 2019a

7.1 Policies and Procedures

Established policies from International Organizations, National Organizations and support from government policies and strategies set the standards framework.

ILO has issued Guiding policies for action. These include the Occupational Safety and Health Convention (No. 155) and the accompanying Recommendation (No. 164). Companies that have an occupational safety and health management system (OSH-MS) set up according to the ILO Guidelines, have better records both on safety and on productivity.

Codes of practice for different business sectors have been also issued. They are practical guides for public authorities and services, employers and workers concerned, specialized protection and prevention bodies, enterprises and safety and health committees. Codes of Practice, though, are not legally binding instruments and do not aim to replace the provisions of national laws or regulations, or accepted standards

The EU Strategic Framework on Health and Safety at Work 2014-2020, provides a framework for coordinating national policies and promotes a holistic culture of prevention. The awareness raising initiatives carried out at EU and national levels have contributed to strengthening a culture of risk prevention. Additional strategic objectives are further national strategies consolidation, facilitate compliance with OSH legislation, particularly by micro and small enterprises, better enforcement of OSH legislation by Member States.

Each state member should have a Health & Safety National Policy, strategy and work plan or action program.

Policies and procedures from companies and organizations. The aim is to establish a proper safety culture at the enterprise level. Positive and proactive measures towards safety management, rather than reactive and negative towards accidents and injuries.

In this transitional period, where newer and newer threats emerge, a challenge is faced, by insufficiency of initiatives with respect to occupational health and safety including standards and regulations[120].

Safety Culture 4.0 needs stable policy and legal framework foundations. Regulation and good governance will be required for the industry 4.0 era. Given that professional service robotics is a relatively new area, issues of legal liability in case of accidents in a public area is not clear. More legislative analyses concerning liability issues need to be undertaken before the technology is launched. The introduction of human enhancement technologies raises new demands on health and safety management to monitor emerging risks, but also poses new legal and ethical questions[121].

There are no legal specifications that applicable in daily work routines, for instance specifications for the cooperation between robots and workers[122]. In addition, in the era of digitalization, as new forms of work with unclear employment status emerge, such as online platforms or in situations where workers are managed by intelligent machines, the boundaries between work and private life are vague[123].

Policies and legal framework should also reinforce employees' protection from loss of positions and increase of inequalities between higher and lower skill employees. Policy-makers should be wary of the fact that advancing technologies reinforce higher skill demand and training, widening the digital divide and putting low-skilled workers at further disadvantage.

Furthermore, in present, there are inadequate legal specifications for the data management. As a result, data policies often do not consider threats induced by industry 4.0[124]. Effective strategies and systems and ethical decisions are needed in the context of privacy and handling the large quantity of sensitive personal data that

[120] Polak-Sopinska A. et al., 2020
[121] EU-OSHA, 2015
[122] Digmayer C., Jakobs E.A., 2018
[123] EU-OSHA, 2019a
[124] Digmayer C., Jakobs E.A., 2018

could be generated. A malfunction, or the generation of incorrect data or advice, could also cause injury or ill health.

Questions arise regarding legal and liability issues, data sharing and storage, the risks of bias in machine learning's competences and the difficulty of allowing for the right to an explanation, including how data about workers are used, firmed up by the EU General Data Protection Regulation (GDPR). The Regulation aims at protecting natural persons from automated profiling, work performance evaluation, movements and behavior monitoring, which are offered by AI systems and thus giving the right to employees to object.

In addition, International Standards, such as ISO, should be focusing on the standardization of quantification tools and dashboards, which are gathering and using employees' data and mostly that employees are involved in those discussions.[125]

Standardization regarding functional machines' safety is developed a long time ago. However, relevant standards considering the risks incurring from networked machines have only just recently being published. ISO/TR 22100-4[126] is intended to describe the relationship between ISO 12100, governing safety, and IT security for machinery[127]. It provides essential information to identify and address IT-security threats, which can influence safety of machinery.

7.2 Design of Process and Machine

Safety Culture 4.0 implementation requires further research to improve the integration of human work and smart solutions. Design and configuration of intelligent machines still need to concentrate on physical, social, mental, and

[125] EU-OSHA, 2018b
[126] https://www.iso.org/standard/73335.html
[127] Bretschneider-Hagemes M., Korfmacher S., von Rymon Lipinski K., 2018

cognitive capabilities of the human being. An interdisciplinary approach to these issues should be adopted drawing on the expertise of teams comprising engineers, IT experts, psychologists, ergonomists, social and occupational scientists, medical practitioners and designers[128].

The use of AI in workplaces can create stress and a range of serious problems if they are not implemented appropriately. Potential Health & Safety issues may also include psychosocial risk factors if, for example, people are driven to work at a cobot's pace (rather than the cobot working at a person's pace) and collisions between cobots and people. Machine-human interaction are creating new working conditions, interconnectivity contains risks of overwork and disruption of work-life balance.

Efficient interaction between humans and machines in such complex system is hard to achieve and should be considered right from the design phase[129].

New type of safety systems need to be introduced—systems that are enabled with avoidance strategies and are capable of preventing or minimizing the risks of collisions by detecting obstacles as well as their motion. Moreover, to avoid unforeseen dangers in the manufacturing setting, the planning of tasks should be done in a more cautious and meticulous way with the inclusion of the limitations of each participant (either it is human or machine). The design of the mechanical systems and safety strategies and alerts in the flow of the process is necessary, in order to prevent unintentional contact between humans and machines, quantify the level of potential injury and minimize the injury[130].

In the era of constant transformation and technological experiments, design plays a central role in the new manufacturing environment. Safety Culture 4.0 should ingrain ergonomics, as the focal point for the improvement in terms of product and production process aiming at the user's well-being and safety. There should be an

[128] Polak-Sopinska A. et al., 2020
[129] Bragança S. et al., 2019
[130] Bragança S. et al., 2019

increased attention to the welfare and safety of the Operator 4.0, who interfaces with the different kind of equipment[131].

Failures in machines that evoke failures in other machines (cascading machine failures) and high expenses for improving the security of machines. The second-level category risks that emerge in the management of digital data comprises three aspects: Data leakage is the main problem perceived in this field as well as corresponding consequences such as trust issues, data manipulation or liability for data[132].

Workers participation in the design of the human-machine interaction could contribute to the embedment of a Safety Culture 4.0 and the avoidance of the new health and safety issues which have been identified, such as **technostress**[133]**,** technology addiction, blurring of boundaries, information overload. Workers could participate in the design of techniques and tools, such as gesture recognition, video analysis and augmented reality. These new tools are used to monitor the realization of new tasks, as well as to recommend operations to the worker in order to complete their job. A central system should be able to alert each worker in case of events that are classified as risky. Moreover, to evaluate the safety of the design of the assembly system by identifying risks associated with each area. In addition, a machine safety mode could be designed for novice workers, in order to prevent actions that could lead to severe injury[134]. Workers must be consulted at all points whenever new technologies are integrated into workplaces, sustaining a worker-centered approach and prioritizing a 'human in command' approach[135]

[131] Laudante E., 2017
[132] Digmayer C., Jakobs E.A., 2018
[133] Valenduc G., Vendramin P. 2016
[134] Kaasinen E. et al., 2020
[135] EU-OSHA, 2018b

7.3 Management/Leadership Commitment on safety

Leadership commitment is an attribute that can be viewed from two different aspects: on the one hand, there is the point of view of the leaders and their actions. On the other hand, there is the aspect of the employees' perception on leadership commitment[136].

Fruhen defines leader's safety commitment as an action that reflects their mindset and drive to support organizational safety.

Different forms of safety commitment perceived by the Leaders, which can also be applicable for Safety Culture 4.0 are the following. Leaders might consider safety as a personal responsibility for employees' wellbeing and therefore more emotional and caring commitment. Safety commitment can be otherwise normative, where safety represents a sense of obligation, but in ethical and moral terms. Alternatively, it can be considered calculative, more transactional, as an obligation for the business survival. These kind of leaders' perceptions on safety commitment also define their relative subsequent actions[137].

[136] Fruhen L.S., Griffin M.A., Andrei D.M., 2019
[137] Fruhen L.S., Griffin M.A., Andrei D.M., 2019

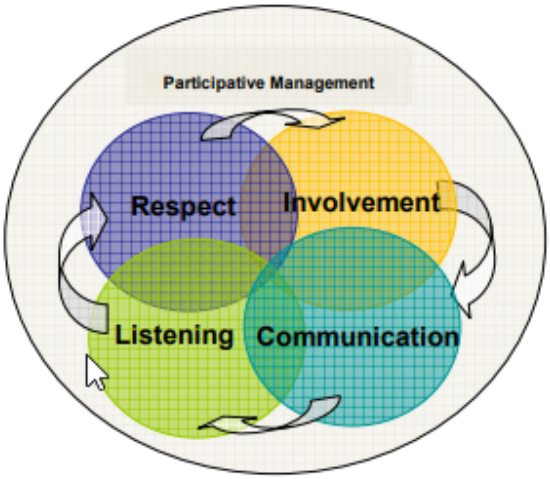


Figure 19 Participating Management- case studies OSH

Employee perceptions concerning management support and commitment to safety are major components of a positive safety culture or climate[138].

Sense making, a term already met at Zohar and Luria's model, is the activity humans use to make sense of their experiences and put them into context with their understanding of the way the world works and to construct meaning. To effectively use sense making to get employee participate in change, the leader observes and listens closely, collaborating with organization stakeholders to make sense of the best way to proceed, prioritize and resolve conflicts[139].

Styles of leadership[140], [141]

The laissez-faire leadership: this style includes avoidance of making decisions, disowning of responsibilities, non- leadership and implies the lowest level of concern for employees' wellbeing.

[138] DeJoy D.M., 2005
[139] Carrillo R.A. , 2011
[140] Zohar D., 2002
[141] Broadbent D.G., 2004

Corrective leadership: management – by exception passive. The Fireman. In this style of leadership, the leader tends to be like laissez-faire, but takes actions when something occurs.

Management – by exception active. The policeman. This style includes mainly error detection and correction based on monitoring performance compared to standards. It tends though, to produce only moderate performance and short-term results.

Constructive leadership: the contingent-reward dimension. The dealer. This is the classic transactional style. It implies an intermediate level of concern for employees' wellbeing, because it requires from the leader to identify individual needs and desires, in order to offer relevant rewards for motivation.

These last two styles, which in fact are transactional, influence safety, because effective monitoring of safety processes and rewarding practices can lead to reliable performance on daily job routine. Supervision based safety models effectiveness, on the other hand, depend also on the priorities set by upper management. This is also indicated in the results of Zohar's survey.

