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Mestre em Ergonomia na Segurança no Trabalho

# Development of a Fuzzy Qualitative Risk Assessment Model applied to construction industry

Dissertação para obtenção do Grau de Doutor em Engenharia Industrial

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This fuzziness, distasteful though it may be, is the price we have to pay for the ineffectiveness of precise mathematical techniques in dealing with systems comprising a very large number of interacting elements or involving a large number of variables in their decision trees.

Lotfi A. Zadeh, 1969
[Biological application of the theory of fuzzy sets and systems,
in: *Proc. Int. SympBiocybernetics of the Central Nervous System*,
Little Brown & Co., Boston, p. 200]

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All errors and limitations remaining in this thesis are mine alone.

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# Abstract

The construction industry is plagued by occupational risky situations and poor working conditions. Risk Assessment for Occupational Safety (RAOS) is the first and key step to achieve adequate safety levels, particularly to support decision-making in safety programs.

Most construction safety efforts are applied informally under the premise that simply allocating more resources to safety management will improve safety on site. Moreover, there are many traditional methods to address RAOS, but few have been adapted and validated for use in the construction industry, thus producing poor results.

The contribution of this dissertation is a qualitative fuzzy RAOS model, tailored for the construction industry, named QRAM (Qualitative Risk Assessment Model). QRAM is based on four dimensions: Safety Climate Adequacy, (work accidents) Severity Factors, (work accidents) Possibility Factors and Safety Barriers Effectiveness.

The risk assessment is based on real data collected by observation of reality, interviews with workers, foreman and engineers and consultation of site documents (working procedures, reports of work accident investigation, etc.), avoiding the use of data obtained by statistical tecnhiques.

To rating each parameter it was defined qualitative evaluators - linguistic variables - which allow to perform a user-friendly knowledge elicitation.

QRAM was, firstly evaluated by “peer” review, with 12 safety experts from Brazil (2), Bulgaria (1), Greece (3), Turkey (3) and Portugal (3), and then, evaluated by comparing QRAM with other RAOS tecnhiques and methods.

The safety experts , concluded that: a) QRAM is a versatile tool for occupational safety risk assessment on construction sites; b) the specific checklists for knowledge elicitation are a good decision aid and, c) the use of linguistic variables is a better way to make the risk assessments process more objective and reliable.

**Keywords:** Risk assessment, construction industry, occupational safety, fuzzy sets.

# Resumo


A indústria da construção, devido às más condições de trabalho, regista maiores índices de sinistralidade laboral que os restantes sectores de actividade. A Avaliação de Riscos para a Segurança Ocupacional (ARSO) é o primeiro e fundamental passo para alcançar níveis de segurança adequados, especialmente para definir programas de segurança.

A maioria das medidas de segurança implementadas nos estaleiros de construção são determinadas de forma informal sob a premissa de que, simplesmente, afectar mais recursos vai melhorar a segurança ocupacional.

Embora existam vários métodos de ARSO, poucos foram adaptados e validados para uso na indústria da construção, pelo que raramente os resultados são adequados.

A contribuição do trabalho apresentado nesta dissertação é um modelo qualitativo difuso de ARSO para a indústria da construção, denominado QRAM.

O QRAM é baseado em quatro dimensões: clima de segurança adequado, fatores de gravidade (expectável em consequência de acidentes de trabalho), factores de possibilidade (de ocorrência de acidentes de trabalho) e, eficácia das medidas de segurança.

A avaliação dos riscos é baseada em dados reais recolhidos por observação directa da realidade, entrevistas com trabalhadores, encarregados e engenheiros e consulta de documentos do estaleiro (procedimentos de trabalho, relatórios de investigação de acidentes, etc.).

A classificação dos factores de risco é efectuada por variáveis linguísticas, o que facilita a obtenção do conhecimento empírico.

O QRAM foi avalidado por um grupo de 12 especialistas em segurança laboral do Brasil (2), Bulgária (1). Grécia (3), Turquia (3) e Portugal (3). Foi igualmente avaliado por comparação com outros métodos e técnicas de avaliação de riscos.

De acordo com a opinião dos especialistas, o QRAM provou ser uma boa ferramenta de ARSO em estaleiros de construção. As listas de verificação e as variáveis linguísticas permitem a recolha de informação de uma forma fácil e sistemática.



**Palavras chave:** Avaliação do risco, indústria da construção, segurança ocupacional, conjuntos difusos.

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# 1. Introduction

Safety is an essential feature to be taken into account in the construction industry, and a robust Risk Assessment for Occupational Safety (RAOS) is the key to achieve it, particularly to support decision-making in safety programs (Ringdahl, 2001).

In general, risk assessment is a complex process that entails the consideration of many qualitative or subjective parameters and, particularly in the construction industry. Due the specific nature of the sector, it must deal with ill-defined and imprecise data and information (Dedobbeleer and Beland, 1991; Ringen and Seegal, 1995; Gillen et al., 1997; Laitinen et al., 1999; Loosemore and Lee, 2001 and Tam et al., 2004). So far, traditional approaches do not seem to provide adequate answers to deal with these issues (Ringen et al., 1995). Moreover, using probability (classical or Bayesian) may mask other aspects of incomplete and imprecise knowledge, thus leading to a false sense of accuracy and precision and consequently to inadequate and/or inefficient decisions.

Furthermore, as pointed by some authors (Karwowski and Mital, 1986; Cornell, 1996; Wang and Ruxton, 1997; Pender, 2001; Sii et al., 2001; Tixier et al., 2002; Faber and Stewart, 2003 and Nilsen and Aven, 2003), most of the traditional RAOS methods present some limitations, such as:

- Inherent imprecision in human-centred systems;
- Difficult to generate mathematical models due to intrinsic uncertainty in this type of problems. For instance, it is difficult to represent and describe unsafe behaviours, caused by human errors;
- Difficult to quantify the effects and consequences of many hazards because they involve several factors with a high level of uncertainty, even when the physical processes are clearly understood;
- Large number of assumptions, judgments and opinions are involved in a risk quantification process, hence, it requires considerable skills from a safety analyst to interpret the results;
- Construction projects are unique by definition. This reduces the relevance and reliability of statistical aggregates derived from probability-based analysis;
- Humans are limited in their ability to encompass and process the full range of information required for holistic decisions;
- Uncertainty and ignorance may be found in many temporal aspects of the flow of knowledge, which are important in construction planning;
- Construction safety parameters and possible outcomes (of unsafety ones) must be communicated to workers and the imprecision of our language does not express these very well.

Considering all the above statements, it is apparent that RAOS in the construction industry is rampant with inadequate data and/or imprecise, ill-defined, and incomplete information, particularly at the design stage, for which traditional quantitative approaches do not give adequate answers. To overcome some of the mentioned problems in assessing occupational safety risks, this work propose a qualitative model for risk assessment, hereafter denoted QRAM (Qualitative Risk Assessment Model), which is based on elicited data and uses a Fuzzy Set Theory (FST) approach, which was proposed by Zadeh (1965). FST provides a natural way of modeling the intrinsic vagueness and imprecision of subjective assessments, while also allows the inclusion of human creativity and intuition, which is an essential ingredient for successful risk analysis (Ru and Eloff, 1996). The final goal of this work is to contribute to work safely by improving risk assessment in construction sites.

The main contributions to innovation reached by this work will be presented in the next section.

## 1.1. Contribution to innovation

The majority of quantitative traditional methods use probabilistic and/or statistic techniques to deal with the intrinsic uncertainty and imprecision of the data and information required. This entails some difficult tasks, such as requiring analysts to estimate parameters, to ensure a sufficiently representative domain or make comparisons with other sites (which in the construction industry is rather difficult due to the uniqueness of each site).

Recently, there are some qualitative approaches using fuzzy sets, proposed in the literature (see for example: Azadeh et al., 2008; Gurcanli and Mungen, 2009), but they having lack a systematic survey of all parameters included in the major four dimensions that should be taken into consideration when performing a RAOS on construction sites, namely: safety climate adequacy, severity factors (expected severity of work accidents consequences), possibility factors (possibility of work accident´s occurrence) and safety barriers effectiveness. Besides, the way to eliciting the required information is a quite subjective, the use of check-lists contributes to produce more objective results.

The inclusion of this four dimensions and respective parameters, plus the fuzzy approach used, are the main ingredients of the proposed QRAM model. In general, the main contributions of the proposed QRAM are:

- to provide a framework for assess and rating factors that need to be evaluated in construction sites RAOS;
- to propose a model for expressing the relationships between the parameters (risk factors), considering the four dimensions: safety climate adequacy, safety barriers effectiveness, severity factors and possibility factors which, in construction industry, are never considered together,
- to use a simple semantic scale and aggregation operators that facilitate the elicitation of information about the parameters to obtain the occupational safety risk levels.

The final aim of QRAM is to obtain the estimate of occupational risk level for the construction sites, by accident mode, as well as to obtain partial classifications for each dimension and rating the factors, included in the risks estimate.

QRAM will focus on elicited data, thus avoiding coarse estimates, to allow the assessment of actual risks on construction sites. The data and information will be obtained by direct observation, interviews with workers and foremen and also from consultation and review of relevant site documentation (health and safety plan, reporting accidents and incidents, records of safety training and meetings, work procedures...), among others. After this elicitation process, QRAM transforms and aggregates the collected data, using fuzzy concepts and techniques to rating the risk levels, by accident modes.

The core of the aforementioned contributions was published in the following journal articles and book chapters. Parts of the thesis were presented in various seminars and conferences both Portuguese and international.

International journals

- Pinto, Abel; Ribeiro, Rita A. and Nunes, Isabel L. (in press) Ensuring the Quality of Occupational Safety Risk Assessment, in edition on *Risk Analysis an International Journal* (ISI - Impact Factor: 2.366).
- Pinto, Abel; Nunes, Isabel L; Ribeiro, Rita A. and Paschoarelli, Luis Carlos (in press) Aplicação preliminar do método QRAM para avaliação de riscos para a segurança ocupacional na construção civil, in Revista Produção, ISSN 0103-6513 (http://dx.doi.org/10.1590/S0103-65132012005000039) (Scopus).
- Pinto, Abel; Ribeiro, Rita A. and Nunes, Isabel L. (2012) Fuzzy approach for reducing subjectivity in estimating occupational accident severity, in *Accident Analysis & Prevention*, Vol. 45, (March), pg. 281-290, ISSN 0001-4575, (DOI: 10.1016/j.aap.2011.07.015) (*ISI* 5-Year Impact Factor: 2.367*; Q1*).
- Pinto, Abel; Nunes, Isabel L. and Ribeiro, Rita A. (2011) Occupational risk assessment in construction industry – Overview and reflection, in *Safety Science*, Vol. 49, No 5, pg. 616-624 (DOI 10.1016/j.ssci.2011.01.003) (*ISI* 5-Year Impact Factor: 1.578*; Q1*).

International conferences

- Pinto, Abel; Nunes, Isabel L. and Ribeiro, Rita A. (2012) Qualitative Occupational Risk Assessment Model: A Fuzzy Approach, in abstracts of the *World Congress on Risk 2012 – Risk and Development in a Changing World*, 17-20 Jul, Sydney-Australia, pg 63-64.

- Pinto, Abel; Ribeiro, Rita A. and Nunes, Isabel L. (2012) Qualitative Occupational Risk Assessment model – an overview, in *Proceedings of International Symposium on Occupational Safety and Hygiene* (SHO12), Feb 9-10, Arezes, P., Baptista, J.S., Barroso, M.P., Carneiro, P., Cordeiro, P., Costa, N., Melo, R., Miguel, A.S., Perestrelo, G.P. (Eds), Publisher SPOSHO, Guimarães (ISBN 978-972-99504-9-0), pg. 460-465.

- Pinto, Abel; Nunes, Isabel L. and Ribeiro, Rita A. (2010) Qualitative Model for Risk Assessment in Construction Industry: A Fuzzy Logic Approach, in *Emerging Trends in Technological Innovation* (First IFIP WG 5.5/SOCOLNET Doctoral Conference on Computing, Electrical and Industrial Systems, DoCEIS 2010), L. M. Camarinha-Matos, P. Pereira, L. Ribeiro (ed.s), 22-24 Feb, Costa de Caparica-Portugal, Springer, ISSN 1868-4238, pg. 105-111 (*ISI Conference Proceedings*) WoS ID 000277119500011.

- Pinto, Abel; Nunes, Isabel L. and Ribeiro, Rita A. (2009) Framework for Ensuring Risk Assessment Completeness in Construction Industry, in *17th World Congress on Ergonomics*, 9-14 Aug, Beijing-Rep Pop. China, CdRom.

Portuguese journals and conferences

- Pinto, Abel; Nunes, Isabel L. and Ribeiro, Rita A. (2011) Método de Avaliação de Riscos para a Segurança Ocupacional na Indústria da Construção, in *Revista Territorium*, 18, pg 55-72, ISBN 0872-8941.

- Pinto, Abel; Nunes, Isabel L. and Ribeiro, Rita A. (2010) Integração de novos Parâmetros na Avaliação de Riscos para a Segurança Ocupacional na Indústria da Construção, II Congresso Internacional e VI Encontro Nacional de Riscos, Universidade de Coimbra, 22 a 25 de Maio de 2010.

- Pinto, Abel; Ribeiro, Rita A. and Nunes, Isabel L. (2010) Parâmetros Comportamentais a Incorporar na Análise e Avaliação de Riscos na Indústria da Construção, in *Revista de Segurança Comportamental*, (ISBN 9771647597000), Ano 1, Nº 1, pg 4-6.

- Pinto, Abel; Ribeiro, Rita A. and Nunes, Isabel L. (2009) Parâmetros qualitativos para a Avaliação dos Riscos na Indústria da Construção, in*Riscos Industriais e Emergentes (III Encontro Nacional de Riscos, Segurança e Fiabilidade)*, C. Guedes Soares, C. Jacinto, A.P. Teixeira, P. Antão (Eds), Edições Salamandra, Lisboa (ISBN 9789726892335), Vol. 2, pg. 845-860.

The main motivations to develop this work will be presented in the next section.

## 1.2. Motivation for develop a new risk assessment for occupational safety model to construction industry

RAOS is a complex process that entails the consideration of many parameters, which are, more often than not, difficult to quantify.

The vagueness of some related concepts, the lack of detailed data on occupational accidents rates and accurate causes, the imprecision in available safety data and the uncertainties in occupational accidents severity may lead to a large uncertainty in results, that could biased RAOS results by underestimated or overestimated the occupational safety risk levels. It should be noted that the quality of those analyses is extremely important for major hazard industries, such as construction industry.

Limitations of RAOS methods, which are pointed and discussed on section 3.2, make clear the need of a new RAOS method, which must use the available information, which is insufficient, imperfect, difuse and notoriously difficult to collect, towards a better RAOS results quality.

My experience of 15 as safety expert gives me the perception and the knowledge that the existing methods based on probabilistic and statistic don't produce good results when applied to construction industry. In fact, RAOS results always produce discussion or unconcern. I want to try to change this plight trying new ways and I heard about fuzzy sets theory. I started to study it and seem a good way to try.

So, my base question to research was: It is possible to produce a more realible RAOS method to construction industry, using fuzzy sets theory to deal with incomplete and imprecise information?

The new method must be able to use insufficient, imprecise and inaccurate information as inputs in RAOS process (such as linguistic terms) and, it is of paramount importance to assess risk factors related to safety climate and safety barriers which, usually, are not take into account on the RAOS process in the construction industry. Also, as pointed and discussed on section 5.4, the calculation of an absolute value to rank safety risks is unnecessary when RAOS aim is to decide about risks acceptability and select risk-reduction barriers.

So, the general features of the new method should be: a) use of imperfect and difuse information to overcome the lack of detailed one, in order to obtain a more accurate safety risk results, b) assess risk factors related to the possibility of work accidents occurrence, c) assess risk factors related to the expected severity of work accidents, d) assess risk factors related to the safety barriers effectiveness, e) assess risk factors related to safety climate on the construction site and, f) present the results in a way that do not distract safety practitioners from the main aim of the RAOS process, that is: to decide about occupational risk acceptability and guiding the design of adequate barriers for risk reduction and control.

The main objectives of this work will be pointed in the next section.

## 1.3. Objectives

The work presented in this thesis aims to develop and evaluate a model for assessing the risk of occupational accidents, on construction sites, using a fuzzy approach, which can subsequently be implemented in an expert system.

The target of the QRAM (Qualitative Risk Assessment Model) is the construction industry, and within this domain it is applicable to a wide range of organizations and/or enterprises in the sector, regardless of size, complexity, construction type and construction processes used.

QRAM aids to identify, evaluate and rating the main risk factors regarding safety climate adequacy, barriers effectiveness, possibility of occupational accidents occurance and expected severity of occupational accidents. QRAM results provide the necessary information to support safety expert's decisions about preventive measures or more protections to be adopted to improve work safety on construction sites.

This work covers two specific objectives:

a) Model development;

QRAM will be developed based on legislation, standards and the best available knowledge, whether in the literature or from experts; using fuzzy logic for data representation and processing, to ratingthe occupational safety risks and highlight the "bad" factors (i.e the ones that most contribute to high risk levels) in order to support decisions about the necessary barriers to prevent and/or protect the workers.

b) Model evaluation

QRAM evaluation was carried out by real test and elicitation of occupational safety experts' opinions.

The methodology that was followed in this work will be described in the next section.

## 1.4. Thesis methodology

This study started with literature review by searching in several data bases, namely: the B.on, the Sirius, the NIOSHTIC and the CIS-IL0. Data bases were searched during the period 2008 to 2011. The search included the key descriptors: safety risk assessment; risk assessment on construction; risk assessment quality; risk assessment reliability; work accidents severity; work accidents possibility; safety barriers, safety measures; safety culture; safety climate; risk tolerance; risk acceptance;

management/supervisory/safety; worker attitudes and safety monitoring. It was focused on studies that emphasized the relationship between factors that may influence occupational safety risks and safety performance.

Regarding to elicitate empirical knowledge from safety experts, interviews were carried out with a purposive sample of 16 Portuguese safety experts The aim was to understand the experts strategies for decision making during the RAOS process and to understand the way they used to rating the risk factors (which depends on they experiences and perceptions). The free interviews lasted between 30 and 90 min,

To evaluate the model, QRAM has been tested at 12 sites in 5 different countries: Brezil (2), Bulgaria (1), Greece (3), Portugal (3), and Turkey (3). On each site, the safety experts were asked about QRAM capability and accuracy to assess the occupational safety risks on construction sites.

The evalution was carried out on construction sites and began with a meeting with the safety expert that was responsible for the safety in the site. During the meting, the safety expert was briefed with the objectives of the research and the explanation of the QRAM features and the methodology to apply it. After, the safety expert performed the RAOS using the QRAM and, in the end, the results were analised and discussed (between me and the safety expert) and the questionnaire depicted in the annex II.1 was filled.

This thesis organization will be presented in the next section.

## 1.5. Thesis organization

This dissertation, in addition to this introductory chapter, has 6 more chapters.

Chapter 2 presents the background on hazards in the construction industry, discussing the main causes of the poor safety performance and its costs.

The following, chapter 3 presents an overview on risk assessment occupational methods both in general and on construction industry and explore its limitaions pointed out by some authors. Discuss the importance of RAOS quality and give some criteria to evaluate it. Ends describing the two RAOS tools more used in Portugal on construction sites.

Chapter 4, introduce the main concepts and techniques of Fuzzy Set Theory (FST) used in this work, pointed out the main advantages of using FST on RAOS and presents, briefly, some related works.

The foremost chapters are the chapter 5 and chapter 6, which, respectively, describe the various stages of development of the system model and present the four QRAM dimensions and present the results of applying the model to real work situations to evaluate it.

The chapter 7 presents the conclusions and pointed some suggestions for future work.

This dissertation ends with the compilation of the references used and 34 annexes, related to chapters 5 (annex I) and 6 (annex II)

Annexes I.1 to I.10 contains the questions to safety climate assess, annex I.11 contains the questions to assess possibility factors affecting falls accident mode, annex I.12 contains the questions to assess possibility factors affecting contact with electricity accident mode, annex I.13 contains the questions to assess possibility factors affecting struck by moving vehicle accident mode, annex I.14 contains the questions to assess possibility factors affecting injured by falling/swinging objects accident mode, annex I.15 contains the questions to assess possibility factors affecting cave-ins accident mode, annex I.16 contains the questions to assess possibility factors affecting hit by rolling/sliding/flying object (including awkward or sudden movement) accident mode, annex I.17 contains the questions to assess possibility factors affecting contact with machinery/equipment moving parts (including trapped between objects) accident mode, annex I.18 contains the questions to assess possibility factors affecting lost buoyancy in water due to the activity accident mode and annex I.19 contains the questions to assess possibility factors affecting fire or explosion (including confined spaces) accident mode

Annex II.1 is the questionnaire used to elicitate expert opinions, annex II.2 shows the results from case 1 safety climate assess, annexII .3 shows the results from case 1 falls work accidents possibility assess, annex II.4 shows the results from case 1 contact with electricity work accidents possibility assess, annex II.5 shows the results from case 1 injured by falling/swinging objects work accidents possibility assess, annex II.6 shows the results from case 1 hit by rolling/sliding/flying object (including awkward or sudden movement) work accidents possibility assess, annex II.7 shows the results from case 1 contact with machinery/equipment moving parts (including trapped between objects) work accidents possibility assess, annex II.8 shows the results from case 1 fire or explosion work accidents possibility assess, annex II.9 shows the results from case 2 safety climate assess, annex II.10 shows the results from case 2 falls work accidents possibility assess, annex II.11 shows the results from case 2 contact with electricity work accidents possibility assess, annex II.12 shows the results from case 2 struck by moving vehicle work accidents possibility assess, annex II.13 shows the results from case 2 injured by falling/swinging objects work accidents possibility assess, annex II.14 shows the results from case 2 cave-ins work accidents possibility assess, annex II.15 shows the results from case 2 hit by rolling/sliding/flying object (including awkward or sudden movement) work accidents possibility assess and annex II.16 shows the results from case 2 contact with machinery/equipment moving parts (including trapped between objects) work accidents possibility assess

# 2. Background on hazards in the construction industry

Construction industry is a very hazardous industry in which fatal and non-fatal occupational injuries occurs frequently (Ringen and Seegal, 1995; Hyoung et al., 2009) due to its unique nature (Tam et al., 2004). It is characterized by continual changes to the environment, use of many different resources, poor working conditions, no steady employment, tough environment (e.g. noise, vibration, dust, handling of cargo and direct exposure to weather agents) and so forth. Furthermore, many times it requires coordination of different interdependent contractors, sub-contractors and operations that may result in increased risk of injury.

Construction occupational accidents arise from a failure in the interaction between the work team, workplace, equipment and materials. These immediate accident factors are affected by shaping factors, whereby the actions, behavior, capabilities and communication of the work team which are affected by their attitudes, motivations, knowledge, skills, supervision, health and fatigue, work scheduling and housekeeping. Insufficient working experience, by temporary workers and new employees, and employment in a company with less than 10 employees are also associated with a more possibility to undergo an occupational accident (Cheng et al, 2010).

It should be noted that task's safety is determined long before the people, procedures, and equipment come together at the work site. The features of the permanent facility can affect (both positively and negatively) the construction workers' safety. For example, when roof perimeters do not contain permanently designed-in fall protection features (e.g. guardrails or anchorage points), workers' safety could be compromised.

Concerning the exposure by building trades, a study made by Baradan et al. (2006) indicated that ironworkers and roofers rank the highest risk in terms of both nonfatal and fatal injuries. Electricians, brick masons, stonemasons and block masons, painters and paperhangers, carpenters, and insulation workers were exposed to high risks, while plasterers and stucco masons, glaziers, tile setters and marble setters, cement masons, and concrete finishers showed the lowest risk levels. Intermediate risk levels were found for drywall installers, construction equipment workers, and carpet, floor, and tile installers.

Occupational injuries and illnesses impacts not only on safety and health, but also on economics, due to the high costs related with work injuries. Hinze et al. (2006) stated that construction safety has gained attention because of the increasing workers' compensation insurance premiums that resulted from a great increase in work injuries medical costs and convalescent care. In fact, studies across industries suggest that injury rates and costs are higher than average in the construction industry (Dong et al., 2007). According to Silverstein et al. (1998), using workers' compensation data from Washington State (USA), the estimated workers' compensation costs for medical treatment and indemnity in construction is four times higher than in other industries.

The causes influencing safety in construction will be discussed in more detail in the next section.

## 2.1. Main causes of poor safety performance

Design professionals (i.e. architects and project engineers) are in decision-making position to impelling to improve construction safety by addressing safety issues during the design process. By construction design, hazards can be eliminated or reduced during construction stage, thus improving safety. However, these professionals continue to discard this intervention as part of their standard practice and, in Portugal, there is no motivating forces, such as: legal, contractual, economic (by increase insurance) or regulatory, which would induce these professionals to adopt safety as their concern and standard practices (Behm, 2005).

Many authors have been addressing the main causes/factors for poor safety performance (Dedobbeleer and Beland, 1991; Ringen and Seegal, 1995; Gillen et al., 1997; Laitinen et al., 1999; Liebing, 2001; Loosemore and Lee, 2001; Tam et al., 2004; Cheng et al., 2010; Sertyesilisik et al., 2010 and Tam and Fung, 2011). Summarizing those works, the most relevant causes for low safety performance in the construction industry are:

- Poor work and safety organization - safety should begin on the planning and definition of detailed procedures to be effectively implemented in the field. Therefore, safety professionals need to be involved during a project's procurement and pre-construction phases;
- Company size – most construction companies are small enterprises, hence it is difficult to ensure internal know-how about safety maters and they also have limited budgets for health and safety measures implementation;
- Lack of coordination - construction industry is an aggregate of many specialized groups working together in the same space. Construction projects typically involve multiple employers and a variety of trades (e.g. roofers, carpenters, electricians, plumbers, painters, etc.), which carry on a diversity of tasks on project sites;
- Economic and time pressure – which may result in relaxing rules and procedures, e.g. reckless operations to ensure finishing on time;
- Lack of data standardization - resulting in lack of information about hazards, risks, accidents causes and so forth;
- Poor communications both internal and external - for example, in many countries a high proportion of the workforce does not speak the native (site location) language, hence it is difficult for safety managers to communicate the potential hazards that may occur;
- Poor involvement of workers in safety matters - workers' involvement should include participation in the development of safety programs and identification of best solutions;
- Constantly changing worksite has marked effects on safety and health - unlike other industrial sites, where tasks are often repetitive and controlled through the workplaces safety design, the construction site allows, and requires, extensive movement of workers from place to place;
- Workers´ specialization- often workers are trained in a single, narrowly specialized construction application, hence they are not familiarized with other materials and equipment's that exist in the workplace;
- Workers responsibilities – comparing with others industries workers are much more responsible for their own protection and organization of their workplace, because site environment changes daily;
- Inadequate training and fatigue of practitioners – this can be particularly serious in the case of operators of heavy machinery because it can affect pedestrian and neighbours (cranes operators, for example);

- Bad equipment selection, use or inspection - selection of appropriate equipment, its correct use and periodic inspection are important factors to ensure efficiency, productivity and safety standards on site;
- Poor safety awareness by top management and project managers – many times there is lack of supervision and regular meetings about safety procedures, either because management is not committed to safety maters or because they are not knowledgeable about these issues;
- Lack of prevention/protection equipment's - due to either small budgets for health and safety measures implementation and lack of safety culture;
- Construction jobs can be far apart - construction workers may have to travel very long distances to find work, uprooting families and increasing the adoption of risk behaviours: alcohol, drugs, prostitutes;
- Construction workers face long-term health risks from the stress of on-and off-again employment and the fear of not having a periodic pay check - due to precarious contracts and sometimes lack of seriousness of some employers.

The lack of management commitment, communication, workers' involvement, attitudes, competence, as well as supportive and supervisory environments, has been pointed out by several authors, as a drawback to achieve a positive safety climate (Rundmo, 2000; Varonen and Mattila, 2000; Glendon and Litherland, 2001; Mohamed, 2002; Haslam et al., 2005; Zohar and Luria, 2005; Meliá et al., 2008; Kouabenan, 2009 and Mohamed and Tam, 2009). To ensure an adequate safety climate, within any organization, is another key aspect to prevent accidents and illnesses. So, the path to improve health and safety on construction sites should include the following influences: a) company culture, b) health and safety management, c) health and safety culture, d) management/supervision e) competence, f) situational awareness, g) communication/participation, h) advice and information and i) design for safe construction.

Haslam et al. (2005) and Brace et al. (2009) highlighted that should be pay more attention to the underlying causal factors in order to sustain improvement in health and safety (H&S). This need is reinforced by the fact that the underlying accident factors emerge from the preconstruction stage of project procurement where project participants have an enormous ability to influence H&S through their decisions and H&S planning (Szymberski, 1997; Brabazon et al., 2000).

Construction project features (CPFs) being organizational, physical and operational attributes of construction projects, fall in this category of underlying causal factors as they emanate from preconstruction decisions by clients, designers and project managers/planners and contribute to accident causation.

Specifically, Carter and Smith (2006) research pointed that existing hazard identification procedures in construction projects are far from ideal. These authors identified several significant obstructions to improving hazard identification such as: failure to share information across projects, lack of resources in smaller projects, subjective hazard identification and risk assessment, reliance upon tacit knowledge, lack of a standardized approach and undefined structures for tasks and hazards.

Most contractors see their health and safety plans, which must include complete risk assessment, as merely a burdensome requirement that they must fulfill in order to avoid government fines and, consequently, they neglect the suitable implementation of these important plans (Wang et al., 2006; Saurin et al., 2008).

## 2.2. Costs of injuries and illnesses

Occupational accidents are associated with high economic and social costs. Economic costs are not only borne on the injured workers, but also on the companies concerned and the governments Costs can be both direct (such as material damages, down-time, financial losses through related insurance premium and a share of the medical expenses) as well as indirect (such as overtime work made necessary by accidents, retraining expenses and intangible factors such as loss of company prestige and deteriorating industrial relations, that could have a substantial impact on the quality and profitability of production). Studies about the social costs, such as: changes in future work activity, impact on family members of injured worker, and impact on (following) quality of life, are very few, so much of such costs remain unknown leading employers to underestimate the cost of occupational injuries Some authors estimate these indire.ct costs for companies at several times the direct costs (Andreoni, 1986; Boden,1999).

Historically, construction has been one of the highest risk industries for fatal and nonfatal injuries, and worldwide remains one of the most hazardous occupations. The Bureau of Labor Statistics (2011) gives a bleak account about USA construction industry where more than a thousand fatal injuries have been recorded every year in the United States between 1995 and 2008. In Portugal, according to Portuguese Statistics National Institute, since 2000 till 2006 almost half of the mortal work accidents occurred in the construction industry (INE, 2011).

Obviously, construction accidents have huge cost implications (Lee et al., 2006). Costs of injuries are very varied, depending on the profession and part of the body injured. For instance, Leigh and Miller (1997) reported that hodman and carpenters are two occupations with high costs of occupational injury and illness. Dement and Lipscomb (1999) found that roofers and carpenters had higher medical costs than the average, by reviewing more than 30,000 workers' compensation claims among North Carolina Homebuilders Association members for the period 1986 to 1994. Waehrer et al. (2007) found that Construction laborers recorded most fatalities (299) resulting in the highest average annual fatality costs at $1200 million. Using more than 20,000 workers' compensation claims by Oregon construction employees between 1990 and 1997, Lipscomb et al. (2003, 2006) report that falls represent the highest costs per workers' compensation claim for residential carpenters, and 14% of claims resulted in 83% of the costs and accounted for 25% of workers' compensation payments on more than $10 million. Shah et al. (2003) estimated that the direct costs of injuries and illnesses from wood framing in residential construction were over $197 million in Washington State based on workers' compensation claims data from 1993 to 1997.

As pointed by Ringdahl (2001) - citing a 1997 study of Bearson and Coleman concerning nine selected European countries which estimates the aggregate economic costs of occupational injury and diseased by country - they showed that the costs are in the range of 2.5% to 6% of the countries Gross Domestic Product (GDP).

# 3. Risk assessment for occupational safety methods

In general, RAOS methods usually combine a hierarchical representation of how events may develop, where event and fault trees are characteristic examples, with procedures for estimating and/or calculating the probability that a specific event or combination of events can occur as well as the severity of potential consequences. RAOS methods impose patterns on the accident causations and influence both data collected and factors identified as causative (Ringdahl, 2004). But, they may act as a filter and biased the results by considering only certain events and conditions (Levenson, 2004).

Moreover hazards are real, risk is a socially constructed concept and consequently, RAOS is inherently subjective and represents a blending of science and judgment of important psychological, social, cultural, and political factors (Slovic, 1999; Slovic et al., 2004). In fact, when a RAOS is performed, it is important to realise that decision-making about accepting certain risks is a complex task, not only due to technical aspects but also to others such as economical, environmental, comfort related, political, psychological and societal acceptance (Suddle, 2009).

RAOS provides procedures for the systematic use of available information to identify hazards and to estimate risks to individuals or populations, property or environment (IEC, 1995; Christensen et al., 2003; ISO 31000:2009; OHSAS 18001:2007). Ringdahl (2001) prefers the term “safety analysis”, instead of “risk assessment” due its use in a broader sense, and suggests the following definition: “*Safety analysis is a systematic procedure for analyzing systems to identify and evaluate hazards and safety characteristics. The pursuit of safety through the elimination of risks also required that the specific risk source actually can be removed from the system without impeding or changing the system’s functioning”*. This is also the main aim of RAOS in the construction industry.

In any industry, the risks of a tasks derives from the hazards associated with the tasks - due to materials, equipment’s, work organization and other workplace conditions - that a worker has to face, when he or she performs the job. For instance, a mason has to climb ladders, work on scaffolds, carry bricks, use tools or be in the neighborhood of cranes. However, knowing/identifying the main potential hazards is not sufficient to derive risk reduction strategies later on. Whether or not a particular activity – such as using a chain saw – is particularly dangerous does not make it a high priority item in itself. The diverse contributions to the overall risk of a task is also determined by the worker´ exposure to the whole set of hazards (Ale et al., 2008). A large number of different RAOS methods are available for industrial processes (see descriptions on Rouvroye and Bliek, 2002 and Tixier et al., 2002). Usually three main steps are identified when performing a RAOS study: 1) identification of potential hazards; 2) assessment of the risks and; 3) hierarchy of risks. RAOS methods can be ranked from simple, comprising only one step, to more complex methods when they involve all the three steps. Moreover, their output data can be qualitative, such as recommendations, or quantitative in the form of an index of risk level.

An interesting taxonomy with 6 categories for RAOS methods is based on its main features (Ringdahl, 2001):

- Technically oriented methods (e.g. EA, HAZOP, FTA, FMEA, Event tree analysis, Deviation analysis, Cause-consequence diagram, Reaction matrix, Consequence analysis models);

- Human oriented methods (e.g. Human reliability assessment, Human error identification, THERP, CREAM);
- Task analysis (e.g. Operator action event tree, Decision/Action flow diagram, Operational sequence diagram, Signal-flow graph analysis);
- Management oriented methods (e.g. MORT, ISRS, SHE, SCHAZOP);
- Accident investigations (e.g. AEB, Change analysis, Multilinear events sequencing, STEP);
- Coarse analysis (e.g. PHA, Check-lists, What-if).

All the above methods are discussed in detail in the relevant literature (Lawley, 1974; Sevcik, 1981; Khan. and Abassi, 1997; Kliem and Ludin, 1997; Hollnagel, 1999; Hammer and Price, 2001; Ringdahl, 2001; Aven, 2003; Cooper et al., 2004 and Loosemore et al., 2006).

Another taxonomy for traditional RAOS methods was presented by Tixier et al. (2002) by considering two main groups: qualitative and quantitative. The second group can be sub-divided into three categories: deterministic, probabilistic, and a combination of deterministic and probabilistic approaches. The deterministic methods take into consideration the products, the equipment's and the quantification of the consequences for various targets such as people, environment and equipment. The probabilistic methods are based on the probability or frequency of hazardous situation occurrences or on the occurrence of potential accidents. Probabilistic methods are mainly focused on the probability of failures on equipment's or components hence they are mostly used for analyzing limited parts of a plant. Deterministic and combined deterministic and probabilistic methods are mainly used to review the whole industrial site.

## 3.1. Risk assessment occupational safety on the construction industry

In practice, the construction industry performs coarse RAOS using mainly PHA and Checklists (Pinto, 2002; Navon and Kolton, 2006).

PHA is a qualitative technique (is not a really methodology), which involves a disciplined analysis of the event sequences, which could transform a hazard into an accident. A hazard is considered anything having the potential to cause harm to workers, property, the public or the environment; this includes energy sources, hazardous materials, bad postures and similar environments (Christensen et al., 2003). The possible undesirable events are identified and analyzed separately. The results provide a basis for determining which categories of hazard should be looked into more closely and which analysis methods are more suitable to deal with them (Brereton et al., 1997); not produce a really risk level.

Checklists can be a valid, reliable, usable, and practicable tool; however, it is not easy to develop a well-designed checklist. Each checklist is restricted to specific contexts, tasks and users (analysts). In certain operating conditions, existing checklists may not be sufficient to reflect the potential safety problems **(**Jou et al., 2009).

A substantial aspect of safety literature and research focuses on identifying and describing the various methods of improving occupational safety on site (i.e. safety program elements, including RAOS). It was identified 10 main contributions in the literature for RAOS in the constuction industry:

1. Hinze (1997) and Hill (2004) identified the essential elements of effective safety programs.

2. Jannadi and Almishari (2003) developed a study concerning the assessment of risk for major construction activities. These authors defined risk as a measure of probability, severity, and exposure to all hazards of an activity. A risk assessment model was developed and computerized to determine the risk associated with a particular activity and as a justification factor for a proposed remedy. Knowing the value of risk helps contractors identifying the high risk of major construction activities and enables them to allocate safety measures in a more efficient manner.

3. Rajendran (2006) evaluates the relative ability of safety program elements to improve site safety.

4. Baradan and Usmen (2006) developed an approach for occupational injury and fatality risk analysis in building trades, based on defining risk as the product of probability (frequency) and severity, and using the risk plans concept to evaluate and rank the trades in terms of nonfatal injury rates.

5. Hallowell (2008) developed, populated and validated a formal method to evaluate construction safety risk and strategically match safety program elements to construction processes. The decision scheme, based on the application of Newton's third law, assumes that every construction activity is associated with specific safety risks and that each safety program element is capable of mitigating a portion of such risks. The results include the quantification of probability and severity values for ten mutually-exclusive and all-inclusive safety risks associated with thirteen worker activities required to construct concrete formwork, and quantified the probability and severity reduction values resulting from the implementation of thirteen safety program elements.

6. Gurcanli and Mungen (2009) described a method for assessment of the risks at construction sites using a fuzzy rule-based safety analysis to deal with uncertain and insufficient data, using historical accident data, subjective experts judgment's and the current safety level of a construction site, which are combined to derive three parameters namely: the accident likelihood, current safety level and accident expected severity.

7. Aneziris et al. (2010) proposed a technique for quantification of occupational risk of the construction of a highway tunnel, based on the Workgroup Occupational Risk Model (WORM) to assess occupational risk at hazard level, activity level, job level and overall company risk. They applied the model on a highway tunnel construction, located in Northern Greece, in two construction phases, namely: a) the excavation and primary support and, b) the final lining and support of the tunnel, to the total of seventeen job positions, such as operators of a drilling machine, a loader, an excavator, a spraying machine, a crane operator, a blaster, a welder, the supervisor of the project, truck drivers and various other workers participating in these construction phases.

8. Rozenfeld et al. (2010) using a lean approach to safety management in construction, developed a structured method for hazard analysis and assessment for construction activities, called "Construction Job Safety Analysis", which required the ability to predict fluctuating safety risk levels in order to support safety conscious planning and pulling of safety management efforts to the places and times where they are most effective.

9. Benjaoran and Bhokha (2010) developed an integrated system for safety and construction management in which safety is integrated with the construction management process by risk analysis throughout design, planning and control phases.

10. Wu et al. (2010) developed a systematic mechanism to interrupt and prevent precursors and immediate accident factors (PaIFs) on construction sites. These PaIFs are occupational risk factors.

11. Albert and Hallowell (2012) enumerate hazard recognition strategies that may be implemented in Construction and Infrastructure projects.

## 3.2. Limitations of risk assessment for occupational safety methods

Many authors (Karwowski and Mital, 1986; Cornell, 1996; Wang and Ruxton, 1997; Pender, 2001; Sii et al., 2001; Apeland et al., 2002; Tixier et al., 2002; Faber and Stewart, 2003; Nilsen and Aven, 2003; Kentel and Aral, 2004) have discussed the limitations of RAOS methods. Most of the methods typically rely on uncertain, imprecise or just incomplete information. Some sources of imprecision that may lead to uncertainty include scarce or incomplete data, measurement errors or biased expert judgments (due to subjective interpretation of the available information). These kinds of uncertainties cannot be treated solely by traditional statistical or probabilistic methods.

RAOS approaches using probabilistic and statistic techniques have been widely used, but often fall short in their ability to allow the incorporation of subjective and/or vague terms and they rely heavily on statistical information that may not be available. This is particularly evident in the construction industry, because there is no systematic recording of relevant safety information.

The main limitations of the probabilistic and statistical approaches, as acknowledged by some authors (Andersson, 1986; Kuchta, 2001; Faber and Stewart, 2003; Nilsen and Aven, 2003), are:

- Probability theory is based on the assumption of randomness, whereas projects deal with consciously planned human actions that are generally not random;
- Construction projects are inherently unique by definition. This reduces the relevance and reliability of statistical aggregates derived from probability-based analysis;
- Probability theory assumes future states can be defined. However, uncertainty and ignorance are inevitable on construction projects, particularly with regard to human actions;
- Humans are limited in their ability to encompass and process the full range of information required for holistic decisions;
- Because uncertainty and ignorance exist, temporal aspects of the flow of knowledge are important in project planning. Probability theory is based on a two-period model that ignores the flow of knowledge over time;
- Project parameters and outcomes must be communicated to interested parties and the imprecision of natural language is difficult to express with probability theory.

Other order of reasons related with technological changes and increased complexity of work systems (which are not accompanied by the development of RAOS methods), are pointed out by Levenson (2004) namely:

- Technology is changing faster than the engineering techniques to cope with the new technology that are being created;
- Digital technology has created a quiet revolution in most fields of engineering and system safety engineering that are changing the nature of the accidents;

- Common accident models are based on an underlying assumption that accidents are the result of an uncontrolled and undesired release of energy or interference in the normal flow of energy but dependence on information systems creating the potential so that a loss of information or incorrect information can lead to risky situations;
- Losses stemming from accidents are increasing with the cost and potential destructiveness of the systems, i., e., new scientific and technological discoveries have not only created new or increased hazards (such as radiation exposure and chemical pollution) but have provided the means to harm increasing numbers of people;
- Complexity has many facets, most of which are increasing in the systems we are building, particularly interactive complexity, i.e., systems with potential interactions among the components that cannot be thoroughly planned, understood, anticipated, or guarded against;
- Humans are increasingly sharing control of systems with automation and moving into positions of higher-level decision making with automation implementing the decisions, what are leading to new types and a new distribution of human error;
- Regulatory and public views of safety are changing.

In addition, it should be pointed that in the construction industry, the main work accidents occur due to (Sawacha et al., 1999; Abdelhamid and Everett, 2000): a) management reckless; b) companies safety policy, c) lack of awareness or training, d) lack of supervision; e) lack of communication; f) lack of means to accomplish the task safely, g) workers lack of knowledge (which potentiates misjudgements, neglect, apathy); h) workers risk perception; i) workers motivation; j) workers recklessness.

Moreover, the term "safety climate" was used (Zohar, 1980) to describe a construct that captures employees' perceptions of the role that safety plays within the organization. Employees continuously observe their work environment and the actions of their fellow co-workers and their supervisors and such observations are used as a basis for the creation of cognitive models associated with safety, i.e. they regulate their actions in the workplace and influence safety (Varonen and Mattila, 2000).

All above factors promote the erosion and degradation of safety work conditions. Hence, to assess factors related with safety climate is also of paramount importance in order to guarantee the reliability of safety management (DeJoy et al., 2004). New RAOS approaches are needed (Levenson, 2004), because actual methods have limited notions of causality—usually linear causality relationships are emphasized—and it is difficult to incorporate non-linear relationships, as for instance, management commitment to safety and safety culture in the organization, which are key factors for assuring an adequate safety climate on construction sites.

Other factors that could have adverse effects in the construction sites were pointed by some authors (Akintoye and MacLeond, 1997; Tam et al., 2004).

- Lack of familiarity and doubts about RAOS methods applicability (the operational application of some methods is difficult because of the lack of their description);
- Time–consuming activity plus lack of information and know-how (the complexity of the methods require specific training for their implementation). Notice that there is a great disconnection between risk analysis technical methods and human factors;
- Most construction projects are seldom large enough to warrant the use of these methods;
- Require availability of sound data to ensure confidence (a large number of assumptions, judgments and opinions are involved subjectively in a risk quantification process, and require a considerable skill for a safety analyst to interpret the results produced);

- Some risks on construction are fairly subjective, hence they are determined based on experience from previous contracts undertaken by the firm (due to a lack of appropriate RAOS methods);
- It is difficult to assess the benefits (it is extremely difficult to quantify the effects and consequences of hazards because they involve many factors with a high level of uncertainty, even when the physical processes are clearly understood);
- RAOS on construction projects is seldom formally requested by clients (i.e., clients expect project management practice to set up risk-free projects);
- RAOS is about people (real work) not scientific models. There are many instances where causes of an accident involved human error and bad decisions taken by designer and management; in such cases it is extremely difficult to generate a mathematical model to represent and describe the required safety behaviour. RAOS in construction industry usually only comprises technical factors and is accomplished, in an intuitive way, to fit the theoretical background and available resources of the person who elaborates its. Safety climate factors are rarely explicitly taken into account.

In addition, important limitations of organizational and human factors in RAOS are the lack of consensus on the set of practical factors related to the safety culture, safety organization, work organization, supervision, leadership, communication and consultation and how these affect the performance of safety, especially in "turbulent" environments such as construction industry. Moreover, most evaluation criteria proposed in the literature (Mearns and Flin, 1999; Guldenmund, 2000) are not easily assessed by using statistical and probabilistic techniques. In this work we assume that most limiting factors are not insurmountable and should be effectively addressed to encourage a broader use of RAOS initiatives in the construction industry.

From all described limitations and inadequacies of RAOS methods, it also seems that the use of fuzzy sets theory may help produce more realistic representations and solutions, as shown by many authors (Andersson, 1986; Maglaras, 1995; Herrera and Viedma, 2000; Nunes, 2003; Liu et al., 2004, Soltani and Fernando, 2004 and Mure et al., 2006). The next chapter discusses in more detail the potential of using a fuzzy sets approach for RAOS, particularly in the construction industry.

## 3.3. Risk assessment occupational safety quality

Models used in RAOS have to represent highly complicated phenomena, which are not always fully understood beause they contain empirical elements that require calibration. Often, the models are used well beyond the range (extrapolate) in which they have been validated.

In many parts of the world (for example, European Union and Australia) RAOS is compulsory in work organizations as a mean of ensuring the implementation of safety programs to avoid work accidents and health injuries (e.g. Europeen Directive 89/391/CEE from the Council, 1989). However, many companies just undertake a superficial analysis of their hazards making RAOS a mere paper exercise without practical interest (only to comply with legal requirements).

An important question that this work addresses is: what constitutes a good RAOS? Authors (Suokas and Kakko, 1989; Suokas and Rouhiainen, 1989; Rouhiainen, 1993; Adamski and Westrum, 2003) pointed that the RAOS quality results depend on several factors such as analysts' qualification, documentation completeness (sufficiency of data), coverage of hazard identification and accuracy of consequences estimation. These factors can affect the results and the analysis' cost-effectiveness. Results may vary depending on: a) initial assumptions, b) simplifications made in the system description and accidents modeling, c) confidentiality (or others) constraints of the object, d) inaccuracy of consequence models, and, e) ill-defined data employed.

Inappropriate results have been leading to criticism of RAOS. Cox (1982) pointed five main causes of criticism: a) inaccuracy of some of the models used, b) incompleteness in the analyses, c) difficulty of checking the final result, d) inadequacy of criteria of acceptability, and, e) complexity and laboriousness of the technique. Suokas and Kakko (1989) pointed to two main causes for biased results: 1) incompleteness in the identification of accident contributors and the accidents models, and 2) inaccuracy of the quantification of risk in terms of frequency and consequences.

An ideal RAOS should identify every hazard present in a workplace, and for each hazard it should identify with accuracy “what might go wrong?”, “how can it happen?”, “how likely is it that this will happen?”, “what are the possible consequences?” and “how to control it?” (Kirchsteiger, 1999 and Ringdahl, 2001, 2004).

In the real world, it is almost impossible to prevent all risks, as there is evidence of hundreds of accidents and occupational diseases that occur daily around the world, even in industries with high safety standards (Hamalainen, 2009). Subjectivity permeates RAOS at every stage of the process, from the initial structuring of a risk problem until the decision which endpoints or consequences to include in the analysis, this is particularly true in identifying and estimating exposures, identifying cause-harm relationships, estimating consequences, deciding which safety barrier to use when planning measures to control risks, and so on.

Perform an “ideal” RAOS (it means: achieving absolute reliable and fit to use results) is almost impossible, but we must strive for the best approximation (Slovic et al., 2004). The RAOS quality is said to be good when the insight of the risk profile and safety barriers (risk controls) reflect an appropriate usage of hazard identification and risk evaluation methods. Moreover, an adequate use of the information about the system under analysis, as well as their background should be clear and accurate (Slovic et al., 2004). The evaluation of these characteristics implies establishing reasonable criteria for assessing the overall RAOS process (Rouhiainen, 1993).

According to Cox (1982) there is no method for guaranteeing completeness in any risk assessment method. To the best of our knowledge, there is no accepted set of criteria for assuring a complete and appropriate in-depth RAOS quality evaluation. Although there is some knowledge dispersed in articles and books, the validity of such theoretical knowledge was not subject to a poll by practical experts. Hence, practical knowledge, acquired by safety experts through years of experience is an important contribution for RAOS.

Measurement of the RAOS adequacy requires more than a formal audit; it requires the identification of the relevant steps of RAOS, as well as knowledge about the importance of each process tasks. According to Suokas and Kakko (1989), Suokas and Rouhiainen (1989), (Rouhiainen) (1993), Juran (1998) and Adamski and Westrum (2003), RAOS quality evaluation will depend on four main features:

- Completeness – extent to which RAOS results have all the required characteristics;
- Accuracy – extent to which RAOS results are correct, and exact;
- Fidelity – representativeness of the model regarding the workplace system;
- Fitness for use - extent to which RAOS results satisfy the explicitly formulated objectives and requirements concerning the intended use for RAOS.

Empirically, one can say that RAOS quality depends on the accuracy with which hazards are identified, and it is a function of the method adopted and the skills of the analyst. It may also concern the precision with which probabilities or consequences can be estimated. Often, for some safety practitioners, the crucial question in evaluating RAOS is whether the most appropriate method has been chosen.

The analyst (team leader) is obviously a key person to identify hazards and influences all stages of the analysis, but the skills and attitudes of the other team members are also important. The problems that arise in the course of identifying hazards have been examined in several studies (Cox, 1982; Suokas, 1985; Suokas and Kakko, 1989; Kirchsteiger, 1999 and Adamski and Westrum, 2003). For example, in the Suokas (1985) study, three analyses of the same object were compared and only 26% of the identified hazards were covered by all three analyses.

RAOS quality also depends on the fidelity of the model to characterize the workplace system, in terms of occupational risks. Despite being difficult to measure this is a very important feature because the workplace is the core of the whole RAOS (Suokas and Rouhiainen, 1993). Several authors such as (Suokas and Kakko, 1989 and Suokas and Rouhiainen, 1993) identified four different ways to evaluate RAOS quality:

1. Carrying out a complete parallel analysis on the same system;
2. Carrying out a parallel analysis on some parts of the same system;
3. Comparing the analysis of accidents´ descriptions which have occurred in corresponding systems, and with systems own experience;
4. Examining the process behind the RAOS process analysis.

The questions associated with this analysis are essential, but usually they are very difficult to answer with enough precision. Since there is a large number of different applications and contexts, it is very hard to reach a universal measure of RAOS quality (Ringdahl, 2001). However it is possible, useful and critical to establish a set of criteria to evaluate the RAOS process quality.

The fourth approach seems more systematic and useful because it is based on the evaluation of the whole process (planning, methodologies, assumptions, decisions, expertise, resources…) and allows organizational learning (Suokas and Kakko, 1989). In spit of these characteristics, it is still a rather difficult and time-consuming procedure.

Furthermore, one basis for obtaining a favorable result consists in good safety analysis procedures — i.e., well planned and implemented.

Summarizing, quality assessment methods must be able to identify all the significant elements in the RAOS process that affect its fitness for use. It may also provide a basis for anticipating and preventing problems when such analyses are planned. A high quality RAOS is the result of a total assessment of the system quality through every aspect of the RAOS process.

## 3.4. Risk assessment for occupational safety on construction sites in Portugal

The construction sector in Portugal does not usually use existing RAOS methodologies (by some of the reasons mentioned before (see 3.3).

RAOS on Portuguese construction sites is performed, mainly, by the use of unsystematic techniques (Pinto, 2002), such as: PHA and audits by check-list. So, in order to evaluate QRAM, its results were compared, with an unsystematic technique procedure and the Workmed® method (Nunes, 2010) which is part of an informatics tool to aid safety and health management. Workmed® method assess some risk factors (such as: safety barriers) that are considered in the QRAM and display risk level results in percentage which facilitates the comparison with QRAM.

### 3.4.1. Unsystematic relative ranking technique

This kind of techniques is not a well-defined RAOS method. It allows comparing the risks of several activities to ranking them and support safety managers in deciding if it is necessary to implement further safety barriers. The procedure that will be shown below is from a company that does not want to be identified.

In short, after the identification of hazards made by audit, PHA or safety expert empirical knowledge and experience, the probability (of work accident occurrence) and the severity (of work accident consequences) are estimated based on matrices, that are variations of the appointed by BS 8800:2004, which are listed on tables 3.1, 3.2 and 3.3.

A typical procedure is accomplished by the following steps:

1. Based on experience, the expert identifies hazards related to: a) materials, b) equipment's, c) location, d) construction methods, and e) other features (such as simultaneous tasks). Although usually called hazards, what he really identify are the accident modes or the contact modes that can occur;

2. After identify the hazards, the likelihood and the severity (for each of the hazards identified) is estimated by criteria shown on the Tables 3.1 and 3.2.

Table 3.1 - Categories for estimate Likelihood (unsystematic technique)

| **Likelihood** | 4 | 3 | 2 | 1 |
|---|---|---|---|---|
| Typical occurrence | Experienced at least once every six months on site | Experienced at least once every year on site. | Are occurred more than once in other sites | No records of occurring. |

Table 3.2 - Categories for estimate Severity (unsystematic technique)

| Severity | 1 | 2 | 3 |
|---|---|---|---|
| Health | Nuisance and irritation (e.g. headaches); temporary ill health leading to discomfort (e.g. diarrhoea). | Partial hearing loss; dermatitis; asthma; work related upper limb disorders; ill health leading to permanent minor disability. | Acute fatal diseases; severe life shortening diseases; permanent substantial disability. |
| Safety | Superficial injuries; minor cuts and bruises; eye irritation from dust. | Lacerations; burns; concussion; serious sprains; minor fractures. | Fatal injuries; amputations; multiple, injuries; major fractures. |

3. Based on the likelihood and the severity estimated, the risk level was determined by the matrix depicted on the table 3.3.

Table 3.3 – Risk level estimation matrix (unsystematic technique)

| **Likelihood** | **Severity** | | |
|---|---|---|---|
| | **3** | **2** | **1** |
| **4** | **12** | **8** | **4** |
| **3** | **9** | **6** | **3** |
| **2** | **6** | **4** | **2** |
| **1** | **3** | **2** | **1** |

4. The tolerability is associated to the risk level by: a) three or below, the risk is acceptable, b) between four and seven, the risk is medium and should be reduced so that it is acceptable, and c) eight and above, the risk is unacceptable (see table 3).

The risk assessment results are used to prioritize the order, to devise, maintain or improve risk controls, as: a) if the risk is considered acceptable, no further action is necessary other than to ensure that the controls are maintained. b) if the risk is considered medium, risk reduction measures should be implemented, within a defined time period, and it might be necessary to consider suspending or restricting the activity, or to apply interim risk control measures, until this has been completed, particularly if the risk levels are associated with extremely harmful consequences and very harmful consequences, and c) if the risk is considered unacceptable, the work activity should be halted until risk controls are implemented to reduces the risk to an acceptable level so that it is no longer very high. If it is not possible to reduce the risk the work should remain prohibited.

### 3.4.2. Workmed® method

Workmed® method (Nunes, 2010) was, initially designed and developed to be incorporating in computerized systems for managing safety and health at work. It has the advantage of being configurable and so adaptable to perform risk assessment in any activity (Nunes, 2010), including construction sites. The method is based on usual classical methods and is been implementing the computerized systems for managing safety and health at work. Is being used in Portugal since 2002 in all activity sectors, namely: industry (including construction), 8 companies and services (including health and public sector), 15 companies. This method estimates the risk level, normalized so that the result will always be in a percentage scale, regardless of the number of indices considered and the scales and weights adopted, as follows:

$$R = \frac{A_F \log(F) + A_E \log(E) + A_S \log(S) + A_D \log(D) + A_T \log(T)}{A_F \log(N_F) + A_E \log(N_E) + A_S \log(N_S) + A_D \log(N_D) + A_T \log(N_T)} x 99 + 1 \quad \text{(eq. 1)}$$

Where:

R - The resulting level of risk for the risk factor in the local score (1-100%);

$A_I$ – Weighting factor index I (I = F, E, S, D and T): values from 0 (not considered for the calculation of the risk level) to 10 (maximum contribution for the risk level);

$N_I$ – Maximum value of the scale values of the index I (I = F, E, S, D and T);

F – Frequency Index of Exposure occurrences to the risk factor (from 1 to 5, see table 3.4);

E – Exposure Index determined by the duration of exposure to risk factor (from 1 to 5, see table 3.5);

S – Severity Index resulting from exposure to risk factor (from 1 to 5, see table 3.6);

D – Deficiency Index of safety conditions in the workplace (from 1 to 5, see table 3.7);

T – Workers exposed Index (associated to workers exposure on worksite (from 1 to 5, see table 3.8).

Contrary to the multiplication used in classical methods, the use of logarithm functions allows a more uniform distribution of the risk levels. Workmed® method uses the following criteria for the indexes mentioned.

Table 3.4 - Frequency Index of Workmed® method

| F | Frequency |
|---|---|
| 5 | One or more times per day. Happens "all the time." |
| 4 | One or more times a week. Everyone remembers this kind of event / situation. |
| 3 | One or more times per month. Some people remember this type of event / situation. |
| 2 | One or more times per year. Does anyone remember this type of event/situation. |
| 1 | Less than once a year. No memory of this type of event / situation. |

Frequency index is of special relevance, being very important in estimating the possibility of occurrence, because if it was not able to obtain frequency rates, the available information allows identifying the mode of accident/risk involved and helps appeal to the "memory" of safety technicians that know the work context.

Table 3.5 – Exposure Index of Workmed® method

| E | Exposure |
|---|---|
| 5 | > 50 % of working hours |
| 4 | 50 % ≥ of working hours > 10% |
| 3 | 10% ≥ of working hours > 5% |
| 2 | 5% ≥ of working hours > 1% |
| 1 | 1% ≥ of working hours > 0% |

Exposure index importance lies in the influence on the possibility of exposure occurs. The almost constant exposure to specific risk (total occupation of the working hours), does not implies a very significant increase in the possibility of exposure occurs. Actually, scheduled tasks can increase safety conditions. Yet, this index can achieve more importance in the calculation of the risk level when it is not possible to establish values for the frequency index or as a complement to it.

Table 3.6 – Severity Index of Workmed® method

| S | Severity |
|---|---|
| 5 | Possibility of death, injury or illness with permanent total disability or very severe. |
| 4 | Injury or illness with temporary total disability, permanent partial or severe. |
| 3 | Injury or illness with temporary partial disability, or moderately severe. |
| 2 | Possibility of injury without disability or mild health problems. |
| 1 | Neither injuries nor health problems. |

Severity index importance is due to there is a reasonable uncertainty about the severity of the consequences that may occur, although it has to recognize that in some situations it can often be high.

Table 3.7 – Deficiency Index of Workmed® method

| D | Deficiency |
|---|---|
| 5 | Safety barriers non-existent or unknown. |
| 4 | Serious deficiencies in existing safety barriers or does not comply with legislation; needs several improvements. |
| 3 | Absence and/or some deficiencies in existing safety barriers, respecting part of the law, presents some problems in situations of abnormal operation. |
| 2 | Sufficient safety barriers but upgradeable, respecting the law, with few requirements below the established standards. |
| 1 | Sufficient and well established safety barriers, respecting international standards, above the required by law. |

The deficiency index on construction sites is based only on visualization of work situations, not allowing to measure with sufficient accuracy other factors like:

1. The duration and frequency of tasks, the conditions under which they are developed, the training actually received by the workers involved and others who may be affected, facilities, equipment and hand tools, distances that materials must be moved manually, size, shape, surface and weight of these materials;

2. The existence of procedures for authorization of work, instructions for operation and maintenance of equipment, actual knowledge of legal requirements, regulations and regulatory issues relevant and related work, control devices and protection supposedly in operation;

3. The results of inspections performed on the labor front.

Table 3.8 – Index of Workers exposed Workmed® method

| T | Workers exposed |
|---|---|
| 5 | > 29 % of workers exposed |
| 4 | > 12 e ≤ 29 % of workers exposed |
| 3 | > 6 e ≤ 12 % of workers exposed |
| 2 | > 3 e ≤ 6 % of workers exposed |
| 1 | ≤ 3 % of workers exposed |

The index of workers exposed is relevant because, in relative terms, it is considered with significant influence in the level of risk involved. A large number of workers exposed involve both an increase in the severity and an increased likelihood.

Table 3.9 – Risk Level rating of Workmed® method

| Valuation | Type and urgency of Control Actions |
|---|---|
| 5<br>Intolerable<br>(92 < RL ≤ 100) | The work cannot be started or continued while the risk is not reduced. If the risk cannot be reduced, the work should be prohibited.<br>If the risk can be reduced, should be checked before the work starts and during its performance if all control measures are implemented and operative. |
| 4<br>Marrowy<br>(81 < RL ≤ 92) | The work cannot be started while the risk is not reduced.<br>If the risk is related to a work in progress, urgent action should be taken. Risk reduction measures must be implemented.<br>Always check before the work starts if control measures are implemented and operative. |
| 3<br>Medium<br>(67 < RL ≤ 81) | Safety measures should be implemented to reduce risk within a defined period of time, but the costs of implementation should be evaluated and limited.<br>If the medium risk is associated with very serious injuries, one must establish more precisely the likelihood of damage and hence the possible need of improve prevention measures.<br>Should be check, at appropriate intervals, if all control measures remain well implemented and operative. |
| 2<br>Tolerable<br>(41 < RL ≤ 67) | The risk has been reduced to the lowest practicable. Requires no additional measure. It can be considered solutions which improve the cost-effectiveness rate. |
| 1<br>Trivial<br>(0 < RL ≤ 41) | It requires no action. |

# 4. Fuzzy Sets Theory

In the real world, vagueness and ambiguity exist due to the limitations of our language and other factors such as context and mood. Human mind allows a certain sloppiness in the descriptions of our environment which is, sometimes, at conflict with the rigor of formal analysis (Steimann, 1997). There are situations in which the meaning of a word or symbol cannot be captured adequately by a crisp set, for instance: the term “cold” denotes the range of cold temperatures, which may vary from context to context but, clearly, always lacks a sharp boundary.

A generalist view of occupational safety risk assumes that risks are characterized by some combination of attributes such as probability, severity, intentionality, voluntariness, disorganization, lack of knowledge, lack of leadership and so on, but no one of these attributes is absolutely essential. In fact, there is no universal set of rules for taking or characterize the risk, e. g., there is no universal set of characteristics for describing the occupational safety risk (Aven, 2009). Assessing risks is, essentially, to know them. And this means that it is essential to have a complete and systemic understanding of the possible causes of an anomaly in the work process, combined with an efficient characterization of the possible consequences resulting of the occurrence of that anomaly.

The degree of complexity of the analysis depends on, among other factors, the availability and reliability of the data needed, which are often difficult to obtain.The characterization must depend on which context the risk is undertaken. So, RAOS must take into account the context and the scope of the analysis. Thus, RAOS deals with uncertain situations, that is, with situations in which it does not have complete and accurate knowledge about the state of the system. So, uncertainty exists.

Uncertainty may be due to: a) incompleteness, when there is lack of information or incomprehensible information, b) ambiguity, due to several possible data interpretations, c) imprecision, due to data that are not precise or exact, d) fuzziness, when there are concepts that have a meaningless definition (such as: safe and confortable) or events unable to be acuratly defined and, e) randomness, when there are events whose features are not yet know until it will happen in the future.

In construction, vague terms are unavoidable, since construction professionals often assess risks in qualitative linguistic terms, as a result increases the uncertainty. In addition, when a large number of people are involved the magnitude of the fuzziness increases (Pender, 2001).

Under these circumstances, probabilistic approaches may not be able to model safety for the whole construction process as effectively and efficiently as Fuzzy Set Theory (FST), because it is a mathematical framework to deal with randomness uncertainty (Zadeh, 1987). RAOS uncertainty in construction are more related with information incompleteness, data ambiguity and imprecision and fuziness of concepts and work situations (see section 3.2).

FST was formulated, in 1965, by Lotfi Zadeh and provides a mathematical framework for the systematic treatment of vagueness and imprecision. More specifically, may be viewed as an attempt at formalization of two remarkable human capabilities: a) the capability to converse, reason and make rational decisions in an environment of imprecision, uncertainty, incompleteness of information, conflicting information, partial truth (environments of imperfect information), and b) the capability to perform a wide variety of physical and mental tasks without any measurements (at least in a quantitative way).

FST have the ability to introduce notions of continuity into deductive thinking. In practice, this means that the use of fuzzy sets allows a conventional symbolic system (specified in the form of rules, tables, or whatever) to adopt continuous behavior, thus to decrease uncertainty.

Zadeh (1978) argues that fuzzy logic is different in character from probability, and is not a replacement for it. There are four main differences between the two techniques (Engelbrecht, 2007): (1) degrees of certainty (given by statistical probability) are meaningful only before the event occurs, membership degrees are relevant even after the event occurs; (2) probability assumes that events are independent, fuzziness is not based on that assumption; (3) probability assumes a closed world model when every data are known, fuzziness never assumes that everything could be known, and; (4) probability is based on subjective frequency measures, fuzziness is based on descriptive measures (by membership functions) of the domain.

By contrast with classical sets, which present a discrete border, a fuzzy set presents a boundary with a gradual contour. Formally, let U be the universe of discourse and *u* a generic element of *U*, then a fuzzy subset *A*, defined in *U*, is a membership function composed by the dual pair:

$$A= \{(u, \mu_A(u)) \mid u \in U\} \qquad \text{(eq. 2)}$$

Where: $\mu_A(u)$ is designated as membership grade of *u* in *A*. The membership function *A* associates to each element *u*, of *U*, a real number $\mu_A(u)$, in the interval [0,1].

To perform operations with fuzzy sets there are, in the literature, panoply of operators (Zimmermann, 1993; Yager and Filev, 1994; Beliakov and Warren, 2001 and Detyniecki, 2001). The most well-known are the intersection, union and media operators, with the first two corresponding to multiplication and sum operations in arithmetic and to "e" and "or" in logic. Further, intersection and union operators can be divided in two classes: a) non-parametric operators – usually known as t-norms and t-conorms and b) the class of parametric ones – which allow expressing synergies in the operations (Zimmermann, 1993; Ribeiro, 1996; Beliakov and Warren, 2001; Detyniecki, 2001). Averaging operators includes parametric and non-parametric operators (Detyniecki, 2001). In general, since most operators objective is to combine concepts, these falls under what is usually called aggregation operators (Beliakov and Warren, 2001; Detyniecki, 2001). In this thesis this latter designation will be used for joining the factors influencing the risk in the construction industry. In section 5 details about the selected aggregation operators will be discussed.

Another important concept in FST is the linguistic variable (Zadeh, 1975, 1978, 1983, 1987). A linguistic variable is defined as a variable whose values are words or sentences in a natural or artificial language. There are decision situations in which the information cannot be assessed precisely in a quantitative form but may be expressed in a qualitative form, and thus, the use of linguistic variables is a good approaach (Ru and Eloff, 1996; Herrera and Viedma, 2000 and Cordón et al., 2002; Ruan et al., 2003).

Formally, a linguistic variable is a variable that admits as values words or sentences in natural language, which can be represented as fuzzy sets.

For example, a linguistic variable "Temperature" (see fig 4.1) could be described by three terms "Cold", "Pleasant", "Hot", each represented by a fuzzy set, where Celsisus-degrees are the interval for the x variable and m(x) the corresponding membership degree.

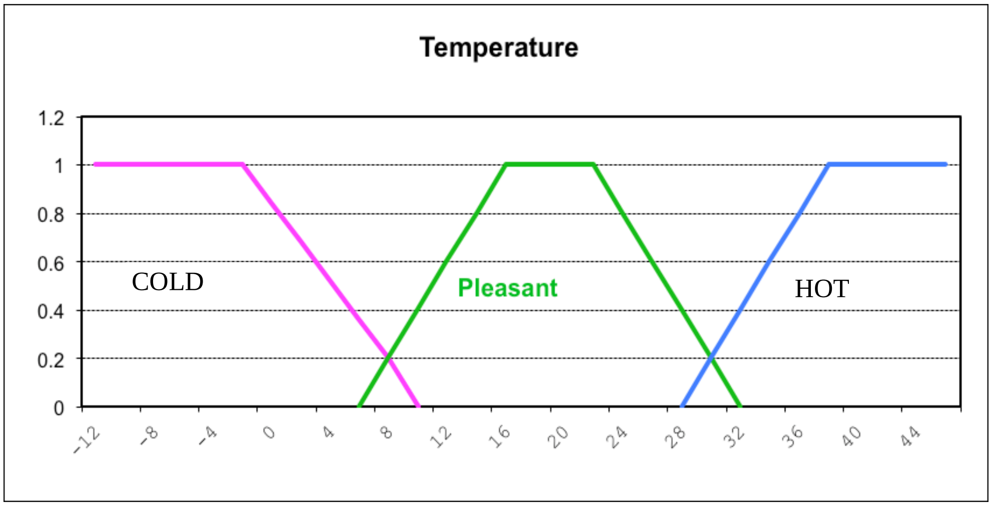


Figure 4.1 – Linguistic variable "Temperature"

Or, in a closer example, given by Markowski et al. (2009), a safety risk level scale which universe of discourse (U) ranges from$10^{-7}$ to $10^{0}$. This scale, it is most suitable for the range of the risks that can be encountered in the construction industry (risk=0 is highly improbable). So, the linguistic variable "Safety Risk Level" could be described by nine terms: "remote", "unlikely", "very low", "low", "moderate", "fairly high", "high", "very high" and "extremely high" (see fig. 4.2).

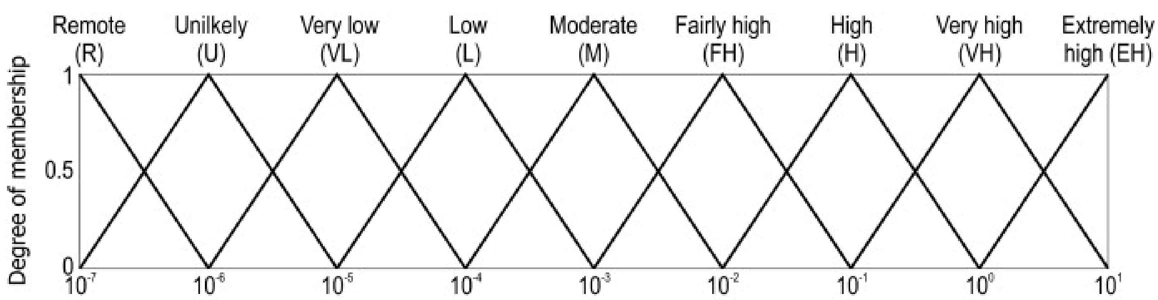


Figure 4.2 – Linguistic variable "Safety Risk Level"

In summary, this section introduced the main concepts from FST that will be used in this thesis and the next sub-sections presents the motivation for using this theory in RAOS and the main related works, respectively.

## 4.1. Advantages of the use fuzzy sets theory in risk assessment occupational safety

The concept of risk assessment, in particular when applied to occupational risks, is mentioned in a vast scientific, technical and legal bibliography. However, the definition of this concept is vague, varied, and often contradictory. Concepts upstream of the concept of risk (e.g. human failure, working conditions, physical or chemical risk factors, consequences' severity, safety climate) are viewed from a methodological point of view in several works, but always in a specific and restricted approach, showing no consistent interfaces.

It is important to be noted that a large volume of data is required for RAOS process, using injury, illness, and fatality statistics data. However, very few construction companies have the required data in quantity and with the quality needed to perform meaningful occupational risk assessemnts.

Many authors (Karwowski and Mital, 1986; Cornell, 1996; Wang and Ruxton, 1997; Pender, 2001; Sii et al., 2001; Tixier et al., 2002; Faber and Stewart, 2003; Nilsen and Aven, 2003; Kentel and Aral, 2004) have discussed the limitations of traditional (probabilistic) methods for RAOS and stated that uncertainties sources include scarce or incomplete data, measurement error, data obtained from expert judgment, or subjective interpretation of available information which cannot be treated solely by traditional statistical or probabilistic methods. By this, probabilistic RAOS methods are not objective: it simply fails to acknowledge its subjectivity.

By other hand, human are capable of abstracting, thinking and reasoning, thus, assessing risks without having necessarily to experience their consequences. Hollnagel (2008) stated that safety cannot genuinely be improved only by looking to the past and taking precautions against the accidents that have happened, it must also look to the future.

When conducting RAOS at construction sites, there is often inadequate data or imprecise information available and safety practices encountered at construction sites are as variable as the sites themselves. Therefore, the use of quantitative occupational risk assessment models based on probabilistic techniques, using data collected at different construction sites and in various types of construction projects, seems that can lead to distorted results and do not reflect the reality of the site under analysis.

Using probability techniques are to assume that risk factors and outcomes fall into well-defined mutually exclusive categories (a random process produces events, by chance; i.e., their variability is significantly observable) and, classical RAOS methods are discrete in nature (due to the use of probability theory). These models of reality are built from enumerable sets of symbols (from factors related to the possibility of work accidents and possible work accidents severity), the complexity of these models invariably increases with the number of symbols employed so, accuracy and simplicity are almost mutually exclusive.

Uncertainty represented on fuzzy systems is a nonstatistical uncertainty, based on expressing vagueness, imprecision and/or ambiguity trough fuzzy membership functions, which is different from statistical uncertainty that is based on the laws of probability and is resolved through observations. Carr and Tah (2001) cites an example: when a coin is tossed it is certain what the outcome is, while before tossing the coin the probability of each outcome is 50%.

In RAOS vagueness and ambiguity exist, due to the limitations of our language, perceptions, context and mood. The large number of people involved (different views, attitudes and beliefs, from diferents analysts must be expected), increases the magnitude of its fuzziness.

Uncertainty, related to RAOS, results on imperfect prediction of future accident scenario risk. Uncertainty derives from: a) the nature of the RAOS, b) the availability of data, c) the quality of the information, d) the skills and preferences of the analyst, e) the methodology used and, f) the time and resources available.

According Markowski et al. (2009), there is three major sources of RAOS uncertainty: 1) in inadequacies and deficiencies in formulation of accident scenario framework, 2) in the occupational accidents severity assessment and, 3) in the lack of knowledge elicited from experts, which is often incomplete, imprecise and fragmentary

The imprecision and inaccuracies in the parameters which are used as an inputs into RAOS process, are called parameter uncertainties, which are inherent because the available data used to understand human-centered systems, are usually characterized by being diverse, incomplete, imprecise and subjective. So,the RAOS inference process needs to be based on incomplete knowledge. As noted before, uncertainty presents in RAOS process is a nonstatistical uncertainty, so the ability of probability theory to deal with it is questioned (Zadeh, 2002).

So, the accuracy of the RAOS results depends on (Markowski et al., 2009): 1) the type of hazards that are being analyzed, 2) whether all significant contributors to the risk have been analyzed, 3) the realism of the models used to estimate probability and severity accidents phenomena, and 4) the uncertainty associated with the imprecision of humans centered input data (i.e., the model capability to operate on information which is perception-based)).

To illustrate the paramount contribution of FST to RAOS, Markowski et al. (2009), stated that the use of FST in RAOS, allows answering questions like: ‘‘how safe is the construction site?’’, instead of ‘‘is the construction site safe?’’. Note that the answers ‘‘no’’ or ‘‘yes’’ are unrealistic in safety maters (and not only on construction), due to the set of reasons given before in this section.