Transformational leadership: Influencing behaviors**.** This style is more powerful in the way it influences the people involved and getting them to commit themselves in achieving their goals. It is proactive and focuses in optimizing individual, group and organizational development. It is value based and it results to greater concern in wellbeing.

The management should be responsible to take the lead in the transformation process, initiate mean of employee empowerment and ensure continuously that the applied approaches are adhered to. The management is responsible to set the framework for all safety-security related means in Industry 4.0[142]. The personal commitment of senior management to OHS often loses impact, as it filters down through the organization to the point where it may not be at all evident on the shop floor. Management commitment is possibly best demonstrated by allocating

[142] Digmayer C., Jakobs E.A., 2018

resources, time and visibility on the shop floor ("walk the talk"), by participating in risk assessments and consultative committee meetings, and by completing actions[143].

7.4 The role of middle managers

Achieving safety objectives closely links middle managers with various and crucial tasks in organizations[144]

1) What are the roles of middle managers in this company?

2) What are the roles of middle managers in safety management?

3) How do middle managers influence safety management?

The contribution of middle managers in the shaping of safety culture in the companies is vital. Middle managers perform multiple roles by the set of different actions. Middle managers control different activities in their sites and therefore they can notice any disruption in their system that can cause incidents. Middle managers can contribute to process safety actively since they can access information on a daily basis and they have more information about process parameters and failures in equipment, so they can more easily notice any deviation from normal conditions.

Concern for employees' safety is expressed and operationalized by supervisory practices. Their actions reflect perceptions on priorities regarding group safety considerations conflicts with production speed, or efficiency and acting safely while performing a job.

Supervisory safety practices work as a link between safety climate and culture. Zohar has proposed that safety climate is formed by the workers' perception of the relative priority of safety versus efficiency goals in supervisory practices. Creating a sustained

[143] Vecchio-Sadus A. M., Griffiths S., 2004
[144] Rezvani Z., Hudson P., 2016

change in supervisory practices becomes a way to put safety climate and culture change into practice[145].

The results from Zohar's survey (see Table 1) indicate that safety climate measures depend on company policies and procedures implementation. The pattern of supervisory, middle managers, safety practices defines the group's safety performance and the in-between-groups variation in a single organization. Subsequently, the effect of overload on personal injury is significantly reduced in subunits with a high safety action supervisor[146].

The role of supervisors is also pointed out in Zohar's and Luria survey and the results from interventions[147]

By combining theories on organizational culture, (safety) climate and complex adaptive systems, it is feasible that cultural change can be created by changing the pattern of interactions between organizational members[148].

The integration of cobots in the industrial environment in the industry 4.0 era, will lead supervisors to operate as decision makers on the smart shop floor, as they will share most of their time collaborating with machine in complex tasks[149]. Humans will assume more leadership and supervisory type of roles, as autonomous systems have not yet entirely replaced human' s logical ability to make decisions. With the support of advanced systems, supervisors will mostly focus on acting as a decision maker for an improved production planning and control.

[145] Zohar, D., 2000a
[146] Zohar, D., 2000a
[147] Zohar, D., Luria, G., 2003
[148] Nielsen K.J., 2014
[149] Bragança S. et al., 2019

7.5 Management empowerment, appreciation and motivation

The aim of employee empowerment is to 'involve' or give employees opportunities to become involved in their work and their employing organization[150].

Subscales for leading by example, coaching, participative decision making and informing showing concern[151].

Employee empowerment promotes feelings of self-worth and belonging and subsequently, promotes safety to a value status[152].

Spreitzer[153] supports that the psychological empowerment consists of four dimensions:

- Meaning: The work I do is very important to me
- Competence: I am confident about my ability to do my job
- Self-determination: I have significant autonomy in determining how I do my job and
- Impact: My impact on what happens in my department is large.

Approaches towards industry 4.0 neglect bottom-up methods that empower employees to participate in decision-making processes related to industry 4.0 risks[154]

The presence of a senior manager, or managers, on the shop floor, or in safety meetings empowers employees. Discussing, or taking the time to congratulate and thank everyone for positive efforts and results is a very important display of appreciation.

[150] Digmayer C., Jakobs E.A., 2018
[151] Yoon Kin Tong D., et al, 2015
[152] Vecchio-Sadus A. M., Griffiths S., 2004
[153] Yoon Kin Tong D., et al, 2015
[154] Digmayer C., Jakobs E.A., 2018

There are appraisal systems and incentives, in order to reinforce and reward positive safety performance results. A way of recognition and reinforcement of an organization's safety culture are awards, ceremonies, safety nominations, celebrated in corporate communications. Advertising the effort increases motivation. Several companies ran competitions for good safety ideas and one even involved employees' families or children[155].

Nevertheless, it is important to remember that the rewards should fall within a reasonable range. Too large rewards might encourage accidents and reporting concealing, whereas ones of minimal value could discourage employees even from participating.

In order to promote the Safety Culture 4.0, it is important that workers are motivated, flexible and open to change so that they can collaborate more effectively[156]. In the new industry 4.0 context, the new manufacturing systems will be self-learning and self-decision making, which might limit the future industrial roles for humans. However, it does not mean that humans will be completely replaced by robots in all parts of manufacturing systems. Instead of a competition to see who is being replaced, the integration of cobots in the industrial environment should be seen as a profitable partnership as the Operator 4.0 will share most of their time collaborating with machine in complex tasks[157]. The importance of this collaboration should always be pointed out as a mean of the necessary psychological empowerment.

[155] Kaluza S. et al, 2012
[156] Bragança S. et al., 2019
[157] Bragança S. et al., 2019

7.6 Employees' commitment and engagement

Job satisfaction is defined as ''a pleasurable or positive emotional state resulting from the appraisal of one's job or job experiences. There is empirical support in the literature for a positive effect of job satisfaction on safety behavior[158].

The exact mechanism how this happens is a controversial issue. It could be through increased safety motivation, concentration on tasks demanding high attention, acquisition of safety knowledge or some combination of them.

Involving employees in exercises regarding quality and increasing their capacity to identify risk in their equipment and workplace turns out to have fruitful results in interpersonal interaction, involvement and awareness. This feeling fosters the willingness to speak up about safety. Moreover, there should be acceptance of personal responsibility for safety.

7.7 Safety Open and Two-Way Communication

In order to implement a Safety Culture and, more specifically a Safety Culture 4.0, a two-way communication is indispensable. Safety communications should always aim to touch both people's hearts and minds. Communication is sharing of ideas[159]. One-to-one conversations should be organized, in order to solicit safety concerns, ideas for improvement.

The communication is two-way, so there is the opportunity for both sides, leader and employee to express both sides' expectations and concerns. Communicative cooperative efforts combine information sharing in top-down approaches, from the

[158] Hadjimanolis A., Boustras G., 2013
[159] Zacharatos A., Barling J., Iverson D.R., 2005

management to the employees and participation in bottom-up approaches, from the employees to the management[160].

Task forces and cross-functional teams should be used and the art of dialogue is vital. Feedback from these conversations, results and suggestions' implementation should come in a timely manner. Safety committee meetings minutes should be demonstrated. Many of these efforts fail because it takes too long to respond or employees see no response to their feedback[161]. These processes help on building strong relationships. Frequent informal safety communications should also be promoted.

Networking and communication among employees, with the support of wireless communication technologies, in the industry 4.0 era, are perceived to be a key factor in achieving employee involvement[162]. Information sharing involvement and cooperation are key factors in establishing a corporate safety culture.

7.8 Training, awareness and competence

Organizations should develop the necessary workforce competencies by investing in their education on a continuous basis[163].

Risk-awareness needs to become an embedded part of the corporate culture – security and safety should be 'lived' by the employees.

In innovation workshops, department representatives share opinions and proposals. These workshops may not lead to total consensus, but what is important is the

[160] Digmayer C., Jakobs E.A., 2018
[161] Carrillo R.A. , 2011
[162] Digmayer C., Jakobs E.A., 2018
[163] Carrillo R.A. , 2011

realization of a safety culture, as a result of shared views and understanding which integrates in the corporate culture[164].

Safety-training programs should target teams and work groups. Such programs can both convey knowledge about safety and strengthen group norms for safety. They need to be relevant to the work-group context.

For example, programs could use group training with ‘‘hands on’’ exercises on safety, simulation and role-playing in work situations and focus on safety responsibilities for safety initiatives around other co-workers[165]. One way to implement positive feedback that enhance an “awareness culture” at work is by making tasks and obligations a game. More and more companies are learning to “game the system”. Organizations could inspire safe and healthy behavior among employees and gain better safety records. Earning points for team-based performance, company-wide “risk-awareness quests” and awards are thus triggering motivation, excitement and fun[166]. By learning and adapting, employees are taking ownership of their work environment.

Leadership development programs should include multiple training methodologies. Available methods are typically classroom-based, away from work. Another way is by employing information derived from various sources, such as leadership and personality scales, 360-degree feedback, and simulations with group observations[167].

Training programs should be designed, to be applicable to employees’ lifestyles both at the workplace and in personal life. To ingrain positive attitudes and behaviors towards safety in the workplace, training programs should be proactive and focus on the employees’ needs.

Training sessions, safety inductions should also be scheduled for the new employees, visitors and contractors.

[164] Digmayer C., Jakobs E.A., 2018
[165] Brondino M., Silva S.A., Pasini M. 2012
[166] Castillo A. P., Meinert S., 2015
[167] Zohar, D., Luria, G., 2003

Another method to improve safety awareness is by promoting internally and externally the implemented improvements. This will lead employees to take and continue active interest in problem solving, define and suitably adjust procedures. The entire workforce should be involved, so that safety is viewed as a value-adding function that contributes directly to the success of the business[168]. Even product quality benefits from the good safety management. The latter was verified in the intervention case study of Zohar and Luria[169]. Quality was improved along with safety management.

Promotion-advertising techniques, marketing tools could be the following:

- A statement that safety is the company's number one priority should be signed by the general manager, to emphasize the top-down priority. Branding a moto, or a logo, in order to draw attention and make the Health and Safety awareness campaign identifiable anywhere in the organization.
- A small library could be set, containing publications, instructional leaflets, legislation, or reports, risk assessments. Procedures, work instructions should be internally available to all, via intranet applications.
- Posters, message displays in special noticeboards, audiovisual demonstration in employees gathering areas can have an effective appeal. Future events, safety results and reporting can be communicated via e-mail, Internet, or social media.
- Organizing special campaigns, such as "Health and Safety Week", or "Month". This can be a promotional event with creative activities focused on health, safety and healthy lifestyle issues. Sometimes families may also participate.
- An incident /accident's root cause analysis can be publicized, in order to demonstrate the reason of the failure. In this way, employees' blame and reporting avoidance is prevented.

[168] Vecchio-Sadus A. M., Griffiths S., 2004
[169] Zohar, D., Luria, G., 2003

- All the above can be advertised in the company's newsletter. Special column on Health & Safety issues or even a dedicated newsletter can be created.

In the Industry 4.0 environment, where different skills and competencies of the workers on the shop floor will be needed, there will be a demand for a different level of personal qualifications[170] that will enable workers to cope with the advanced manufacturing technologies. The operations and tasks of a given productive process will be significantly different from what they have been so far, encompass very complex, interconnected, and automated systems. The future technical skills and qualifications of Industry 4.0 workers are IT knowledge and abilities, Data and information processing and analytics, Statistical knowledge, Organizational and processual understanding, Ability to interact with modern interfaces.

Industry 4.0 training should focus more than ever on promoting organizational knowledge use, which consists of:

· generating new knowledge

· accessing valuable knowledge from outside sources

· using accessible knowledge in decision making

· embedding knowledge in process, products, or services

· representing knowledge in documents etc.

· facilitating knowledge growth

· transferring existing knowledge into other parts of the organization

· measuring knowledge assets.[171]

[170] Bragança S. et al., 2019
[171] Kelloway E.K., Barling J., 2000

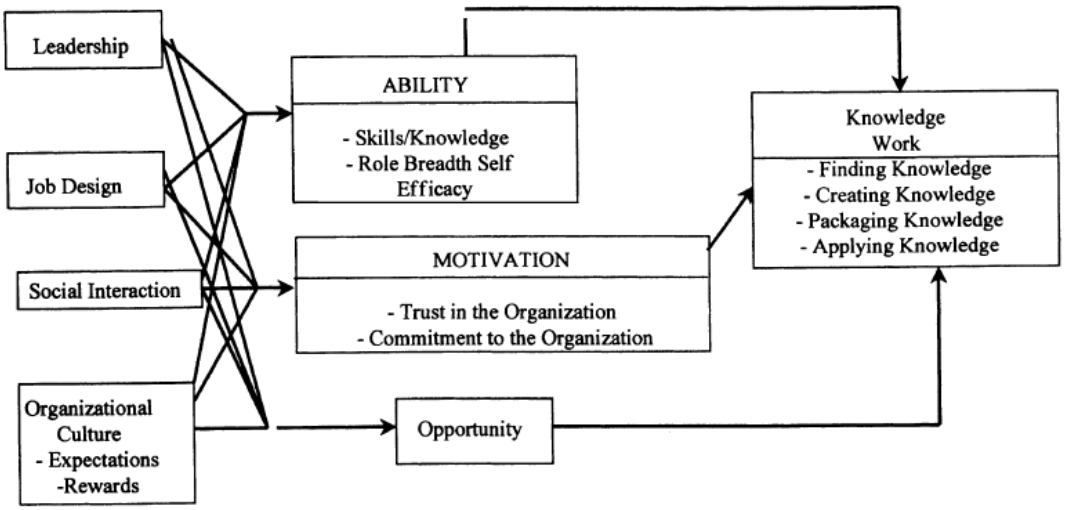


Figure 20 Model of knowledge use in organizations.

In the Safety for the future context, where robots, will be a part of the workforce, tailored training programs should be provided to workers who will be programming, operating, maintaining or sharing the workplace with these robots.

On the other hand, Industry 4.0 technologies can be used in training. Virtual reality factory-based training can be used before actual implementation of new production lines. E-learning modules facilitates training, learning at the worker's pace.

Strategies are required that raise the awareness of employees to changes induced by industry 4.0 and strengthen continuously their qualification as preparation for a changing workplace. In this context, managers are responsible to provide such strategies top down[172].

About 40 % of human resources' departments in international companies now use AI applications and 70 % consider this a high priority for their organization[173].

[172] Digmayer C., Jakobs E.A., 2018
[173] EU-OSHA, 2019a

Digitalization also offers opportunities for more effective OSH training, advanced workplace risk assessment, communication and OSH inspections

In this era of digitalization, organizations should develop interdisciplinary workforce, support requalification, build the awareness to recognize and understand digital opportunities and threats by cultivating a mind-set of digital safety culture. They should retrain current employees, by upgrading their skills for Industry 4.0 requirements and recruit by focusing on capabilities on working with a great variety of tasks. At the same time, reinforcement of aging personnel will be necessary, as the new demands will limit the pool of appropriately skilled workforce[174].

7.9 Trust

Trust and organizational commitment are central ingredients in creating a positive safety culture. An organization may have explicit policy statements related to these qualities and top management may even believe that they are practiced, but these policies and beliefs should basically be considered as valid and applicable by all level employees.

Managers should share information, proving affective commitment and demonstrating how important safety is, so that employees will have greater trust in management. Employees appreciate the reciprocity of those instances when management takes safety seriously and, in turn, show more trust in management.

This trust is gained by communicating the messages, “I respect you,” “You are valued.”[175]

[174] Lorenz M. et al. 2015
[175] Carrillo R.A. , 2011

In addition, trust in management encourages voicing of safety concerns and reporting of incident, creating thus a cooperation and open organizational climate.

Trust has been defined as comprising both a cognitive and an affective component. The cognitive component reflects the belief that management is sufficiently skilled to justify employees' confidence in their actions. The affective component reflects the belief that management will not do anything deliberately to harm employees, vindicating employees' faith in management's intentions. Employees' willingness to use their knowledge for organizational ends is a function of both their trust in the organization and their commitment to the organization[176].

Another aspect of trust is the belief of good plant design, working conditions, engineering systems and housekeeping of the working environment. This should be embedded to the leadership and middle managers, who are responsible for setting the parameters of production. Workers, who are the ones on the shop floors, should also acknowledge the importance of the confidence in these aspects for their safety performance.

Moreover, in the Industry 4.0 era, new technologies in the workplace could be received with a degree of anxiety or skepticism. Workers may have concerns about their safety or job security having to work with collaborative robotic systems and managing those fears can take time. This trust could be achieved by showing workers how a robot can benefit their safety or job quality[177].

[176] Kelloway E.K., Barling J., 2000
[177] Vargas S., 2018

7.10 Employees trust in their co-workers and co-workers interrelations

As it was mentioned above, improving safety performance depends on the leadership' assumption, that there is an ingrained wisdom available in the workforce. In addition, organizations operate relying on rules and procedures, but also on relationships between individuals. This is a concept recognized by the complexity theory[178].

Even though it is the responsibility of the organizations to keep procedures and documentation up to date and organize strategic planning, it is also upon individuals' response and ability to adapt to those changes that might ensure the successful implementation of this planning.

When examining (Annex 1), at group level the association of supervisor's safety climate and co-workers' safety climate, it is indicated that coworker safety climate may reduce the effect of supervisor's safety climate. These findings agree with Chiaburu and Harrison[179] findings that co-worker support was a better predictor than was leader support of many employee outcomes[180].

The relationships between co-workers create an ambience of cooperation and support. As Chiaburu[181] describes in his survey, there were three kind of connections, expressed by the following statements: prototypical statements for positive valence of coworker actions were "helps with a difficult task", or, "helps with getting the job done" and "gives work-related information" by an instrumental supportive coworker", whereas an affectively supportive coworker "cheers up" and "is understanding or sympathetic".

[178] Carrillo R.A. , 2011
[179] Chiaburu D.S., Harrison D.A., 2008
[180] Brondino M., Silva S.A., Pasini M. 2012
[181] Chiaburu D.S., Harrison D.A., 2008

Coworkers could be an important source of commitment, as they offer help to each other and could be mentoring in safety issues. They contribute to role perceptions, positive turnover and performance and can further on influence to a deeper commitment to one's organization

Therefore, working in teams promotes safety because it urges employees to feel more responsible of their own and each other's safety. Teamwork provides coworkers the sense of the common purpose for occupational safety. The opportunity for decentralized decision-making can also enhance safety climate because it provides those people who are more familiar with the situation greater opportunities for control[182].

These teams should be given the opportunity to participate in short safety meetings, weekly, or monthly, where co-workers play an active role in discussing safety issues, initiatives or problems and propose ways to improve safety. People solve problems, adapt, get the work done, sometimes without explicit directions and learn from each experience.

As mentioned before, rewarding and acknowledgement of the successful performance, is an enhancing factor for safety culture, even more particularly where workers work close together in teams[183].

In the Industry 4.o era, cobots can actually reduce worker stress and risks of injury. However, technology can also cause alienation between workers and team development. The use of new technologies can reduce the availability of work for humans[184].

[182] Zacharatos A., Barling J., Iverson D.R., 2005
[183] Brondino M., Silva S.A., Pasini M. 2012
[184] EU-OSHA, 2018b

7.11 Well-being and privacy respect

In order to establish a Safety Culture 4.0, workforce, employees, managers, workers on the shop floor need to be prepared for the effect of digitalization and robotics. These effects on workforce's motivation and wellbeing are not widely known. Psychosocial factors related to robotics will require more attention.[185]

Multidisciplinary teams should be participating in the decisions for utilizing digitalization, ICT and other new technologies. Stakeholders' consultation should be included in the implementation of these new technologies. Amazon has patented a wristband, which tracks warehouse workers' locations and vibrates to 'nudge' them in the direction of their next assignment. It has been reported that many of them feel that their main interaction during any shift is with robots rather than colleagues[186]. Further on, the constant stress, technostress, of being monitored and that movements or performance are constantly monitored and evaluated is dangerous for human mental health.

Monitoring technology for well-being is still a huge challenge. In this case, social sciences, instead of science and engineering, should provide the significant solutions. Monitoring technology for well-being is an aspect for which employees should be well informed.[187]

Moreover, as a potential cyber attack emerges as new risk in the workforce's health, measures on the respect of privacy and security should be taken and communicated clearly and effectively.