FST allows the treatment of imprecise and incomplete information in a more precise and the simplest way, from a mathematical point of view (Dubois, 2006; Siler and Buckley, 2005). In addition, Gentile (2004) stated that the safety assessment is a ‘‘fuzzy issue’’ and subsequently the FST can be effectively included into RAOS process to substantially reduce knowledge uncertainty.

Thus, FST presents a natural way of modelling the intrinsic vagueness and imprecision of safety concepts by providing a very precise approach for dealing with uncertainty which grows out of the complexity of human behaviour. It also allows the inclusion of human creativity and intuition, which is an essential ingredient for successful RAOS (Ru and Eloff, 1996). This statement lies in the recognition that while the role of facts is to provide an answer to expected value (because facts are the same for everyone), the subjective process will produce as many answers as there are people involved. In fact, even when the probabilities are know (in occupational safety it is made always by oversimplifications), analysts should take into account *utility* aspects (Bernstein, 1996), such as: risk perception, usefulness or workers satisfaction, which are fuzzy concepts. For example, there are people who are terrified by thunderstorms even being aware that it is highly unlike that lightning will strike precisely where they are standing.

These people value in excess the possible consequences, instead of the probability of being hit. RAOS analysts should try to elicit this kind of aspects because answer to them can be important to the acceptance of RAOS results, effectiveness of risk response measures and workers motivation.

Besides the reasons given before, aditional motivation for using FST in this work derives from sharing the opinion of many authors, as for instance:

- Andersson (1986) stated that RAOS methods, because they are applied to human-centered systems, should be based on possibility and/or fuzzy sets theories, instead of traditional theory of probability;
- Maglaras (1995) notes that fuzzy sets usually require less information than probabilistic methods to achieve the same level of results;
- Liu et al. (2004) refer that a safety model using a fuzzy rule-based inference system can be more appropriately used to carry out risk analysis associated with incomplete safety information;

- Mure (2006) pointed that an effective prevention of accidents and health harms is only possible through an in-depth study of their dynamics. For this purpose, it is necessary to have instruments available for characterizing harmful events, and that a fuzzy logic approach seems a suitable instrument for this kind of application.

So, FST is not an alternative to, but an enhancement of classical RAOS approaches. By virtue of fuzzy sets, models may exhibit continuousbehaviour and thus address safety problems more adequately.

## 4.2. Related work using fuzzy sets theory in occupational risk assessment

Moreover, there is extensive literature regarding the usage of fuzzy concepts and methods in RAOS, in related fields such as human factors, Ergonomics, risk management and safety. Regarding Ergonomics applications we highlight the following works:

- Karwowski et al (1987) developed LIFTAN, a fuzzy knowledge base for analysis of manual lifting tasks.
- McCauley-Bell and Badiru (1994 a,b) developed a fuzzy expert system to quantify the risks of upper extremity occupational injuries in manufacturing environments. Specifically, it used the AHP method and fuzzy modeling to develop mathematical predictions for risk level in the organizational, task and personal categories for an individual.
- Wang and McCauley-Bell (1995) used fuzzy modelling to predict risks of cumulative trauma disorders using fuzzy regression analysis.
- Nunes and Ribeiro (2003) developed the Ergo_X Expert System, a multi criteria decision making model for identifying, assessing and controlling ergonomic risk factors responsible for the development of Work Related Musculoskeletal Disorders.
- Hanson et al (2003) used fuzzy logic to model relations between human perception, human characteristics and workplace structure applied to car interior design.
- Karwowski et al (2006) developed a model for measuring the electromyography (EMG) responses for 10 trunk muscles in manual-lifting tasks using a fuzzy relational rule network (FRRN).

Considering risks in project management in construction applications, the following works could be highlighted:

- Kangary and Riggs (1989) developed an approach for project risk assessment in construction, which included a linguistic analysis (qualitative).
- Carr and Tah. (2001) developed a formal model for qualitative risk assessment in construction projects. Risk description and their consequences are defined using linguistic variables and by using fuzzy approximation and composition, the relationships between risk sources and the consequences on project performance measures can be identified and quantified consistently.
- Soltani and Fernando (2004) developed a fuzzy based multi-objective path planning model for movement of materials, plant and site operative from one place to another on construction sites.

Regarding the literature in safety management systems the following fuzzy approaches are highlighted:

- Carr and Tah (2001) developed a methodology for evaluating the risk exposure, considering the consequences in terms of time, cost, quality, and safety performance measures, for a project based on fuzzy estimates of the risk components and using descriptive linguistic variables.

- Tam et al (2002) developed a non-structural fuzzy decision support system to evaluate the safety management systems and prioritize these measures with the consideration of various decision criteria.
- Gentile (2004) established a novel conceptual framework for the analysis of inherent safety and proposes a methodology that addresses several of the limitations of the methodologies available for current inherent safety analysis, based on a hierarchical fuzzy model that analyzes the interaction of variables relevant for inherent safety and process safety in general.
- Oke et al (2006) developed a fuzzy safety control model for the prevention of accidents and failures in oil and gas production activities on offshore platforms.
- Dagdeviren and Ihsan (2008) proposed a fuzzy AHP (Analytical Hierarchical Process) method to determine the level of faulty behavior risk (FBR) in work systems, using weights and fuzzy linguistic variables and applied in a real manufacturing company.
- Yang et al. (2008) develop a fuzzy rule-based, including Bayesian reasoning for prioritizing failures in FMEA - failure mode and effects analysis. The technique is specifically intended to deal with some drawbacks concerning the conventional use of fuzzy logic (i.e. rule-based) methods in FMEA.

Regarding literature about risk analysis for work accidents, the following are the most interesting approaches that include FST concepts:

- Lee and Halpin (2003) developed a study for quantifying the effects of accidents by defining one of the indirect costs, the productive time lost owing to accidents in utility trenching operations. It used fuzzy-logic-based analysis to estimate safety factor´s performance (training, supervision, and preplanning) in utility trenching operations and also to quantify the productivity loss due to process delays resulting from accidents during excavation and pipe installation.
- Nunes (2005) developed AR_X, an expert system aimed at supporting risk analysis. The main objective of this system is to identify and evaluate exposure to occupational risks and advice on measures to implement in order to control risks. The methodology supports the assessment of potential factors that contribute for accident occurrence and guides the user on the adoption of corrective measures. The AR_X performs an Accident Risk Degree assessment based on the evaluation of protection factors and risk factors that are relevant to the situation under analysis.
- Azadeh et al. (2008) developed a fuzzy expert system for performance assessment of health, safety, environment (HSE) and ergonomic factors in a gas refinery with the following objectives: 1) reduce human error, 2) creation of expert knowledge and 3) interpretation of large amount of vague data, using fuzzy rules.

Finally, two RAOS inspiring works, specifically related with the usage of FST in the construction industry are:

- Gurcanli and Mungen (2009). Proposed a method for assessment of the risks that workers are exposed that has been described on 3.2.
- Aneziris et al. (2010) proposed a technique for quantification of occupational risk that has been described on 3.2.

It should be noted that this two works although using FST to perform OSRA, the methods proposed have different features and the assessment is coarser than with QRAM.

# 5. Conceptual Qualitative Occupational Risk Assessment model

The Qualitative Occupational Risk Assessment model (QRAM) is defined by the following four dimensions: Safety Climate Adequacy ($SC$), Severity Factors ($S$), Possibility Factors ($AP$) and Safety Barriers Effectiveness ($SB$). Figure 1 depicts the four dimensions considered in QRAM.

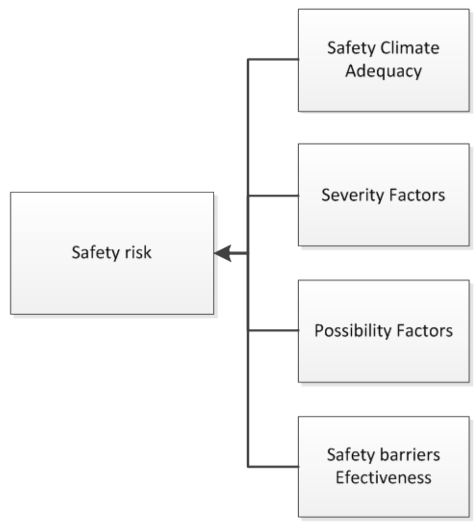


Figure 5.1 QRAM dimensions

These four dimensions are used to estimate the risk for the following nine accident modes:

1. Falls;
2. Contact with electricity;
3. Struck by moving vehicle (including heavy equipment);
4. Injured by falling/dropped/collapsing object/person/wall/vehicle/crane which falls under gravity (including building or structure collapse and slipping hand held tool);
5. Cave-ins (while or after excavation);
6. Hit by rolling/sliding object or person (including stuck against object or equipment and caught in or compressed by equipment or objects);
7. Contact with machinery moving parts (including injured by hand held tools operated by oneself);
8. Lost buoyancy in water;
9. Fire and Explosion.

This accident list is based on a preliminary list of accident modes, for occupational accident scenarios by Ale et al. (2008), which is adapted for the construction industry by the following works (Jeong, 1998; Müngen and Gürcanli, 2005 and Hyoung et al., 2009).

The selection of the four dimensions ( $SC$ , $S$ , $AP$ , $SB$ ) is based on critical risk concepts, namely: 1) risk is the uncertainty about the severity of the consequences of an activity with respect to something that humans value (Aven and Renn, 2009) and, 2) the probability and severity of an adverse effect/event occurring to man or the environment following exposure, under defined conditions, to a risk source(s) (EU; 2000). Since in this work it is used fuzzy set theory instead of probability theory, the concept of probability is substituted by the concept of possibility. Therefore, the risk associated with the four dimensions of QRAM expresses a combination of (Christensen et al, 2003):

- Possibility of an unwanted outcome (i.e. a work accident in a safety context), including technical, organizational and behavioral factors;
- Severity of the accident;
- Extending consequences/effects under given specific circumstances (e.g. existence of safety barriers).

The technically oriented RAOS methods referred in 3 do not focus safety climate factors. Human oriented methods, task analysis and management oriented methods considered some factors related to safety climate (such as: formation and training, safety organization and communication) which are assessed as part of the possibility of accident occurrence. However, Mohamed (2002) and Larsson (2005) found, that a positive safety climate and supportive psychological climate in construction industry are important for occupational safety because it may provide indications of workers safety behavior, originating simultaneously from policy and procedural actions of top management and from supervisory actions exhibited by frontline supervisors and it can provide a "measure" of the workforce's perception, and attitudes toward safety within the organizational atmosphere (at a given point in time, like the overall risk assessment). As described in 5.6, safety climate must be assessed, mainly, by site workers perception so, in QRAM, safety climate is a dimension of the model.

## 5.1. Qualitative Occupational Risk Assessment model general formulation

The general formulation of QRAM for an accident mode (i =1,..9) is:

$$R_i(x) = \theta_{and}[SC, S_i(x), AP_i(x), SB_i(x)] \qquad \text{(eq. 3)}$$

Where:

$R_i(x)$ - is the estimated risk for the ith accident mode in the x activity;

$\theta_{and}$ - is the Fuzzy-AND aggregation operator;

$SC$ - is the safety climate assessment adequacy for the whole site –First dimension;

$S_i(x)$ - is the expected work accident severity for the ith accident mode in the x activity – Second dimension;

$AP_i(x)$ - is the possibility of work accident occurrence for the ith accident mode in the x activity – Third dimension;

$SB_i(x)$ - are the safety barriers effectiveness for the ith accident mode in the x activity – Fourth dimension.

Each of the four dimensions is composed by several factors that will be discussed later in this chapter. Here, we just present a brief introduction about the four dimensions that are included in the QRAM.

**Safety Climate Adequacy** – This dimension estimates the adequacy of the site safety climate. Its importance lies in facilitating or impeding the maintenance of safety barriers and consequently the management of safety risks, i.e., safety climate factors are not direct agents in the occurrence of work accidents but create the conditions for accidents happening. Neal et al. (2000) affirm that safety climate is a variable between organizational climate and safety performance. QRAM uses a list of 101 factors to assess the SC (described later).

**Severity Factors –** This dimension estimates the expected occupational accidents severity by assessing factors related to the amount of energy dissipated/absorbed by the victim's body that can be evaluated in situ like, heights, speeds, weights, morphology of moving vehicles, etc, and using the biomechanical limits of the human body appointed in several studies, such as: Prasad (1999), Eppinger et al. (2000), Yang (2002), Chaffin et al. (2006) and Sayed et al. (2008).

**Possibility Factors** – This dimension estimates the possibility of work accident occurrence by using a list of possible factors. Each accident mode has a specific list (which varies depending on the accident mode, for inatance, falls has 76 questions and lost in water has 13).

**Safety Barriers Effectiveness** – This dimension estimates the effectiveness of the safety barriers implemented on site. To estimate the SB, the safety barriers were divided into four groups, according with (Hollnagel, 2008) classification: 1) physical or material, 2) functional, 3) symbolic and, 4) incorporeal.

Both safety climate and possibility of work accident will be rated with the linguistic variable "adequacy" (section 5.3). Safety barriers will be assessed with the linguistic variable "SB-effectiveness" (section 5.3). To obtain the final estimated value for QRAM, the composing factors of each dimension will be aggregated with specific aggregation operators (see section 5.4).

Further, QRAM analysis could be performed in two ways: in a faster way by accident mode that can occur in workplaces or, more in-depth, listing all activities for each job performed at the site, analysing and ranking the risk by the accident modes for each activity. There may be various levels of detail and the analysis will depend on what is wanted to do with the results, and some operational factors, including: a) type and relevance of available data, b) degree of accuracy required to the obtained results and, c) available resources.

The QRAM method includes the following 14 steps:

- Step 1 - Identification of the factors affecting the safety climate on site by the use of the checklist "Safety Rules and Procedures", "Workers' Competence", "Safe Work Behavior", "Management Commitment", "Supervisory Action Towards Safety", "Communication and Participation", "Supportive Environment", "Safety planning", "Work Pressure over Safety" and "Safety Management System".

- Step 2 – Rating of the identified safety climate factors using the fuzzy linguistic variable "adequacy" (see table 5.1). For each factor, the analyst assessment is made by taken the semantic term which was more times chosen by the interviewed.

- Step 3 – Final evaluation of the safety climate on site by using the specialized aggregation operator Fuzzy-OR (see eq. 12).

- Step 4 – Job analysis for identification and listing the activities which are carried on site;

- Step 5 - For each activity, identification of accident modes possible to occur – from the list "accident modes". This identification should be made by the analyst, based on the site work conditions and could be assited by site managers and workers;

- Step 6 - For each accident mode, identification of the factors affecting the possibility (of occurrence) of each accident mode, by the use of the questionnaires that expresses the relations between occupational accident scenarios and possibility factors, namely:: "Questionnaire about factors affecting Falls", "Questionnaire about factors affecting contact with electricity", "Questionnaire about factors affecting struck by moving vehicle", "Questionnaire about factors affecting injured by falling/swinging objects", "Questionnaire about factors affecting cave-ins", "Questionnaire about factors affecting hit by rolling/sliding/flying object (including awkward or sudden movement)", "Questionnaire about factors affecting contact with machinery/equipment moving parts (including trapped between objects)", "Questionnaire about factors affecting Lost buoyancy in water due to the activity" and "Questionnaire about factors affecting fire or explosion (including confined spaces)"**.**

- Step 7 – Rating of the possibility factors identified using the fuzzy linguistic variable "adequacy" (see table 5.1).

- Step 8 – Estimation of the possibility of occurrence of the accident mode in a construction site by using the specialized aggregation operator Fuzzy-OR (see eq. 12).

- Step 9 - For each accident mode, estimation of the expected severity, by the use of the linguistic variables depicted on figures 5.5 to 5.12 (taken into account the site work conditions).

- Step 10 - For each accident mode, identification of the safety barriers implemented on site, by safety barriers type, namely: Physical (or material), Functional, Symbolic and Incorporeal.

- Step 11 – Rating the safety barriers effectiveness using the fuzzy linguistic variable "effectiveness" (see table 5.2). The analyst should check key points, namely: (1) safety barriers design – including interfaces and work modifications that were required, (2) checking/supervision of construction and installation, (3) human factors for safety barriers operation and maintenance – availability, commitment and competence of personnel, (4) inspections and maintenance programs, (5) supervision of maintenance tasks, (6) safety barriers management – including communication and coordination, conflict resolution and the existence of spares (when required) and (7) fullfillment of the apllied regulations.

- Step 12 - For each accident mode, estimation of the effectiveness of the safety barriers implemented on site, by using the specialized aggregation operator Hammacher-OR (see eq. 10).

- Step 13 – For each accident mode, perform the risk level final evaluation on construction site, by aggregating the four dimensions using an average aggregation operator Fuzzy-AND (see eq. 8).

- Step 14 –Conclusions& recommendations **-** For each accident mode, identify the factors to be improved firstly which are the ones found to be “inadequate”, then the “low adequate” and so on. This is, should be prioritized, by descending order of aggressiveness, the factors potentially more aggressive for workers safety (and safety barriers against them must be advised).

## 5.2. Linguistic variables for rating risk factors

To assess the contributing risk factors that are included in each dimension of QRAM, ten linguistic variables (Zimmermann 1996) were built. One is “Adequacy”, which allows rating the factors to assess in safety climate and in possibility of work accident. The second linguistic variable is “SB-effectiveness” which allows rating the factors included in the safety barriers dimension. These two variables provide a scale for the analyst to perform the elicitation of the ratings for the risk factors. The other eight are used to estimate the expected severity of work accidents, in a graphic way (see figures 5.5 to 5.12).

To determine the greater or lesser degree of adequacy (in terms of fitness for the intended purpose) of each factor that contributes to the safety climate and possibility (of work accident) factors, was defined the linguistic variable “Adequacy”. This linguistic variable includes six semantic terms that are represented by triangular membership functions, as shown in figure 2. The semantic terms and the respective domain intervals for the membership functions are:

- “inadequate”, domain [0.0, 0.2];
- “low adequate”, domain [0.0, 0.4];
- “almost adequate”, domain [0.2, 0.6];
- “adequate”, domain [0.4, 0.8];
- “very adequate”, domain [0.6, 1.0];
- “strongly adequate”, domain [0.8, 1.0].

The main advantage of using semantic terms is that it allows a more user-friendly elicitation of knowledge because the checklists are answered semantically.

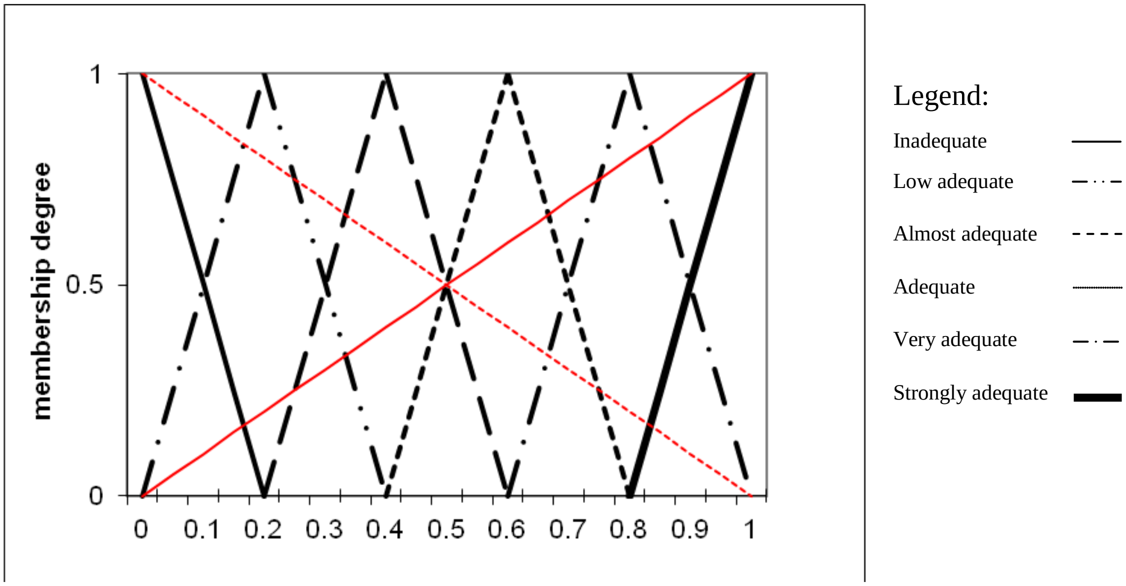


Figure 5.2. Linguistic variable "Adequacy"

As can be observed, it was defined continuous membership functions for each term of the linguistic variable "Adequacy". However, to simplify the rating and calculation process the conversion method proposed by Cheng and Hwang (1992), is used to discretize the fuzzy terms of the linguistic variable "Adequacy". Information loss resulting from this discretization does not significantly affect the assessment results, as shown in the interesting application of Simões-Marques (1999). This discretization process is as follows. First, it consider two fuzzy linear functions, a maximizing one $\mu_{max}(x)$ (eq. 4 - see red line on figure 5.2) and a minimizing one $\mu_{min}(x)$ (eq. 5 - see red dotted line on figure 5.2). Second, it is determined the values of the intersection of the left side (E) of each linguistic term with the minimizer and the right side (D) of each linguistic variable term with the maximizer.

$$\mu_E(A) = \sup_x[\mu_A(x) \wedge \mu_{\min}(x)] \qquad \text{(eq. 4)}$$

and

$$\mu_D(A) = \sup_x[\mu_A(x) \wedge \mu_{\max}(x)] \qquad \text{(eq. 5)}$$

And, finally, the membership grade for each semantic term (see table 5.1) is obtained through the expression:

$$\mu_T(A) = [\mu_D(A) + 1 - \mu_E(A)]/2 \qquad \text{(eq. 6)}$$

From the above discretization process, the set of discrete terms that will be used in the linguistic variable "Adequacy", as well as their meaning and respective membership values, is shown in table 5.1. The inverted logic of using low memberships for the most adequate factors is due to the fact that for risks the lower the better (e.g. 0 membership means absence of threats to safety).

Table 5.1 – Linguistic variable “Adequacy” for assess accident´s possibility and

safety climate influencing factors

| Semantic term | Meaning | Membership grade (1-µ) |
|---|---|---|
| Strongly adequate | All factors are controlled by effective and reliable, in any event, safety measures (best practices and/or other relevant conditions apply). | 0.06 |
| Very adequate | All factors are controlled by effective and reliable safety measures (best practices and/or other relevant conditions apply). | 0.21 |
| Adequate | Safety measures are sufficient for the requirements. | 0.41 |
| Almost adequate | Some factors are not well controlled. Accidents can occur. Safety measures should be improved. | 0.56 |
| Low adequate | Some factors are not controlled. Accidents are likely to occur. Safety measures do exist but are not really effective. Safety measures are insufficient for the requirements. | 0.78 |
| Inadequate | Some factors are out of control. Accidents are likely to occur frequently (incidents are continuously experienced). Safety measures do not fit the requirements. | 0.94 |

The use of negation membership values makes possible to obtain a kind of “direct” estimate for the possibility of accidents occurrence, where 0 corresponds to the impossibility of occurring accidents (i.e. the factors are strongly adequate) and 1 corresponds to high possibility of occurrence (i.e. factors are inadequate). In this fashion, we are able to convey the logic of considering that “strongly adequate” implies very low (membership grade = 0.06) possibility of occurring accidents. Conversely, inadequate factors (membership grade = 0.94) are the ones that most contribute to the accident occurrence possibility.

It is important to note if the possibility of occurrence of work accident s or the safety climate adequacy on site is “inadequate” it means the risk of accident is high, hence we use the negation values to express how the factors affecting negatively the possibility of occurrence (e.g. “low adequate” means “high” possibility of occurrence, hence its membership grade is 0.78 –see table 5.1).

Another linguistic variable defined in this work is “SB-effectiveness”, used for assessing SB. To build this linguistic variable, the same discretization process - as for “Adequacy” - was used and the details about the SB-effectiveness linguist variable are shown in table 5.2

Safety barrier types are always related to a hazard and/or an accident sequence, in a preventive and/or protective way. Given their diversity and their specific characteristics, their assessment cannot be performed based solely on specific and strictly objective criteria but should also include some qualitative (subjective) assessments, i.e. SB assessment should also rely on safety expert knowledge and experience as well as on the knowledge of the risks´ characteristics.

Table 5.2 – Linguistic variable “SB-Effectiveness” for assess safety barriers effectiveness

| Semantic term | Meaning | Membership grade (1-μ) |
|---|---|---|
| Excellent | The safety barrier is adequate, is well built and works effectively in a very reliable way (takes into account workers expected bad practices) and is robust. | 0.06 |
| Very good | The safety barrier is adequate, is well built and works effectively, in a very reliable way (takes into account workers expected bad practices) and is robust, but requires umpteen resources to be implemented and/or maintained. | 0.21 |
| Good | The safety barrier is adequate, is well built and works effectively (takes into account workers expected bad practices) but is intrusive or its robustness is not assured in some extreme events (e.g., fire). | 0.41 |
| Partial | The safety barrier is not effective enough or there are doubts about its reliability (e.g. depends on humans in order to achieve its purpose). | 0.56 |
| Insufficient | The safety barrier did not perform always as expected or includes shortcomings that could make it unreliable. | 0.78 |
| Bad | The safety barrier is ineffective (do not achieve its purpose) or could have a counter-effect (increased other risks in some way or could creates new risks). | 0.94 |

The main criteria that should be considered for SB assessment (Hollnagel, 2004 and Taylor, 1988 cited in Sklet, 2006) are: fitness to the purpose, fitness for usage, reliability, proper implementation, ease of comprehension (for symbolic barriers), knowledge of their applicability (for incorporeal barriers), robustness, functionality, response time, etc.

An interesting definition of SB effectiveness is the ability (of a safety barrier) to perform a safety function during a period, in a non-degraded mode and in pre-specified conditions (Andersen et al., 2004). In this work the definition of effectiveness applied to SB has a broader scope and includes the adequacy, reliability, robustness and specificity in order to produce the intended (or expected) result. Hence, here the definition is: “effectiveness” evaluates the ability of a SB to achieve its purpose, when it is needed and how well it can withstand the variability of the environment and not lead to other accidents.

Was followed the criteria and evaluation levels defined by Hollnagel (2008), about how barriers systems can achieve their purpose (see table 3). The set of 8 attributes according to Hollnagel (2008) are: 1) Efficiency, which means “how well the SB meets its intended purpose”, 2) Resources (cost), which means “what is needed to design, develop, implement and maintain a SB”, 3) Robustness (reliability), which means “how well a SB can withstand the variability of the (work) environment”, 4) Implementation delay, which means “the time interval from conception to implementation of a SB”, 5) Applicable to safety critical tasks, which means “is a proper solution to risks on critical tasks”, 6) Availability, which means “whether a SB can fulfill its purpose when needed”, 7) Evaluation, which means “how easy it is to determine whether a SB works as expected, both during design and actual use”, and 8) Independence on humans (during operation), which means: “the extent to which a barrier does not depends on human actions to achieve its purpose”.

It should be noted that for some types of safety barriers, not all the above criteria are relevant or necessary in order to describe the barrier effectiveness. Hollnagel (2008) used a linguistic scale with eleven different semantic terms to evaluate the SB types regarding the set of 8 attributes, just described, as shown in table 5.3. However, it can be observed that some of the terms are similar in terms of attributes classification. For example: 1) "high" in criteria Efficiency is similar to both "short" in Implementation-delay and "easy" in Evaluation (because they represent the same concept in terms of importance or weight of safety barriers), 2) "medium-high" and "low-high" have similar meaning when related with Robustness and Availability, respectively, 3) "medium" has no similar terms, 4) "low-medium" and "medium-long" again express the same concept in terms of importance for Resource-needs and Implementation-delay, respectively and, 5) "low", "long" and "difficult" have the same meaning for Efficiency, Implementation-delay and Evaluation, respectively.

Due to the described similarity between the semantic terms for evaluating the 8 criteria of Hollnagel (2008), regarding the different types of safety barriers, a fuzzy approach is used to simplify the process. This fuzzification process implies the creation of a fuzzy membership function (Zimmerman, 1993) to represent the importance scale. The defined discrete fuzzy set is:

**IMPORTANCE-SCALE**= [high/1, medium-high/0.8, medium/0.6, low-medium/0.4, low/0.2, uncertain/0].

The numerical values used in the membership function, took in consideration an equal division of the [0-1] scale for the 5 discriminative linguistic terms of Hollnagel (2008). It should be noted that here it is assumed that "uncertain" is outside the fuzzy function (value 0) because there is no knowledge about its degree of belonging (i.e. it does not belong with any degree to the defined fuzzy set), while with probabilities this value would be 0.5.

Using the fuzzy set "importance–scale" to evaluate each SB type it allow to determine their final importance/weight by using a simple averaging operator, as depicted in table 5.3. The calculation of the SB-Importance (i.e. weight of each safety barrier type) is the first step to estimate SB´s effectiveness; the remaining steps to determine the SB effectiveness are described in section 5.9.

Table 5.3 – SB types' evaluation, according to Hollnagel (2008) and its fuzzification

| **Criteria** | **Safety Barriers Types** | | | |
|---|---|---|---|---|
| | **Physical (Ling term/ Membership)** | **Functional (Ling term/ Membership)** | **Symbolic (Ling term/ Membership)** | **Incorporeal (Ling term/ Membership)** |
| Efficiency | High/1 | High/1 | Medium/0.6 | Low/0.2 |
| Resource needs | Medium–high/0.8 | Low–medium/0.4 | Low–medium/0.4 | Low/0.2 |
| Robustness | Medium–high/0.8 | Medium–high/0.8 | Low–medium/0.4 | Low/0.2 |
| Implementation delay | Long/0.2 | Medium–long/0.4 | Medium/0.6 | Short/1 |
| Applicable to safety critical tasks | Low/0.2 | Medium 0.6 | Low/0.2 | Low/0.2 |
| Availability | High/1 | Low–high/0.8 | High/1 | Uncertain/0 |
| Evaluation | Easy/1 | Difficult/0.2 | Difficult/0.2 | Difficult/0.2 |
| Independence on humans | High/1 | High/1 | Low/0.2 | Low/0.2 |
| **SB-IMPORTANCE** | **0.75** | **0.65** | **0.45** | **0.27** |

It should be noted that Hollnagel (2008) evaluation included both Personal Protective Equipment's (PPE) and collective protection devices in the physical type. However, these two types of equipment's have significant differences regarding efficiency, availability and independence on humans – hence they should not have been included in the same group. The SB-effectiveness linguist variable that was proposed in table 5.2, takes into account this aspect (the higher rating for SBs that depends on humans in order to achieve its purpose is "partial".

## 5.3. Estimating risk levels: factors aggregation

To obtain the final estimate for occupational safety risk, it is needed the aggregation of all risk factors that had been rated by the analysts using the linguistic variables. First the factors pertaining to each dimension are aggregated - to obtain a dimension estimate - and then the four dimensions are also aggregated to obtain the final occupational safety risk estimation. Any aggregation of values implies using an arithmetic or logical operator (e.g. sum, average, maximum, multiplication etc.).

Aggregation operations on fuzzy sets are operations by which several fuzzy sets are combined in some way to produce a single representative value, either fuzzy or crisp (Pedrycz and Gomide, 2007).

However, the choice of the aggregation operator is a difficult task since it is a context-based problem. There is no simple rule to choose the adequate operator among the existing variety, but Zimmerman (1993) pointed eight important criteria that can be helpful to select the appropriate operator, namely: axiomatic strength, empirical fit, adaptability, numerical efficiency, compensation, range of compensation, aggregating behavior and required scale level of membership functions. Beliakov and Warren (2001) added another criterion: semantic clarity.

In occupational safety risk assessment little is known about how the factors should be aggregated and most of the time a simple average - and many times misleading – is used. Since safety experts usually provide their perceptions about the behavior and corresponding empirical data by considering practical cases, in this work the aggregation operator was chosen by considering the most adequate qualities for risk assessment: 1) empirical fitness, 2) adaptability, and 3) semantic clarity. The reasoning used regarding these qualities are:

1. Empirical fitness - The value 1 (one) corresponds to a very high risky situations (or to a factors that may cause these situations) and the value 0 (zero) corresponds to an absence of risk (or to a factors that may cause these situations);

2. Adaptability - The aggregation of the membership degrees of the various factors should generate a synergistic effect (positive or negative, according to the case). For instance, for the SB it is needed a union operator (positive synergetic effect) to ensure that the more barriers there is less risk exists;

3. Semantic clarity - The result should allow to discriminate the factors that have contributed most negatively to the estimated risk level.

Hence, to choose the operator for aggregating the four risk dimensions, an initial comparative study was performed with intersection and union operators (min, max, multiplication and sum), which gave results inconsistent with the reality perceived by the experts. After, a more in-depth comparative study was done with parametric operators, to assess their suitability. SB dimension, due to the synergistic effect, proved to be the most complex. The comparative study uses nine different combinations of evaluations for the four types of SB as depicted in Table 5.4.

From the comparative study performed, the “Fuzzy-AND” (see equation 7), “Hammacher-OR” (see equation 9) and “Fuzzy-OR” (see equation 11) operators, seemed the most appropriate to model the reality of safety risk on construction sites. Next, it will be provided a brief background for the parametric operators compared and how the tests were performed for selecting the most suitable operators for QRAM.

Next it is explained the selection of operator for aggregating the factors - for the dimension SB effectiveness; the other three dimensions followed the same rational.

For SBs effectiveness, it needs an operator from the class of “Union” (OR) because it want to express a synergistic positive effect. A positive synergy allows expressing the added value of having more than 1 SB type in construction sites, i.e. if we have two SB in a site their “sum/combination” should be bigger than their simple arithmetic sum operator. An example is: if we have two “good” SB then their combination should be a little better than just “good”. From the most well-known union operators we tested the following: “Max”, “Yager”, “Dubois&Prade”, “Hamacher-OR” and “Fuzzy–OR” (Zimmerman, 1993). In summary, the union operator selection took in consideration the fact that having multiple SB behaves like a set of protective layers whose result should always be better than the worst barrier. So, observing table 5.4 it is clear that:

1. The “Yager” operator does not fit because it is not sufficiently discriminative (e.g. only cases 3 and 6 have aggregated effectiveness levels different from 1);

2. The “Max” operator does not display any synergetic effect, i.e. it always chooses the highest classification achieved for all 9 cases disregarding any compensation for having more than one with good classification;

3. If all the SB is “excellent” the result should be higher than the average. “Yager”, “Dubois&Prade” and “Hamacher-OR” operators fit this empirical knowledge (case 1=1);

4. If all barriers are “bad”, the result should be “insufficient” but should encompass the added value (synergetic effect) because a set of four bad SB have a better performance than one single bad SB. In this case only the “Hamacher-OR” operator fit this empirical knowledge (case 3=0.22);

5. If the four barriers are “good”, the result should be “excellent” (though somewhat less excellent than four “excellent”). Again only the “Hamacher-OR” operator fit the empirical knowledge (case 4=0.96);

6. If it has two barriers “partial” and two barriers “bad”, the result should be “good” due to the synergistic effect of this combination of SB working together, resulting in a “good” performance. In this case only the “Hamacher-OR” operator fit (case 6 = 0.69), since “Yager” results in “excellent” level (0.94) and the others results in “partial” level (0.41);

7. If it have two barriers “excellent” and two barriers “bad”, the result should continue to be “excellent” but with a slight added reward (synergistic effect of two “excellent” SB) . “Yager” and “Hamacher-OR” operator fit this requirement (case 8=1);

8. If we have one barrier “excellent” and three barriers “bad”, the result should still be “excellent” but with a lesser degree because the safety level decreases a little, i.e. in this case the result should be somewhat less excellent than the previous one (point 7). “Dubois&Prade”, “Hamacher-OR” and “Fuzzy-OR” operators fit this empirical knowledge and present an adequate discriminative effect (0.94 and 0.95 in case 9).

Table 5.4 – Aggregation operators comparative study results

| | **SB Effectiveness** | | | | **Aggregation operators** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Case** | **Physical** | **Functional** | **Symbolic** | **Incorporeal** | **Yager** | **Dubois &Prade** | **Hamacher -OR** | **Fuzzy-OR** | **Max** |
| 1 | Excellent /0.94 | Excellent /0.94 | Excellent /0.94 | Excellent /0.94 | 1.00 | 1.00 | 1.00 | 0.94 | 0.94 |
| 2 | Very good /0.78 | Very good /0.78 | Very good /0.78 | Very good /0.78 | 1.00 | 0.98 | 1.00 | 0.78 | 0.78 |
| 3 | Bad/0.06 | Bad/0.06 | Bad/0.06 | Bad/0.06 | 0.24 | 0.06 | 0.22 | 0.06 | 0.06 |
| 4 | Good/0.56 | Good/0.56 | Good/0.56 | Good/0.56 | 1.00 | 0.70 | 0.96 | 0.56 | 0.56 |
| 5 | Partial/0.41 | Partial/0.41 | Partial/0.41 | Partial/0.41 | 1.00 | 0.41 | 0.88 | 0.41 | 0.41 |
| 6 | Partial/0.41 | Partial/0.41 | Bad/0.06 | Bad/0.06 | 0.94 | 0.41 | 0.69 | 0.41 | 0.41 |
| 7 | Good/0.56 | Good/0.56 | Bad/0.06 | Bad/0.06 | 1.00 | 0.61 | 0.83 | 0.56 | 0.56 |
| 8 | Excellent /0.94 | Excellent /0.94 | Bad/0.06 | Bad/0.06 | 1.00 | 0.99 | 1.00 | 0.94 | 0.94 |
| 9 | Excellent /0.94 | Bad/0.06 | Bad/0.06 | Bad/0.06 | 1.00 | 0.94 | 0.95 | 0.94 | 0.94 |

From the observations made on points 1-8 above, it is clear that Hammacher union operator (Hammacher-OR) is the one that best answers the quality criteria for SB effectiveness estimation and, consequently, it is the one selected for our tool.

The aggregation operator "Fuzzy-AND" was first suggested by Werners (1984) (in Zimmerman, 1993) is a parametric fuzzy operator which results vary between the min operator and the arithmetic mean.

$$O_{and}(\mu_A(x),\mu_B(x)) = \gamma.\min(\mu_A(x),\mu_B(x)) + \frac{(1-\gamma).(\mu_A(x)+\mu_B(x))}{2} \qquad \text{(eq. 7)}$$

$$x \in X, \gamma \in [0,1]$$

In QRAM this operator is used for aggregating the four dimensions, such as

$$O_{and}(\mu_i(x)) = \gamma.\min_{i=1}^{4}(\mu_i(x)) + \frac{(1-\gamma).(\sum_{i=1}^{4}\mu_i(x))}{4} \qquad \text{(eq. 8)}$$

$$x \in X, \gamma \in [0,1]$$

Formally, the Hammacher-OR operator is (Zimmerman, 1993):

$$O_{Ham}(x) = \frac{(1-\gamma^{'})\mu_A(x).\mu_B(x)+\mu_A(x)+\mu_B(x)}{1+\gamma^{'}.\mu_A(x).\mu_B(x)}$$

$$x \in X, \gamma^{'} \in [-1,+\infty] \qquad \text{(eq. 9)}$$

However, since we also need to incorporate the relative importance for each SB type, as described in section 5.3, it was selected the version with relative importance weighting, such as:

$$O_{Ham}(x) = \frac{(1-\gamma^{'})w_A\mu_A(x).w_B\mu_B(x) + w_A\mu_A(x) + w_B\mu_B(x)}{1+\gamma^{'}.w_A\mu_A(x).w_B\mu_B(x)}$$
$$x \in X, \gamma \in [-1, +\infty]$$

(eq. 10)

For the safety climate and possibility of work accident occurrence it was also chosen, for the same reasons, the “Fuzzy-OR” operator.