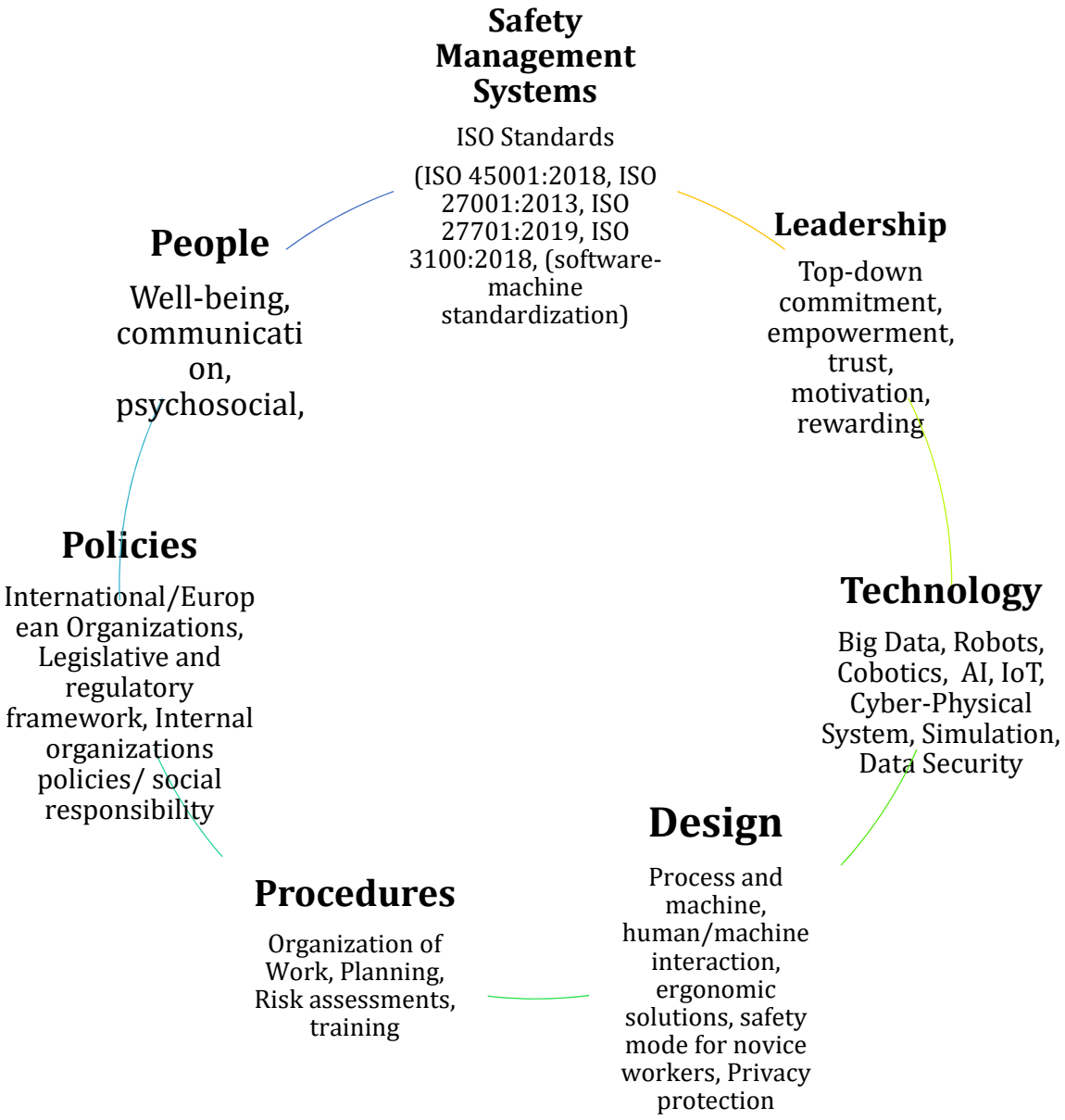
Vigorous increase in the number of devices with Internet connectivity as well as widespread exchange and processing of data over the Internet network entails a growing threat of a potential cyber-attack, which could pose a risk to the health and

[185] EU-OSHA, 2015
[186] ILO 2019
[187] EU-OSHA, 2019b,

safety of workers[188]. A necessary requirement is to ensure access control to systems in order to prevent security breaches.

[188] Polak-Sopinska A. et al., 2020

Safety and Security Culture attributes



8. Conclusion-Thoughts

In the last almost thirty years, scientists, engineers, regulators, safety experts, authors have undertaken the enormous task of identifying the characteristics of Safety Culture and its operationalization in organizations. The notion of safety culture has been analyzed through different scientific aspects, not only connected with business management, but also with anthropological, social, psychosocial and psychological dimensions. Safety culture and its proxy safety climate emanate and are an integral part of the overall organizational culture. Organizations should recognize that beliefs, values, attitudes and behaviors function reciprocally with organization culture and leadership commitment.

Models have been developed, in order to outline the basic components of safety culture and the means by which these are expressed in organizations' operation. Tools have also been designed which help organizations identify, through statistical analysis, quantitative, or qualitative, the validity of factors that contribute to safety culture. Even though, safety experts and scholars have sometimes received safety culture assessments with criticism and doubt, nevertheless, they can provide a diagnosis of the organization's status, compared with a benchmark, or previous results. The assessments results can also give an idea of the effectiveness of safety improvements and interventions implemented in the organizations. Organizations acknowledge that cultural development is a perpetual effort and that the resulting culture from this process cannot be judged as good, or bad, but as open, strong, positive and supportive.

Therefore, cultural development and more specifically, safety culture is an ongoing process, which needs the support of multidisciplinary teams. To proceed from models to practices that ameliorate safety results and ingrain a strong and positive culture, the integrated contribution of all processes is indispensable, top-down and bottom-up.

In the new Industry 4.0 paradigm, where manufacturing amalgamates with digitalization of data and information, there will be a shift to new labor standards, from more manual labor to a more knowledge-based work. New skills and new means of communicating will be required. The use of technological achievements, Artificial Intelligence, the Internet of Things, Big Data analysis, Real-time communication, cloud computing, data and advanced analytics will consequently bring new requirements for safety. Man–machine cooperation remote sensing, monitoring and control, autonomous equipment, autonomous production or assembly and interconnectivity will set a new environment for the workforce, new perceptions of safety and new factors for shaping a Safety Culture 4.0.

In Section 7 of this Master Thesis, the following questions were posed for the understanding of the new Safety Culture 4.0.

- To what extent will these new technologies alter the parameters of the safety culture construct?

The Safety Culture 4.0 construct will include beyond the traditional physical risks, the new risks from the collaboration of humans and machines, concerns for data security, privacy and their effect on the psychological safety of the workforce. Even though, the fourth industrial revolution is an age of advanced technology, it should be focusing on people and developing a psychological safety climate connected with employees' well-being. In this new context, the term of safety is interrelated with that of security.

The amount of effort the companies put into protecting their workers from the known hazards provide a strong indicator of their safety culture and also CSR ethics. In addition, monitoring technology for employees' well-being remains a huge challenge. The contribution of social sciences, along with engineering, is needed to provide

significant and human centered solutions, respecting privacy security and stress monitoring. Therefore, organizations will need to also embed the culture of ethics and morality in their operation of applying advanced technologies.

- Are current safety management systems good enough to cope, or will they need to be adapted?

New revised international standards should be developed to cover the new risks. International Standards, such as ISO, should be focusing on the standardization of not only the machines' functionality, but also the risks from networking, interconnectivity and security, which can influence safety of machinery and have an effect on people. Moreover, with the help of ISO Standards, procedures are implemented in the organizations for the protection of business data, privacy and personal data. It is crucial that employees participate in the consultation process of the standardization. In addition, with the ISO standards implementation in organizations, factors that will be needed for the Safety Culture 4.0, are cultivated.

- Will the safety culture construct need specific tools and methodologies or will validated universal models still be applicable?

The question raised is whether the defined levels or layers of safety culture, such as basic assumptions, values, beliefs, and artifacts will still be valid in the Industry 4.0 era. Basic assumptions on safety, or generally, as the implicit, obvious for the members, invisible, pre-conscious aspects of an organization. The terms of hardware, software, and people/liveware are included in current safety culture models. Hardware, as the physical environment, Software, which might be rules and procedures, legislation, safety management and policy, People, which is the "liveware", all level of employees, workers, supervisors, senior management, safety committees, specialists, authorities, unions and Behavior, which are the attitudes

towards risk taking. The artefacts, which include the outward expression of the safety culture is the equipment, such as personal protective equipment, behaviors etc.

Provided that the machines will not totally replace humans in the workplace, the attributes of safety culture will still be present. Policies and procedures, management and supervision, competence and skills. On the other hand, the tools and models already developed to understand and analyze safety culture will need to adapt, in terms of including the new concepts of Safety Culture 4.0, such as the new digital environment, the addition of security management, the sense of isolation and insecurity by the use of the new technologies. The addition of collaborative machine in the "liveware", as humans' co-workers and their interrelations. The notion of creating routinized and sense-making processes, which shape safety climate, will need time to be established and will probably depend on the progressive implementation of new technologies in the workplace.

To question current models, practices and beliefs and reflect on how they might be perceived in design and operation of Industry 4.0 practices needs not only thorough research, but also time for evaluation.

- What do the smart factories need to do to implement Safety Culture 4.0 in their workforce[189]?

Smart manufacturing and smart factories will have to adapt to the new requirements**.** **Leadership** should take appropriate strategies and policies, taking into consideration the new requirements of Industry 4.0. Safe and smooth change management should take place with the contribution of OSH and HR specialists, in order to reinforce the workforce in copying with an effective transformation.

In the Industry 4.0 era, emphasis should be put on the people that will operate the machines and robots or collaborate with equipment, such as cobots. Rethinking technological design of hardware and software is crucial in this new effort for a

[189] Cooper M.D., 2019

culture of innovation and technological **design**. The design of new intelligent tools should concentrate on not only the physical safety, but also social, mental and cognitive attributes of Safety Culture 4.0. There is the necessity of a multidisciplinary contribution of not only engineers and designers, but also IT, psychologists, ergonomists, social and occupational scientists.

The new work environment, with the increase of digitalization, will create a great variety of tasks in the workplace. The need of advanced and continual **training** on the new technologies, risk and opportunities is indispensable. Training should be focused on the new required upgraded skills and qualifications for the changing workplace. Collaboration and good practices should be exchanged through countries, organizations and companies. Increasing the training efficiency of workers by combining new ICT technologies will be necessary.

Intrinsic **motivation** and fostering employees' creativity will also be necessary to support decentralized decision-making. The importance and value of the human-machine collaboration should be pointed out for the psychological empowerment of the workforce.

Middle managers will operate as decision makers on the shop floor. An open and two-way **communication** should be developed in the organization, in order to foster a strong Safety Culture 4.0. Task forces, teams should be formed. There should be a clear and effective open channel of communication between cross-functional teams, creating a network of information regarding safety.

The new Industry 4.0 environment could be received with anxiety and skepticism from the employees, due the fear of replacement by intelligent machines job loss. The concept of the benefit for quality, production and safety should be embedded in the organizations, so that trust can still be a bonding element. In addition, the value of the human contribution in the shaping of the Safety Culture 4.0 should be acknowledged and elevated.

Finally, in addition to workplace and equipment design, in order to secure and protect employees/workers, social responsibility and cyber security by design and by default

is also necessary. It is non-negotiable that employees' **well-being and privacy** protection should be taken into consideration in the design of processes and machines.

In conclusion, the aim is not to predict the future, but to make all necessary efforts to identify and explore the challenges emerged from a new era, thereby strengthening the effectiveness of today's actions and strategies for creating a Safety Culture 4.0. The ultimate target is to harness the power of technology and build resilient organizations, ensuring at the same time employees' well-being.

9. Annex

9.1 Table 1: Surveys' results summary

Study	N	Design	Industrial sector	Sample description	Measurement method	Level of analysis	Indicators/Measures	Statistical Analysis	Results	Limitations
Nielsen (2014)	169	Pre-experimental (one group pretest–posttest) Multiple subscales from various safety climate scales, document analysis, observations, registration of safety-related interactions, semi structured interviews and a questionnaire	Manufacturing Industrial lifts (n=1) **Denmark**	~275 workers + 5 supervisors, the safety manager, the production manager and the CEO. Workers completed the questionnaire (91.2%). At follow-up workers participated (80.9%). (74.4%) completed the questionnaire both times. male-a mean age of 45.6 years (SD = 10.3), and a mean seniority 11.4 years (SD = 8.9). Nonparticipants at baseline-on average 9.1 years younger (p b .01) and 4.2 years less seniority (p b .05) than participants	Schein's three different layers of culture: **artifacts, espoused values and basic assumptions**. Safety climate was measured using Zohar's (2000) two five item scales covering 'Supervisor expectations' and 'Supervisor actions' (alpha = .88 and .87, respectively).	Organization	**Artifacts** **Behavioral indicators** Unsafe behavior by the workers/Questionnaire ---> Unchanged Management commitment to safety/Questionnaire ---> Higher Statements about safety/Interview ---> Higher **Structural conditions** Safety standard of equipment and machines/Inspection reports ---> Higher Form and number of formal safety meetings/Minutes of Meetings ---> More meetings The composition of the HSC/Minutes of Meetings ---> Improved **Documents** Visible safety information/Direct observation ---> Bulletin Boards Safety signposting/Inspection by health and safety advisor ---> Up to code Inspection reports/Inspection by work environment authorities ---> Up to Code **Safety Climate/Questionnaire** **Espoused values** **Structural conditions** Formal safety policies and objectives/Direct observation ---> Established Accident registration and analysis/ Interviews-observation---> Used for	Paired t-test	Significant improvement on six of the nine safety culture subscales	• No control group • Single organization

							prevention The inclusion of safety on the agenda of meetings/Interviews-observation ---> Safety part of meetings **Attitudes** Attitudes toward safety/ Questionnaire-interviews ---> Higher Shared safety responsibility/Questionnaire-interviews ---> Unchanged Economic priority of safety/ Interviews-observation ---> Higher Use of external health and safety advisors/ Interviews-observation ---> More positive **Basic assumptions Identified by analysis of artifacts and espoused values**			

Nielsen et al. (2015)	105	Quasi-experimental (nonequivalent pretest–posttest control group)	Manufacturing Metal & wood processing (n=4) **Denmark**	Safety representatives, supervisors, safety manager and top management	Modified Danish Safety Culture Questionnaire of 8 validated scales. Semi-structured interviews of 1—1 1/2 h were carried out with two randomly selected groups of workers (the same groups at both baseline and follow-up), the safety representative (s), supervisor(s) and top management represented by the managing director (who was either the sole owner or part of the ownership in all enterprises) at both baseline and follow-up. At follow-up the interviews also	Organization	**Management support ---> Questionnaire/Interviews Worker involvement ---> Questionnaire/Interviews Visible activities and ---> quantitatively by a simple number count and the percentage of activities implemented at follow-up Culture change process (affective commitment, trust, balanced attributions and reciprocity) ---> Questionnaire/Interviews** Worker unsafe behavior low perceived management commitment to safety Relevant safety issues were identified (e.g. unsafe behavior, faulty equipment, bad housekeeping and lack of safeguards) Possible solutions were proposed (e.g. better housekeeping, improved signposting, changes in work procedures and purchasing improved equipment and more suitable types of safety gloves/goggles). Association between perceived management commitment to safety, worker behavior and the occurrence of accidents	t-test, one-way ANOVA	Significant increase in all three safety culture subscales for one of the two intervention groups and significant decrease in two of the three safety culture subscales for one of the two control groups •Int1-the effect evaluation showed an improved safety level, while the process evaluation showed a high management commitment and worker involvement coupled with the implementation of visible activities. It is possible to improve the safety level during a 26 weeks intervention period •Int2-improvements in safety level, while the process evaluation showed shortcomings in key elements of the integrative safety management model (management commitment, trust and reciprocity). Management commitment was not sufficient. Difference in intervention effect. Influence of external factors	•Lack of randomization •Troublesome recruiting phase could give selection bias. • In a Danish context, there is open exchanges between workers and management. This type of intervention may not be successful in more authoritative countries or in enterprises with poor or conflict based relations between workers and management

					dealt with evaluating the project and project activities DeJoy's integrative approach to safety management Zohar's safety climate theory GROW-model (Whitmore, 2009), and safety coaching (Wiegand, 2007)					

Brondino M., Silva S.A., Pasini M. 2012	991	Two-level design (individual level and the work-group level)	Production companies (n=5) **Italy**	Blue collar workers	Multilevel Structural Equation Model (ML-SEM)analysis	Organization Supervisors Co-workers	**Organizational safety climate (OSC)** **Supervisor's safety climate (SSC)** **Co-workers' safety climate (CSC)** The importance of co-workers as a safety climate agent side by side supervisors at group level **Organization -Safety communication-Safety training-Safety systems - Values** **Supervisors- Reaction to workers behaviors- Effort to improve safety - Safety communication - Safety mentoring - Safety systems - Values** **Safety compliance** **Safety participation**		Co-worker support was a better predictor than was supervisor's support of many employee outcomes	Future research could obtain: • Independent measures of each dimension. • Objective measures of behaviors • Larger sample • Larger number of organizations

Milijić et al. 2014	1098 (83,75% response rate)	H1: the type of organization does have an influence on safety climate indicators H2: the position of the employee in the firm does have important influence on safety climate indicators	Production companies (n=9) **Serbia**	Production workers, Workers indirectly related to production, Administrative workers and Managers	Multicriteria Decision Analysis (MCDA). Combination of qualitative and quantitative criteria	Organization	Seven factors: **Safety awareness and competency** **Safety communication** **Organizational environment** **Management support** **Risk judgment and management reaction** **Safety precautions and accident prevention** **Safety training**	PROMETHEE and GAIA methods	Both hypotheses were confirmed on the base of the results of further analyses	

Zwetsloot G. I.J.M et al, 2017	8819 total 2491 manufacturing	Quantitative-Qualitative interviews and national workshops	(n=27) (n=22) (n=7) manufacturing (n=13) EU	Managers (leaders and supervisors) 30% and workers 66%	Quantitative methodology (11 ZAV topics, 72 item survey)- PEROSH ZAV Survey Qualitative methodology - interviews and national workshops	Organizational-Individual	ZAV or safety promotion programs • **ZAV commitment-organizational** • **ZAV commitment-individual** • **ZAV communication-organizational** • **ZAV communication-individual** • **Safety culture for ZAV implementation** • **Management safety priority**, • **Safety empowerment** • **Safety justice** • **Safety climate-group level** • **Safety learning actions (incidents and good-practice)** • **Safety resilience** • top management support and an 'open atmosphere' • systematic communication and dialogue on incidents • a focus on things that go right.	T-test	**Greatest differences in scores seen in regards to safety justice and safety communication – individual** **High commitment to ZAV of their managers and of their workforce** **Qualitative findings on communication** Management safety communication scored relatively high. The scores for communication on the individual level were however, relatively lower. Companies in the manufacturing sector scored higher on both management and individual communication than their peers in construction and in 'other' sectors. There were two companies in which workers gave higher scores for individual communication than their managers. **Safety justice issues** are a particular area that the ZAV companies should continue focusing on in sharing and learning	North-West Europe countries No SMEs

Zohar D., 2002	411		Industrial lifting equipment	Production workers	Safety culture and leadership questionnaires	Workers-groups Leadership	**Group level safety climate** with three factors: **preventive action, reactive action, prioritization** **Leadership** (laissez-faire, Corrective, Constructive, transformational) **Assigned safety priority** (cut corners and work faster, ignore safety rules, disregard safety issues etc.) **Risk Level:** likelihood of injury and relative level of hazards Injuries: date, location, type and treatment **Correlation of categories of leadership with safety climate level/assigned priority/safety priority**	Descriptive Statistics and Intercorrelations. Nested ANOVA	Transformational and contingent-reward leadership were correlated with preventive actions Corrective and laissez-faire leadership are negatively correlated with climate prioritization Transformational and contingent-reward leadership predict injury rate and are mediated by climate preventive action. Management-by-exception active and passive are correlated to preventive action and injury. Transformational leadership was positively related to climate scores under high and low assigned priority Lower safety priority mitigated the effect of constructive leadership on safety climate, whereas the reverse applies for transformational leadership. Increasing Management-by-exception active resulted in higher climate under high assigned priority and lower climate under low priority. Corrective supervisors adjust performance standards according to their assigned priorities, in which safety has no status	Small sample size and restricted between - group variance