The aggregation operator “Fuzzy-OR” first suggested by Werners (1984) (in Zimmerman, 1993) is a parametric fuzzy operator which results vary between the maximum operator and the arithmetic mean. This operator produces good results in decision environments, where empirical human decision performs well.

$$O_{or}(\mu_A(x), \mu_B(x)) = \gamma.\max(\mu_A(x), \mu_B(x)) + \frac{(1-\gamma).(\mu_A(x) + \mu_B(x))}{2} \qquad \text{(eq. 11)}$$
$$x \in X, \gamma \in [0,1]$$

Or, generalized to n factors

$$O_{or}(\mu_i(x)) = \gamma.\max_{i=1}^{n}(\mu_i(x)) + \frac{(1-\gamma).(\sum_{i=1}^{n}\mu_i(x))}{n} \qquad \text{(eq. 12)}$$
$$x \in X, \gamma \in [0,1]$$

This operator allows compensation between the membership values of the aggregated membership values, in which the parameter $\gamma$ indicates the degree of nearness to one of the operators. In the boundaries of this operator, when $\gamma = 1$ the “Fuzzy-OR” becomes the “max” operator and for $\gamma = 0$ becomes the arithmetic mean (in Zimmerman, 1993).

Concluding, in this thesis the Fuzzy-OR operator was chosen, for aggregating the risk factors in the first and third dimensions (safety climate and possibility), because it allows (with an appropriate $\gamma$) appropriate discrimination of the most inadequate factors.

By trial and error, with the collaboration of the safety experts were chosen the following parameter ($\gamma$) values:

Fuzzy-OR (eq. 12) - $\gamma$ =0.4 (to aggregate factors from the first and third dimensions);

Hammacher-OR (eq. 10) - $\gamma$ =0.98 (to aggregate factors from the fourth dimension);

Fuzzy-AND (eq. 8) - $\gamma$ =0.4 (to aggregate the four dimensions to estimate the risk level);

## 5.4. Insight about Qualitative Risk Assessment model results

Usually safety practitioner's main concern when performing RAOS is to obtain a value for the risk to rank the different risks. Usually they do not exploit correlations among risk-reducing opportunities, based on risk factors. As a result, they generally make suboptimal risk management recommendations. Cox (2009) stated that **"**priority lists do not generally produce effective risk management decisions".

Cox (2009) also stated that the calculation of an absolute value to rank risks is unnecessary, if the RAOS aim is to decide about risk acceptability and select risk-reduction measures and can distract safety practitioners from the main aim of the RAOS process: to decide about occupational risk acceptability and recommend adequate measures for risk control and management.

So, RAOS methods should have a tool/metric by which the results of a risk analysis can be translated into recommendations on the risks tolerability and respective improve actions.

QRAM follows the rational of the ALARP (As Low a level As Reasonably Practicable) framework (Melchers, 2001) for "decoding" the results obtained with QRAM and make them useful for the safety practioners to improve their sites' safety. The ALARP principle is that "the residual risk shall be as low as reasonably practicable", derived from the Health and Safety at Work Act 1974, which requires "provision and maintenance of plant and systems of work that are, as far as is reasonably practicable, safe and without risks to health" (Melchers, 2001).

The key concept in determining whether a risk is ALARP is the definition of "reasonably practicable". This term was established, in the UK, by a court of law (in 1949, with the case of Edwards vs. National Coal Board). This determination meaning is that risks must be averted (avoided, protected or controlled by other adequate way) unless there is a gross disproportion between the costs and the benefits of doing so.

The ALARP approach requires.site safety managers to demonstrate that: 1) the site is fit for its intended purposes, 2) the risks associated with its functioning are sufficiently low and, 3) sufficient safety and emergency measures have been instituted (or are proposed). At the top of ALARP framework are risks that are unacceptable whatever are the benefits associated with the activity. Any legal requirements that are not meet are always unacceptable. At the bottom are risks that are broadly acceptable and can be regarded as insignificant and adequately controlled. Between these two areas of risk is the tolerable (ALARP) region within which risks need to be reduced to "as low as reasonably practicable".

The region between the upper bound for tolerability, the basic safety limit (BSL), and the lower target level, the basic safety objective (BSO), is the so-called ALARP region (French et al., 2005). When risks are in the ALARP area a "dynamics" to identify best practice to decrease risk level should be created, and then seek to ensure that it becomes the general practice at site in order to decrease risk level to the acceptable region.

So, an acceptable risk means that it does not be regarded as negligible or something that can be ignored, but rather as something that needs to be keeping under review and reduced still further if and when and how it is possible.

ALARP limits are established by empirical knowledge; QRAM results consider 3 regions for the risk values obtained: acceptable (below 0.30), ALARP (between 0.30 and 0.70, including these values) and unacceptable (above 0.70). These three regions were determined by analysis of the QRAM features and expert opinions.

Although risk control is out of scope in this thesis (is part of risk management), the aim of risk assessment is to determine and implement safety barriers to lower the risk level. Hence, when evaluating existing SBs, or considering changes to such controls, consideration should be given to measures that reduce the likelihood of harm, or to measures that reduce the severity of harm, or a combination of the two. The following hierarchy should be applied (according to BS 8800:2004):

1. If practicable, eliminate hazards altogether, or combat risks at source, e.g. use a safe substance instead of a dangerous one.

2. If elimination is not practicable, try to reduce the risk at source, e.g. by use of low voltage electrical appliances; introduce machinery guards.

3. Finally, reduce risk via procedures and safe systems of work, adopting PPE only as a last resource, after all other safety barriers had been considered.

As mentioned before, to further discuss measures to reduce the risks and improve site safety is outside the scope of this thesis hence no more details are provided here.

## 5.5. Safety Climate Adequacy: First dimension

Budworth (1997) calls the measurement of safety climate as taking the ‘‘safety temperature’’ of a company. Safety Climate importance lies in facilitating or impeding the maintenance of safety barriers and consequently the management of safety risks, i.e., safety climate factors are not direct agents in the occurrence of work accidents but create the conditions for accidents happening. Neal et al. (2000) stated that the safety climate is a variable between organizational climate and safety performance.

In the last dozen years, studies addressed the development of safety climate measures and supported safety climate relevance. For instance, Varonen and Matilla (2000) identified a structure for safety climate (measured by means of a questionnaire in wood-processing industry), based on: perceptions of workers; correlations between the safety climate and the safety practices of the company; safety level of the work environment; and occupational accidents. They concluded that the better the safety climate of the company was, the lower was the accident rate. In another study, Muniz et al. (2005) demonstrated the key role that company manager’s play in the promotion of employees’ safe behavior, both directly through their attitudes and behaviors, and indirectly by developing a safety management system. Zohar and Luria (2005) developed a multilevel model to appraise the safety climate, based on a multilevel-of-analysis which interprets safety climate as a convergent level of adjusted perceptions or appraisals of relevant policies, procedures and practices as indicators of desired role behavior, indicating that the organization-level and group-level climates are globally aligned, and the effect of organization climate on safety behavior is fully mediated by group climate level.

Literature on construction-industry accidents reveals that the factors influencing the incidence of accidents are generally similar in many countries and pointed that inadequate safety measures and poor safety awareness (by both workers and management) are the major reasons for the high incidence of occupational accidents in this industry (McVittie et al., 1997; Sawacha et al., 1999; Abdelhamid and Everett, 2000; Tam et al., 2004; Chi et al., 2005; Macedo and Silva, 2005; Aksorn and Hadikusumo, 2008).

According to Mohamed (2002) safe work behaviors (in construction) are consequence of the existing safety climate, which, in turn, is determined by the identified independent constructs. Likewise, Larsson (2005) found, that a positive safety climate and supportive psychological climate in construction industry are rather important for safety. So, safety climate may provide indications of workers safety behavior, originating simultaneously from policy and procedural actions of top management and from supervisory actions exhibited by frontline supervisors. It provides a “measure” of the workforce’s perception on attitudes towards safety within the organizational atmosphere (at a given point in time, like the overall risk assessment).

Therefore, as stated by Dedobbeleer and Beland (1991) factors related to safety climate should be considered (and measured) on RAOS processes. This work also advocates this posture, thus safety climate factors are considered in QRAM. Specifically, safety climate dimension is grounded in the Safety Climate model of Mohamed (Mohamed, 2002), which was developed for construction sites and is based on 11 sets of factors: management commitment, communication, safety rules and procedures, supportive environment, supervisory environment, workers’ involvement, personal appreciation of risk, appraisal of work environment, work pressure, safe work behavior and competence.

### 5.5.1. Safety Climate Adequacy Formal Model

The Mohamed (2002) model was adapted for the QRAM SC dimension by introducing other conclusions of subsequent works (namely, Mearns et al., 2004; Larsson, 2005, Zohar and Luria, 2005; Muniz et al., 2005; Lingard et al., 2011) and empirical knowledge of six Portuguese safety expert. The adapted safety climate aspects rely on three aspects: workers, management and safety work environment and each one has its own subset of factors divided in groups.

The expert knowledge was elicited from a pole of six Portuguese safety experts on construction, with ten or more years of experience, using a guided brainstorming to assess whether: a) the set of factors is feasible in construction industry (time spent and available data), b) usefulness of evaluate safety climate and, c) the chosen set of factors give a correct picture of safety climate on site. At the end of this process a set of safety climate factors were identified as being enough and critical. These factors are related to workers, to management and safety work environment and are discussed below. Figure 5.3 depicts the architecture of the safety climate dimension, which includes the number of factors (posed as questions) for each parameter to be considered in this QRAM dimension.

The SC dimension formal model is:

$$S_C = \theta_{Or}(\overset{8}{\underset{1}{S_R}}, \overset{7}{\underset{1}{C}}, \overset{9}{\underset{1}{B}}, \overset{16}{\underset{1}{M_C}}, \overset{13}{\underset{1}{L}}, \overset{12}{\underset{1}{CP}}, \overset{8}{\underset{1}{S_E}}, \overset{10}{\underset{1}{S_P}}, \overset{9}{\underset{1}{P}}, \overset{9}{\underset{1}{S_M}}) \qquad \text{(eq. 13)}$$

Where: each of the ten composing parameters are depicted with subscript and superscript indexes to indicate the number of factors included in each of them (1,…,n).

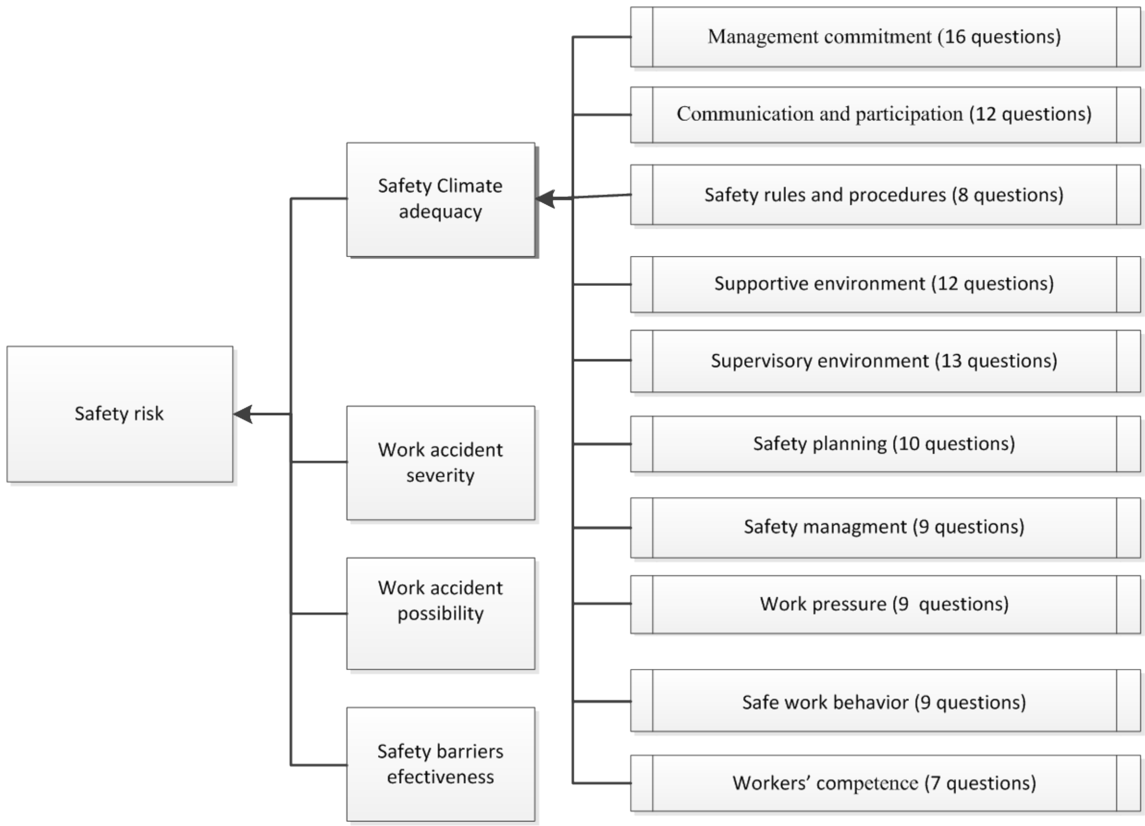


Figure 5.3. Safety Climate Adequacy

The parameters are:

**Safety Climate factors related to workers -** Workers' involvement is an important aspect in maintaining safety barriers. It should include procedures for reporting incidents and potentially hazardous situations. Here it is considered three classes of parameters: Safety rules and procedures; Worker´s competence; and Safe work behavior. Each parameter includes several factors that are evaluated, as above described with linguistic variables and are posed as questions to the safety experts to elicit the evaluation.

- **Safety Rules and Procedures** - This parameter evaluates the extent to which workers perceive safety rules and procedures as promoted and implemented by the organization. It includes eight factors (questions to be evaluated) which are shown in annex I.1.

- **Workers' Competence** – This parameter evaluates workers experience and knowledge of safety issues (Burke et al., 2002). It includes seven factors which are shown in annex I.2.

- **Safe Work Behavior -** This parameter evaluates, by observable actions and opinions, the workers behavior related to safety. It includes nine factors to be evaluated which are shown in annex I.3.

**Safety Climate factors related to management -** Management's commitment is an important element of the safety climate due to its role beyond organizing and providing safety resources, policies and working instructions. The greater the level of management commitment toward safety is, the more positive is the safety climate. This aspect includes two classes: Management commitment and Supervisory action towards safety.

- **Management Commitment -** This parameter evaluates the role that management plays in promoting safety. It includes sixteen factors which are shown in annex I.4.

- **Supervisory Action Towards Safety -** This parameter evaluates the ability of supervisors to ensure that safety rules and procedures are carried out during daily operations. It includes thirteen factors which are shown in annex I.5.

**Safety Climate factors related to safety environment -** Environment refers to the degree of trust and support within a group of workers (confidence that people have in working relationships with coworkers), the safety planning and management (tidy and well planned sites are more likely to provide a high level of safety performance), the degree to which employees feel under pressure to complete the work and the ways of formal and informal means of communication to promote and communicate its commitment and issues regarding safety. It can be seen as a "measure" of general morale (Mearns et al., 2004; Muniz et al., 2007).

- **Communication and Participation -** This parameter evaluates the effectiveness of communication and participation efforts. It includes twelve factors, suggested by Muniz et al. (2007), which are shown in annex I.6.

- **Supportive Environment -** This parameter evaluates the degree of trust and support within a group of workers, i.e. the confidence that people have in working relationships with coworkers and general morale. It includes eight factors which are shown in annex I.7.

- **Safety planning -** This parameter evaluates the level of safety's integration in the work planning to identify and control safety hazards. It includes ten factors, suggested by Mearns et al. (2004),, which are shown in annex I.8.

- **Work Pressure over Safety -** This parameter evaluates the workers perception of valuing expediency over safety when working under pressure. It includes nine factors which are shown in annex I.9.

- **Safety Management System -** This parameter evaluates the safety's integration in the overall management to maintain safe conditions on site. It includes nine factors, suggested by (Mearns et al., 2004), which are shown in annex I.10.

To elicit the evaluation for each composing factor (question) that define the safety climate (see eq. 13), the analyst, uses the "adequacy" linguistic variable choosing the grade that best suits the factor under analysis (see table 5.1), and then the corresponding grades are aggregated using the Fuzzy-OR operator (see eq. 11). With this aggregation it is obtained an estimate for the safety climate adequacy. In general, if the final value obtained for safety climate is close to 1 (one) it corresponds to a good safety climate and a value close to 0 (zero) corresponds to a bad safety climate. The same logic applies to each individual parameter of the SC.

### 5.5.2. Dimension discussion

Although there are several tools for assess the safety climate on construction sites, as mentioned on section 5.5, the QRAM model extended and systematized existing works. Further it also proposed a uniform evaluation scale for rating the adequacy of each factor, the linguistic variable "adequacy", which facilitates the elicitation and assessment of this dimension.

A critic to this dimension of QRAM – pointed during the evaluation tests made to the whole model (by some experts) - was that safety climate had too many questions and this is in line with the opinion of the reviewers of the paper submitted to the Safety Science journal (still in the review process). With these opinions the model must be reformulated and approximately 40% of the factors could be removed. In this chapter we show the original questionnaire because it was the one that was used to mader the QRAM evaluation tests (as described in the chapter 6).

Another critic made by the experts relates with the questions "form" since some were made in the positive (example: are tools equipped with the appropriate and properly mounted handles?) and others in the negative (example: are there (on site) poorly designed handles/grips?). On future work this aspect will be improved by having all questions in the same positive direction, thus making the questionnaire more user-friendly.

## 5.6. Severity Factors: Second dimension

In RAOS, assessing risk always has an element of subjectivity. A bad judgment about a risk level will result in false alarms and inappropriate preventive actions or, in the worst cases, no action at all. Estimate the expected severity grade is an important component of judging occupational risks and in QRAM it is one of the four essential dimensions considered.

The notion of severity is useful for understanding occupational risks and mitigating them. However, as soon as one delves deeper into the question in terms of specific cases, it becomes obvious that it is rather difficult to estimate the severity factors and respective severity levels because of: 1) the existing multiplicity of possible consequences for a given accident and, 2) the diversity of points of view regarding possible severity assessments (potential victims, actual victims, medical staff (physicians), workers, managerial staff and safety managers). The apparently simple and easily applicable notion of conducting a severity assessment of an accident becomes complex in practice because of the assessment's imprecision and strong dependence on the analyst's perception.

How does one estimate the severity in a proactive analysis with accuracy and in a practical way, in the construction industry? A method to estimate the level of the expected severity of potential work accidents would be of undeniable value to construction companies seeking to improve their understanding of such events. However, because an occupational accident at a construction site could cause multiple consequences of highly variable severity, it is a difficult issue to model.

To capture the multifaceted nature of work accidents consequences in the construction industry, a more complete approach involves simultaneous consideration of several measurement factors for the severity of the accidents. The measurement is no longer simple but is complex because possible correlations between the different factors must be taken into account, to the intricate nature of consequences severity be correctly addressed and not reduced to a simple juxtaposition of factors (Cuny and Lejeune, 1999).

Related works as Cuny and Lejeune (1999) use factors such as, number of days off work and degree of permanent disablement to establish precise levels on the severity scale. Gennarelli and Wodzin (2006) pointed out several dimensions of severity, including threat to life, mortality (theoretical, expected, and actual), amount of energy dissipated/absorbed, hospitalization (need for intensive care), treatment cost, treatment complexity, length of treatment, temporary and permanent disability, permanent impairment and quality of life; however, they did not establish a measurement scale. Other authors (Aneziris et al., 2008) proposed or used “coarse” scales to assess levels of consequence severity, namely: lethal injuries, nonlethal permanent injuries, and recoverable injuries. In this work, it is planned to qualitatively assess the occupational accident severity from predictors related to the amount of energy dissipated/absorbed that can be evaluated in situ, such as heights, speeds, weights, and morphology of moving vehicles, relating them with the biomechanical limits of the human body, pointed in several studies (Viano, 1989 cited in Yang, 2002; McElhaney and Myers ,1993; Prasad, 1999; Eppinger et al., 2000; Yang, 2002; Sayed et al., 2008).

In this work, were defined severity functions (also called fuzzification process) to allow a better express of the imprecise severity of work accidents. Fuzzy membership functions (Zadeh, 1965; Ross, 2004) allow easy normalization and uniformization of all data; therefore, they are usefull to estimate the work accident severity expected grade on construction sites. This fuzzification process facilitates to handling uncertainty when assess work accident severity, offering a user-friendly assessment method. In addition, since QRAM uses an overall fuzzy approach, this dimension is seamlessly integrated in the QRAM model.

In this work, the first attempt to model work accident severity was to collect and analyze statistical data of the relation between factors as heights and landing surfaces with physical consequences (body fractures, respiratory arrest, etc.). In Portugal, we contacted five insurance companies, construction associations, and the statistical bulletin of the Office of Strategy and Planning; in Brazil, we contacted Fundacentro; and in England, we contacted the Health and Safety Executive. Unfortunately it was not possible to obtain the necessary data, from any of these organizations, because there are no available statistics about physical aspects of work accidents.

A second attempt was to model work accident severity using the empirical knowledge of a group of safety experts. However, the experts disagreed about various predictors; for example, for falls, the range of results (for maximum severity depending on the height) varied between 1.2 and 4.0 m. The experts failed to agree on a commum value, and when questioned about their reasons, they failed to provide a rational explanation.

Therefore, in QRAM we followed a different approach, with a four-step process, which is detailed in the next sub-section.

## 5.6.1. Severity formal model

In this thesis a four-step process is used to define the linguistic variables for severity of accidents estimation: 1) based on the literature, it was identified a list of accident modes for occupational accident scenarios (see section 5.1), 2) it was selected the energy of related factors considered to be important in evaluating the severity of each accident mode, 3) the relationships between these factors (energies) and human biomechanical limits are considered using physical models and, 4) all severity functions associated with each accident mode are determined using fuzzy sets.

On step two, a brainstorming session, attended by two Ph.D. professors, one Ph.D. student and three M.Sc. students, all with research experience related to safety, was conducted. In the brainstorming session, the complete set of energies and other factors that could contribute to the severity of each accident mode was discussed. Then, it was identified which factors were relevant, in practice, and which predictors could characterize them and how.

Hence, the relationships between energy factors and severity were established by physics models, taking into account the biomechanical limits of human body. Then, the linguistic variables, associated with each accident mode, were developed. Severity linguistic variables expresses how serious a certain accident consequences can be, so values close to 0 corresponds to the absence of any damage (to any worker) and close to 1 correspond to the maximum severity.The rationale provided by BS 8800:2004 (BSI, 2004) was also considered to establish the meaning of the extreme harm level (severity 1): premature death or permanent major disability (fatal injuries, amputations, multiple injuries or serious fractures).

Figure 5.4 depicts the linguistic variables considered in the severity dimension of the QRAM model.

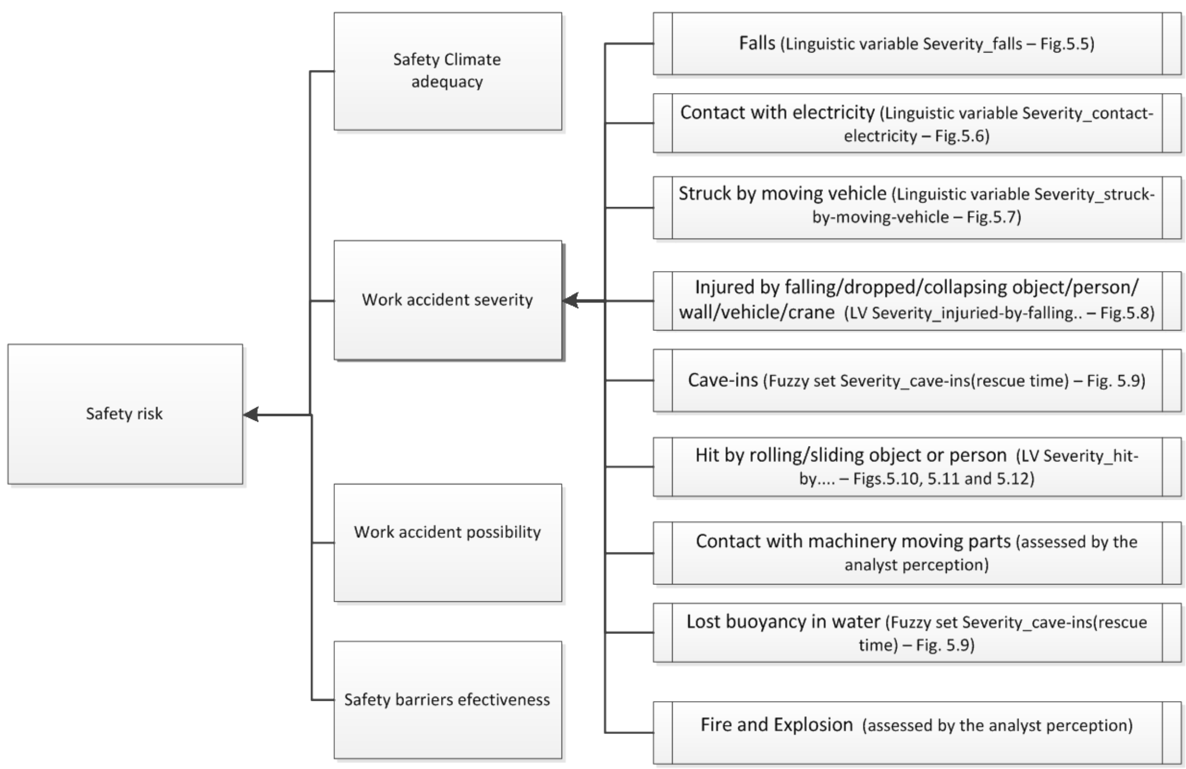


Figure 5.4 - Work accident's severity

To model the membership functions (fuzzification) for the nine accident modes it is considered the body parts most likely to be affected (e.g., neck), particularly in the case in which workers do not use any personal protective equipment. In the literature (Prasad, 1999; Eppinger et al., 2000; Chaffin et al., 2006 and Sayed et al., 2008) there are specific models for body segments that describe the severity of the consequences of an impact. Hence, this work started by compiling, from the literature, a threshold of values for the biomechanical limits of the human body in terms of injury forces for the most common different affected body parts, as follows.

**Head injury criteria:** There are several models for head injury criteria, and some models are more sophisticated than others. Some of these models use data that are hard to collect at construction sites (Sayed et al., 2008). In most studies, head injury severity is a function of the average head acceleration and its time duration (Prasad, 1999 and Eppinger et al., 2000). For head threshold limits, we will use the values depicted in table 5.5, as proposed by Yang (2002).

Table 5.5 - Head tolerances to impact loads (Yang 2002)

| **Cranial bones** | **Compression Force (kN)** |
|---|---|
| Frontal | 3.6 – 9.0 |
| Zygoma | 0.5 – 2.9 |
| Temporo-Parietal | 5.0 – 12.5 |
| Occipital | 2.0 – 4.2 |
| Maxilla/Mandible | 0.8 – 3.4 |

**Neck Injury Criteria**: In terms of peak tensile force, the limit suggested (based on available biomechanical data) by McElhaney and Myers (1993) is 3.1 kN. Eppinger et al (2000) pointed for tension forces the values of 8.216 kN (Large Sized Male – LSM) and 4.287 kN (Small Sized Female – SSF) and, for compression forces the values of 7.44 kN (LSM) and 3.88 kN (SSF).

**Chest Injury Criteria**: Viano (1989) cited by Yang (2002) pointed for thorax lateral impact injury tolerances a force of 5.5 kN.

**Femur Injury Criteria**: Eppinger et al. (2000) pointed forces values of 12.7 kN (LSM) and 6.8 kN (SSF).

**Tibia Injury Criteria**: The maximum allowable tibia compressive force (for break) could not exceed 8 kN (Mertz, 1993).

**Ventricular fibrillation (due to the passage of electrical current in the heart)**: The threshold is 40 mA, in AC current (by Standard IEC 479-1:1984).

**Rescue time:** According to Guidelines 2000 for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care (2000), the percentage of survival decreases approximately 7% to 10% with every minute that defibrillation is delayed, and after 10 minutes the probability of survival is almost 0.

As mentioned previously, the fuzzification of the severity of injuries was made by considering the 9 accident mode (see section 5.1.).

**Falls -** The severity of an injury is determined by the fall height and the impact surface (Cory and Jones, 2006). In this accident mode it is selected the neck injury because it is considered the most likely and serious injury that can occur.

Were considered two factors: a) Height of fall (it determines the velocity at the impact surface) and, b) Type of surface (given an impact velocity, it determines the magnitude of the force exerted on the fallen person).

All the physical equations referred in this section may be found in (Tipler and Mosca, 2009).

To characterize the fall event, the impact velocity is determined using:

$$V = \sqrt{2gh} \qquad \text{(eq. 14)}$$

Where $g$ is the acceleration due to gravity (9.81 m/s²), and h is the fall height.

The change in momentum during impact (I) is determined using the following equation:

$$I = mV(COR + 1) \qquad \text{(eq. 15)}$$

Where *m, V,* and *COR* are, respectively, the body mass, the impact velocity, and the coefficient of restitution of the impact surface. The *COR* is a measure of the elasticity of the surface. In falls onto a surface with a low *COR*, such as sand pile, most of the energy from the fall will be dissipated, conversely, in falls onto surfaces with a high *COR*, such as concrete, most of the fall energy will be absorbed by the body upon impact. This energy absorption typically leads to a greater risk of injury (Thompson *et al.* 2009).

As the human body limits, proposed in literature, are in terms of force**.** The change in momentum corresponds to exert a force during a certain period of time, considering that the force exerted during the time of the impact is constant (this expression is an approximation because typically, the interaction forces during impact displays a very thin Gaussian shape and therefore a peak intensity much higher than the value determined for the mean force). Formally the force formula is:

$$F_{med} = I/\Delta t \qquad \text{(eq. 16)}$$

According to Thompson et al. (2009), the impact durations ranged from 12.1 milliseconds to 27.8 milliseconds (for young children falls), and impact durations are lower for surfaces with lower coefficients of restitution. Since impact durations also depend on the object deformation, in this work we consider impact duration of 28 milliseconds for adults.

Thompson et al. (2009) proposed a *COR* of 0.39 for carpet floor, and points that this *COR* was found to be not significantly associated with injury severity. Therefore, here we consider 0.39 for sand surface (or similar) and 0.8 for concrete ground (or similar).

For sand surface, if we consider a Portuguese worker average weight is 74 kg (Barroso et al., 2005) and a compression neck injury of 7440 N (Eppinger et al, 2000), by eq. 14, 15 and 16, it follows that:

$$7440 * 28 * 10^{-3} = 1.39 * 74\sqrt{2 * 9.8 * h} \Rightarrow h = \frac{(7440 * 28 * 10^{-3})^2}{(1.39 * 74)^2 * 2 * 9.8} \Rightarrow h = 0.21 \quad m$$

Unfortunately, the resulting value of 0.21m does not match the empirical expert knowledge. Likewise considering only the head weight (which have a value of 5.0 kg, according Thorn et col.,1998), the value for the drop height is 45,3 m, which also does not match the empirical knowledge, as shown:

$$h = \frac{(7440 * 28 * 10^{-3})^2}{(1.39 * 5)^2 * 2 * 9.8} \Rightarrow h = 45.3 \quad m$$

Chafin et al (2006) refer head, neck and trunk as the main body segment and point to weight value of 31.22 kg for a 5% percentile male. Using this data, the h is 1.16 m.

The problem of concordance with the empirical knowledge may be related to the estimated time of impact. Thompson's article (2009) is not clear about the indicators used to estimate the collision times and we assumed they were for an adult.

The fall height is defined as the distance from the body's center of mass at the start of the fall to the ground. The center of mass, in the sagittal plan, is at a point equivalent to 57% of the height for males and 55% for females (Knudson, 2007). The average Portuguese worker (male) height is 1.69 m (Barroso et al., 2005), so the body mass center is at a height of 0.96 m.

Hence, in this thesis it is assumed that the fall height limit -calculated from the surface where the feet stands - is 0.20m (20 cm), which corresponds to a severity level of 1. For concrete surface, we assume that any height fall is always dangerous so severity limit 1 is considered for any fall greater than 0 cm. After all the above considerations, we propose a linguistic variable for neck injuries, denoted severity_falls-height (see fig. 5.5) with two labels, Severity_falls = [Sand-surface, Concrete_surface], where each label is represented by the following membership functions (Figure 5.5 depicts this linguistic variable):

$$\text{Sand surface} = \begin{cases} 0.05x, & 0 \le x \le 20 \\ 1, & x > 20 \end{cases} \qquad \text{(eq. 17)}$$

$$\text{Concrete surface} = \{1, \quad x \ge 0$$

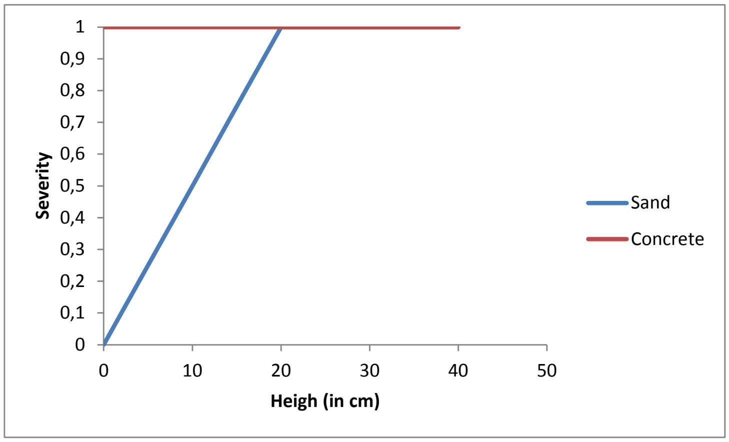


Figure 5.5 - Linguistic variable Severity_falls

There are some limitations on this falls accident severity template. The mass center of the human body can move around because joints allow the masses of body segments to move. Whereby, the change in momentum during impact was measured at the center of mass, so the change in momentum is difficult to determine accurately.

Safety experts agree, based on their experiences, that thebody point of contact is crucial to the accident severity; for example, when the worker hits with the back, severity is always greater (compared with other similar falls in height and surface), because is a helpless fall (worker cant use the arms to cushion the fall). Contact surface could also be important, especially in small falls, and obviously the severity may be different if the impact is on corners or sharp edges or iron points.

There are several other factors that could contribute to this type of injury, namely: initial body position, fall dynamics, body mass and age. However, in this work these were not considered due to the reasons given in 5.6.2.

**Contact with electricity** - For this representation we consider two factors: a) Level of voltage, and b) work environment Humidity.

The severity of electrical injuries can vary widely, from an unpleasant tingling sensation, caused by low-intensity current to thermal burns, cardiopulmonary arrest, and death. Thermal burns may result from burning clothing that is in contact with the skin or from electric current traversing a portion of the body. When current transverses the body, thermal burns may be present at the points where the current entered and exited the body and crosses internally along its pathway. Cardiopulmonary arrest is the primary cause of immediate death due to electrocution (Cooper, 1995). Cardiac arrhythmias, including: ventricular fibrillation, ventricular asystole, and ventricular tachycardia that progresses to ventricular fibrillation, may result from exposure to low or high-voltage current. Respiratory arrest may result from electrical injury to the respiratory center in the brain or from tetanic contractions or paralysis of respiratory muscles (Browne and Gaasch, 1992).

In this work, because ventricular fibrillation is the most drastic physiological effect due to the lack of human body resilience, it was used as a criterion to model the severity. As predictor, we use the tension value, in volts. As in the others accident modes, we consider that there are no protection devices.

The standard IEC 479-1:1984, states that the value of 40 mA (AC current) for the threshold of ventricular fibrillation (is the lower limit of current likely to cause the heart to cease functioning correctly, which is not a single value of current, but varies with its duration), for transit times shorter than 3 s and a probability exceeding 50% for currents of 90 mA for passage times above 5 s.

The IEC 479-1:1984 standard, also states that the impedance of the human body is voltage dependent (varies inversely as a function of the voltage applied) and path dependent (varies depending on the current path through the human body), so it depends on the current path through the human body.

However, IEEE Std 80**:**1986, pointed to other important variables such as: human mass body and Soil Resistivity. The IEC 479-1 safety criteria are rather complexes while the safety criteria of IEEE Std 80 are simplified and addresses more relevant practical factors. Given the fact that the safety criteria include comfortable safety margins, one can conclude that the simplicity of IEEE Std 80 does not compromise safety, so its criteria was followed in this work.

According to information provided by REN (2011), in Portugal the value of soil resistivity varies with geographical location and with the seasons, however it can be considered 100 (Ωm) as the average value.

Using a conservative criteria about shock duration, it was choosen the value of 189.6 V as a voltage limit to reach maximum severity, according with the permissible touch voltages per IEEE Std 80:1986, considering a 50 kg human body and a probability for ventricular fibrillation of 0.5%.

In accordance with IEC 479-1standard, moisture (normal water) lowers the impedance values of the human body by 10% to 25%. By conservative criteria we assume 25% and considering that the other factors remains, by Ohm's Law, in wet environments the maximum voltage decreases 25%, from 189.6 V to 142.2 V.