Chiaburu D.S., Harrison D.A., 2008	50 studies	Literature review	not defined	Coworkers	Pearson's correlation coefficient r	Coworkers	**Leader's effect** Transformational, Laissez-faire, Contingent reward, Initiating structure, Consideration, Non contingent reward, Contingent punishment, Non contingent punishment, Leader–member exchange **Uniqueness of coworkers** **Co-workers relationships** support, antagonism **Co-workers role perceptions** role ambiguity, role conflict, role overload **Work attitudes** job satisfaction, job involvement, organizational commitment **Withdrawal** effort reduction, absenteeism, intention to quit, reduced turnover **Individual effectiveness** counter productive work behaviors organizational citizenship behaviors: altruism, courtesy, helping) **Organizational effectiveness** counter productive work behaviors (Organizational) organizational citizenship behaviors (Organizational): consciousness, civic virtue, sportsmanship task performance **content support** instrumental, affective **severity of antagonism** low, high **social intensity**	meta-analytic equation modeling	Coworker influences tend to be as large as and in many instances larger than, parallel effect sizes for leader influences Coworker support is associated with reduced levels of the aspects of role perceptions: role ambiguity, role conflict, and role overload Positive connection between coworker support and job satisfaction, job involvement and organizational commitment. Coworker support is associated with more effort, fewer absences from work. Negative connection between coworker support and employee's intention to quit, as well as actual quitting. Coworker support is linked to both kinds of counter productive work behaviors (individual and organizational) and positive contributions of support to organizational citizenship behaviors (individual and organizational) and task performance. Coworker support is a stronger contributor to role ambiguity, role conflict and intent to quit under high versus low social intensity conditions. The predicted pattern was also evidenced for job satisfaction and task performance, respectively, at high versus low levels of social intensity.	No controlled experiments. Third variables could confound some of the relationships

Rundmo T., 2000	N=730 95% response rate		13 plants Europe and in USA and Canada and covered the aluminium, magnesium, agricultural production of fertilizers energy and petrochemical divisions of the company Norsk Hydro.	random sample	Questionnaire	Organization employees rationalistic and emotional approach	**Safety climate** Acceptability of rule violations Priorities of safety versus production Supervisor and friend commitment Management commitment Union representatives commitment **Safety attitudes** Fatalism Belief in accident prevention **Safety status** Employee influence and communication with management Status of personal protection measures Status of safety rules and instructions **Risk perception** Cognitive component Emotional component **Risk behavior**	Cronbach's alpha. SEM analysis	There were possibilities for further improvements of the safety attitudes as well as the safety climate. The attitude related to belief in accident prevention/activity in safety promotion was `non-ideal' for the majority of the respondents. A great percentage also rated management and supervisor commitment and involvement in safety work to be non-ideal and Almost 50% of the respondents did agree in attitudes, which accepted employees violating rules and taking chances in their job. The strongest predictor of behavior was acceptability of rule violations. - Management priority of safety versus production goals and employee fatalism related to safety and accident prevention was the most significant predictor of acceptability of rule violations. Supervisor commitment and involvement in safety work was also strongly correlated with rational judgements of risk.	The method does not fulfil strict experimental conditions necessary for inferring cause. However, during the past few years SEM (Structural Equation Modelling) analysis has gained wide applicability for testing models in the social sciences.

Hadjimanolis A., Boustras G., 2013	N=270	Pilot testing of the questionnaire with 10 respondents	Services and manufacturing industry Cyprus		Combination of Questionnaires	Organization employees	Organizational and safety policies and their effect on safety performance Work attitudes like job satisfaction and organizational commitment relate to safety perceptions (safety climate) Work attitudes affect safety performance The impact of safety climate on safety performance H1 The higher the level of organizational health and safety (OHS) policies and procedures, the higher the organizational commitment of the employee. H2. The higher the level of OHS policies and procedures, the higher the level of job satisfaction. H3. The higher the level of OHS policies and procedures, the more positive the safety climate. H4. The higher the level of OHS policies and procedures, the higher the safety performance of the company		The three main predictors of safety performance in order of importance are safety climate (OHS) policies, programs, and organizational commitment.	The cross-sectional design makes difficult the establishment of relationships between predictors and sequential

Zohar, D., 2000a	534	Safety climate questionnaires Interviews	Metal-processing plant (not specified)	Production workers		Group-level safety climate	Hypothesis I: Safety climate perceptions will predict behavior dependent Injury rates in organizational subunits, after controlling for hazard level. Hypothesis 2: Safety climate perceptions will predict behavior dependent injury of individual group members, after controlling for role overload and job risk, measured as individual-level variables Criticism/penalty for unsafe behavior Praise/reward for safe behavior Delivered safety expectations suggesting emphasis/de-emphasis of safety issues Job risk Role overload Microaccidents	Descriptive Statistics and Intercorrelations Among Variables in the Aggregated and non-aggregated Data one-way analysis of variance	Correlation of perceptions of supervisory action and expectation perceptions perceptions of supervisory action correlated appreciably, although no significantly, with microaccident rate Some supervisors are perceived as significantly more committed to safety than others Hypothesis I: Safety climate perceptions provided significant prediction of subunit injury records over the 5-month period after climate measurement. Subunit risk failed to predict microaccident rate. --> microaccidents included only behavior-dependent injuries, or that unsafe actions play a much larger role than unsafe conditions, confirming that human action is the dominant cause of industrial accidents Hypothesis 2: Significant correlation of role overload and likelihood of injury The effect of overload on personal injury is significantly reduced in subunits with a high safety action supervisor 1. Employees develop homogeneous perceptions concerning supervisory safety practices (i.e., within-group homogeneity)	

									2. these perceptions vary between subunits, resulting in significantly different safety climate scores (i.e., between-groups variance) 3. Climate scores predict subunit safety records in the months following climate measurement	
Digmayer C., Jakobs E.A., 2019a	10	Participatory observation, document analysis and interviews with employees	metalworking company	representatives from the process departments	Qualitative (content analysis)		**Perception of Industry 4.0, Perceived risks of Industry 4.0** **Requirements of a safety culture 4.0.** Current state of safety and safety culture in the company as perceived by employees as well as requirements and barriers of these aspects in Industry 4.0. 1) **Assumptions:** Shared understanding of safety The role model function of the management The self-perception of employees **2) Values/Attitudes** Attitudes towards hardware Attitudes towards software Attitudes towards people Attitudes towards risks **3) Artifacts** Safety measures on machines Digital safety measures Training for safety empowerment			Outcomes

9.2 Table 2: Surveys with interventions results summary

Based on the surveys analyzed above, as well from OSH case studies, the following interventions were implemented, in order to ameliorate safety climate

Study	Interventions	Intervention Type	Results
Nielsen (2014)	Health & safety committee: • monthly meetings • introduce additional members • new task of analyzing accidents Health & safety organization: • Discuss safety performance and produce action plans • Distribute minutes of safety meetings • safety column in in-house magazine • safety on the agenda of other non-safety meetings and part of daily supervisor-worker interactions Safety representatives: • Introduce safety themes Accident analysis and prevention Safety campaigns Weekly safety topics Safety visions and objectives Safety specific bulletin boards Safety information at works council Safety information to all workers from CEO Safety as part of staff meetings Safety part of production meetings Column on safety in staff magazine Focus on supervisors commitment to safety in day to day interactions with workers Safety themes	Safety management system - general (SMS-G): Safety committee • Motivation (M): Importance of safety	Significant improvement on six of the nine safety culture subscales

Nielsen et al. (2015)	• Short workshop with the enterprises' safety organization with focus on the safety organization's performance • Workshop where workers and supervisors discussed safety issues identified at baseline • Short workshop on safety management and leadership followed by a number of individual safety coaching sessions with supervisors (Posing open questions, guiding the supervisor to set realistic goals and activities between each session and encouraging supervisor ownership, commitment and responsibility for the proposed activities)	• Motivation (M): Supervisor commitment • Motivation (M): Workforce participation	Significant increase in all three safety culture subscales for one of the two intervention groups and significant decrease in two of the three safety culture subscales for one of the two control groups •Int1- improved safety level, high management commitment and worker involvement, implementation of visible activities •Int2- improvements in safety level, while the process evaluation showed shortcomings in key elements of the integrative safety management model (management commitment, trust and reciprocity). Management commitment was not sufficient. Difference in intervention effect. Influence of external factors
Zwetsloot G. I.J.M et al, 2017b	**Functional tools:** Safety briefings, newsletters, info screens, videos, safety days and events, monthly safety themes and mobile apps. **Communicating safety matters and empowering workers:** supervisors' active role. Effective supervisor communication. Dialogue based communication practices, such as morning meetings, toolbox talks, safety walks and workshops, feeling of openness and trust within the company. **Supervisors training** in dialogue-based communication and to act as safety facilitators	• Communication • functional Tools	**Safety justice and safety communication – individual** **High commitment to ZAV of their managers and of their workforce** **Qualitative findings on communication** Management safety communication scored relatively high. The scores for communication on the individual level were however, relatively lower. Companies in the manufacturing sector scored higher on both management and individual communication than their peers in construction and in 'other' sectors. There were two companies in

			which workers gave higher scores for individual communication than their managers. **Safety justice issues** are a particular area that the ZAV companies should continue focusing on in sharing and learning
Kines et al. (2013)	Four dialogue meetings between an on-site research team member(s) and the owner/manager and at least two owner/ manager led dialogue meetings with the workers to: • gain commitment from the leader • reflect on their leadership role • prioritize safety • increase safety communication • identify safety problems • establish remediation activities and priorities • initiate tangible safety activities • follow up and evaluate the activities	Safety management system culture/motivation (SMS-C/M): Top management commitment • Motivation (M): Importance of safety	Significant increases on six of the eight factors, whereas comparison groups showed significant increase from baseline to follow-up on only one factor (i.e. safety participation)