Finally, the linguistic variable with two labels, Severity_contact-electricity= (Dry_environment, Wet-environment) was proposed (see fig. 5.6), which is represented by the following membership functions:

$$\text{Dry environment} = \begin{cases} 0.00714x, & 0 \le x \le 140 \\ 1, & x > 140 \end{cases} \quad \text{(eq. 18)}$$

$$\text{Wet environment} = \begin{cases} 0.00526x, & 0 \le x \le 190 \\ 1, & x > 190 \end{cases} \quad \text{(eq. 19)}$$

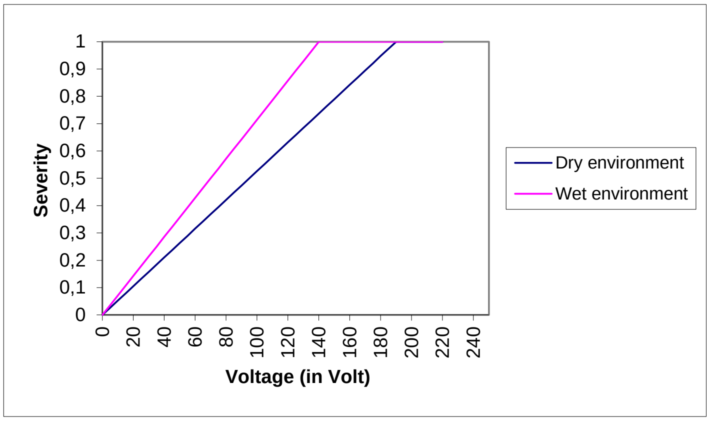


Figure 5.6.- Linguistic variable Severity_contact-electricity

There are some limitations on this accident mode severity template. For ventricular fibrillation as a severity criterion, rescue time can be an important predictor, however, it was not consider due to the practical difficulty of evaluating this factor because it is impossible to predict the time-delay for the arriving of a defibrillator.

**Struck by moving vehicle -** For this accident mode were considered the factors proposed by Mizuno and Kajzer (1999): a) Vehicle speed and mass (it determines the energy impact at human body); b) Vehicle design (vehicle geometry).

It should be pointed that to the best of our knowledge, there are no studies relating to being struck by moving vehicles on construction sites, so data from road accidents studies were extrapolated.

The vehicle geometry is very important to determine the accident severity. The study by Lefler and Gabler (2004) pointed that, given an impact speed, the probability of serious head and thoracic injury is substantially greater when the striking vehicle is an LTV (light transport vehicle) rather than a conventional car. The vehicle geometrydetermines the probable zone of human body contact: lower limbs, main body or head (including neck). Another study developed by Ballesteros et al. (2004), pointed that pedestrians hit by SUVs and pick-up trucks were more likely to have more severe injuries (compared to conventional cars) but the increase in danger may be explained primarily by larger vehicle weights and faster vehicle speeds. Regardless of vehicle weight, pedestrians struck at slower speeds by SUVs, pick-ups, and vans incurred in a rate of brain, thoracic, and abdominal injuries twice that of those struck by conventional cars, which indicates that vehicle design surely contributes to accident severity.

Considering that at the moment of impact the worker is stopped (otherwise, it just needs to add $m_W V_W$ on the right side of the eq. 20) and also considering that the collision is perfectly inelastic (i.e., after the collision vehicle and worker go together), it follows that:

$$(m_w + m_v)V_{(w+v)} = m_v V_v \quad \text{(eq. 20)}$$

Where $m_W$ is the worker mass, $m_V$ is the vehicle mass and $V_V$ is the vehicle speed. Now, considering that $V_{(w+v)}$ is the (scalar) velocity of the whole worker + vehicle, it follows that:

$$V_{(w+v)} = \frac{m_V}{m_W + m_V} V_V \quad \text{(eq. 21)}$$

Further, the change in momentum during impact (on the worker body) is determined by:

$$M = m_W \Delta V_{(w+v)} \quad \text{(eq. 22)}$$

However, since the human body limits established in literature are in terms of force (Viano, 1989 cited in Yang, 2002; McElhaney and Myers, 1993; Prasad, 1999; Eppinger et al., 2000; Yang, 2002; Sayed et al., 2008), the change in momentum (I) corresponds to exert a force (eq. 16) during a certain period of time

($F_{med} = I/\Delta t$)

For a Skid Steer Loader with a 3348 kg of mass (manufacturer's manual) and assuming that this machine geometry is similar to a conventional car where the impact mainly affects the lower limbs. Considering, again, the impact duration of 28 milliseconds, the Tibia Injury Criteria (Mertz, 1993) of 8 kN and for an average weight Portuguese worker of 74 kg (Barroso et al., 2005), by equations 16, 21 and 22, the maximum vehicle speed is 3.08 m/s (11.09 km/h).

For a hydraulic excavator, with a 21860 kg of mass, assuming that this machine geometry is similar to a SUV and the chest injury criteria is 5.5 kN, the maximum vehicle speed is 2.08 m/s (7.49 km/h).

Finally, the linguistic variable with two labels, Severity_ struck-by-moving-vehicle = (Skid Steer Loader, Hydraulic Excavator), was proposed (see fig. 5.7), which is represented by the following membership functions:

$$\text{Skid Steer Loader} = \begin{cases} 0.09x, & 0 \le x \le 11.08 \\ 1, & x > 11.08 \end{cases} \quad \text{(eq. 23)}$$

$$\text{Hydraulic Excavator} = \begin{cases} 0.13x, & 0 \le x \le 7.49 \\ 1, & x > 7.49 \end{cases} \quad \text{(eq. 24)}$$

The main limitation of the presented template is that the vehicle stiffness is not considered since on construction sites most vehicles have hard surfaces (do not allow surface deformation).

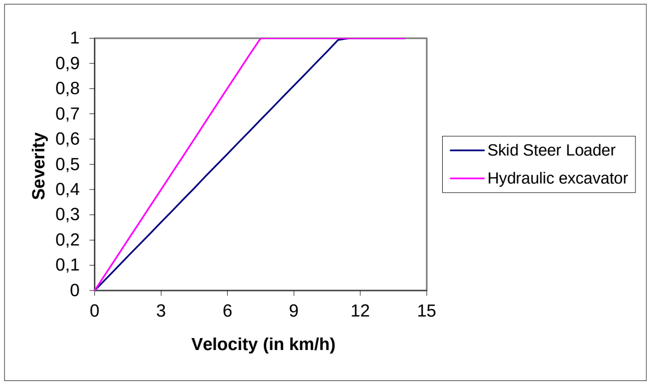


Figure 5.7.- Linguistic variable Severity_ struck-by-moving-vehicle

**Injured by falling/dropped/collapsing object/person/wall/vehicle/crane which is falling under gravity -** For modeling this accident mode it was considered two parameters: a) Height of fall (it determines the velocity at impact surface); b) Object mass (together with the velocity determines the energy impact);

In case of falling objects, the most exposed body part is the head. The object most commonly used on construction sites, in Portugal, is the brick 11 (made of clay and measures 30x20x11), with a mass of 4,5Kg (manufacturer's data). So, to characterize the fall event, the impact velocity was determined using equation 14 ( $V_B = \sqrt{2gh}$ )

Due to the principle of conservation of momentum and considering that the collision is perfectly inelastic, ie, during the collision brick and worker's head go together, it follows that:

$$(m_B + m_H)V_{(h+b)} = m_B V_B + m_H V_H \quad \text{(eq. 25)}$$

Where $m_B$ is the brick mass, $V_B$ is the brick velocity, $m_H$ is the head mass, $V_H$ is the head velocity and $V_{(h+b)}$ is the (scalar) velocity of the whole head + brick.

Thorn et col. (1998) present a head form table listing weights, shapes and sizes of skulls, here we choose the DOT Medium with circumference of 56cm and a mass of 5.0 kg. From (14) and (25) it follows that:

$$V_{(h+b)} = 2.09\sqrt{h} \quad m/s \quad \text{(eq. 26)}$$

and the change in momentum during impact (I),on the head, is determined by:

$$I = m_H \Delta V_{(h+b)} \quad \text{(eq. 27)}$$

$$I = 10.45\sqrt{h} \quad N.m/s$$

The average force applied on the head was determined using equation 16 ( $F_{med} = I/\Delta t$ )

Where: $\Delta t$ is the contact time duration between the brick and the head (deceleration time), such as

$$\Delta t = \frac{\Delta x}{V_{(h+b)}} \qquad \text{(eq. 28)}$$

Where: $\Delta x$ is the elastic absorption of the skull bones (it was consider 5mm – extrapolated from Gennarelli,1984)

Hence the force for this case is: $F_{med} = 0.00436h$ (eq. 29)

In a vertical object fall the head bones most likely to be hit are the frontal and the parietal. Considering the average values pointed for tolerances to impact loads, Yang (2002) pointed thebreak forces values of 6.3 kN for the frontal bone and 8.75 for the parietal bone. Choosing the smallest value the severity reaches the maximum for a fall at 1.44 m height (and for an object with 4.5 kg mass).

The most widely used tools on construction sites are hammers and flat chisels. Considering a claw hammer with a mass of 800g, for the frontal bone biomechanical limit of 6.3 kN (Yang, 2002), the severity will reach the maximum for a hammer fall from 16.9 m height.

Finally, the linguistic variable with two labels, Severity_ injured-by falling/dropped/collapsing object/person/wall/vehicle/crane = (Brick 11, Claw hammer), was proposed (see fig. 5.8), which is represented by the following membership functions:

$$\text{Brick 11} = \begin{cases} 0.69x, & 0 \le x \le 1.44 \\ 1, & x > 1.44 \end{cases} \qquad \text{(eq. 30)}$$

$$\text{Claw hammer} = \begin{cases} 0.06x, & 0 \le x \le 16.9 \\ 1, & x > 16.9 \end{cases} \qquad \text{(eq. 31)}$$

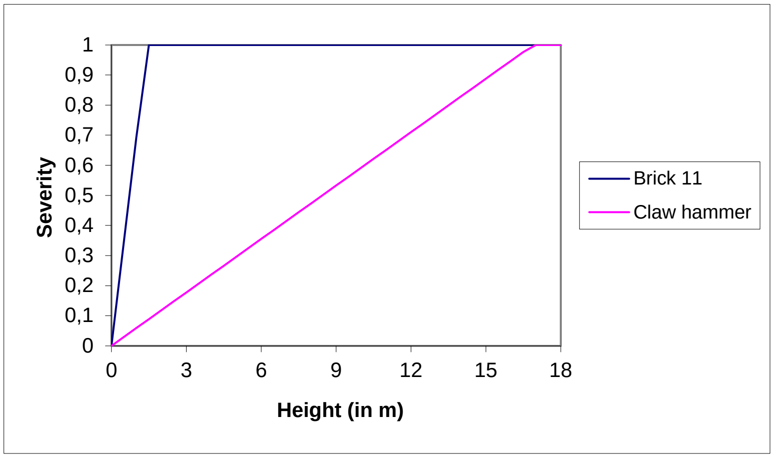


Figure 5.8 - Linguistic variable Severity_ injured-by-falling/dropped/

collapsing object/person/wall/vehicle/crane which is falling under gravity

The main limitation of this template is that the object stiffness is not considered because on construction sites almost all objects (that may fall) have hard surfaces (do not allow surface deformation). The object geometry (e.g.: corners or sharp edges) was also not considered because on a fall it's not possible to accurately estimate which object hedge will hit the worker.

**Cave-ins -** For modeling Cave-ins it was considered that the rescue time as the overrinding factor, because the life of an injured worker, who is deprived of air, depends on the rescue celerity.

According the Guidelines 2000 for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care (2000), the percentage of survival decreases approximately 7% to 10% with every minute that defibrillation is delayed and, after 10 minutes, the probability of survival is almost 0. In this work (see fig. 5.9) it was proposed a fuzzy set, Severity_cave-ins = (Rescue time) represented by the following membership function:

$$\text{Rescue time} = \begin{cases} 0.1x, & 0 \le x \le 10 \\ 1, & x > 10 \end{cases} \qquad \text{(eq. 32)}$$

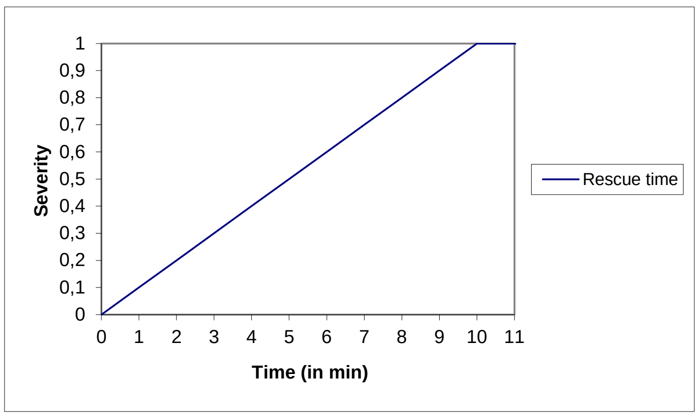


Figure 5.9 - Fuzzy set Severity_cave-ins (rescue time)

The main limitation for this template is the soil typehas not been considered (e.g.: soft or with rock blocks), but it is difficult to establish a relationship between soil type and the occupational accident severity. In the literature search, was not found any mention about this subject and safety experts do not agreed to relate the soil type as a determining factor in cave-in severity because, for example, if a rocky soil may cause more serious injuries can also create channels or air bags that maintain the life of the victim.

**Hit by rolling/sliding object or person -** For the modeling this accident it was considered two factors: a) Object mass and velocity (determines the energy impact) and, b) Object geometry (e.g.: corners or sharp edges).

In construction sites this accident mode commonly happens due to release of stones from slopes.

A stone, sliding from a slope with an angle of $\theta$ and considering that there is no friction (is difficult to estimate because the friction depends on soil type, soil moisture, shape and surface of the stone…), hits the victim with a force:

$$F = m.g.sen\theta \qquad \text{(eq.33)}$$

Where g is the acceleration due to gravity (9.81 m/s²), m is the object mass and $\theta$ is the slope angle.

A small/medium stone (until 1000 kg) has no large volume and most likely it will reach the victim's legs, so it was used a Tibia Injury criteria value of 8 kN (Mertz, 1993). From equation 33,, a spheroid stone, sliding from a slope with an angle of 70.0 degrees, with a mass weight of 868.7 kg (or more) can crack the tibia worker.

Another example is been hit by a rolling boom of a hydraulic excavator. A boom of a hydraulic excavator hits the victim with a “force”:

$$P = I.\alpha \qquad \text{(eq. 34)}$$

Where I is the moment of inertia (it depends on the geometry of the rolling object) and $\alpha$ is the angular acceleration.

The boom moment of inertia, considering as a thin bar – (a bar whose length is much larger than the diameter), whose axis of rotation is at one end, could be calculated, approximately, by:

$$I = \frac{1}{3} M.L^2 \qquad \text{(eq. 35)}$$

Where: M is the boom mass and L the boom range.

For a hydraulic excavator, with a boom mass of 5820 kg and a boom range of 9 meters (at 1.2 m height)., At a 1.2 m height, the body part that can be hit is the chest. Thorax lateral impact injury tolerance has a force of 5.5 kN according Viano (1989) cited by Yang (2002). So, the maximum $\alpha$ is 0.035 rad. $s^{-2}$ corresponding to a linear acceleration at the boom tip of 0.315 $m.s^{-2}$ .

For a backhoe loader with a boom mass of 2547 kg and a boom range is 4.5 meters (at 1.2 m height), the maximum $\alpha$ is 0.21 $s^{-2}$ corresponding to a linear acceleration at the boom tip is 0.96 $m.s^{-2}$ .

In sites with small spaces and blind spots, there is a strong possibility of collisions between workers. Considering a frontal shock between two workers, the change in momentum during impact (I) is determined by :

$$I = m_{w1} * V_{w1} + m_{w2} * V_{w2} \qquad \text{(eq. 36)}$$

The value for the mean force is determined by equation 16 ( $F_{med} = I/\Delta t$ ).

Considering a frontal shock between two workers with 74 kg of body mass (mean weight Portuguese workers according Barroso et al. (2005)), moving at a speed of 1.4 m/s and that both are moving in opposite directions and in view of an impact duration of 28 milliseconds. For neck injury criteria of 7440 N according to Eppinger et. al (2000):

$$7440 * 28 * 10^{-3} = 74 * V_{w1} + 74 * V_{w2} \Rightarrow 2,81 = V_{w1} + V_{w2} \qquad \text{(eq. 37)}$$

The linguistic variables Severity_ hit by rolling/sliding object or person: tibia/Sliding stone, Neck/( Hydraulic excavator, Backhoe loader) and Collision between workers was proposed (see figs. 5.10, 5.11 and 5.12)**,** which is represented by the following membership functions::

A. related with Tibia (Figure 5.11):

Sliding stone = $$\begin{cases} 0.00115x, & 0 \le x \le 868.7 \\ 1, & x > 868.7 \end{cases}$$ (eq. 38)

B. related with neck (Figure 5.10):

Rolling object Hydraulic excavator = $$\begin{cases} 3.17x, & 0 \le x \le 0.315 \\ 1, & x > 0.315 \end{cases}$$ (eq. 39)

Rolling object Backhoe loader = $$\begin{cases} 1.04x, & 0 \le x \le 0.96 \\ 1, & x > 0.96 \end{cases}$$ (eq. 40)

C. Collision between workers (Figure 5.12):

Collision between workers= $$\begin{cases} 2.81x, & 0 \le x \le 0.356 \\ 1, & x > 0.356 \end{cases}$$ (eq. 41)

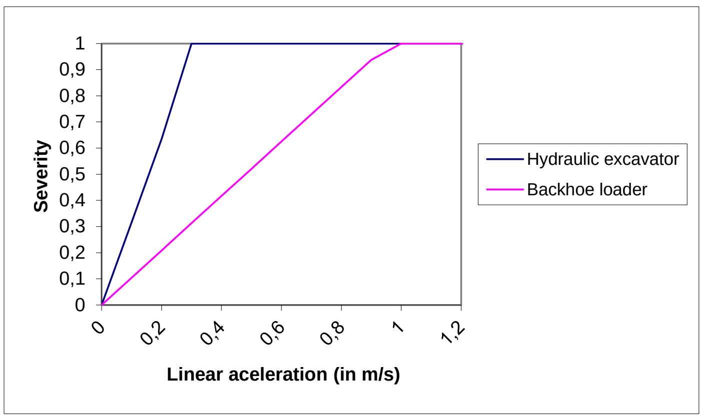


Figure 5.10 - Linguistic variable Severity_hit for neck/(Rolling object Hydraulic excavator, Rolling object Backhoe loader)

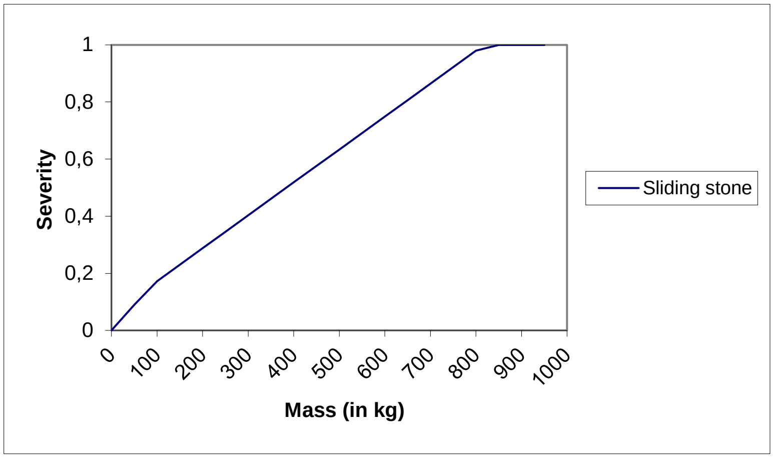


Figure 5.11 - Linguistic variable Severity_hit-for tibia/Sliding stone

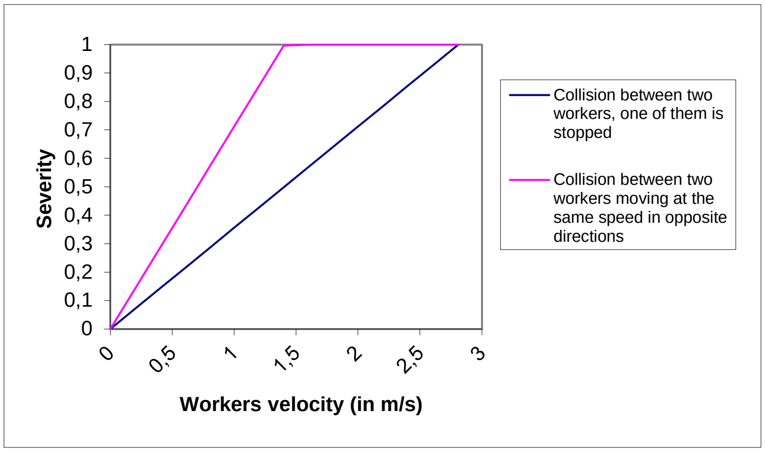


Figure 5.12 - Linguistic variable Severity_hit for workers-collision

**Contact with machinery moving parts (any injury type)** - In this accident mode it was not distinguished any type of injury physical part because they are all equally severe, depending on the machine type, power and category. It also includes hand held tools operated by the worker. For the modeling it is considered two main factors: a) machine category: b) machine power.

Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 determines a set of particularly dangerous machines categories, namely: a) circular saws (single- or multi-blade) for working with wood and material with similar physical characteristics or for working with meat and material with similar physical characteristics, of the following types: b) sawing machinery with fixed blade(s) during cutting, having a fixed bed or support with manual feed of the work piece or with a demountable power feed; c) sawing machinery with fixed blade(s) during cutting, having a manually operated reciprocating saw-bench or carriage; d) sawing machinery with fixed blade(s) during cutting, having a built-in mechanical feed device for the work pieces, with manual loading and/or unloading and; e)sawing machinery with movable blade(s) during cutting, having mechanical movement of the blade, with manual loading and/or unloading.

For all these categories of machinery, in QRAM the severity should be considered as the maximum (equal to 1). For other machine types, the analyst must estimate the severity based on the body part that is likely to be affected, the type of injury that could be produced and the machine power. In summary, this factor in the QRAM model is usually evaluated with severity 1 but when more information is available it is possible to tune this parameter.

**Lost buoyancy in water -** The outcome following a drowning depends on the duration of the submersion, the water temperature, and how promptly CPR is started. Case reports have documented intact neurologic survival in small children following prolonged submersion in icy waters (Suominen et al., 2002). For modeling this parameter it was considered the rescue time, because the life of an injured person who is deprived of air depends on it.

Based on survival rates rescue time (Guidelines 2000 for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care, 2000), the same fuzzy set, depicted on Fig. 5.9 (Severity_cave-ins = (Rescue time)) should be used.

A limitation in this template is that the water temperature was not considered because in countries with moderate climate, like Portugal, there are no icy temperatures. Another limitation is that in waters with high currents, the current can complicate and increase the rescue time because it moves the location of the victim, but no data about this could be found.

**Fire and Explosion (any injury type) -** Regarding this factor the QRAM considers always a maximum severity because: 1) the found models are not related with specific accidents or injuries, e.g. Pennes' equation and thermal wave model of bio heat transfer – TWMBT (Liu et col., 1999), and 2) factors such as temperature of skin surface, activation energy, thickness of tissue… are almost impossible to estimate due to its variation (human, geographical and climatic).

Also, for explosions there was no suitable data found and the pole of safety experts suggested to always expect the maximum severity (equal to 1) for any explosion. In cases where there are no hazardous places belonging to the zones with frequency and duration of the occurrence of an explosive atmosphere determined by the Directive 99/92/EC of the European Parliament and of the Council of 16 December 1999, the severity assessment should be made based on safety analyst knowledge and perception.

### 5.6.2. Dimension discussion

From the literature survey, there is very few data referring to severity of occupational accidents on construction sites, which is the scope of this work. So it was necessary to extrapolate data from other areas, namely, traffic accidents and home child accidents, to surrogate for the adult male human body response. This might bring model limitations that were not yet determined. Moreover, QRAM considered the maximum severity for certain cases, e.g. skull fracture and tibia fracture but in (empirical experts' knowledge), there are cases where a skull fracture had a more rapid recovery than a tibia fracture (perhaps because the medical staff pay much more attention to critical cases).

There are some other influencing factors not considered in the severity dimension of QRAM because, in practice, they were not significant to improve safety and some can even raise ethical questions (to assess and manage). The main parameters not consider in this dimension of QRAM are:

1. The BMI score, because in practice, its management is difficult and raise ethical questions (it is not acceptable, by social and ethical reasons, to choose (and/or exclude) workers by their BMI score);

2. The impact angle, because in practice, be difficult to accurately estimate (which, in some cases will determine if the applied force is compressive or tensile, or in other cases, will determine the bending moment or the shear force, in long bones);

3. The movement kinematics, because in practice, be difficult to accurately estimate (e.g., in a fall from height is difficult to estimate in advance the area of the body which will be impacted);

4. The worker gender, because in Portugal, the working population on construction sites is overwhelmingly male;

5. The worker age, because in practice, its management is difficult and raises ethical questions (due to social and ethical reasons it is not acceptable prohibit people above a certain age to work);

6. The worker physical fitness, because due to social and ethical reasons it is not acceptable to choose workers by their physical fitness);

7. The hour (of the day) that accident happens. According to López et al. (2011), the severity of occupational accidents suffered by construction workers, in Spain, at the interval of time between 13:00 and 17:00 has incomprehensibly high rates of severe and fatal accidents. However, in practice it's impossible to accurately estimate the time that the accident will occur.

8. Regarding the shape of severity curves, the lack of knowledge about the severity evolution due to the increase of energy involved in work accidents, it was chosen the simplest shape that is a straight line.

## 5.7. Possibility Factors: Third dimension

RAOS methods must also estimate the possibility of the occurrence of work accidents since it is an essential component of the overall occupational risk.

The notion of the possibility of occurrence of work accidents seems very clear and extremely useful to understand occupational risks and hence mitigate them. But, as soon as one digs into specific cases, it transpires that the concept application becomes a complex task. Complexity derives from the multiplicity of possible combinations of precursors and immediate factors for a given accident mode due to the diversity of equipment's, materials, worker's personal characteristics (age, training, experience, etc.), work organization, organization of safety culture, leadership, etc...

Phimister et al. (2004) and Wu et al. (2010) defined: a) precursors factors as signs that always seem to precede the accidents caused by occupational safety hazard on construction sites and; b) immediate factors as the failure in the interaction between the work team, workplace, equipment and materials, which are important exacerbating factors of accidents on construction sites. Differences between precursors and immediate factors lie essentially on time constraints. Immediate factors always have a short period for taking preventive actions, while precursors allow taking early preventive measures (Phimister et al., 2004). Precursor factors consist not only of factors related with workers, environment, equipment and material but, also, in their mutual interactions.

On this dimension, the focus was to define a model for estimate the degree of the possibility of occurrence of accidents and identifie the chain of factor linking the hazard to the accident. This information would be of undeniable value to organizations seeking to improve their understanding of the complexity of work accident to prevent them. The possibility estimation implies the determination, based on the “adequacy” (or inadequacy) of several factors, as described in the next sub-section.

### 5.7.1. Possibility Formal Model

Since each accident mode may be caused by a specific set of factors, the extent of these factors represent the evaluation of the work situation, under analysis and determine the greater or lesser possibility of occurring work accidents. The considered factors for assessing the possibility of accident occurrence were mainly obtained from the MOSH Checklist for Self-Inspection (2011) and was improved with knowledge elicited from the pole of six safety experts. In the annexes I.11 to I.19 are presented the prepared checklist of questions with the identified the possibility factors, that will serve as the basis for the dimension evaluation and respective rating. Moreover, since the factors are viewed by accident mode, figure 5.13 shows how many factors were considered in this QRAM model dimension, since each question corresponds to one factor. Each question of the checklist will be answered by the safety expert using the linguistic variable “Adequacy” (see table 5.1) to rating the adequacy of each factor is. (i.e. the safety analist will rate each question using one of the six terms, from strongly adequate to inadequate, that are described on table 5.1).

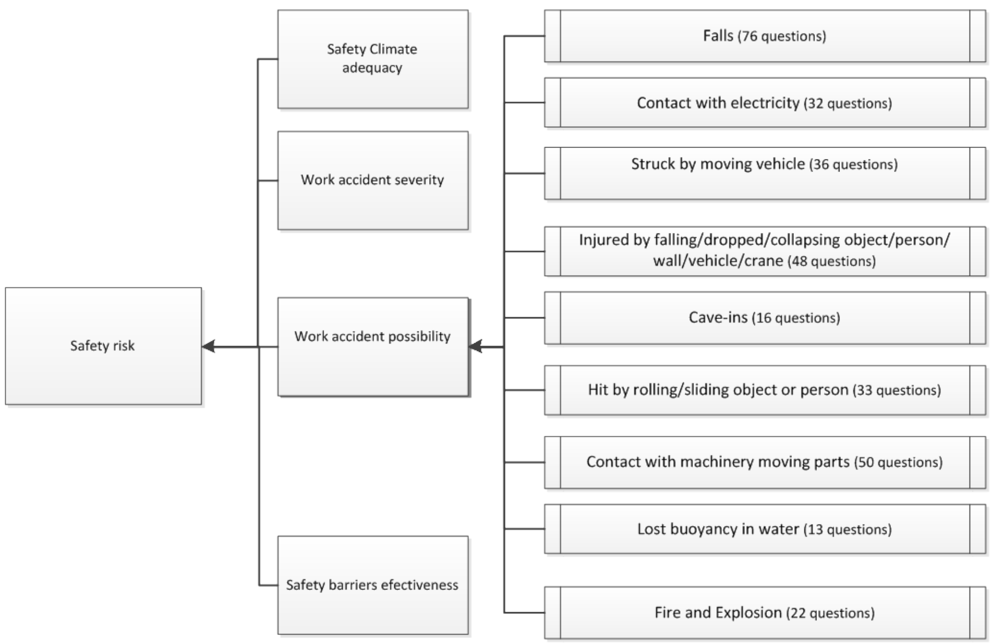


Figure 5.13.- Work accident’s possibility

After the rating process, the factors are aggregated with the “Fuzzy-OR” operator (see eq. 12).

Formally, the mathematical expressions that will be considered per each accident mode for the possibility of work accident occurrence are depicted in table 5.6.

Table 5.6 - Possibility Factors for each accident mode

| | | |
|---|---|---|
| $AP_F = \theta_{or} F_f \quad f = 1...76$ | $AP_E = \theta_{or} E_e \quad e = 1...32$ | $AP_S = \theta_{or} S_s \quad s = 1...36$ |
| $AP_{Fo} = \theta_{or} Fo_r \quad r = 1...48$ | $AP_{Ci} = \theta_{or} Ci_i \quad i = 1...16$ | $AP_H = \theta_{or} H_h \quad h = 1...33$ |
| $AP_M = \theta_{or} M_m \quad m = 1...50$ | $AP_{LW} = \theta_{or} Fe_y \quad y = 1...13$ | $AP_{FE} = \theta_{or} FE_z \quad z = 1...22$ |

**Possibility factors affecting Falls (F) -** The evaluation and rating of the 76 questions, which are shown in annex I.11, allow to assessing the factors that contribute to the possibility of work accidents by fall, including falls on the same level and numerous other types of falls from heights (from ladders, roofs, moveable platforms, etc.

**Possibility factors affecting contact with electricity (E) -** The evaluation and rating of the 32 questions, which are shown in annex I.12, allow to assessing the factors that contribute to the possibility of work accidents by contact with electricity.

**Possibility factors affecting struck by moving vehicle (S) -** The evaluation and rating of the 36 questions, which are shown in annex I.13, allow to assessing the factors that contribute to the possibility of work accidents by struck by moving vehicle.

**Possibility factors affecting injured by falling/swinging objects (Fo) -** The evaluation and rating of the 48 questions, which are shown in annex I.14, allow to assessing the factors that contribute to the possibility of work accidents by injured by falling/swinging objects, including persons, dropped or collapsing objects (such as: walls, vehicles, cranes, etc.).

**Possibility factors affecting Cave-ins (Ci)** - The evaluation and rating of the 16 questions, which are shown in annex I.15, allow to assessing the factors that contribute to the possibility of work accidents by cave-ins either extension or ditch.

**Possibility factors affecting Hit by rolling/sliding/flying object (including awkward or sudden movement) (H) -** The evaluation and rating of the 33 questions, which are shown in annex I.16, allow to assessing the factors that contribute to the possibility of work accidents by hit by rolling/sliding object or person (including awkward or sudden movement).

**Possibility factors affecting Contact with machinery/equipment moving parts (including trapped between objects) (M) -** The evaluation and rating of the 50 questions, which are shown in annex I.17, allow to assessing the factors that contribute to the possibility of work accidents by contact with machinery or work equipment moving parts (including trapped between objects).

**Possibility factors affecting Lost buoyancy in water due to the activity (LW) -** The evaluation and rating of the 13 questions, which are shown in annex I.18, allow to assessing the factors that contribute to the possibility of work accidents by lost buoyancy in water.

**Possibility factors affecting Fire or explosion (including confined spaces) (FE) -** The evaluation and rating of the 22 questions, which are shown in annex I.19, allow to assessing the factors that contribute to the possibility of work accidents by fire or explosion (including work on confined spaces).

### 5.7.2. Dimension discussion

The possibility of work accident dimension model supports the analysts in expressing their subjectivity in assessing occupational accidents possibility of occurrence, through the use of the defined checklist and the use of the linguistic variable “Adequacy”. The aim is to determine the greater or lesser possibility of each factor to contribute to the occurrence of an occupational accident and thus contributing to advances in determining the quality of the overall occupational risk assessment.

There are some other factors that may increase the risk of accidents, which are not considered in the Possibility dimension because we only selected the ones, directly affecting the possibility of occupational accidents and that may be assessed directly on-site. Obviously QRAM is a work-in-progress but its versatility makes the task of adding more factors rather simple. For instance, body weight influences postural stability, and is an important risk factor for falling occupational accidents (Gauchard et al., 2003; Hue et al. 2007). Psychotropic medications are associated with an increased risk of falls among the elderly (Ray, 1992; Landi et al., 2005), both psychotropic drugs and excessive alcohol consumption increase the risk of occupational and traffic accidents (Mura et al., 2003). Disabilities, especially physical, sensory and cognitive disabilities, carry a high risk for occupational (specially falls) accidents (Zwerling et al., 1997; Zwerling et al., 1998; Chau et al., 2004 a,b).

Besides the described works there are many other important studies and identified factors that may affect the possibility of occupational accident occurrence, such as: age, training, temporal factors, shiftwork, fatigue and sleepiness, temporary employment, foreign contractors, foreignemployees and workers performing tasks that were not a usual job requirement (Hertz and Emmett, 1986, Hallsten, 1990, Jimeno and Toharia 1993, 1996, Dinges, 1995, Spurgeon et al. 1997, Nag and Patel 1998, Hamermesh 1999, Chau et al., 2004 a,b), Nakata et al., 2006, Fabiano et al. 2008, Khlat et al. 2008, Williamson et al., 2011). In summary, most of the factors just described, were not considered in this work for two main reasons: a) some characteristics of the construction make it impossible to have proactive data that can be used in their evaluation and, b) other management factors, such as, age, disabilities, alcohol and drugs consumption, smoking, etc., could pose ethical issues.

Two important issues need further research to improve this dimension. It was assumed that all factors are independent of each other and that all have the same importance (weight) however, in real world, this is not the case and these are open issues to be investigated in the future.

## 5.8. Safety barriers Effectiveness: the forth dimension

As mentioned before, RAOS methods aims to produce guidance how to reduce risks of work accidents (and incidents) either by eliminating hazards, preventing initiating events, and/or protecting against unwanted events (accidents).

In the construction industry, prevention and protection usually involve the use of some sort of barriers. Prevention consists on blocking or hampering initiating factors from triggering or contributing to an accident. Protection consists on blocking or hindering accident´s consequences severity.

Prevention and protection can be accomplished by using the following four types of barrier systems, namely: physical, functional, symbolic and incorporeal, either individually or, in a more reliable way, in combination (Hollnagel 2008). Protection involves the use of either physical or functional barrier systems (Duijm et al., 2003). Prevention is preferable to protection, in other words, risks should be reduced by reducing their frequency of occurrence other than by mitigation actions (Dianus and Fiévez, 2006).

Although some kind of safety barriers have been used since the origins of our species (Sklet, 2006) to protect humans and property from enemies and natural hazards (e.g. floods, fires) there is no commonly/general accepted definition for them. Different authors (Johnson, 1980; Svenson, 1991; Kecklund et al., 1996; Ringdahl, 2003; Sklet, 2006; EC, 2006; Hollnagel, 2004, 2008) use different terms with similar meanings, such as: barrier, safety barrier, defense, safety defense, protection barrier, protection layer, safety critical element, safety function or safety system. Without a clear definition and delimitation of the concept, a safety barrier could be any physical entity, any technical aspect (e.g. hardware component) or even any procedural or organizational element of the work environment, which aims to avoid, prevent, control, or mitigate undesired events such as work accidents and incidents. Moreover, European regulations and International standards (EC, 1996; IEC, 1998, 2002; ISO, 1999, 2000) enhance the importance of considering safety barriers to reduce the risk of accidents. Reason (1990) stated that most of the accidents are due to a combination of an unexpected event with a dysfunctional or missing barrier, rather than to a single initiating action.

To ensure adequate levels of occupational safety by preventing work accidents or minimizing their consequences, it is first of all necessary to identify all involved risks and its characteristics. Any SB design should only be attempted after completing the occupational risk assessment process thus ensuring its adequacy by function specificity. Guldenmund et al. (2006) stated that each SB has to be designed (or ordered) according to particular specifications and must be built or delivered including installation and adjusted for use. Even for checking the performance of existing SB it needs to know, in detail, the characteristics of the risks that intend to be reduced.

As referred before, another point to consider is that when dealing with vague and/or imprecise knowledge or concepts, like effectiveness, adequacy, efficiency or performance, this cannot be accurately estimated by probabilities so a more realistic approach may be used. Fuzzy variables with linguistic semantic terms, as discussed in the section 5.2 seem to be a more adequated mathematical framework.

In general, a barrier is any obstacle that obstructs the access, the progress or the spread of something. A common definition of safety barrier is an obstacle (physical barrier), which function is to protect vulnerable targets (e.g. humans, environment, objects…) from hazards (e.g. dangerous energy) (Haddon, 1973, 1980; Kaplan, 1990). Later, this concept was extended to a “defense in depth” (Hollnagel, 1999); meaning a set of barriers (barrier system), located along the chain between hazards and possible accidents (or unwanted events), where each one (barrier element) is not sufficient to protect the target from the hazard, but working as a whole they can.

The term “defense barrier” was defined by Reason (1997) as ‘‘the various means by which the goals of ensuring the safety of people and assets can be achieved”. The same author divided defenses in ‘‘hard defenses”, such as physical barriers and alarms, and ‘‘soft defenses” such as regulation, procedures, and training and refers to defense-in-depth as ‘‘successive layers of protection”. Comparing with other similar terms, such as: safety barrier, protection barrier or protection layer, defense concept has a wider range.

Accident investigations highlight the influence that management has on safety barriers effective operation. For example, MTO-analysis (Human, Technology, and Organization) applied in accident investigations, defined safety barrier as ‘‘any operational, organizational, or technical solution or system that minimizes the probability of events to occur, and limit the consequences of such events’’ (Bento, 2003). Svenson (1991) pointed that is useful and very necessary to use a more precise terminology particularly to make a distinction between barrier systems and barrier functions. Barrier function, describes the modes by which it is possible to prevent or to protect against the hazards. Barrier system, describes the means by which the barrier functions are fulfilled.