Zohar, D., Luria, G., 2003	The analysis resulted in the following five categories: a) informative exchange (general warnings, reminders, information, and explanations) b) Directive exchange (instructions, directives, and priorities) c) Corrective exchange (referring to irregularities, mistakes and deviations from standards) d) Supportive exchange (expression of satisfaction, recognition, and appreciation) and e) Inquisitive exchange (i.e., asking for data, updated information, and subjective assessments from subordinates).	safety practices, procedures safety behavior	Company B: Correlation analyses, testing sequential relationships between supervisory and workers' practices showed that unsafe behavior dropped from an initially low base-rate to a near-zero frequency. Company C: Changes in managerial policy resulted in modified supervisory roles, with supervisors becoming accountable for safety behavior of subordinates Safety and Quality improving at about the same rate
Kaluza S. et al, 2012 OSH Case study 12 Group TVH (Thermote & Vanhalst)	Participative Management • Respect, implying involvement • Involvement, implying communication • Communication, implying listening • Listening, leading to cooperation between employees and management 1. Creation of a learning environment 2. Shared responsibility for Health, Safety, Quality and Environment Topics (HSQE)	Motivation Communication Problem-solving and solution-finding Employees involving	Knowledge of critical and practical points within the work process. The communication was simplified. Close relationship between the HR Manager, HSQE advisor, supervisors, lifting instructors and employees Improved level of wellbeing at work Better problem solving Decrease of number of accidents
Kaluza S. et al, 2012 OSH Case study 7 Kovokon Popovice, s.r.o.	The 4 underlying activities of the program are: 1. Less manual handling and therefore less risk of injuries by introducing a robotized workplace. 2. Enhancing Leadership, Organization, Recognition & Assessment as well as controls by implementing the five step program, aimed at managing health and safety in 5 steps for four main categories. 3. Improving communication within the company and assessing the activities and capabilities of the workforce by	Robotized workplace leadership, Organization, hazard recognition & assessment, control activities Communication People involvement Internal and external processes and performances / benchmark performance	Employee involvement, cooperation with external parties, Certification of core areas of management systems and Internal expertise on risk prevention

	introducing the concept of "Investors In People". 4. Optimizing the organization's performance by implementing the EFQM Excellence model assessment. This is based on key results, customer results, people results and society results. The focus in this program is on leadership driving the strategy that is delivered through people, partnerships, resources, processes, products and services.		
Kaluza S. et al, 2012 OSH Case study 9 Henkel Iberica	**1. Accident prevention management system**: a. Risk assessment and prevention action plan b. Prevention resource personnel c. Training plans in safety and health endorsed by management d. Leadership accountability for SHE issues e. Sustainability Council, dealing with SHE themes f. SHE standards and other commitments **2. Prevention resources personnel** Involving managers, supervisors, area and departmental heads, as well as maintenance and engineering workers. **3. Training** plans in safety and health endorsed by management Classroom and online training **4. Leadership accountability for SHE issues** Team and individual objectives, zero accidents target **5. Establishment of the Sustainability Council**, dealing with SHE themes: Legal Compliance, Corporate Communications, SHE, Purchasing and the various business units, chaired by the Domestic CEO **6. SHE standards and other commitments**: SHE standards, ISO certifications, Code of conduct: the Teamwork and Leadership Code The six primary principles are as follows:	Standards Code of Conduct Leadership Commitment Mutual trust and respect Management's involvement and employee's wellbeing: Leadership style: Sharing the strategic vision Company culture The degree of alignment of these elements	Radical reduction in work accident occurrences

	1. Inspire trust 2. Set targets 3. Assign tasks and delegate decisions 4. Convince and motivate 5. Achieve targets and evaluate performance 6. Lead by example		
Kaluza S. et al, 2012 OSH Case study 8 SPIE Belgium	The changes in the behavioral component contains the following elements **1) Two-way communication**: Alignment of cultures of toolbox meetings, written notes and informal Discussions, good communication by both parties and trust in the certified management system, audits, well-structured system for reporting **2) Employee involvement**: in the decision-making Process, LMRA (Last Minute Risk Analyses) training program for all employees, weekly tours for the observation of safety and prevention **3) Encouraging a learning culture**: the employee looks for reasons and tries to find answers to the following questions: What precisely happened? Why haven't we been aware of the risk? What can we do to avoid a similar issue in the future? Everyone in the company has a VCA certificate (Qualification in accordance with the Safety, Health and Environment Checklist for Contractors) **4) Leadership**: Board, and non-operational managers will also make monthly site safety visits, supervisors motivate their employees to work in a safe manner on a daily basis	Two-way communication Involvement of the employees Learning Culture Leadership	Proactive approach towards work accidents. Lack of accidents Alignment of the safety cultures of the two companies

Kaluza S. et al, 2012 OSH Case study 11 British Sugar	**The New Health and Safety Management Model** Safety Standards Booklet: required leadership qualities, skills and behaviors **Safety Standards Teams**: cross section of employees and are led by senior managers Commitment from the UK Leadership Team (the Board) **Behavioral Audits** **Training** IOSH (Institute for Occupational Safety and Health) "Directing Safely" training, Annual top up of behavior audit training, NEBOSH (National Examination Board in, Occupational Safety and Health) General Certificate qualification. **Reporting Software** Recording of accidents, incidents and near misses in a common format **Steering Group** coordinates safety standards teams, ensures consistency, allocates extra resources as necessary and resolves any problems that arise **Safety Climate Survey** Health and Safety Climate Survey tool safety climate assessment every 2 years for benchmarking **Safety Award Scheme** There is an award specifically for contractors where a prize is a donation to charity for the three winners	Commitment Leadership Safety is a key priority incorporated within the values of the organization Employee involvement	60% fall in injuries and a 75% drop in RIDDOR Near miss reporting has increased by 346%. Recognition from RoSPA (Royal Society for Prevention of Accidents) DuPont Safety Award

10. References

- Aburumman M., Newnam S., Fildes B., 2019, Evaluating the effectiveness of workplace interventions in improving safety culture: A systematic review, Safety Science 115 (2019) 376–392

- Arnold J. A. et al., 2000, The empowering leadership questionnaire: the construction and validation of a new scale for measuring leader behaviors, Journal of Organizational Behavior, J. Organiz. Behav. 21, 249-269 (2000)

- Attwood D. et al., 2006, Safety culture, Chapter 19, Human Factors Methods for Improving Performance in the Process Industries, American Institute of Chemical Engineers

- Aven T, Kristensen V., 2005, Perspectives on risk: review and discussion of the basis for establishing a unified and holistic approach, Reliability Engineering and System Safety 90 (2005) 1–14

- Badri A., Boudreau-Trudelc B., Souissi A.S., 2018, Occupational health and safety in the industry 4.0 era: A cause for major concern?, Safety Science 109 (2018) 403–411

- Berger, P. L., Luckmann, T., 1966, The social construction of reality: A treatise in the sociology of knowledge. Garden City, NY, Anchor Books

- Besnard D., et al., 2017, La culture de sécurité, Comprendre pour agir, Groupe de travail « Culture de sécurité », no1-2017, Institut pour une culture de sécurité industrielle

- Boudreau, F. A., Newman, W. M. 1993, Understanding social life: An introduction to sociology. Minneapolis, MN, West Publishing Company

- Bragança S. et al., 2019, A Brief Overview of the Use of Collaborative Robots in Industry 4.0: Human Role and Safety, Springer Nature Switzerland AG 2019

- Bretschneider-Hagemes M., Korfmacher S., von Rymon Lipinski K., 2018, The Role of Standardization for Occupational Safety and Health (OSH) and the Design of Safe and Healthy Human-Computer Interaction (HCI) Commission for Occupational Health and Safety and Standardization (KAN), Sankt Augustin, Germany, Springer International Publishing AG, part of Springer Nature 2018

- Broadbent D.G., 2004, Maximizing Safety performance via Leadership Behaviours, 28th World Congress of Psychology, Beijing, August 2004

- Brondino M., Silva S.A., Pasini M. 2012, Multilevel approach to organizational and group safety climate and safety performance: Co-workers as the missing link, Safety Science 50 (2012) 1847–1856

- Carrillo R.A. , 2011, Complexity and safety, Journal of Safety Research 42 (2011) 293–300

- Castillo A. P., Meinert S., 2015, Occupational safety and health in 2040: Four scenarios. How will the next generation in Europe deal with occupational safety and health issues? A project of the European Trade Union Institute (ETUI) in cooperation with the Institute for Prospective Analyses (IPA)

- Casey et al 2017, Safety Climate and Culture: Integrating Psychological and Systems Perspectives, Journal of Occupational Health Psychology 2017, Vol. 22, No. 3, 341–353

- Casey T.W, Neal A., Griffin M., 2019, LEAD operational safety: Development and validation of a tool to measure safety control strategies Safety Science 118 (2019) 1–14

- CEFEDOP, 2019, Artificial or Human Intelligence? European Centre of the Development of vocational training, Briefing Note 2019

- DeJoy D.M., 2005, Behavior change versus culture change: Divergent approaches to managing workplace safety, Safety Science 43 (2005) 105–129

- Chiaburu D.S., Harrison D.A., 2008, Do Peers Make the Place? Conceptual Synthesis and Meta-Analysis of Coworker Effects on Perceptions, Attitudes, OCBs and Performance, Journal of Applied Psychology, 2008, Vol. 93, No. 5, 1082–1103

- Christian et al., 2009. Workplace safety: a meta-analysis of the roles of person and situation factors. Journal of Applied Psychology 94, 1103–1127.

- Cooper D., 2001, Improving Safety Culture: A practical Guide, Applied Behavioral Sciences, Hull 2001

- Cooper M.D., 2016, Navigating the Safety Culture Construct: A review of the evidence

- Cooper M.D., 2018, The Safety Culture Construct: Theory and Practice, Safety Cultures, Safety Models Taking Stock and Moving Forward, Springer Open 2018

- Cooper M.D., 2019, The efficacy of industrial safety science constructs for addressing serious injuries & fatalities (SIFs), Safety Science 120 (2019) 164–178

- Choudhry R.M., Fang. D., Mohamed S., 2007, The nature of safety culture: A survey of the state-of-the-art, Safety Science 45 (2007) 993–1012

- Digmayer C., Jakobs E.A., 2018, Employee Empowerment in the Context of domain-specific Risks in Industry 4.0, 2018 IEEE International Professional Communication Conference

- Digmayer C., Jakobs E.A., 2019a, Developing Safety Cultures for Industry 4.0. New Challenges for Professional Communication, 2019 IEEE International Professional Communication Conference (ProComm)

- Digmayer C., Jakobs E.A., 2019b, Let's put the V in smart factory: Empowering employees to shape a safety culture for Industry 4.0, International Conference on Competitive Manufacturing, COMA '19

- EFFRA 2017, Factories of the Future Public-Private Partnership, Progress Monitoring Report for 2017

- EU-OSHA, 2015, A Review on the future of work: Robotics, Discussion Paper

- EU-OSHA, 2018a, Foresight on new and emerging occupational safety and health risks associated with digitalisation by 2025, European Risk Observatory Report, European Agency of Health and Safety at Work

- EU-OSHA, 2018b, OSH and the future of work: Benefits and risks of artificial intelligence in workplaces,

- EU-OSHA - ESENER 3, 2019, Third European Survey of Enterprises on New and Emerging Risks (ESENER 3)

- EU-OSHA, 2019a, Digitalisation and occupational safety and health (OSH) - An EU-OSHA research programme, European Agency of Health and Safety at Work, 2019

- EU-OSHA, 2019b, Monitoring technology: The 21st century's pursuit of well-being, Discussion Paper

- Fleming M., 2001, Safety culture maturity model, Prepared by The Keil Centre for the Health and Safety Executive

- Forest J.J., 2012, How to Evaluate Process Safety Culture, Wiley Online Library

- Fruhen L.S., Griffin M.A., Andrei D.M., 2019, What does safety commitment mean to leaders? A multi-method investigation, Journal of Safety Research 70 (2019) 169–180

- Ghobakhloo M., 2020, Industry 4.0, digitization, and opportunities for sustainability, Journal of Cleaner Production 252 (2020) 119869

- Guldenmund F.W, 2000, The nature of safety culture: a review of theory and research, Safety Science, Volume 34, Issues 1–3, 2000 pages 215-257

- Guldenmund F.W, 2007, The use of questionnaires in safety culture research – an evaluation, Safety Science 45 (2007) 723–743

- Guldenmund F.W, 2010, (Mis) understanding Safety Culture and Its Relationship to Safety Management, Risk Analysis, Vol. 30, No. 10, 2010

- Guldenmund F.W, 2016, Organizational Safety Culture, The Wiley Blackwell Handbook of the Psychology of Occupational Safety and Workplace Health, First Edition. Edited by Sharon Clarke, Tahira M. Probst, Frank Guldenmund, and Jonathan Passmore. 2016 John Wiley & Sons, Ltd. Published 2016 by John Wiley & Sons, Ltd.