Many safety barriers division were suggested in the literature, of which we highlight:

- Duijm et al. (2003), presents a division based on the action verbs to avoid, to prevent, to control, and to protect: 1) avoid intends to suppress all the potential causes of an event by changing the design of the equipment or the type of product used, 2) prevent intends to reduce the probability of an event by suppressing part of its potential causes or by reducing their intensity, 3) control intends to limit the deviation from a normal situation to an abnormal (and unacceptable) one and, 4) to protect intends to cover or shield from injury or loss (the environment) from the consequences of an event that has occurred.

- Schupp (2004, in Sklet, 2006) divided SB in two types related to "hazard targets", namely: 1) primary barriers which are associated with primary hazards (hazards that could be directly harmful to humans) and, 2) secondary barriers which are associated with functional hazards (hazards that could indirectly become hazardous to humans).

- Hale (2003) and Kjellén (2000) divided SB in two types related to dependence on actions in order to achieve its function, namely: 1) passive barriers (do not requires any action to achieve its function in reducing risk) and, 2) active barriers (requires an action to achieve its function).

- Guldenmund et al (2006) divided barrier systems in two groups, hardware and behavioral elements, related with the risk assessment and management process:
  - A- Hardware related: 1) hazard (scenario) identification, barrier selection and specification; 2) monitoring, feedback, learning and change management; 3) design specification, purchase, construction, installation, interface design/layout and spares; 4) inspection, testing, performance monitoring, maintenance and repair.
  - B- Behavior related: 1) procedures, plans, rules and goals; 2) availability, manpower planning; 3) competence, suitability; 4) commitment, conflict resolution; 5) coordination, communication.

In this dimension of QRAM we follow the division of Hollnagel (2008) because it seems the most realistic and applicable in the construction industry. This author divides barrier systems, in four types, by describing their aim and function, namely:

- Physical or material – the aim is to prevent accidents or mitigate its consequences by blocking mass and/or energy flow. Examples of physical barrier systems are buildings, walls, fences, railings, bars, cages, gates, containers, fire curtains, etc. An important characteristic of a physical barrier is that it does not have to be perceived or interpreted by someone (or something) in order to work and can therefore be used against energy and material, as well as opposed to people.

- Functional – the aim is to create at least one pre-condition to be met before an action could be performed, for instance, by establishing an interlock, either logical or temporal. It may or may not require human action, i.e. some requires a user to change from one state to another; others are autonomous and can change depending on external conditions. A functional barrier system could not be visible or discernible by a human user, although its presence usually is indicated in some way.

- Symbolic – it requires an act of interpretation by someone, indirectly through their 'meaning'. They are omnipresent everywhere by a variety of visual and auditory signs and signals, warnings (by text or symbol), alarms, etc.

- Incorporeal – it requires incorporating knowledge from users to achieve their purpose. This type has not physical presence in the working site. In safety occupational context, incorporeal barrier systems are related to organizational aspects, such as, rules and procedures for actions (that are imposed by the organization), knowing and complying with regulations and standards, etc.

In summary, QRAM SB dimension follows the division proposed by Hollnagel (2008) because it seems more flexible, understandable and quite appropriate for the construction industry (i.e. it is closer to what is usually considered a good practice).

## 5.8.1. Safety Barriers Effectiveness Formal Model

Usually, in construction sites there are formal and informal safety barriers elements in parallel, often overlapping. Sometimes this works as safety redundancy, which makes the safety system less vulnerable to changes and supports safety preservation (safety resilience). Ringdahl (2009) describes this as a safety web rather than a distinct set of barriers. This feature can improve safety resilience but, on the other hand, this interaction between safety barriers could decrease its effectiveness and/or create new risks, hence, it complicates the analysis and evaluation of the implemented safety barriers system (Ringdahl, 2009). Further, the analyst should understand well the safety barriers elements and systems implemented, and its interactions, to understand its adequacy and availability. To achieve this understanding he should observe directly the site, and perform interviews with workers, foreman and engineers (to understand the informal safety barriers) and consultation of site documents (working procedures, reports of work accident investigation and others) in order to understand its reliability, robustness and resilience.

In QRAM model, the first step for assessing SB in the construction industry is to identify which are the safety barriers implemented, per accident mode.

Figure 5.14 depicts the SB model for fire and explosion accident mode. The other accident modes follow the same rational.

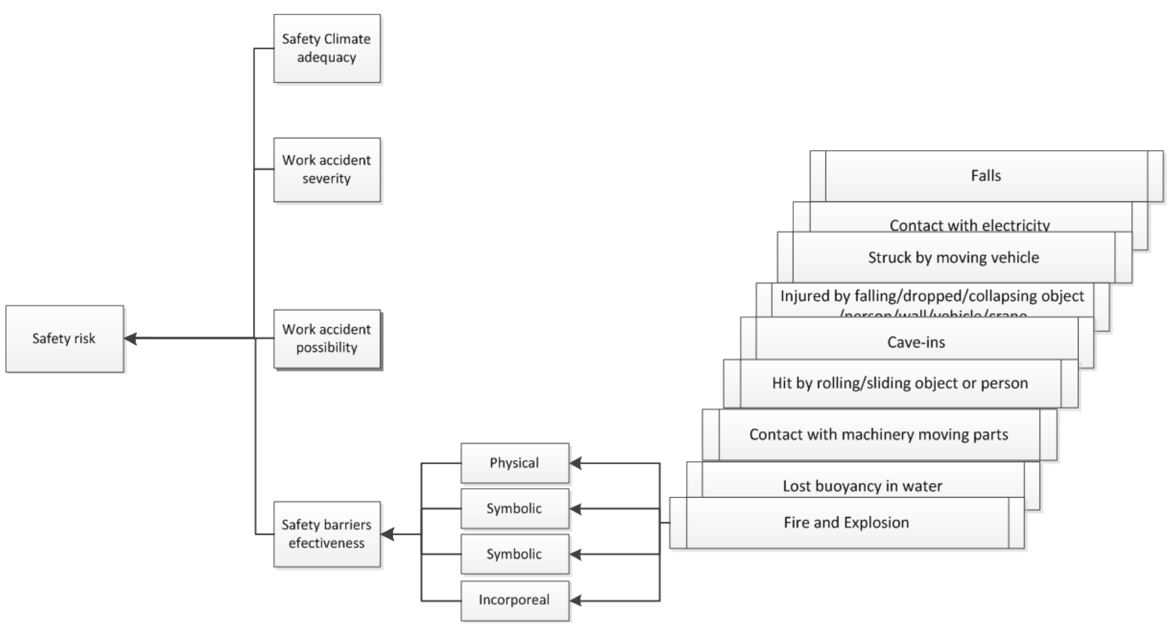


Figure 5.14.-.Safety barriers effectiveness

Table 5.7 shown the SB dimension- using the Hollnagel (2008) division into four classes, with some examples of safety barriers used on construction sites for each accident mode

Table 5.7 – Identified safety barriers on construction sites

| **Accident mode** | **Examples on construction** | | | |
|---|---|---|---|---|
| | **Physical** | **Functional** | **Symbolic** | **Incorporeal** |
| Contact with electricity | Keep safety distances to the electric lines (2 m until 1 kV, 4 m between 1 kV and 60 kV, 5 m to over 60 kV). Hand electric powered tools with double insulation. Enclosure doors locked. | CHPtD. Stroke limiters in aerial lift equipment's working near energized lines. Residual-current devices. Residual current circuit breakers. | Signaling enclosure doors and other spots with electrical risk. Lock-out procedures. Training, instructions, procedures, safety meetings. | Law: Directive 92/57/CEE, 24-06-1992 and Directive 98/34/EC, 20-07-1998 |
| Struck by moving vehicle | Vehicles safety belts. Separate routes for vehicles and pedestrians. | Antilock Brake Systems. Speed bumps. | Traffic plans established in the sites. Traffic signals. Warning vests. Vehicles inspections procedures. Machine horn signs. Training, instructions, safety meetings. | Speed restrictions. Law (in Portugal: Decreto Lei n.º 114/94, 03/05/1994; revue by Decreto –Lei n.º 44/2005, 23/02/2005) |
| Injured by falling objects | Accessible areas within the swing radius of the rotating superstructure of the crane properly barricaded or protected. Scaffoldings provided with toe-boards. Materials stored in tiers stacked, racked, blocked, interlocked, or otherwise properly secured to prevent sliding, falling, or collapse. Helmets. Falling Object Protective Structures on vehicles. | Mobile Elevating Work Platforms (MEWP'S) provided with stability devices | Demarcation areas around portable ladders. Forbidden of work in MEWP'S with winds exceeding 40 km/h. Training, instructions, procedures, and safety meetings. | Law: Directive 92/57/CEE, 24-06-1992 and Directive 89/655/CEE, 30/11/1989, revue by Directive 95/63/CE, 05/12/1995 and Directive 2001/45/CE, 27/06/2001. Formal works inspections. |
| Cave-ins | Shoring systems. Anchorage of existing structures (walls, trees, poles). | Construction Hazards Prevention through Design (CHPtD). | Excavation area demarcated and signalized. Training, instructions, procedures, safety meetings. | Law: Directive 92/57/CEE, 24-06-1992 |

| Accident mode | Examples on construction | | | |
|---|---|---|---|---|
| | **Physical** | **Functional** | **Symbolic** | **Incorporeal** |
| Hit by rolling/ sliding object | Abrasive wheel grinders provided with safety guards. Vehicles loaded safely. | MEWP'S provided with stability devices. Rolling Over Protective Structures on vehicles. | Excavation area demarcated and signalized. Training, instructions, procedures, safety meetings. | Forbidden throw tools or other objects |
| Contact with machinery moving parts | Machinery guards in risky spots (e.g. belts, gears, shaft, pulleys, sprockets, spindles, drums, fly wheels, and chains). Guards in removable mechanical transmission devices. | Power-operated interlocking movable guards. | Signaling of risky spots. Lock-out procedure. Training, instructions, safety meetings. | Law: Directive 2006/42/CE,10-01-2006. |
| Fire or explosion | Flammable, combustible and explosives materials stored in appropriated containers and in appropriated conditions. | Energy limiters and relief devices | Signaling of risky spots. Training, instructions, procedures, safety meetings. | Law: Directive 92/57/CEE, 24-06-1992. |

For obtaining an evaluation for any SB system the safety experts should follow the sequence of the possible chain of events, either by starting with the accident modes and going backwards or starting in the hazard and look forward to the probable work accident. In general, for each accident mode, QRAM analysis should be guided with questions such as:

- What technical mean could prevent work accident mode X and in what circumstances? And how?
- What human action could prevent work accident mode X and in what circumstances? And how?
- What organizational routine could prevent work accident mode X and in what circumstances? And how?
- Are there any legal or other requirements applicable to it?

To answer these questions, the analyst should check key points, namely: 1) safety barriers design – including interfaces and work modifications required, 2) checking/supervision of construction and installation, 3) human factors of safety barriers operation and maintenance – availability, commitment and competence of personnel, 4) inspections and maintenance programs, 5) supervision of maintenance tasks, 6) SBs management – including communication and coordination, conflict resolution and the existence of spares (when required) and, 7) risks review (including the SBs). These data can be obtained by direct observation and analysis of documents such as: a) safety barriers project, b) accidents and incidents research reports, c) inspections and maintenance programs and reports, etc…

There is a difference in effectiveness between the use of personal protective equipment's (PPEs) and collective protective equipment; this proposed model reflects this fact. Since PPEs depend on humans to achieve its purpose (and only offers limited protection to a part of the body of one worker), its maximum effectiveness will be classified as "partial" (never reach the "excellent", "very good" or "good" grades).

By the same reason (dependence on humans), work instructions and procedures, training, signalization, alarms, or more generally, for all symbolic barriers type the maximum effectiveness should be “partial”.

Between “excellent” and “very good” there is no difference with regard (directly) to safety, the difference lies on resources efficiency and intrusiveness to the production process. An efficient and not intrusive SB have better acceptance at all organization levels and, therefore, should be “excellent”.

This work do not present more details about defining a checklist with questions to obtain the classifications for effectiveness of safety barriers because there are a very big set of safety barriers that can be used on construction sites and there are some checklists available on literature that can be used.

In summary, to assess SB Effectiveness, the safety analist should: 1) identify, by accident mode, all the safety barriers implemented in the site, 2) understand how to work the safety barriers to divide them is the four types pointed by Hollnagel (2008), 3) for each type, using the linguistic variable “SB Effectiveness” (see table 5.2) rating their effectiveness and, 4) for each accident mode, estimate the SB effectiveness by aggregating the rated grades by the OR operator (see eq. 9) with a parameter, $\gamma = 0.98$.

## 5.8.2. Dimension discussion

To better understand the presented QRAM SB dimension, see the following examples.

Using a safety net as an example, safety nets are barrier systems because their effectiveness depends on the physical device and the riggers training, inspection and maintenance procedures. So, physical effectiveness is “excellent” if the net complies with EN 1263-1 standard and is mounted to cover all possible points of fall. If there are cheaper preventive techniques available (to ensure the same level of effectiveness), effectiveness should be considered “very good”. If the site is located in a climate adverse place, e.g. snow and strong winds, its effectiveness should be “good” (because reliability may be compromised). If the net does not cover one spot (e.g. in a corner or a pillar…) or is fitted far away from the work position, effectiveness should be “partial”. If the safety net does not comply with any recognized and accepted standard (even if its robustness seems to be adequate) effectiveness should be “bad” (because there are no guarantees about its robustness). If the safety net possesses some defects (color changes, broken wires or ropes…) effectiveness should be “bad” (because its robustness may be compromised).

If the safety net rigging is carried out by riggers who are fully qualified and are inspected and systematically maintained, symbolic effectiveness should be “partial”. If the safety net is not inspected or systematically maintained, within appropriate intervals, symbolic effectiveness should be “insufficient”. If the safety net rigging are carried out by riggers who are not qualified symbolic, effectiveness should be “bad”.

Now considering an illustrative example with two safety barriers types, a physical one and a symbolic one, and by direct observation the analyst classified the two safety barriers, as depicted in table 5.8. Then using the respective relative importance/weights and the weighted Hammacher-OR operator (see eq. 9) with a parameter, $\gamma = 0.98$ the result for the SB effectiveness estimation is:

$$SBEfectiveness = \frac{(1-0.98)*0.75*0.94*0.45*0.41+0.75*0.94+0.45*0.41}{1+0.98*0.75*0.94*0.45*0.41}$$

SBEfectiveness = 0.79.

Since the effectiveness results from aggregation of two safety barriers that contribute to mitigate the same risk, one excellent and important and one partial and less important, the effectiveness result is "very good" = 0.79. This result matched the conservative empiric expert knowledge of the safeyt experts' pole.

Table 5.8 - Illustrative example of SB effectiveness for Safety Nets

| **SB Type** | **Analyst Assessment** **(Semantic term and respective grade)** | **Analyst choice justification** |
|---|---|---|
| Physical (weight=0.7) | Excellent/0.94 | The net complies with EN 1263-1 standard and is mounted to cover all possible points of fall and there aren't cheaper preventive techniques available that ensure the same level of effectiveness |
| Symbolic (weight=0.4) | Partial/0.41 | The safety net rigging is carried out by riggers who are fully qualified and are inspected and systematically maintained |

Now, let's considering another example, the use of safety helmets to protect workers heads against falling objects, which is also a barrier system. If the physical device (the helmet) complies with the EN397:1995 standard (or other similar), is in good condition, is suitable for the workplace and can be adapted to the users morphology, so physical effectiveness should be "partial". If the helmet has small defects such as: color changes, small changes in structure (small holes for ventilation, for example), paintings (names or something else), stickers (some manufacturers advise against), etc. or is not suitable for the workplace or can't be adapted to the users morphology, physical effectiveness should be "bad" (because there are no guarantees about its robustness). If the helmet does not comply with EN397:1995 standard (or other similar) or has defects such as fissures, physical effectiveness should be "bad" (because there are no guarantees about its robustness). If workers had training and know how properly use, inspect, maintain and clean and there is a procedure for the proper PPEs management, symbolic effectiveness should be "partial". If workers didn't inspect, maintain or clean the helmets regularly (but use them and had training) or the company don't manage PPEs properly, symbolic effectiveness should be "insufficient". If workers didn't have training or there is no procedure for PPEs management symbolic effectiveness should be "bad". Table 5.9 depicts the classifications for this example, considering two similar "partial" classification of SB elements (0.41) but since they have different importance weights, when applying the Hammacher-OR operator (see eq. 9) with a parameter $\gamma = 0.98$, it results on a SB Effectiveness= 0.47, i.e. it can be classified as a little better than a "partially safe" SB system. This result matched the conservative empiric expert knowledge of the safeyt experts' pole.

Table 5.9 - Illustrative example of SB effectiveness for Safety Helmets

| SB Type | Analyst Assessment (Semantic term and respective grade) | Analyst choice justification |
|---|---|---|
| Physical (weight 0.75) | Partial/0.41 | The helmet complies with the EN397:1995 standard, is in good condition, is suitable for the workplace and can be adapted to the user morphology. |
| Symbolic (weight =0.45) | Partial/0.41 | The user (worker) had training and know how properly use, inspect, maintain and clean and there is a procedure for the proper PPIs management. |

Another example of safety barriers widely used at construction is the fall arrest system. Although it is a PPE that protects the entire body their effectiveness is not the same as collective protective equipment. The use of this equipment carries the risk of orthostatic syndrome (Seddon, 2002). If all physical device (harness, ropes, lanyards, shock absorbing, etc.) complies with the EN361 standard (or other similar), are in good condition, are suitable for the workplace, can be adapted to the users morphology and there are sufficient and robust anchor points to which workers could fasten their personal fall arrest equipment, so physical effectiveness should be “partial”. If the harness (or accessories) has small defects such as: color changes, small changes in structure geometry etc. or is not suitable for the workplace, physical effectiveness should be “bad”. If the harness (or accessories) does not complies with the EN361 standard (or other similar) or has defects or there aren’t sufficient or robust anchor points to which workers could fasten their personal fall arrest equipment, physical effectiveness should be “bad”. If workers had training and know how properly use, inspect, maintain and clean and there is a procedure for the proper PPEs management and work at height, including emergency rescue, symbolic effectiveness should be “partial”. If workers didn’t inspect, maintain or clean the equipment daily (but use them and had training) or the company don’t manage PPEs properly, symbolic effectiveness should be “insufficient”. If workers didn’t have training or there are no procedure for PPEs management or emergency rescue is not assured, symbolic effectiveness should be “bad”.

Incorporeal barriers, such as legal requirements (or others), should be “excellent” if the company identify, access and apply legal or other requirements, keep this information up-to-date and communicates, timely, relevant information about these requirements to persons working under its control and other interested parties, in an efficient way, using a documented procedure. If the company doesn’t have a documented procedure, incorporeal safety barriers should be considered “very good”). If the company identify access and apply legal or other requirements, keep this information up-to-date but not communicate, timely, relevant information, incorporeal effectiveness should be “partial”. If the company identify access and apply legal or other requirements, keep this information up-to-date but not communicates relevant information, effectiveness should be “partial”. If the company don’t identify or access or apply legal or other requirements or don’t keep this information up-to-date or not communicates, timely, relevant information, incorporeal effectiveness should be “bad”.

The advantages of the proposed dimension model are:

Supports proactive estimates by identifying effective, adequate, efficient, reliable and robust features of the safety barriers;

Uses the useful four types of safety barriers proposed by Hollnagel (2008) and enumerates the criteria to be used for the assessment of their effectiveness;

Both technical and organizational safety barriers, formal and informal, can be analyzed in a uniformly way;

The tool is easy to understand for safety practitioners and construction technical personnel because it uses semantic evaluations such as “good”, “very good”, etc. This understanding is important because it facilitates discussions about safety barriers design problems and potential improvements.

Disadvantages are:

The safety barriers division on 4 types could, in some contexts, be confused for safety practitioners (example, if there is a legal requirement to put a physical barrier, is this a physical or a incorporeal barrier?);

The diversity of possible safety barriers makes it difficult to identify all types;

The method only gives an estimate of effectiveness and does not provide recommendations to improve SB design.

In summary, it seems that the proposed procedure may reduce the subjectivity in assessing SB effectiveness by estimating their ability to achieve their purpose, i.e., how well they can withstand the variability of the work environment in construction sites. Moreover, it was presented exampples to better clarify the usage of the proposed procedure and how to interpret the results. In addition, since our proposed procedure is quite versatile and adaptable, it will contributes to advances in determining the quality of the overall occupational risk assessment in construction sites.

# 6. Qualitative Risk Assessment Model application test and results discussion

In this chapter it will be discussed the application of the QRAM method to 12 different construction sites. In sections 6.1 and 6.2 it is presented detailed applications of the QRAM model, step by step, in Portugal (cases 1, and 2). Section 6.3 discusses the results of applying QRAM on 10 construction sites in Brazil (cases 3 and 4), Bulgaria (case 5), Greece (cases 6, 7 and 8), Portugal (case 12) and Turkey (cases 9, 10 and 11), with the objective of comparing the results of the QRAM model with the expert opinions, requested to verify if the results correspond to their empirical knowledge, using a 5-point semantic Likert scale: Strongly Approve, Approve, Undecided, Disapprove and Strongly Disapprove (see Annex II.1). In section 6.4 QRAM is compared with other techniques, currently used to assess safety risks on construction sites, and section 6.5 includes a general discussion of the QRAM evaluation.

## 6.1. Qualitative risk assessment model application on a construction site – Case 1

To illustrate the application of the QRAM model to a real situation, it was apllied to a remodeling of the interior of a luxurious apartment, located in central Lisbon. When the analysis was carried out, 2 plasterers and 4 painters was working, headed by a foreman. All workers had fixed-term contracts. Some pictures taken in the worksite are presented in figure 6.1.

**Step 1 and step 2.** Consist on the identification and rating of the factors affecting the safety climate on site. To rate the safety climate factors (with the linguistic variable "Adequacy" – see table 5.1), the foreman, one painter and one plasterer were interviewed (to assess the safety climate factors). For each factor, the analyst assessment was made by taken the semantic term which was more times chosen by the interviewed pool. In annex II.2 it is presented the analyst assessments for each safety climate factor.

**Step 3.** Consist on the determination of the safety climate final estimation. In this case, by aggregating all safety climate factors, using equation number 12, the determined Safety Climate Level is 0.82. Since 0 means good safety climate and 1 means very bad, 0.82 is considered a bad safety climate; therefore, the site safety climate needs to be improved.

Figure 6.1 – Photo’s from construction site case 1

**Step 4.** Consist on the identification and listing of all work tasks performed on the site. When the analysis was carried out, the tasks being performed were: a) repair of cracks in plaster, b) preparation for painting ceilings and c) painting of walls and ceilings. Note that it was only analyzed the task a).

**Step 5.** For each task, was identified the accident modes possible of occurring. During the execution of task a), repair of cracks in plaster, the accident modes that are possible to occur (determined by the analyst) are: falls, contact with electricity, injured by falling/swinging objects, hit by rolling/sliding/flying object (including awkward or sudden movement), contact with machinery/equipment moving parts (including trapped between objects) and fire or explosion (including confined spaces).

**Step 6 and Step 7.** On step 6 and step 7, for each accident mode, the analyst identified and rated the factors affecting the work accidents possibility factors. In annexes II.3, II.4, II.5, II.6, II.7 and II.8 it is presented the analyst assessment for each accident mode. It should be noted that some factors are specific of certain construction types and are not applicable to all construction sites, hence, the factors "not applicable" in this construction site were deleted from the list.

**Step 8.** On Step 8 it is estimated the final evaluation of the work accident possibility of occurrence. By aggregation of all possibility factors, using QRAM equation 12, the possibility of occurring work accidents is depicted in table 6.1.

Table 6.1 - Work accidents possibility level for the accident modes analyzed in case 1

| ***Accident Mode*** | Possibility level |
|---|---|
| Falls | 0.67 |
| Contact with electricity | 0.74 |
| Injured by falling/swinging objects | 0.75 |
| Hit by rolling/sliding/flying object (including awkward or sudden movement) | 0.71 |
| Contact with machinery/equipment moving parts (including trapped between objects) | 0.72 |
| Fire or explosion | 0.84 |

Since in QRAM scale, 0 means no possibility that a work accident occurs and 1 means that a work accident is very likely to occur (just do not know when), if the possibility of work accidents is higher than 0.3 it should be improved (see section 5.4). In this test case for all accident modes the possibility of occurring accidents is higher than 0.3 hence the site needs to be improved regarding the risky factors affecting this dimension.

**Step 9.** On step 9 the expected work accidents severity is estimated. For each accident mode, the estimation of the expected severity is made using the linguistic variables presented in section 5.6. Therefore the expected severity for each accident mode is depicted on table 6.2.

Table 6.2 - Work accidents severity estimation for the accident modes analyzed in case 1

| Accident mode | Task characterization | Severity Assessment | |
|---|---|---|---|
| | | Criteria | Value |
| Falls | Workers working at 1.5 meters height, over a hard impact surface (similar to concrete surface) | Fig. 5.5 | 1.00 |
| Contact with electricity | Workers use electrical power tools, 220VAC in a dry environment | Fig. 5.6 | 1.00 |
| Injured by falling/ swinging objects | Workers use, at 1.5 meters in height, tools with mass and geometry similar to the claw hammer | Fig. 5.8 | 0.10 |
| Hit by rolling/sliding/ flying object | Due to the meager space and blind spots, there is a strong possibility of collision between workers, one stopped and another moving at 1 m/s | Fig. 5.12 | 0.72 |
| Contact with machinery/ equipment moving parts (including trapped between objects) | At this site, there aren't machines belonging to the particularly dangerous machine categories determined by the Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006, mustly there are manual and electric handling tools. | Safety expert estimation | 0.20 |
| Fire or explosion | There are no hazardous places belonging to the zones with frequency and duration of the occurrence of an explosive atmosphere determined by the Directive 99/92/EC of the European Parliament and of the Council of 16 December 1999, however there are in use some flimsy flammable substances. | Safety expert estimation | 0.10 |

**Step 10.** On step 10, safety barriers implemented on the site are identified, for each accident mode, by its SB type, namely: physical (or material), functional, symbolic and incorporeal (see column 2 of the table 6.3).

**Step 11 and step 12.** These steps consist on estimating the safety barriers effectiveness. For each accident mode, the effectiveness of the safety barriers implemented on the site were evaluated, using the fuzzy linguistic variable "effectiveness" (see table 5.2), and then using the aggregation operator, equation 10, the effectiveness was estimated (see column 4 of the table 6.3). The notation N/A used in the table 6.3 means "not applicable", because that type of safety barrier was not in use on the site for prevent/protect that accident mode.

Table 6.3 – SB effectiveness estimation for the accident modes analyzed in case 1

| Accident mode | SB Existence | SB Rating | SB Effectiveness |
|---|---|---|---|
| Falls | Physical: None implemented | Physical: N/A | 0.94 |
| | Functional: None implemented | Functional: N/A | |
| | Symbolic: None implemented | Symbolic: N/A | |
| | Incorporeal: Some legal requirements were being met | Incorporeal: **Insufficient** | |
| Contact with electricity | Physical: Electric powered tools with double insulation | Physical: **Very good** | 0.10 |
| | Functional: Residual current circuit breakers | Functional: **Excellent** | |
| | Symbolic: None implemented | Symbolic: N/A | |
| | Incorporeal: Some legal requirements were being met | Incorporeal: **Insufficient** | |
| Injured by falling/swinging objects | Physical: Some workers wore the safety helmet | Physical: **Insufficient** | 0.79 |
| | Functional: None implemented | Functional: N/A | |
| | Symbolic: None implemented | Symbolic: N/A | |
| | Incorporeal: Some legal requirements were being met | Incorporeal: **Insufficient** | |
| Hit by rolling/sliding/flying object (including awkward or sudden movement) | Physical: Abrasive wheel grinders provided with safety guards. Some workers wore the safety gloves | Physical: **Good** | 0.54 |
| | Functional: None implemented | Functional: N/A | |
| | Symbolic: None implemented | Symbolic: N/A | |
| | Incorporeal: Some legal requirements were being met | Incorporeal: **Insufficient** | |
| Contact with machinery/equipment moving parts (including trapped between objects) | Physical: None implemented | Physical: N/A | 0.59 |
| | Functional: Command type man killed in the manual tools | Functional: **Good** | |
| | Symbolic: None implemented | Symbolic: N/A | |
| | Incorporeal: Some legal requirements were being met | Incorporeal: **Insufficient** | |
| Fire or explosion | Physical: Inks, varnishes and solvents stored in appropriated containers | Physical: **Good** | 0.53 |
| | Functional: None implemented | Functional: N/A | |
| | Symbolic: None implemented | Symbolic: N/A | |
| | Incorporeal: Some legal requirements were being met | Incorporeal: **Insufficient** | |

**Step 13**. This is the final step of QRAM model, where the overall risk level for the site being analyzed is determined. For each accident mode, the final evaluation of the risk level on this construction site was determined by aggregating the values of the four dimensions, previously estimated, using the equation 8. The final risk level, for each accident mode, is depicted in the table 6.4.

Table 6.4 - Work accident risk level for the accident modes analyzed in case 1

| Dimensions / Accident Mode | Safety Climate | Possibility | Severity | Safety Barriers effectiveness | Risk Level |
|---|---|---|---|---|---|
| Falls | 0.82 | 0.67 | 1.00 | 0.94 | 0.78 |
| Contact with electricity | | 0.74 | 1.00 | 0.10 | 0.44 |
| Injured by falling/swinging objects | | 0.75 | 0.10 | 0.79 | 0.41 |
| Hit by rolling/sliding/flying object (including awkward or sudden movement) | | 0.71 | 0.72 | 0.53 | 0.63 |
| Contact with machinery/equipment moving parts (including trapped between objects) | | 0.72 | 0.20 | 0.59 | 0.43 |
| Fire or explosion | | 0.84 | 0.10 | 0. 53 | 0.38 |

As can be observed, falls accident mode displays a "high" risk level and considering the ALARP (As Low As Reasonably Possible) approach zones, it is unacceptable. This implies that safety related with this accident mode must be quickly improved; the other accident modes are within the acceptable ALARP zones, hence safety should be improved if it is technically and financially practicable.

**Step 14.** This step deals with conclusions& recommendations aiming to lowering the risks. It is performed after obtaining the risk level for the construction site regarding all dimensions and factors affecting the construction site.

The most immediate conclusions are described above, in step 13. The risk of falls is unacceptable with a value of 0.78, which means that the work cannot continue to be made as it is being executed. All the other accident modes have some risk, not too serious, but attention should be paid to them to reduce ALARP risks. To advise about the measures that should be implemented, the analyst must begin by observing, for each accident mode, what is the dimension - and its corresponding factors - that most contributes to the final level of risk. In this case, it is obvious that the safety climate level is very bad (0.82 to 1.00) and it is therefore necessary to lower it. Within this dimension - safety climate - the analyst must find out which questions (factors) were rated as "Inadequate" and propose measures to improve them (see short example on table 6.5)

Table 6.5 - Advised safety measures for case 1

| Questions rated as "inadequate" | Advised measures to improve it |
|---|---|
| Written work procedures match the way tasks are done in practice? | Written work procedures must be rewritten to match the way tasks are done in practice. |
| Written work procedures are technically accurate and adequate sources of safety information? | Written work procedures must be rewritten in a technically accurate way in order to be adequate sources of safety information. |
| Written work procedures are complete and easy to read and understand? | Written work procedures must be rewritten to be complete and easy to read and understand. |
| Written work procedures are always available whenever needed be consulted? | Written work procedures must be always available whenever needed be consulted. |
| Workers can easily identify the applied procedure for each job? | Workers must be trained to easily identify the applied procedure for each job. |
| Rules enforce the use of personal protective equipment whenever necessary? | Workers must be trained on rules that enforced the use of personal protective equipment whenever necessary. |
| Rules require detailed work plans from subcontractors or self-employed individuals? | Rules should be established to require detailed work plans from subcontractors or self-employed individuals. |
| The definition of responsibilities and accountabilities is quite adequate? | Responsibilities and accountabilities must be properly defined and must be communicated to employees. |

After tackling the worst dimension the analyst should verify which dimension is the second worst, after, the third worst and so forth. In this case, the second worst is safety barriers dimension (still observing the falls accident mode). The analysis of the results, for the other accident modes, is made in the same way.

Notice that measures taken to improve the safety climate will affect the whole construction site, because they are transversal to the whole site, covering all accident modes and all activities.

A brief discussion about possible recommendations for the second worst classified dimension, possibility of work accidents occurence, is described next.

About **falls**, working on the ceilings should be performed on stable platforms;portable ladders should be used only in short-term jobs (not exceeding 30 min) and that do not require the worker side loads. **Contact with electricity**, measures should be taken to prevent unauthorised persons from working on the installation under tension and to protect flexible cords and cables against damage.**Injured by falling/swinging objects**, simultaneous activities in a small space should be properly planned and the weight of the loads moved manually should be known before starting to move them to ensure it is carried out in a safe way and is appropriately supervised. **Hit by rolling/sliding/flying object (including awkward or sudden movement)**, machines and tools should be inspected (by the users) at the beginning of each shift to assure that they are free of defects and workers should be aware of the dangers of incorrect usage of tools or aids. **Contact with machinery/equipment moving parts (including trapped between objects)**, he power actuated tools should be left unloaded until they are ready for immediate use and workers should be aware of the dangers of using hand tools in an unsafe position. **Fire or explosion**, workers should be aware of the dangers of smoking in the immediate vicinity of flammable substances.

## 6.2. Qualitative risk assessment model application on a construction site – Case 2

In this case, QRAM model was applied to a construction site of a pumping station and a pipeline. It is a very different type of construction site (from the case 1), using different construction methods and equipment's and it is exposed to atmospheric events. When the analysis was performed, the activities that were being carried out are: a) opening of trench, installation of conduct, b) iron assembling and, c) welding of metal profiles. Working on the site were: a safety coordinator, a safety technician, a construction engineer, 2 foremen, 1 welder, 3 iron assemblers, 3 machine operators and 8 unskilled workers (see figures 6.2 and 6.3).

**Step 1 and 2.** On step 1 and step 2 the factors affecting the safety climate on site are evaluated and rated. To rate the safety climate factors it was interviewed the safety coordinator, a foreman, an iron assembler and a machine operator. Annex II.9 presents the evaluations for each safety climate factor.

**Step 3.** By aggregating all safety climate factors (see eq. 12), the Safety Climate Level is 0.49, which is considered acceptable (although it could be improved).

**Step 4.** The identification of work tasks took place in two work fronts: a) construction of pumping station and, b) construction of a pipeline. On front a) the activities that were being carried out were iron assembling and welding of metal profiles and, on front b) the activities that were being carried out were opening of the trench and installation of the conduct.

**Step 5.**On front a) the activity that was analysed was the iron assembling and the accident modes identified as the ones that are likely to occur are: falls, contact with electricity, struck by moving vehicle (including heavy equipment), injured by falling/swinging objects, hit by rolling/sliding/flying object (including awkward or sudden movement), contact with machinery/equipment moving parts (including trapped between objects) and cave-ins (while or after excavation).

On front b) the activity analysed was the opening of the trench and the accident modes identified as the ones that are likely to occur are: falls, contact with electricity, struck by moving vehicle (including heavy equipment), injured by falling/swinging objects, hit by rolling/sliding/flying object (including awkward or sudden movement), contact with machinery/equipment moving parts (including trapped between objects) and cave-ins (while or after excavation).

It should be noted that this front is later on used to compare the QRAM with other techniques, currently used to assess safety risks on construction sites (see section 6.4).

Figure 6.2 – Photo’s from construction site case 2, front a)

Figure 6.3 – Photo’s from construction site case 2, front b)

**Steps 6 and 7.**On front a) construction of pumping station, for each accident mode, the analyst identified and rated the factors affecting the work accidents possibility. In annexes II.10, II.11, II.12, II.13, II.14, II.15 and II.16 it is presented the analyst assessment for each accident mode. As refered before it should be noted that some factors are specific of certain construction types and are not applicable to all construction sites, hence, the factors “not applicable” in this construction site were deleted from the list.

**Step 8.**The final evaluation of each work accident possibility is estimated by aggregation their respective possibility factors, using equation 12, and the results are depicted in table 6.6.

Table 6.6 - Work accidents possibility level for the accident modes analyzed in case 2

| **Accident Mode** | **Possibility level** |
|---|---|
| Falls | 0.56 |
| Contact with electricity | 0.62 |
| Struck by moving vehicle | 0.52 |
| Injured by falling/swinging objects | 0.65 |
| Cave-ins | 0.52 |
| Hit by rolling/sliding/flying object (including awkward or sudden movement) | 0.53 |
| Contact with machinery/equipment moving parts (including trapped between objects) | 0.50 |

**Step 9.** On this step the expected work accidents severity are estimated. For each accident mode, the estimation of the expected severity is made with the linguistic variables presented in section 5.6. A summary of the expected severity, for the different accident modes, is depicted on table 6.7.

Table 6.7 - Work accidents severity estimation for the accident modes analyzed in case 2

| **Accident mode** | **Task characterization** | **Severity Assessment** | |
|---|---|---|---|
| | | Criteria | Value |
| Falls | Workers carrying out work at 8 meters in height over a concrete surface | Fig. 5.5 | 1,00 |
| Contact with electricity | Workers were used electrical power tools, 220VAC in a wet environment | Fig. 5.6 | 1.00 |
| Struck by moving vehicle | A hydraulic excavator was operating on site | Fig. 5.7 | 1.00 |
| Injured by falling/swinging objects | Possibility of objects bigger than a claw hammer falling from 8 m height | Fig. 5.8 | 1.00 |
| Cave-ins | First aid may take more than 10 m. | Fig. 5.9 | 1.00 |
| Hit by rolling/sliding/flying object | Possibility of sliding object with weighing more than 800 kg | Fig. 5.10 | 1.00 |
| Contact with machinery/equipment moving parts (including trapped between objects) | At this site, there are machines belong to the particularly dangerous machine categories determined by the Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 | Safety expert estimation | 1.00 |

**Step 10**. On this step the safety barriers implemented on site were identified, for each accident mode, by its SB type, namely: physical (or material), functional, symbolic and incorporeal (see column 2 of table 6.8).

**Step 11 and step 12.** These steps consist on estimating the safety barriers effectiveness. For each accident mode, the effectiveness of the safety barriers implemented on the site were evaluated, using the fuzzy linguistic variable "effectiveness" (see table 5.2), and then using the aggregation operator, equation 10, the effectiveness was estimated (see column 4 of the table 6.8).

Table 6.8 – SB effectiveness estimation for the accident modes analyzed in case 2

| Accident mode | SB Existence | SB Rating | SB Effectiveness |
|---|---|---|---|
| Falls | Physical: None implemented | Physical: N/A | 0.94 |
| | Functional: None implemented | Functional: N/A | |
| | Symbolic: None implemented | Symbolic: N/A | |
| | Incorporeal: Some legal requirements were being met | Incorporeal: **Insufficient** | |
| Contact with electricity | Physical: Electric powered tools with double insulation | Physical: **Excellent** | 0. 05 |
| | Functional: Residual current circuit breakers (30 mA) | Functional: **Excellent** | |
| | Symbolic: None implemented | Symbolic: N/A | |
| | Incorporeal: Some legal requirements were being met | Incorporeal: **Partial** | |
| Struck by moving vehicle | Physical: None implemented | Physical: N/A | 0. 76 |
| | Functional: None implemented | Functional: N/A | |
| | Symbolic: High visibility vests. Reversing alarm | Symbolic: **Partial** | |
| | Incorporeal: Some legal requirements were being met | Incorporeal: **Insufficient** | |
| Injured by falling/swinging objects | Physical: Safety helmets | Physical: **Partial** | 0. 20 |
| | Functional: Locking system in case of load excess | Functional: **Excellent** | |
| | Symbolic: None implemented | Symbolic: N/A | |
| | Incorporeal: Some legal requirements were being met. Safety inspections | Incorporeal: **Insufficient** | |
| Cave-ins | Physical: Shoring | Physical: **Good** | 0. 49 |
| | Functional: None implemented | Functional: N/A | |
| | Symbolic: None implemented | Symbolic: N/A | |
| | Incorporeal: Some legal requirements were being met. Safety inspections | Incorporeal: **Partial** | |
| Hit by rolling/sliding/flying object (including awkward or sudden movement) | Physical: Abrasive wheel grinders provided with safety guards. Some workers wore the safety gloves. Safety helmet. | Physical: **Good** | 0. 53 |
| | Functional: None implemented | Functional: N/A | |
| | Symbolic: None implemented | Symbolic: N/A | |

| Accident mode | SB Existence | SB Rating | SB Effectiveness |
|---|---|---|---|
| | Incorporeal: Some legal requirements were being met. Safety inspections | Incorporeal: **Insufficient** | |
| Contact with machinery/equipment moving parts (including trapped between objects) | Physical: Protection devices | Physical: **Good** | 0.20 |
| | Functional: Command type man killed in the manual tools | Functional: **Good** | |
| | Symbolic: Signals | Symbolic: **Partial** | |
| | Incorporeal: Some legal requirements were being met. Safety inspections | Incorporeal: **Insufficient** | |

**Step 13.** This is the final step of QRAM model, where the overall risk level for the site being analyzed is determined. For each accident mode, the final evaluation of the risk level on this construction site was determined by aggregating the values of the four dimensions, previously estimated, using the equation 8. The final risk levels, for each accident mode, are depicted in table 6.9.

Table 6.9 - Work accident risk level for the accident modes analyzed in case 2

| Accident Mode | Safety Climate | Possibility | Severity | Safety Barriers | Risk Level |
|---|---|---|---|---|---|
| Falls | 0.49 | 0.56 | 1.00 | 0.94 | 0.64 |
| Contact with electricity | | 0.62 | 1.00 | 0.05 | 0.34 |
| Struck by moving vehicle | | 0.52 | 1.00 | 0.76 | 0.61 |
| Injured by falling/swinging objects | | 0.65 | 1.00 | 0.20 | 0.43 |
| Cave-ins | | 0.52 | 1.00 | 0.49 | 0.57 |
| Hit by rolling/sliding/flying object (including awkward or sudden movement) | | 0.53 | 1.00 | 0. 53 | 0.59 |
| Contact with machinery/equipment moving parts (including trapped between objects) | | 0.50 | 1.00 | 0.20 | 0.41 |

**Step 14.**In this step a brief overview of recommendations is provided for this site. About safety measures to be taken, safety climate needs to be improved. It could be done by making the writing procedures available whenever they need to be consulted and also by giving to the safety personnel the power to do their job correctly, by listening and acting on the workers feedback and by undertaking campaigns to promote safe working practices. Furthermore, the work place must be properly signalized and legal requirements must be fully met and SB should be implemented to avoid falls in the trenches.

The recommendations per accident mode after observing the results obtained with QRAM are:

- About falls, the risk level 0.64 is the higher, so it should be the first priority to tackle (improve). For example,should be improved the lighting levels on workplaces.
- Struck by moving vehicles has the second higher risk level, with 0.61. So, it should be the second factor to tackle (or improve). For example, space enough must be created to maneuver the vehicles safely (avoiding the vehicle to enter pedestrian zones when being maneuvered),

obstructions (sharp bends, pillars, other vehicles, stacks of material, etc.) should be make clearly visible and traffic warning signs should be improved.

- Hit by rolling/sliding/flying object (including awkward or sudden movement) has the third higher risk level with 0.59, so, it should be the third risk to be improved, as for example: observers and aides must keep a safe distance from the work heavy equipment's.
- Cave-ins has the fourth higher risk level with 0.59, so, it should be the fourth risk to be to improved and measures could be: vehicle speed should be properly reduced in roads near excavations (to reduce vibration).

For thehe other accident modes, some measures could be taken, with lower priority, to improve safety, namely: **Contact with electricity**,should be taken measures to prevent unauthorised persons from working on installations under tension and metal ladders should not be used when working on or near electrical equipment.**Injured by falling/swinging objects**, zones of swinging/hanging loads or in the vicinity of rotating arms or counterweights should be clearly indicated by means of marking and/or signaling and danger zones of hanging loads should be indicated by means of marking and/or signaling. **Contact with machinery/equipment moving parts (including trapped between objects)**, power actuated tools should be left unloaded until they are ready for immediate use and locations where objects, machines or obstacles were placed too closely to each other so that workers could be trapped if the objects or machines started moving should be clearly indicated by means of marking and/or signaling.

## 6.3. Qualitative risk assessment model application results for cases 3 to 12

This section presents the results of the practical application of QRAM to 10 different construction sites. Nine of the cases are related with different building types (school, house, and hotel) and one is a highway construction. The objective is to compare the results of the QRAM model with the elicited expert opinions (Questionnaire in annex II.1). The data gathered are summarized in tables 6.10 to 6.12.

The table 6.10 presents the data relating to the respective construction company details: a) in column 1 is the case test number; b) in column 2 is the country where the test was performed; c) in column 3 is the construction company basic data, d) in column 4 is the construction type, e) in column 5 is the construction basic description; and f) in column 6 is the list of accident modes that has been analyzed.

The table 6.11 presents the data relating to occupational safety risk level; a) in column 1 is the case test number, b) in column 2, is the safety climate level, c) in column 3 is the accident mode, d) in column 4, is the severity level (for the accident mode), e) in column 5, is the possibility level, f) in column 6, is the safety barriers effectiveness and g) in column 7, is the occupational safety risk level (for the accident mode). On the columns 2 and 5, the S stands for Strongly adequate, the V for Very adequate, the A for Adequate, the Aa for Almost adequate, the L for Low adequate and, the I for Inadequate; the number following the letter is the number of questions rating with that semantic term. On column 6, Ph stands for safety barrier Physical type, the F for the Functional type, the S for the Symbolic type and the I for the Incorporeal type; E stands for Excellent, the VG for Very good, the G for Good, the P for Partial, the Ins for Insufficient and the B for Bad.

All the risks on the unacceptable (red) zone must be lowered quickly (and works should be stopped until the risk is reduced), the others on the ALARP (yellow) zone should be lowered, with different priorities according the risk level, following technical and economic ALARP criteria.

After applying the model to real construction sites, ten safety experts, linked to the construction sites (with different profiles and expertise) were requested to verify if the QRAM results (partial results of each dimension and the risk level) correspond to their empirical knowledge. This was done using a 5-point semantic Likert scale (Strongly approved, Approved, Undecided, Disapproved and Strongly disapproved).

The table 6.12 presents the ten experts opinions, gathered from the QRAM application to cases 3 to 12; a) in column 1 is the case test number, b) in column 2 is the experts basic data, c) in column 3 is the construction company data, d) in column 4 is the experts opinions about safety climate dimension , e) in column 5 is the experts opinions about severity dimension, f) in column 6 is the experts opinions about possibility dimension, g) in column 7 is the experts opinions about safety barriers dimension and, h) in column 7 is the experts decisions about QRAM risk levels results.

Table 6.10 - Company data and construction brief descriptions from cases 3 to 12

| Case | Country | Company data | Construction type | Construction brief description | Accident modes analysed |
|---|---|---|---|---|---|
| 3 | Brazil | Private company with over 250 employees with a safety engineer on site. | Housing building | Building with eleven floors with concrete structure and masonry walls. When the evaluation was conducted, masonry work (on the upper floors) and specialized work (sewers, water and electricity supply) were on-going. About fifty workers were on site. | Falls, Contact with electricity, Struck by moving vehicle, Injured by falling object, Hit by rolling/sliding object, Contact with machinery moving parts, Fire and Explosion. |
| 4 | Brazil | Private company with less than 250 employees, with a part-time safety engineer (at the headquarters, had never visited the site). | School building | Ground floor building with concrete structure and masonry walls. When the evaluation was conducted, the masonry work was starting and the structure work was being concluded. Twenty-three workers were on site. | Falls, Contact with electricity, Struck by moving vehicle, Injured by falling object, Hit by rolling/sliding object, Contact with machinery moving parts, Fire and Explosion. |
| 5 | Bulgaria | Private company with less than 250 employees, with a safety technician at headquarters that goes to the site when requested. | Housing building | Building with five floors with concrete structure and masonry walls, built on the riverbank (on cliff). When the evaluation was conducted, finish works (painting, paving, carpentry) were ongoing and the roof (traditional roof with slope and tile coverage) was being concluded. About thirty workers were on site. | Falls, Contact with electricity, Struck by moving vehicle, Injured by falling object, Hit by rolling/sliding object, Contact with machinery moving parts, Lost buoyancy in water, Fire and Explosion. |

| Case | Country | Company data | Construction type | Construction brief description | Accident modes analysed |
|---|---|---|---|---|---|
| 6 | Greece | Private company with more than 250 employees, with a safety technician on site. When the evaluation was conducted were six sub contractors on site. | Housing building | Set of three buildings with four floors with concrete structure and masonry walls. When the evaluation was conducted, masonry work and conclude structure work (on one of the buildings) and specialty work (sewers, water and electricity supply) and finish works (painting, paving, carpentry) on the other two were ongoing. About seventy workers were on site. | Falls, Contact with electricity, Struck by moving vehicle, Injured by falling object, Hit by rolling/sliding object, Contact with machinery moving parts, Fire and Explosion. |
| 7 | Greece | Private company with more than 250 employees, with a safety engineer at headquarters that goes to the site when requested. When the evaluation was conducted was one sub contractor on site. | Housing building | Rebuild of a building with five floors with concrete structure and masonry walls. When the evaluation was conducted, finish works (painting, paving, carpentry), works on the roof (traditional roof with slope and tile coverage) and painting of the facades were ongoing. Seventeen workers were on site. | Falls, Contact with electricity, Struck by moving vehicle, Injured by falling object, Hit by rolling/sliding object, Contact with machinery moving parts, Fire and Explosion. |
| 8 | Greece | Private company with less than 250 employees, with a part-time safety technician (at the headquarters, had never visited the site). | Housing building | Building with two floors with concrete structure and masonry walls and garden. When the evaluation was conducted, works on the roof (traditional roof with slope and tile coverage), painting works (inside and outside) and modulation of the ground in the garden were ongoing. Twelve workers were on site. | Falls, Contact with electricity, Struck by moving vehicle, Injured by falling object, Hit by rolling/sliding object, Contact with machinery moving parts, Fire and Explosion. |

| Case | Country | Company data | Construction type | Construction brief description | Accident modes analysed |
|---|---|---|---|---|---|
| 9 | Turkey | Private company with more than 250 employees, with a safety technician at headquarters that goes to the site when requested (in this construction step). When the evaluation was conducted was one sub contractor on site. | Housing building | Building with nine floors with concrete structure and masonry walls. When the evaluation was conducted, only excavation works were ongoing. Eleven workers were on site. | Falls, Contact with electricity, Struck by moving vehicle, Injured by falling object, Hit by rolling/sliding object, Cave-ins, Contact with machinery moving parts, Fire and Explosion. |
| 10 | Turkey | Private company with less than 250 employees, with a safety technician on site. When the evaluation was conducted were two sub contractors on site. | Services building | Building with ten floors with concrete structure and masonry walls. When the evaluation was conducted, masonry work (on the ground floors and basement), specialty work (communications and electricity supply) and finish works (painting, paving, carpentry) were ongoing. About one hundred workers were on site. | Falls, Contact with electricity, Struck by moving vehicle, Injured by falling object, Hit by rolling/sliding object, Contact with machinery moving parts, Fire and Explosion. |
| 11 | Turkey | Private company with more than 250 employees, with a safety technician on site (watched several spots along the construction). | Highway | Construction of a highway with four lanes, in a plain ground. When the evaluation was conducted, works of grading and compaction of the ground were ongoing. Seven workers were on the visited spot. | Falls, Contact with electricity, Struck by moving vehicle, Contact with machinery moving parts, Fire and Explosion. |

| Case | Country | Company data | Construction type | Construction brief description | Accident modes analysed |
|---|---|---|---|---|---|
| 12 | Portugal | Private company with more than 250 employees, with a safety technician at headquarters that goes to the site when requested. The site had a safety coordinator. When the evaluation was conducted were five sub contractors on site. | Hotel building | Rebuild of a building with five floors with resistant stone walls and wooden floors and construction of a new building with four floors with concrete structure and masonry walls. When the evaluation was conducted, works of installation of plasterboard partitions and specialty work (sewers, water and electricity supply) and finish works (painting, paving, carpentry), in the old building and masonry works on the new building were ongoing. About fifty workers were on site. | Falls, Contact with electricity, Struck by moving vehicle, Injured by falling object, Hit by rolling/sliding object, Contact with machinery moving parts, Fire and Explosion. |

Table 6.11 - Safety risks level results for cases 3 to 12

| Case | Safety Climate Level | Accident modes | Severity | Possibility | Safety barriers | Accident mode Risk level |
|---|---|---|---|---|---|---|
| 3 | **0.587** (S - 27; V - 5; A - 19; Aa - 15; L - 12; I - 23) | Falls | **1.000** | **0.597** (S - 14; V - 11; A - 18; Aa - 3; L - 7; I - 22) | SB effective. = **0.361** (Ph–VG; S-B; I-Ins) | 0.64 ALARP Zone |
| | | Contact with electricity | **1.000** | **0.611** (S - 5; V - 1; A - 12; Aa - 2; L - 3; I - 8) | SB effective.=**0.125** (Ph-VG; F-VG; S-B; I-Ins ) | 0.58 ALARP Zone |
| | | Struck by moving vehicle | **1.000** | **0.598** (S - 4; V - 7; A - 10; Aa - 2; L - 3; I - 10) | SB effective. = **0.761** (S-P; I-Ins ) | 0.74 Unacceptable Zone |
| | | Injured by falling object | **1.000** | **0.544** (S - 7; V - 11; A - 18; I - 12) | SB effective. =**0.618** (Ph–P; S-B; I-Ins) | 0.69 ALARP Zone |
| | | Hit by rolling/sliding object | **0.600** | **0.713** (S - 2; V - 3; A - 6; Aa - 5; L - 2; I - 15) | SB effective. = **0.618** (Ph–P; S-B; I-Ins) | 0.63 ALARP Zone |
| | | Contact with machinery moving parts | **1.000** | **0.599** (V - 13; A - 18; Aa - 6; I - 13) | SB effective.=**0.103** (Ph-G; F-E; S–P; I - Ins ) | 0.47 ALARP Zone |
| | | Fire and Explosion | **0.500** | **0.445** (S - 5; V - 4; A - 9; L - 4) | SB effective. = **0.761** (S–P; I-Ins) | 0.57 ALARP Zone |
| 4 | **0.662** (V - 5; A - 46; Aa - 15; L - 12; I - 23) | Falls | **1.000** | **0.708** (V - 3; A - 22; Aa - 17; L - 9; I - 24) | SB effective. =**0.618** (Ph–P; S-B; I-Ins) | 0.75 Unacceptable Zone |
| | | Contact with electricity | **1.000** | **0.662** (S - 1; A - 13; Aa - 7; L - 2; I - 8) | SB effective. = **0.329** (Ph-G; F-P; S-B; I-Ins ) | 0.66 ALARP Zone |
| | | Struck by moving vehicle | **1.000** | **0.695** (V - 6; A - 11; L - 5; I - 14) | SB effective. = **0.849** (S-Ins; I-Ins ) | 0.80 Unacceptable Zone |
| | | Injured by falling object | **1.000** | **0.599** (S - 2; V - 7; A - 25; L – 2; I - 12) | SB effective. =**0.618** (Ph–P; S-B; I-Ins) | 0.72 Unacceptable Zone |
| | | Hit by rolling/sliding object | **1.000** | **0.813** (V - 5; A - 6; I - 22) | SB effective. = **0.788** (S– Ins; I-Ins) | 0.81 Unacceptable Zone |
| | | Contact with machinery moving parts | **1.000** | **0.715** (V - 4; A - 17; Aa - 3; L - 3; I - 22) | SB effective. = **0.365** (Ph -P; F-P; S-Ins; I-Ins) | 0.68 ALARP Zone |
| | | Fire and Explosion | **0.500** | **0.554** (V - 9; A - 7; L – 2; I - 4) | SB effective. = **0.761** (S-P; I-Ins ) | 0.62 ALARP Zone |

| Case | Safety Climate Level | Accident modes | Severity | Possibility | Safety barriers | Accident mode Risk level |
|---|---|---|---|---|---|---|
| 5 | **0.480** (V - 22; A -69; L - 10) | Falls | **1.000** | **0.689** (V - 1; A - 25; Aa - 10; L - 36; I - 3) | SB effective. = **0.168** (Ph-E; S-P; I-P) | 0.58 ALARP Zone |
| | | Contact with electricity | **1.000** | **0.534** (A - 21; Aa - 8; L – 2) | SB effective. = **0.115** (Ph -VG; F-G; S-P;I-P) | 0.53 ALARP Zone |
| | | Struck by moving vehicle | **1.000** | **0.494** (V – 2; A - 15; Aa - 19) | SB effective. = **0.710** (S-P; I-P) | 0.67 ALARP Zone |
| | | Injured by falling object | **1.000** | **0.529** (S - 2; V - 2; A - 32; Aa - 3; L - 9) | SB effective. = **0.572** (Ph-P; S-B; I-P) | 0.64 ALARP Zone |
| | | Hit by rolling/sliding object | **0.700** | **0.569** (S - 1; V - 4; A - 11; Aa -14; L – 2; I - 1) | SB effective. = **0.449** (Ph-P; S-P; I-P) | 0.55 ALARP Zone |
| | | Contact with machinery moving parts | **1.000** | **0.663** (V - 4; A - 18; Aa -3; L –3; I - 16) | SB effective. = **0.103** (Ph-E; F-E; S-P; I-Ins) | 0.56 ALARP Zone |
| | | Lost buoyancy in water | **1.000** | **0.388** (S – 1; A - 12) | SB effective. = **0.449** (Ph-P; S-P; I-P) | 0.58 ALARP Zone |
| | | Fire and Explosion | **0.500** | **0.367** (S – 3; V – 7; A - 9; Aa - 3) | SB effective. = **0.710** (S-P; I-P) | 0.51 ALARP Zone |

| Case | Safety Climate Level | Accident modes | Severity | Possibility | Safety barriers | Accident mode Risk level |
|---|---|---|---|---|---|---|
| 6 | **0.701** (V - 5; A - 46; L - 12; I - 38) | Falls | **1.000** | **0.734** (A - 25; Aa - 11; L - 12;I - 27) | SB effective. = **0.572** (Ph-P; S-B; I-P) | 0.75 Unacceptable Zone |
| | | Contact with electricity | **1.000** | **0.659** (A - 15; Aa -6; L – 4; I - 6) | SB effective. = **0.283** (Ph-P; F-P; S-P; I-P) | 0.66 ALARP Zone |
| | | Struck by moving vehicle | **1.000** | **0.623** (V – 5; A - 13; Aa - 9; L - 2; I - 7) | SB effective. = **0.761** (S-P; I-Ins ) | 0.77 Unacceptable Zone |
| | | Injured by falling object | **1.000** | **0.569** (S – 1; V – 4; A - 31; Aa - 4; L - 3; I - 5) | SB effective. = **0.618** (Ph-P; S-B; I-Ins ) | 0.72 Unacceptable Zone |
| | | Hit by rolling/sliding object | **1.000** | **0.570** (V - 5; A - 14; Aa – 11; I - 3) | SB effective. = **0.797** (S–Ins; I-Ins) | 0.77 Unacceptable Zone |
| | | Contact with machinery moving parts | **1.000** | **0.626** (V – 9; A - 22; Aa - 2; L - 4; I - 13) | SB effective. = **0.488** (Ph-P; F-B; S-Ins; I-P) | 0.70 Unacceptable Zone |
| | | Fire and Explosion | **0.500** | **0.521** (S - 3; V - 2; A - 14; I - 3) | SB effective. = **0.761** (S-P; I-Ins) | 0.62 ALARP Zone |
| 7 | **0.730** (A - 51; I - 50) | Falls | **1.000** | **0.679** (V – 7; A - 25; Aa - 11; L - 12; I - 20) | SB effective. = **0.572** (Ph-P; S-B; I - P) | 0.74 Unacceptable Zone |
| | | Contact with electricity | **1.000** | **0.611** (S – 6; A - 12; L – 7; I - 6) | SB effective. = **0.373** (Ph-P; F-P; S-B; I-P) | 0.68 ALARP Zone |
| | | Struck by moving vehicle | **1.000** | **0.781** (A - 13; Aa - 4; L - 7; I - 12) | SB effective. = **0.710** (S-P; I-P) | 0.80 Unacceptable Zone |
| | | Injured by falling object | **1.000** | **0.723** (A - 29; Aa - 4; L - 3; I - 12) | SB effective. = **0.489** (Ph-P; S-P; I-Ins ) | 0.73 Unacceptable Zone |
| | | Hit by rolling/sliding object | **0.700** | **0.613** (A - 19; Aa – 9; I - 5) | SB effective. = **0.409** (Ph-P; S-B; I-Ins) | 0.61 ALARP Zone |
| | | Contact with machinery moving parts | **1.000** | **0.735** (A - 31; L - 4; I - 15) | SB effective. = **0.663** (Ph-Ins; F-B; S-Ins; I-Ins) | 0.78 Unacceptable Zone |
| | | Fire and Explosion | **0.500** | **0.559** (V - 2; A - 17; I - 3) | SB effective. = **0.762** (Ph – Ins; S-B; I-Ins) | 0.64 ALARP Zone |

| Case | Safety Climate Level | Accident modes | Severity | Possibility | Safety barriers | Accident mode Risk level |
|---|---|---|---|---|---|---|
| 8 | **0.742** (A - 44; L - 14; I - 43) | Falls | **1.000** | **0.689** (V - 1; A - 25; Aa - 10; L - 36; I - 3) | SB effective. = **0.801** (Ph-Ins; S-B; I-B) | 0.81 Unacceptable Zone |
| | | Contact with electricity | **1.000** | **0.724** (S – 2; A - 14; L – 9; I - 4) | SB effective. = **0.538** (Ph-P; F-Ins; S-B; I-B) | 0.75 Unacceptable Zone |
| | | Struck by moving vehicle | **1.000** | **0.683** (S – 4; V – 2; A - 13; Aa - 4; L - 7; I - 5) | SB effective. = **0.710** (S-P; I-P) | 0.78 Unacceptable Zone |
| | | Injured by falling object | **1.000** | **0.670** (V – 5; A - 30; Aa - 4; L - 3; I - 6) | SB effective. = **0.699** (Ph -Ins; S-Ins; I-Ins) | 0.78 Unacceptable Zone |
| | | Hit by rolling/sliding object | **1.000** | **0.816** (V - 5; A - 6; I - 23) | SB effective. = **0.917** (S-B; I-Ins) | 0.87 Unacceptable Zone |
| | | Contact with machinery moving parts | **1.000** | **0.764** (A - 25; Aa – 2; L - 4; I - 19) | SB effective. = **0.663** (Ph -Ins; F-B; S-Ins; I-Ins) | 0.79 Unacceptable Zone |
| | | Fire and Explosion | **0.500** | **0.390** (V - 1; A - 5) | SB effective. = **0.761** (S – P; I - Ins | 0.60 ALARP Zone |
| 9 | **0.653** (V - 9; A - 53; L - 10; I - 29) | Falls | **1.000** | **0.708** (V - 3; A - 22; Aa - 17; L - 9; I - 24) | SB effective. =**0.513** (Ph–G; S-B; I-Ins) | 0.72 Unacceptable Zone |
| | | Contact with electricity | **1.000** | **0.380** (V – 3; A - 9) | SB effective. = **0.329** (Ph-G; F-P; S-B; I-Ins ) | 0.59 ALARP Zone |
| | | Struck by moving vehicle | **1.000** | **0.772** (A - 13; Aa - 4; L - 7; I - 10) | SB effective. = **0.761** (S-P; I-Ins ) | 0.80 Unacceptable Zone |
| | | Injured by falling object | **1.000** | **0.650** (V – 5; A - 33; Aa - 4; L - 3; I - 3) | SB effective. = **0.462** (Ph–G; S-Ins; I-Ins) | 0.69 ALARP Zone |
| | | Hit by rolling/sliding object | **1.000** | **0.803** (V - 2; A - 8; I - 15) | SB effective. = **0.788** (S–Ins; I-Ins) | 0.81 Unacceptable Zone |
| | | Cave-ins | **1.000** | **0.557** (V – 2; A – 13; L - 1) | SB effective. = **0.321** (Ph-VG; S-Ins; I-Ins) | 0.63 ALARP Zone |
| | | Contact with machinery moving parts | **1.000** | **0.723** (A - 24; I - 12) | SB effective. = **0.369** (Ph-G; F-Ins; S-Ins; I-Ins) | 0.69 ALARP Zone |
| | | Fire and Explosion | **0.500** | **0.338** (V - 3; A - 2) | SB effective. =**0.618** (Ph–P; S-B; I-Ins) | 0.64 ALARP Zone |

| Case | Safety Climate Level | Accident modes | Severity | Possibility | Safety barriers | Accident mode Risk level |
|---|---|---|---|---|---|---|
| 10 | **0.644** (V - 12; A - 46; Aa - 7; L - 10; I - 26) | Falls | **1.000** | **0.597** (S - 14; V - 11; A - 18; Aa - 3; L - 7; I - 22) | SB effective. = **0.423** (Ph-G; S-Ins; I-P) | 0.67 ALARP Zone |
| | | Contact with electricity | **1.000** | **0.744** (A - 14; Aa – 2; L – 9; I - 4) | SB effective. = **0.181** (Ph-G; F-G; S-P; I-P) | 0.64 ALARP Zone |
| | | Struck by moving vehicle | **1.000** | **0.661** (S – 4; V – 2; A - 17; Aa - 2; L - 7; I - 3) | SB effective. = **0.710** (S-P; I-P ) | 0.75 Unacceptable Zone |
| | | Injured by falling object | **1.000** | **0.612** (S – 4; V – 10; A - 24; Aa - 7; I - 3) | SB effective. = **0.321** (Ph-VG; S-Ins; I-Ins ) | 0.64 ALARP Zone |
| | | Hit by rolling/sliding object | **0.700** | **0.763** (V - 1; A - 17; I - 15) | SB effective. = **0.797** (S–Ins; I-Ins) | 0.73 Unacceptable Zone |
| | | Contact with machinery moving parts | **1.000** | **0.734** (S – 3; V – 3; A - 22; L - 4; I - 18) | SB effective. = **0.455** (Ph-P; F-Ins; S-Ins; I-Ins) | 0.71 Unacceptable Zone |
| | | Fire and Explosion | **0.500** | **0.680** (V - 1; A - 3; Aa – 3; I - 1) | SB effective. = **0.761** (S-P; I-Ins) | 0.65 ALARP Zone |
| 11 | **0.734** (A - 28; Aa - 25; L - 10; I - 38) | Falls | **1.000** | **0.597** (S - 14; V - 11; A - 18; Aa - 3; L - 7; I - 22) | SB effective. = **0.513** (Ph-G; S-B; I-Ins) | 0.71 Unacceptable Zone |
| | | Contact with electricity | **1.000** | **0.719** (A - 19; L – 6; I - 5) | SB effective. = **0.240** (Ph-G; F-G; S-Ins; I-Ins) | 0.67 ALARP Zone |
| | | Struck by moving vehicle | **1.000** | **0.631** (S – 4; V – 2; A - 23; L - 3; I - 3) | SB effective. = **0.710** (S-P; I-P ) | 0.77 Unacceptable Zone |
| | | Contact with machinery moving parts | **1.000** | **0.751** (V – 4; A - 23; L - 4; I - 19) | SB effective. = **0.530** (Ph-P; F-B; S-Ins; I-Ins) | 0.75 Unacceptable Zone |
| | | Fire and Explosion | **0.500** | **0.836** (A - 1; L – 1; I - 2) | SB effective. =**0.761** (S-P; I-Ins ) | 0.71 Unacceptable Zone |

| Case | Safety Climate Level | Accident modes | Severity | Possibility | Safety barriers | Accident mode Risk level |
|---|---|---|---|---|---|---|
| 12 | **0.747** (A - 28; Aa - 25; I - 48) | Falls | **1.000** | **0.679** (V – 7; A - 25; Aa - 11; L - 12; I - 20) | SB effective. = **0.801** (Ph-Ins; S-B; I-B) | 0.83 Unacceptable Zone |
| | | Contact with electricity | **1.000** | **0.670** (V – 3; A - 19; L – 2; I - 4) | SB effective. = **0.413** (Ph-G; F-Ins; S-B; I-Ins) | 0.71 Unacceptable Zone |
| | | Struck by moving vehicle | **1.000** | **0.362** (V – 4; A - 6) | SB effective. = **0.710** (S-P; I-P) | 0.71 Unacceptable Zone |
| | | Injured by falling object | **1.000** | **0.704** (A - 27 L - 4; I - 7) | SB effective. =**0.561** (Ph–P; S-Ins; I-Ins) | 0.75 Unacceptable Zone |
| | | Hit by rolling/sliding object | **0.700** | **0.816** (V - 5; A - 6; I - 22) | SB effective. = **0.710 (**S-P; I-P) | 0.74 Unacceptable Zone |
| | | Contact with machinery moving parts | 1.000 | **0.773** (A - 25; L - 4; I - 21) | SB effective. = **0.488** (Ph-P; F-B; S-Ins; I-P) | 0.75 Unacceptable Zone |
| | | Fire and Explosion | 0.500 | **0.554** (V - 9; A - 7; L – 2; I - 4) | SB effective. = **0.761** (S-P; I-Ins) | 0.64 ALARP Zone |

Table 6.12 - Expert opinions regarding evaluations obtained with QRAM for cases 3 to 12

| **Case** | **Experts Data** | **Company Data** | **Experts evaluation** | | | | |
|---|---|---|---|---|---|---|---|
| | | | **Safety Climate** | **Severity** | **Possibility** | **Safety Barriers** | **Risk level** |
| 3 | Safety engineer, with 15 of experience in the current position and in the industry. Involved in: developing RA, implementing RA and evaluating RA. | Big company working on buildings (residences, factories…) | It is a good way to consider safety climate data should be more practical by reducing the number of questions because some are repeated (i. e. get the same information by performing the question differently). **APPROVED**. | It is a practical and objective way to estimate severity but I am not sure about results reliability. **UNDECIDED.** | The model is very intuitive and easy to apply and allows characterizing in a reliable way the possibility of work accidents occurrence. **STRONGLY APPROVED.** | It is easy to apply but it is not intuitive. It needs some time to be well understood. **UNDECIDED.** | **APPROVED.** |
| 4 | Safety technician, with 16 of experience in the current position and in the industry. Involved in: developing RA and implementing RA. | Big company working on buildings (residences, factories…) | It is easy to apply and even pedagogical, but it has too many questions and some seem to repeated. **APPROVED.** | It works well in some accident modes (falls, contact with electricity and struck by moving vehicle) and not in others (hit by rolling/sliding object). **APPROVED.** | Allows to estimate quickly and accurately the possibility of occurrence of an accident. **STRONGLY APPROVED.** | Allows estimating the SB effectiveness in a reliable way. **APPROVED.** | **STRONGLY APPROVED.** |

| Case | Experts Data | Company Data | Experts evaluation | | | | |
|---|---|---|---|---|---|---|---|
| | | | **Safety Climate** | **Severity** | **Possibility** | **Safety Barriers** | **Risk level** |
| 5 | Construction engineer, with 11of experience in the current position and in the industry. Involved in: implementing RA. | Average company working on buildings (residences, factories…). | Don´t know much about safety climate. **NO OPINION.** | Estimate the severity correctly needs time and expertise. **APPROVED.** | It is quick to apply. **APPROVED.** | The categorisation should be re-examined in terms of the legal requirements category. I do not think that this is clearly defined. It may be closely associated with other categories also. **APPROVED.** | **APPROVED.** |

| Case | Experts Data | Company Data | Experts evaluation | | | | |
|---|---|---|---|---|---|---|---|
| | | | **Safety Climate** | **Severity** | **Possibility** | **Safety Barriers** | **Risk level** |
| 6 | OSH Labour Inspector, with 11 of experience in the current position and 3 in the industry. Involved in evaluating RA. | OSH Labour Inspection | Using QRAM method to complete ORA is a structured way to qualitatively assess the risks in the construction projects which is a step in front if taken into account the changing environment of the construction sector. However, the set of safety climate factors should be redefined and measured by skilled and experienced assessors to guarantee the effectiveness, efficiency and satisfaction. **UNDECIDED.** | Severity has to be further investigated and researched. More risks and their severity should be included in the proposed method. **UNDECIDED.** | The scale used to measure possibility seems appropriate. **APPROVED.** | The categories in which safety barriers are distinguished should be re-examined with a clear distinction between them. Further research should be made in the bibliography to check the categorisation of safety barriers. Besides, legal requirements are present in all categories of safety barriers. It needs a more clear distinction of the categories of safety barriers. **UNDECIDED.** | **UNDECIDED.** |

| Case | Experts Data | Company Data | Experts evaluation | | | | |
|---|---|---|---|---|---|---|---|
| | | | Safety Climate | Severity | Possibility | Safety Barriers | Risk level |
| 7 | Mechanical Engineer – Safety Engineer, with 4 of experience in the current position and 18 in the industry. Involved in: developing RA, implementing RA and evaluating RA. | Big company working on buildings (residences, factories…), infrastructures (including roads), sea and rail works. | Safety Climate represents a more restricted set of factors related mainly to individual perceptions and not to issues such as safety management or safe work behaviours (which I consider a result of safety climate and not a part of it). Some factors related to safety climate require significant expertise to evaluate, others require a lot of time for this reason, I believe that both efficiency and effectiveness are subject to risk analysts experience, knowledge and commitment. **UNDECIDED.** | They address only particular dimensions of severity (in respect to mechanical or electrical hazards). **DISAPPROVED.** | **APPROVED.** | Cat. confusing and incomplete. I would consider safety barriers as layers of immediate (physical, mechanical etc.), basic (procedures, training, signs) and underlying (mgt commitment, organizational arrangements) measures, and I would not incorporate h&s legislation in these since this can be taken into account in all types of measures as minimum requirements. **UNDECIDED.** | **UNDECIDED.** |

| Case | Experts Data | Company Data | Experts evaluation | | | | |
|---|---|---|---|---|---|---|---|
| | | | **Safety Climate** | **Severity** | **Possibility** | **Safety Barriers** | **Risk level** |
| 8 | OSH Labo Inspector with 10 of experience in the current position and in the industry. Involved in evaluating RA. | OSH Labor Inspection | The set of factors contributing to "Safety Climate" could be redefined and include only the factors dealing with employee and management perception of safety. The expected quality of the output of ORA using QRAM depends on the ability of users (is quite subjective). **UNDECIDED.** | More risks and their severity function could be added. **APPROVED.** | Doesn't seem improper. **APPROVED.** | The categories of safety barriers should be clear so as not to be repeated (for example, legal requirements coincide with physical safety barriers in many cases). **UNDECIDED.** | **APPROVED.** |

| Case | Experts Data | Company Data | Experts evaluation | | | | |
|---|---|---|---|---|---|---|---|
| | | | **Safety Climate** | **Severity** | **Possibility** | **Safety Barriers** | **Risk level** |
| 9 | Mechanical Engineer – Safety Engineer, with 8 of experience in the current position and 21 years in the industry. Involved in: developing RA, implementing RA and evaluating RA. | Big company working on buildings (residences, factories…), infrastructures (including roads), bridges and viaducts. | Safety climate very important to plan safety. QRAM method allow a structured analysis to qualitatively assess safety climate. The proposed model has more questions than necessary. **APPROVED.** | I am not sure that it addresses all severity factors. **UNDECIDED.** | Facilitates the estimation of work accidents occurrence on site. Although the check-list seems complete, there is always the possibility that there are factors other than those listed. **APPROVED.** | This categorization could be confusing in construction industry and if safety technicians don't understand well the methodology this will affect the quality of results **APPROVED.** | **APPROVED.** |
| 10 | OSH technician, with 14 of experience in the current position and in the industry. Involved in: developing RA and implementing RA. | Big company working on buildings (residences, factories…), infrastructures (including roads). | This model has too many questions, when compared with similar models that I know. I think it can be simplified by reducing the number of questions. The data needed is easy to obtain but I doubt its reliability because is based in workers and foremen responses **APPROVED.** | Incomplete. More risks and their severity should be included in the proposed method. **UNDECIDED.** | Good usability and the way to estimate possibility seems appropriate. **APPROVED.** | The categories in which safety barriers are divided are not incorrect but are not intuitive. It is needed a more clear distinction of the safety barriers categories. **APPROVED.** | **APPROVED.** |

| Case | Experts Data | Company Data | Experts evaluation | | | | |
|---|---|---|---|---|---|---|---|
| | | | **Safety Climate** | **Severity** | **Possibility** | **Safety Barriers** | **Risk level** |
| 11 | Safety technician, with 10 years of experience in the industry. Involved in: implementing RA. | Average company working on buildings (residences, factories…). | Seems incomplete because there aren't factors about management perception of safety. **APPROVED.** | More risky situations and their severity functions must be added. It is important that each severity function be carefully validate. **APPROVED.** | Appropriate and complete and produce good results in less time than other methodologies that I know. **APPROVED.** | The safety barriers division should be clearer. It is not easy to understand. More investigation on applied on SB is needed. **APPROVED.** | **APPROVED.** |
| 12 | Safety technician level V, with 26 years of experience in the current position and in the industry. Involved in: developing and implementing RA. | Big company working on buildings (residences, factories…), infrastructures (including roads), bridges, viaducts, Sea and Rail Works and football stadium. | Allows to estimate an important risk factor that is very important to be estimated, but should be simplified. **APPROVED.** | The model seems to be an easy way to estimate severity with some accuracy but there are lacks of risky situations that are likely to occur on construction sites. It could provide quality results in some accident modes such as: falls, contact with electricity and struck by moving vehicle; in the other I am not convinced of the appropriateness of the model. **UNDECIDED.** | Covers all factors that may cause a work accident in almost all kinds of construction projects where I had worked. Allows estimating quickly and accurately the possibility of occurrence of an work accident. Repeats some issues already addressed in the safety climate as training, use of PPEs and safety planning. **STRONGLY APPROVED.** | Allows estimating the SB effectiveness in a reliable way but only by experienced safety technicians on construction industry. **APPROVED.** | **APPROVED.** |

## 6.4. Qualitative risk assessment model comparison with other methods

In this section the QRAM results are directly compared with other techniques, currently used to assess safety risks on construction sites. For simplifying the comparison it will be used data from the front b) of case 2, above presented.