- Hale et al., 2010, Evaluating safety management and culture interventions to improve safety: Effective intervention strategies, Safety Science 48 (2010) 1026–1035

- Hadjimanolis A., Boustras G., 2013, Health and safety policies and work attitudes in Cypriot companies, Safety Science 52 (2013) 50–56

- Hofstede, G., Hofstede, G. J. Minkov M., 2010. Cultures and organisations: software of the mind. Intercultural Cooperation and Its Importance for Survival McGraw-Hill, London.

- HSE 2005, A review of safety culture and safety climate literature for the development of the safety culture inspection toolkit, Research Report 367

- Hudson P., 2007, Implementing a safety culture in a major multi-national, Safety Science 45 (2007) 697–722

- International Nuclear Safety Advisory Group, 1991. Safety Culture. 75-INSAG-4, In: Series, S. (Ed.). International Atomic Energy Agency, Vienna.

- IAEA Safety Culture Perception Questionnaire for License Holders Working document, May 2017

- ILO 2019, Safety and Health at the heart of the future work - Building on 100 years of experience, International Labour Organization

- Kaasinen E. et al., 2020, Empowering and engaging industrial workers with Operator 4.0 solutions, Computers & Industrial Engineering 139 (2020) 105678

- Kaluza S. et al., 2012, Leadership and occupational safety and health: An expert analysis, European Agency for Safety and Health at Work, 2012

- Kamble S.S. et al., 2018, Sustainable Industry 4.0 framework: A systematic literature review identifying the current trends and future perspectives, Process Safety and Environmental Protection 117 (2018) 408–425

- Kelloway E.K., Barling J., 2000, Knowledgework as organizational behavior, International Journal of Management Reviews Volume 2 Issue 3 pp. 287–304

- Kines et al., 2011, Nordic Safety Climate Questionnaire (NOSACQ-50): A new tool for diagnosing occupational safety climate, International Journal of Industrial Ergonomics 41 (2011) 634-646

- Laudante E., 2017, Industry 4.0, Innovation and Design. A new approach for ergonomic analysis in manufacturing system, The Design Journal, An International Journal for All Aspects of Design

- Lawrie M., Parker D., Hudson p., 2006, Investigating employee perceptions of a framework of safety culture maturity, Safety Science 44 (2006) 259–276

- Le Coze J. C., 2019, How safety culture can make us think, Safety Science Volume 118, October 2019, Pages 221-229

- Lorenz M. et al. 2015, Man and machine in industry 4.0: How will technology transform the industrial workforce through 2025, Boston Consulting Group 2015

- Milijić et al., 2014, Multicriteria analysis of safety climate measurements at workplaces in production industries in Serbia, International Journal of Industrial Ergonomics 44 (2014) 510-519

- Min J. et al. 2019, The Fourth Industrial Revolution and Its Impact on Occupational Health and Safety, Worker's Compensation and Labor Conditions, Safety and Health at Work 10 (2019) 400-408

- Nielsen K.J., 2014, Improving safety culture through the health and safety organization: A case study, Journal of Safety Research 48 (2014) 7–17

- Payne S. C. et al., 2010, Leading and lagging: Process safety climate incident relationships at one year, Journal of Loss Prevention in the Process Industries 23 (2010) 806-812

- Podgórski D. et al., 2017, Towards a conceptual framework of OSH risk management in smart working environments based on smart PPE, ambient intelligence and the Internet of Things technologies, International Journal of Occupational Safety and Ergonomics, 23:1, 1-20

- Polak-Sopinska A. et al., 2020, Impact of Industry 4.0 on Occupational Health and Safety, In: Karwowski W., Trzcielinski S., Mrugalska B. (eds) Advances in Manufacturing, Production Management and Process Control. AHFE 2019. Advances in Intelligent Systems and Computing, vol 971. Springer, Cham

- PRISM 2005, “Safety Culture Application Guide for the European Process Industries (Warwickshire, UK: European Process Safety Center)

- Reason, J.T., 1997. Managing the Risks of Organizational Accidents. Ashgate, Aldershot, UK.

- Reniers, G.L.L., 2010. Multi-plant Safety and Security Management in the Chemical and Process Industries. Wiley-VCH, Weinheim, Germany.

- Reniers, G.L.L., 2011, Continuously and simultaneously optimizing an organization’s safety and security culture and climate: the Improvement Diamond for Excellence Achievement and Leadership in Safety & Security (IDEAL S&S) model, Journal of Cleaner Production 19 (2011) 1239-1249

- Reniers, G.L.L., 2017, On the future of safety in manufacturing industry, Manufacturing Engineering Society International Conference 2017, MESIC 2017, 2, Procedia Manufacturing 13 (2017) 1292–1296

- Reniers G., Khakzad N. 2017, Revolutionizing Safety and Security in the Chemical and Process Industry: Applying the CHESS concept, Journal of Integrated Security Science, Delft University of Technology

- Rezvani Z., Hudson P., 2016, Breaking the clay layer: The role of middle management in the management of safety, Journal of Loss Prevention in the Process Industries 44 (2016) 241-246

- Rollenhagen C., 2010, Can focus on safety culture become an excuse for not rethinking design of technology? Safety Science 48 (2010) 268–278

- Rundmo T., 2000, Safety climate, attitudes and risk perception in Norsk Hydro, Safety Science 34 (2000) 47-59

- Schein E.H. 2010, Organizational Culture and Leadership, John Wiley & Sons, Inc. 4th Edition

- Slovic P et al., 2004, Risk as Analysis and Risk as Feelings: Some Thoughts about Affect, Reason, Risk, and Rationality, Risk Analysis, Vol. 24, No. 2, 2004

- Smith A. P, Wadsworth, E. J. K, 2009, Safety culture, advice and performance, The associations between safety culture and safety performance, health and wellbeing at an individual level, and safety culture, competent occupational safety and health advice, and safety performance at a corporate level, Report submitted to the IOSH Research Committee, Centre for Occupational and Health Psychology

- Sniderman B., et al. 2018, Fewer sleepless nights, How leadership can build a culture of responsibility in the digital age, Deloitte Review, Issue 22, January 2018

- Snyder H., 2019, Literature review as a research methodology: An overview and guidelines, Journal of Business Research 104 (2019) 333–339

- Stackhouse M. Turner N. 2019, How do organizational practices relate to perceived system safety effectiveness? Perceptions of safety climate and co-worker commitment to safety as workplace safety signals, Journal of Safety Research 70 (2019) 59–69

- Strauch B, 2015, Can we examine safety culture in accident investigations, or should we? Safety Science 77 (2015) 102–111

- Tabor J., 2016, Safety Culture in the manufacturing enterprises, Instytut Ekonometrii i Informatyki

- Ταργουτζίδης Α. 2007, Το φαινόμενο του εργατικού ατυχήματος: Μοντέλα ατυχημάτων, ανθρώπινο λάθος, αντίληψη κινδύνου, Ελληνικό Ινστιτούτο Υγιεινής και Ασφάλειας της Εργασίας, Αθήνα, Νοέμβριος 2007

- Uttal, B. 1983, The corporate culture vultures, Fortune Magazine, 17th October

- Valenduc G., Vendramin P. 2016, Work in the digital economy: sorting the old from the new, European Trade Union Institute, Working Paper 2016.03

- Vargas S., 2018, Robots in the workplace. As new technologies bring robots side by side with human workers, what are the safety implications? Safety and Health, March 2018

- Vecchio-Sadus A. M., Griffiths S., 2004, Marketing strategies for enhancing safety culture, Safety Science 42 (2004) 601–619

- Vierendeels G. et al., 2018, An integrative conceptual framework for safety culture: The Egg Aggregated Model (TEAM) of safety culture, Safety Science 103 (2018) 323–339

- Yousefi et al 2016, Validity Assessment of the Persian Version of the Nordic Safety Climate Questionnaire (NOSACQ-50): A Case Study in a Steel Company, Safety and Health at Work 7 (2016) 326-330

- Yoon Kin Tong D. et al, 2015, Leadership empowerment behaviour on safety officer and safety teamwork in manufacturing industry, Safety Science 72 (2015) 190–198

- Zacharatos A., Barling J., Iverson D.R., 2005, High-Performance Work Systems and Occupational Safety, Journal of Applied Psychology, 2005, Vol. 90, No. 1, 77–93

- Zohar, D., 2000. A group-level model of safety climate: testing the effect of group climate on micro-accidents in manufacturing jobs. Journal of Applied Psychology, 85, 587–596.

- Zohar D., 2010, Thirty years of safety climate research: Reflections and future directions, Accident Analysis and Prevention 42 (2010) 1517–1522

- Zohar D., 2002, The effects of leadership dimensions, safety climate and assigned priorities on minor injuries in work groups, Journal of Organizational Behavior, 23, 75-92 (2002)

- Zohar, D., Luria, G., 2003, The use of supervisory practices as leverage to improve safety behavior: A cross-level intervention model, Journal of Safety Research 34 (2003) 567–577

- Zohar, D., Luria, G., 2005, A multilevel model of safety climate: cross-level relationships between organization and group-level climates. Journal of Applied Psychology 90, 616–628.

- Zohar D., 2010, Thirty years of safety climate research: Reflections and future directions, Accident Analysis and Prevention 42 (2010) 1517–1522

- Zwetsloot G. I.J.M et al, 2013, The case for research into the zero accident vision, Safety Science 58 (2013) 41–48

- Zwetsloot G. I.J.M et al., 2017, The importance of commitment, communication, culture and learning for the implementation of the Zero Accident Vision in 27 companies in Europe, Safety Science 96 (2017) 22–32