### 6.4.1. Summary of qualitative risk assessment model applied to case 2 front b)

A summary of the results, obtained by applying the QRAM method, for case 2 front b) are depicted in tables 6.13 to 6.16. The estimated safety climate level on this site was 0.49.

Table 6.13 - Work accident possibility from case 2 front b

| Accident Mode | Possibility level |
|---|---|
| Falls | 0.80 |
| Contact with electricity | 0.53 |
| Struck by moving vehicle | 0.56 |
| Injured by falling/swinging objects | 0.62 |
| Cave-ins | 0.60 |
| Hit by rolling/sliding/flying object (including awkward or sudden movement) | 0.73 |
| Contact with machinery/equipment moving parts (including trapped between objects) | 0.67 |

Table 6.14 - Work accident severity estimation from case 2 front b

| Accident mode | Task characterization | Severity Assessment | |
|---|---|---|---|
| | | Criteria | Value |
| Falls | Workers carrying out work at 8 meters in height over a concrete surface | Fig. 5.5 | 1,00 |
| Contact with electricity | Workers were used electrical power tools, 220VAC in a wet environment | Fig. 5.6 | 1.00 |
| Struck by moving vehicle | A hydraulic excavator was operating on site | Fig. 5.7 | 1.00 |
| Injured by falling/swinging objects | Possibility of objects bigger than a claw hammer falling from 8 m height | Fig. 5.8 | 1.00 |
| Cave-ins | First aid may take more than 10 m. | Fig. 5.9 | 1.00 |
| Hit by rolling/sliding/flying object | Possibility of sliding object with weighing more than 800 kg | Fig. 5.11 | 1.00 |
| Contact with machinery/equipment moving parts (including trapped between objects) | At this site, there are machines belong to the particularly dangerous machine categories determined by the Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 | Safety expert estimation | 1.00 |

Table 6.15 - Safety barriers effectiveness from case 2 front b

| Accident mode | Safety Barriers Existence | SB Rating | SB Effectiveness |
|---|---|---|---|
| Falls | Physical: None implemented | Physical: **Bad** | 0.91 |
| | Functional: None implemented | Functional: N/A | |
| | Symbolic: None implemented | Symbolic: **Bad** | |
| | Incorporeal: No legal requirements were being met | Incorporeal: **Bad** | |
| Contact with electricity | Physical: Electric powered tools with double insulation | Physical: **Good** | 0. 20 |
| | Functional: Residual current circuit breakers (30 mA) | Functional: **Good** | |
| | Symbolic: Overhead power lines unmarked | Symbolic: Insufficient | |
| | Incorporeal: Legal requirements were being met | Incorporeal: **Good** | |
| Struck by moving vehicle | Physical: None implemented | Physical: **Bad** | 0. 67 |
| | Functional: None implemented | Functional: N/A | |
| | Symbolic: High visibility vests. Reversing alarm | Symbolic: **Partial** | |
| | Incorporeal: Some legal requirements were being met | Incorporeal: **Partial** | |
| Injured by falling/swinging objects | Physical: Safety helmets | Physical: **Partial** | 0. 53 |
| | Functional: None | Functional: **Bad** | |
| | Symbolic: Slopes heads a little clean | Symbolic: **Insufficient** | |
| | Incorporeal: Few legal requirements were being met. | Incorporeal: **Insufficient** | |
| Cave-ins | Physical: Shoring | Physical: **Excellent** | 0. 20 |
| | Functional: None implemented | Functional: N/A | |
| | Symbolic: No systematic procedure | Symbolic: **Insufficient** | |
| | Incorporeal: Some legal requirements were being met. Safety inspections | Incorporeal: **Partial** | |
| Hit by rolling/sliding/ flying object (including awkward or sudden movement) | Physical: None implemented | Physical: **Bad** | 0. 81 |
| | Functional: None implemented | Functional: N/A | |
| | Symbolic: No systematic procedure | Symbolic: **Insufficient** | |
| | Incorporeal: Few legal requirements were being met. | Incorporeal: **Insufficient** | |
| Contact with machinery/equipment moving parts (including trapped between objects) | Physical: Protection devices | Physical: **Good** | 0.15 |
| | Functional: Command type man killed in the manual tools | Functional: **Very Good** | |
| | Symbolic: Very few signals | Symbolic: I**nsufficient** | |
| | Incorporeal: Some legal requirements were being met. Safety inspections | Incorporeal: **Partial** | |

Table 6.16 - Risk level results for case 2 front b, using QRAM method

| Accident Mode | Safety Climate | Possibility | Severity | Safety Barriers | Risk Level |
|---|---|---|---|---|---|
| Falls | 0.49 | 0.80 | 1.00 | 0.92 | 0,68 |
| Contact with electricity | | 0.42 | 1.00 | 0.20 | 0,40 |
| Struck by moving vehicle | | 0.56 | 1.00 | 0.67 | 0.60 |
| Injured by falling/swinging objects | | 0.62 | 1.00 | 0.53 | 0.59 |
| Cave-ins | | 0.60 | 1.00 | 0.20 | 0.42 |
| Hit by rolling/sliding/flying object (including awkward or sudden movement) | | 0.73 | 1.00 | 0. 81 | 0.65 |
| Contact with machinery/equipment moving parts (including trapped between objects) | | 0.57 | 1.00 | 0.15 | 0.39 |

### 6.4.2. Risk assessment occupational safety unsystematic technique applied to case 2 front b)

A safety expert on construction was asked to apply the usual RAOS unsystematic technique, described on 3.4.1, to the front b) case and the results obtained are summarized on table 6.17, the task analyzed was the opening of the trench.

1. Based on experience, the safety expert identified the accident modes that can occur: Falls, Contact with electricity, Struck by moving vehicle or heavy equipment, Injured by falling/swinging objects, Hit by rolling/sliding/flying object, Contact with machinery/equipment moving parts (including trapped between objects). He didn't identify Cave-ins (when asked justify he said that with those shoring, cave-ins are very unlikely to occur),
2. For the identified accident modes, he evaluated qualitatively the likelihood and severity using, respectively, the criteria depicted on tables 3.1 and 3.2,
3. For each accident mode, he estimated the risk level using the matrix depicted on table 3.3. The table 6.17 shows the risks estimation and the resulting priority for the control actions that must be taken.

Table 6.17 - Risk level results for case 2 front b, using an unsystematic RAOS technique

| Accident mode | Likelihood | Severity | Risk estimation | Priority |
|---|---|---|---|---|
| Falls | 2 | 2 | 4 | Medium |
| Contact with electricity | 2 | 2 | 4 | Medium |
| Struck by moving vehicle | 1 | 3 | 3 | Acceptable |
| Injured by falling/swinging objects | 1 | 2 | 2 | Acceptable |
| Hit by rolling/sliding/flying object | 2 | 1 | 2 | Acceptable |
| Contact with machinery/equipment moving parts | 2 | 2 | 4 | Medium |

### 6.4.3. Workmed® method applied to case 2 front b)

The Workmed® method (described in 3.4.2) was applied to case 2, front b, by a skilled safety expert (who knows well the method). The results obtained are shown on table 6.18. As in the previous performance, the analyst had to take decisions about to rate factors, based in its empirical knowledge.

Table 6.18 - Risk level results for case 2 front b, using the Workmed® method

| **Weights** | 9 | | 3 | | 3 | | 1 | | 4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Accident modes** | $A_f$ | F | $A_e$ | E | $A_s$ | S | $A_d$ | D | $A_t$ | T | Risk Level [%] |
| Falls | 9 | 2 | 3 | 5 | 3 | 4 | 1 | 4 | 4 | 4 | 69 |
| Contact with electricity | 9 | 1 | 3 | 5 | 3 | 2 | 1 | 3 | 4 | 4 | 43 |
| Struck by moving vehicle | 9 | 2 | 3 | 5 | 3 | 3 | 1 | 3 | 4 | 4 | 66 |
| Injured by falling/swinging objects | 9 | 3 | 3 | 5 | 3 | 1 | 1 | 3 | 4 | 4 | 67 |
| Cave-ins | 9 | 1 | 3 | 5 | 3 | 2 | 1 | 2 | 4 | 4 | 41 |
| Hit by rolling/sliding/flying object | 9 | 2 | 3 | 5 | 3 | 4 | 1 | 3 | 4 | 4 | 68 |
| Contact with machinery/equipment moving parts | 9 | 1 | 3 | 5 | 3 | 1 | 1 | 2 | 4 | 4 | 35 |

### 6.4.4. Discussion of comparison of qualitative risk assessment model with the other methods

The two analysed methods, plus the QRAM, have only in common the concept that the risk is proportional to the possibility of occurrence and the severity of the consequences. The RAOS unsystematic technique is neither objective nor systematic, so the results depend heavily on the knowledge and experience of the analysts. The Workmed® method is a configurable method, therefore adaptable to perform risk assessment in any activity, but loses specificity and does not analyze all risk factors as fully as the QRAM. Further, this method is not divided into four dimensions as QRAM, although it considers some factors related to the safety climate and safety barriers.

The comparison of the risk level results obtained with QRAM and the other two methods, shown that QRAM final results are comparable with those obtained by the other methods (see table 6.19). It is important to note that the site chosen to perform this comparison had a safety climate unusually good (for construction sites - 0.49, in QRAM); if the safety climate was bad (what is more normal on construction sites in Portugal) risk level results obtained by QRAM would be higher than those obtained with other methods that do not incorporate this dimension. Furthermore, QRAM enables a detailed assessment for each dimension, and, within each dimension for each contributing factor thus providing a versatile tool for assessing the overall risk level and also all contributing factors, which clearly distinguishes this method from the other two compared methods.

Table 6.19 – Risk level results

| Accident Mode | QRAM Risk Level | Workmed Risk Level [%] | Unsystematic technique |
|---|---|---|---|
| Falls | 0,68 | 69 | Medium |
| Contact with electricity | 0,40 | 43 | Medium |
| Struck by moving vehicle | 0.60 | 66 | Acceptable |
| Injured by falling/swinging objects | 0.59 | 67 | Acceptable |
| Cave-ins | 0.42 | 41 | --------------- |
| Hit by rolling/sliding/flying object | 0.65 | 68 | Acceptable |
| Contact with machinery/equipment moving parts | 0.39 | 35 | Medium |

In conclusion, QRAM produces results that are aligned with those obtained with other methods but also allows an in-depth characterization and classification of all the risks present in the sites - through the rating of their composing factors - that facilitates identifying the factors that should be improved for increasing the site safety.

## 6.5. Chapter conclusions

The results and expert opinions supported that the QRAM is a good alternative to existing RAOS methods; specifically for the construction industry.

QRAM was approved by all the 12 safety experts by: strongly approved, 1 (8.3%), approved, 9 (75.0 %) and undecided, 2 (16.7%). By dimensions, safety climate was approved by 8 (66.7%), 3 were undecided (25.0%) and 1 had no opinion (8.3%); expected severity was approved by 6 (50.0%), 5 were undecided (41.6%) and 1 disapproved (8.3%); possibility of work accidents occurrence was strongly approved by 3 (25.0 %) and approved by 9 (75.0%); safety barriers effectiveness was strongly approved by 1 (8.3%), approved by 9 (75.0%) and 2 were undecided (16.7%).

QRAM application to several sites proved to be a general and suitable operational tool for risk managers to evaluate safety vulnerabilities on construction sites, since it provides a more detailed picture of the safety situation. The needed information to run QRAM can be elicited by interviews from site operatives and by direct observation, as shown in the cases tested.

The main advantages of QRAM are:

- Consideration of four dimensions that are essential in construction sites for determining the risk level: safety climate adequacy; possibility of occurrence of work accidents, expected severity of work accident and also safety barriers effectiveness. These four dimensions provide the experts with a thorough analysis of all parameters involved in the risk assessment of construction sites.
- The criteria for assessment is clearly defined with the identification of the most important factors for each dimension and leads to the clarification of issues that, so far, have not been formally addressed by safety experts on construction sites.
- The specific checklists proposed for the elicitation of risk information (which are exploited through a clearly understandable representation) are a good guide for the analysts, and the use of the linguistic variables to assess them, proved to be a versatile and robust way of estimating the risks and to provide more accurate recommendations.

The experts that participated in the QRAM evaluation considered that the linguistic scale measurement has the advantage of being intuitive and quick to apply. Moreover, they considered that QRAM framework enforces a more systematic risk assessment process, thus avoiding "analysts' creativity" and a more reliable and uniform way to assess the risks. The experts also commented that the application of QRAM, although easy to implement requires experience to achieve good results.

In addition, although there are some differences, not very significant, in methods of construction, culture, ability/qualifications of both safety technicians and workers, there were no significant differences in the opinions of experts from different countries. Further, on the road construction site, there was no difference or difficulty on the tests carried out comparatively to the sites of buildings construction. Only in the safety climate, the three Greek experts who contributed to the study rated as "undecided" its "approval" decision.

Finally, there are still open issues in the QRAM method, e.g. the weighting of the dimensions remains to be explored. There are other potential improvements to the method through simplification of the "safety climate" and "severity of expectable consequences".

Lastly, in the future it will be important to carefully consider other application situations; QRAM has only been tested on buildings and roads construction.

# 7. Conclusions and future work

A labour workforce is a valuable asset to construction industry which is a major source of employment in Portugal and plays a vital role in the local economy. In this work it was addressed the problematic of assessing occupational accident´s risks in the construction industry and a novel method, denoted QRAM (Qualitative Risk Assessment Method), is proposed, which incorporate uncertainties by using fuzzy sets theory.

The QRAM model is accident mode oriented and was built on the analysis of the limitations of the existing RAOS methods when applied in construction sites. The model supports risk reduction and was tailored to the specific needs of the construction industry.

QRAM framework conception was based on the features of construction work environments, the fundamentals laws of physics and engineering and the characteristics of human behaviour.

Construction industry records high accident rates, which results mainly in absenteeism, loss of productivity, permanent disability, and fatalities. Many safety problems found in construction sites are explained by a combination of reasons, such as the high-risk nature of construction work, the limited knowledge, the economic and time pressures, the constantly changes on worksites and the lack of risk awareness of construction workers and managers.

In fact, several studies have established that construction workers are more likely to be injured than workers in other industries. The majority of accidents occur due to the inability to predict, identify, and respond to occupational risks at the workplaces. A large proportion of occupational risks on construction sites are usually not identified due to a lack of reliable statistical data which are required by the use of probabilistic RAOS methods. By other hand, studies suggest that most accidents and injuries are attributed to unsafe acts, rather those unsafe working conditions.

Unsafe acts are related (by any way) with an inadequate safety climate, which is not considered in the existing RAOS methods described in literature; this may lead to an underestimation of the risk associated with the task to be performed. This increases interactive complexity and make it difficult for the analysts to consider all the potential expected system states, abnormal situations and disturbances that can occur, in a reliable way, by the use of statistical data.

Besides, much of the data related to RAOS are imprecise, ill-define or vague in nature and not numerical; instead it is expressed as words or even sentences in natural language (such as: hazardous, very risky, risk acceptable, safe enough…).

The imprecision, ill-definedness and vagueness that tend to characterize RAOS factors are predominantly subjective and linguistic in their nature and can be expressed more easily and reliably in a qualitative way by linguistic variables which are a mathematical concept from fuzzy sets theory.

The complexity of the safety systems should force to alter the traditional approaches to RAOS and thus, to accept as unavoidable a substantial degree of fuzziness in the description of the safety systems behavior, as well as in their characterization. This fuzziness, distasteful though it may be, is the price it has to be paid for the ineffectiveness of precise mathematical techniques in dealing with this type of systems that comprise a very large number of interacting elements and involving a large number of variables.

It is understandable that the most effective way for improving safety performance is to prevent accidents before they occur. To improve safety performance of the construction industry, safety professionals are carrying out RAOS on sites. Previous research revealed that safety professionals on construction sites lacked systematic risk assessment techniques considering all relevant risk factors (including safety climate) and historical statistical data are not available for the objective use of probabilistic RAOS methods; hence they conducted assessments without following any structured method and simply by relying in their experience and perception. However, safety professionals' understandings and perceptions of safety risks will affect the quality and reliability of RAOS results.

Further, to achieve a good safety performance (to lower the risk), safe work practices must be sought, effective management commitment is needed, effective communication should be sought with workers, effective safety instructions should be provided to workers and safety awareness should be increased. Studies on the role of organizational and psychosocial factors in influencing risk behaviors and the likelihood of injury at work proved that safety climate has great impact in workplaces safety. However, estimating the safety climate using the existing models is a time consuming process, embedded with gross simplifications and imprecisions and requires important resources (it requires to visit and revisit the site in order to come up with conclusions relating to the real situation). Furthermore, current safety climate assessment methods do not provide a direct relationship between safety climate level and safety risks level. So, new methods both reliable and user friendly are needed to construction industry.

The conceptual goal of RAOS process is to eliminate the risk, but it would be naive to believe that this may be completely achieved because the resources are limited (the really aim is to prevent and/or minimize the occurrences of accidents and hazards that threaten workers in the work place). So, the question "How safe is safe enough" must be answered and the available resources should be efficiently allocated. Organizations have moral, legal, and financial responsibilities to limit the risks their operations pose, but spending resources on risk reduction projects whose benefits are grossly disproportionate to their costs will weakness the organization competitive position.

The acceptable risk problem has been discussed in the literature and the ALARP – 'as low as reasonably practicable' – concept based on the notion of a maximum acceptable individual or societal risk is one of the most spread and used. QRAM results ranks the risks obtained in 3 regions: acceptable (below 0.30), meaning that no more safety barriers are needed, ALARP (between 0.30 and 0.70, including these values), meaning that the risk should be lowered if the resources needed are not disproportionate to the benefits and, unacceptable (above 0.70) meaning that the work can't be performed with such risk (must be stopped). This way of displaying results proved to be more helpful for the safety managers.

To rank the safety risks at construction sites, QRAM provides a practical way to rating the risk factors which are taxonomically divided into four dimensions, namely: Safety Climate Adequacy, Severity Factors, Possibility Factors, and Safety Barriers Effectiveness.

Each dimension is composed by a set of factors which are assessed and rated by linguistic variables. To obtain the final estimated risk level, the composing factors of each dimension are aggregated by specific aggregation operators.

The set of data required to running this method would be captured in 3 ways: 1) by direct observation of the site workplaces, 2) by consult of the site documentation (safety plan, work accident reports, safety meeting records…) and 3) by interviewing site workers, supervisors and managers. Thus, avoid using (usually unreliable) historical data.

In addition, QRAM provides a novel way to handle imprecision and uncertainty in the factors influencing the risk by using FST to rate the risk factors and to aggregate them.

QRAM method allows supporting risk characterization, by rating factors that may influence the safety condition in natural language (linguistic variables) to help safety managers to decide:

a) If the risk is acceptable and,
b) Pointed a prioritization of safety barriers to be taken.

In summary, the use of probabilistic RAOS models at constructions sites requires analysts to make harsh estimates based on their experience and perceptions, while FST proved be a good framework for RAOS especially because it allows the use of ill-defined data and the use of empirical knowledge to deal with fuzzy (real) concepts. Besides the safety studies and techniques using FST developed in recent years, the application of FST to construction occupational safety has not yet been fully explored.

This thesis presents a structured method (QRAM) to assess occupational safety risks at constructions sites. The method was been tested and evaluated in 12 sites in different countries: Brezil (2), Bulgaria (1), Greece (3), Portugal (3), and Turkey (3), and proved be an operational tool for risk managers, like competent authorities, site managers and the risks experts to evaluate safety vulnerabilities on construction sites, providing a detailed picture of the situation.

To conclude, this research provides a tool that should help construction industry to decrease safety risks on sites to avoid workers' injuries and provides further areas of research for interested parties.

This thesis was divided in 7 chapters. The first one discussed concepts and related works to RAOS. Chapter 2 presents the background on hazards in the construction industry. Chapter 3 presents an overview on risk assessment occupational methods. Chapter 4 is focused on the concepts and techniques of FST used in this work. Chapter 5 describes the various stages of development of the model and presents the four QRAM dimensions. Chapter 6 is devoted to applying the model to real work situations to evaluate the model. Chapter 7 presents the conclusions and suggestions for future work.

This dissertation ends with the compilation of the references used and 34 Annexes.

## 7.1. Strengths and limitations

The construction community has largely neglected the treatment and storage of data concerning occupational safety and health, related to accidents, risk management from the individual worker behaviour to the organization-level. Such information is essential to produce accurate models. In the construction industry, reliable historical data does not exists, so they use data from other industries or similar sites. Another problem is that occupational historical data may include no extreme observations (for the proper data treatment), but this does not preclude that such events occurring in the future.

The lack of data and information was one of the main limitations on this work development. This prevented, for example, being able to assign a weight to each dimension of the model to express the relative importance of each dimension. They do not contribute equally to the risk level but there isn't information about that.

The severity dimension could be modeled in a manner more consistent with reality if the accident investigation records were more rigorous and recorded data/information that would allow linking factors such as drop height, landing surface, fall dynamics, personal data (age, fitness, BMI…) with the severity of the accident consequences.

According to the safety expert pool, QRAM method seems to be a good tool for occupational safety risk assessment on construction sites and allows an easy and explicit identification of the accident factors, making the communication between the stakeholders easier or at least more straightforward and structured. The specific checklists used for the elicitation of risk information (which are exploited through a clearly understandable representation) are a good aid to analysts and the use of the linguistic variables to assess them is a better way to make the estimates more objective. They considered that the linguistic scale measurement has the advantage of be intuitive and quick to apply. However, using QRAM enforces a more systematic risk assessment process but leaving little space to the analysts' creativity

QRAM results were presented in 3 semantic levels to facilitate the understanding of the risk factors assessment by safety experts and non-experts.

An important advantage of QRAM is that it shows clearly which factors have an influence on risk control and/or have to be improved. It gives site managers better information to decide how to invest in safety measures. The necessary evaluation of the safety climate enables them to improve their safety functions, and is favourable to get their commitment to obtain a better level of safety on site.

Concluding, the results of QRAM application proved its ability to identify and rate all the significant factors that could affect safety on construction sites and its fitness for use, providing a good basis for anticipating safety troubles, before or during construction and thus, preventing safety problems.

## 7.2. Future work

In future developments it is desirable to research a model to "measure" the accuracy of safety climate dimension and perform more detailed comparisons of QRAM with other "so-called" quantitative methods (WORM for example) and to assess the advantages and disadvantages of each framework in occupational risk assessment and management.

Further, the severity dimension needs to be simplified in order to better incorporate the empirical knowledge of safety experts.

In addition to the important issues of validity and reliability, there are still other matters open for questioning. For instance, the weighting of the dimensions remains to be explored. Although the reasoning of equally and unequally weighted systems appears to be sound, there is no empirical evidence or scientific knowledge for its support.

Lastly, the relationship between barrier types and occupational safety risk level is still open for more research.

Although the limitations appointed and the additional research work that should be done to improve the QRAM method, the tests made prove that it allows the analyst to resolve the difficulties of traditional methods to deal with the uncertainties due to imprecise, ill-define or vague data and to use their own perceptions and the workers perceptions to make more accurate occupational risk estimations, in a more user friendly way.

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# Annexes

# Annex I

## Annex I.1 – Safety Climate assess, questions related with Safety Rules and Procedures

| **Safety Rules and Procedures** | |
|---|---|
| $S_{R1}$ | Written work procedures match the way tasks are done in practice? |
| $S_{R2}$ | Written work procedures are technically accurate and adequate sources of safety information? |
| $S_{R3}$ | Written work procedures are complete and easy to read and understand? |
| $S_{R4}$ | Written work procedures are always available whenever needed to be consulted? |
| $S_{R5}$ | Workers can easily identify the applied procedure for each job? |
| $S_{R6}$ | Rules enforce the use of personal protective equipment whenever necessary? |
| $S_{R7}$ | Rules require detailed work plans from subcontractors or self-employed individuals? |
| $S_{R8}$ | The definition of responsibilities and accountabilities is adequate? |

## Annex I.2 - Safety Climate assess, questions related with Workers' Competence

| **Workers' Competence** | |
|---|---|
| $C_1$ | Workers received adequate training to perform theirs jobs safely (when entering on site, changing jobs or using a new technique)? |
| $C_2$ | Workers use, keep, inspect and test the appropriate personal protective equipment as indicated? |
| $C_3$ | Workers know and correctly use relevant safety procedures? |
| $C_4$ | Workers report, appropriately, incidents and accidents? |
| $C_5$ | Workers take general precautions to avoid the dangers of workplace hazards? |
| $C_6$ | Workers identify and communicate potentially hazardous situations? |
| $C_7$ | Workers apply appropriate work practices to reduce exposures to hazards? |

## Annex I.3 - Safety Climate assess, questions related with Safe Work Behavior

| Safe Work Behavior | |
|---|---|
| $B_1$ | In this site safety plays an effective role in preventing accidents? |
| $B_2$ | In this site safety makes it possible to get the job done? |
| $B_3$ | In this site safety is not restrictive and superficial? |
| $B_4$ | In this site safety helps to increase workers' productivity? |
| $B_5$ | In this site safety contributes to workers satisfaction on work? |
| $B_6$ | In this site safety inspires workers to work more safely? |
| $B_7$ | In this site safety has a positive influence on morale? |
| $B_8$ | In this site workers are proud to take part of it? |
| $B_9$ | In this site workers have proactive behaviors in removing workplace safety hazards? |

## Annex I.4 - Safety Climate assess, questions related with Management Commitment

| Management Commitment | |
|---|---|
| $M_{C1}$ | Management clearly considers safety as important as production? |
| $M_{C2}$ | Management expresses concern if safety procedures are not adhered to? |
| $M_{C3}$ | Management acts decisively when a safety concern is raised? |
| $M_{C4}$ | Management acts quickly to correct safety problems? |
| $M_{C5}$ | Management commitment to safety is visible (e.g. by usage of PPEs)? |
| $M_{C6}$ | Management praises site employees for working safely? |
| $M_{C7}$ | Management disciplines site employees for working unsafely? |
| $M_{C8}$ | Management considers a person's safety behavior when moving/promoting people? |
| $M_{C9}$ | Management requires each manager to help improve safety in his/her department? |
| $M_{C10}$ | Management uses any available information to improve existing safety rules? |
| $M_{C11}$ | Management gives safety personnel the power they need to do their job correctly? |
| $M_{C12}$ | Management clearly communicates and continues to bring safety information to site employees' attention at all levels within the site? |
| $M_{C13}$ | Management operates an open-door policy on safety issues? |
| $M_{C14}$ | Management encourages feedback from site employees on safety issues? |
| $M_{C15}$ | Management undertakes campaigns to promote safe working practices? |
| $M_{C16}$ | Management provides a sufficient budget for safety on site? |

## Annex I.5 - Safety Climate assess, questions related with Supervisory Action Towards Safety

| **Supervisory Action Towards Safety** | |
|---|---|
| $L_1$ | Supervisors have positive safety behaviors? |
| $L_2$ | Supervisors usually engage in regular safety talks? |
| $L_3$ | Supervisors welcome reporting safety hazards/incidents? |
| $L_4$ | Supervisors are a good resource for solving safety problems? |
| $L_5$ | Supervisors do not allow working around safety procedures even to meet important deadlines? |
| $L_6$ | Supervisors value workers ideas about improving safety even when significant changes to working practices are suggested? |
| $L_7$ | Supervisors say a "good word" to workers that pay special attention to safety? |
| $L_8$ | Supervisors make sure that workers receive all the equipment needed to do the job safely? |
| $L_9$ | Supervisors discuss how to improve safety with workers? |
| $L_{10}$ | Supervisors listen to and act upon feedback from site employees? |
| $L_{11}$ | Supervisors communicate lessons from accidents to improve safety performance? |
| $L_{12}$ | Supervisors appropriately report incidents, accidents, and/or illnesses? |
| $L_{13}$ | Supervisors wear personal protective equipment even if it is uncomfortable? |

## Annex I.6 - Safety Climate assess, questions related with Communication and Participation

| **Communication and Participation** | |
|---|---|
| $CP_1$ | Site safety policy and objectives are clearly communicated to site employees' at all levels within the site? |
| $CP_2$ | Workers participate in hazard identification, risk assessment, determination of risk controls (safety barriers) and personal protective equipment's choice? |
| $CP_3$ | Workers and subcontractors are consulted and involved in the ongoing review of safety? |
| $CP_4$ | Workers and subcontractors are consulted and involved in accident investigation? |
| $CP_5$ | Workers participate in work planning? |
| $CP_6$ | There is good communication at shift hand over? |
| $CP_7$ | Communication with the supervisors regarding safety matters is easy? |
| $CP_8$ | There is a fluent communication embodied in periodic and frequent meetings, campaigns or oral presentations to transmit principles and rules of action? |
| $CP_9$ | Information is available to workers prior to modifications and changes in production processes or job positions? |
| $CP_{10}$ | When starting in new job position, it is provided written information about procedures and correct way of doing tasks? |
| $CP_{11}$ | Written circulars elaborated and meetings organised to inform workers about risks associated with their work and how to prevent accidents? |
| $CP_{12}$ | Information flow (e.g. policy, procedures, vertical and horizontal channels, scheduled and unscheduled meetings) are used in support of various types of decision-making processes? |

## Annex I.7 - Safety Climate assess, questions related with Supportive Environment

| Supportive Environment | |
|---|---|
| $S_{E1}$ | Subcontractors' safety records are inspected before awarding contracts? |
| $S_{E2}$ | Coworkers adopt a no-blame approach to highlight unsafe work behavior? |
| $S_{E3}$ | Coworkers often remind each other on how to work safely? |
| $S_{E4}$ | Coworkers believe it is their business to maintain a safe workplace environment? |
| $S_{E5}$ | Coworkers always offer help when needed to perform the job safely? |
| $S_{E6}$ | Coworkers endeavor to ensure that individuals are not working by themselves under risky or hazardous conditions? |
| $S_{E7}$ | Coworkers maintain good working relationships? |
| $S_{E8}$ | Coworkers ensure that the workload is reasonably balanced among themselves? |

## Annex I.8 - Safety Climate assess, questions related with Safety planning

| Safety planning | |
|---|---|
| $S_{P1}$ | Does safety started at design stage? |
| $S_{P2}$ | Construction schedule is reasonable? |
| $S_{P3}$ | Safety is a primary consideration when determining site layout? |
| $S_{P4}$ | Chances of being involved in a site accident are quite large, due to unsafe conditions? |
| $S_{P5}$ | Operating site conditions may hinder one's ability to work safely? |
| $S_{P6}$ | Detecting potential hazards is not a major aim of the site planning exercise? |
| $S_{P7}$ | Working with defective equipment is not allowed under any circumstances? |
| $S_{P8}$ | Potential risks and consequences are identified prior to execution? |
| $S_{P9}$ | Weather (and soil conditions) are considered in work planning? |
| $S_{P10}$ | Training includes effective skills practice for normal work and skill practices for emergencies? |

## Annex I.9 - Safety Climate assess, questions related with Work Pressure over Safety

| Work Pressure over Safety | |
|---|---|
| $P_1$ | Is there sufficient “thinking time” to enable workers to plan and carry out their work to an adequate standard? |
| $P_2$ | Are there enough workers to carry out the required work? |
| $P_3$ | Workers consider that is necessary depart from safety requirements for production’s sake? |
| $P_4$ | Workers perceive that operational targets conflict with some safety measures? |
| $P_5$ | Workers consider that is normal to take shortcuts at the expense of safety? |
| $P_6$ | Workers tolerate minor unsafe behaviors performed by coworkers? |
| $P_7$ | Workers consider that is not acceptable to delay periodic inspection of plant and equipment? |
| $P_8$ | Management is strict about working safely when work falls behind schedule? |
| $P_9$ | Supervisors refuse to ignore safety rules when work falls behind schedule? |

## Annex I.10 - Safety Climate assess, questions related with Safety Management System

| Safety Management System | |
|---|---|
| $S_{M1}$ | Are periodic checks conducted on execution of prevention plans and compliance level of regulations? |
| $S_{M2}$ | Are systematic inspections conducted periodically to ensure effective functioning of whole system? |
| $S_{M3}$ | Are accidents and incidents reported, investigated, analyzed and recorded? |
| $S_{M4}$ | Are external evaluations (audits) periodically conducted of validity and reliability of prevention management system? |
| $S_{M5}$ | Personal protective equipment usage is monitored to identify problem areas? |
| $S_{M6}$ | Is ensured daily housekeeping at all workplaces? |
| $S_{M7}$ | After using, any tools and small machinery these are stored in a correct place? |
| $S_{M8}$ | Safety devices on machines are maintained in good operating? |
| $S_{M9}$ | Are there markings and sign-posting of all risks and relevant safety information? |

## Annex I.11 – Questions to assess Possibility factors affecting Falls

| **Possibility factors affecting Falls** | |
|---|---|
| ***General*** <br> To what extent: | |
| F1 | The work (at height) was properly planned to be carried out in a safe way (especially work on or near fragile roof surfaces, on a roofs and store floors being built or demolished or erecting/dismantling/altering scaffolding) and properly supervised? |
| F2 | Were simultaneous activities at the same location properly planned to be carried out in a safe way and appropriately supervised? |
| F3 | Are fragile surfaces (unable to support a load such as: dome lights, glass sheets, asbestos cement sheet, plastic sheet, corroded metal sheet, rotten woods, roof lights, bridged materials in silos, crusted surfaces of sludge lagoons) identified? |
| F4 | Are floor openings and storey floor edges properly protected? |
| F5 | Are skylights openings guarded by fixed standard railings on all exposed sides or are covers capable of supporting 100 kg installed? |
| F6 | Are the wall openings with 1.20 m or more above ground properly protected? |
| F7 | Are the means to access to workplaces at height are adequate and properly protected? |
| F8 | The working surface provides sufficient grip (refers to surfaces that were not made or designed to climb onto, walk on or provide support)? |
| F9 | Are form and scrap lumber with protruding nails and all other debris kept clear from work areas, passageways, and stairs? |
| F10 | Are work platforms adequate and robust enough (to resist to wind and other forces exerted by falling objects or by workers when using hand-operated tools) and protected by guardrails (top railings at least 1 meter above the working platform, foot rails at no less than 15 cm and intermediate rails so that no openings are greater than 47 cm, around the perimeter)? |
| F11 | Is assured that working platforms are not overloaded and the the loads correctly distributed? |
| F12 | Are extension platforms outside a wall properly guarded with side rails or equivalent guards? |
| F13 | Are the standard railings used and installed properly for open sided floors platforms with 1.20 m or more above ground or floor levels? |
| F14 | Are proper measures taken so that employees working at a height greater than 1.20 m are protected from falling? |
| F15 | Are opening areas properly protected? |
| F16 | Are stairways, runways and wall opening areas well illuminated? |
| F17 | Are lighting levels adequate (functioning and position of lights to ensure that all floor areas are evenly lit and all potential hazards, e.g. obstructions and spills can be clearly seen)? |
| F18 | Are the workplaces maintained clean and tidy, with floors and access routes kept clear of slippery (due to mud, wetness, moisture, oil, grease, powder, insufficient drainage, freezing, snow or ice…) and obstacles were workers could slip or trip? |
| F19 | The working floors are not uneven and/or unstable (it means that the surface was on level, there were not loose or unstable floor parts, wrinkled carpets, etc.) or have dangerous thresholds or steps? |
| F20 | Are the works stopped due to inclement weather (i.e. when workers could be thrown off-balance by the wind, snow, heavy rain…)? |
| F21 | Are assured that cranes and lifts are fixed on solid foundations? |
| F22 | Is strictly prohibited to stay at height while this was not necessary for carrying out tasks? |
| F23 | Is strictly prohibited to talking on the mobile telephone during work? |
| F24 | Are the workers protected from the risk of being pushed or bumped by swinging objects and/or by major gusts of wind? |
| F25 | Are workers aware of the dangers of lose their balance when using hand tools (e. g. lipping, tripping, taking a wrong step, being bumped by someone and consequently losing the balance)? |
| F26 | Are workers aware of the dangers of not using the right equipment for climbing on objects (such as vehicles) or descend from them (e. g. jumping out of a lorry at quite a height (without using the stairs) or climbing on a vehicle on the outside)? |
| F27 | Are workers aware of the dangers of leaving or entering the vehicle, while it was not yet (entirely) brought to a standstill by the driver? |

| ***Possibility factors affecting Falls (continuation)*** | |
|---|---|
| ***Scaffolds***<br>To what extent: | |
| F28 | Is the scaffold adequate to the use (able to support loads and provide good access to workplaces), regularly inspected and kept in good condition? |
| F29 | Are all workers involved in the erection, alteration and dismantling of scaffolds competent to perform the task? |
| F30 | Are scaffolds secured to the building or structure in enough places (known that was strong enough) to prevent collapse? |
| F31 | Are scaffolds inspected for defects and damaged parts prior to use? |
| F32 | Do scaffolds protect the users against falls (top railings at least 1 metre above the working platform, foot rails at no less than 15 cm and intermediate rails so that no openings are greater than 47 cm, around the perimeter whilst the distance between the outside wall and the scaffolding exceeded 10 cm)? |
| F33 | There are safe accesses to the scaffold's platforms such as a staircase, an access tower or a passenger lift? |
| F34 | Are mobile scaffolds wheels adequate (diameter greater than or equal to 15 cm) and respect the stability condition (height/width at least 3.5)? |
| F35 | Have mobile scaffolds wheels a braking system (kept in good condition) that prevents their uncontrolled movement? |
| F36 | Are mobile scaffolds protected on (all) edges? |
| F37 | Are mobile scaffolds inspected to detect signs of metal fatigue (e.g. hair cracks and/or corrosion)? |
| F38 | Extent are suspended scaffolds safely adequate (in EU countries must bear the "CE" mark) and are regularly inspected and kept in good condition? |
| F39 | Is it forbidden to work in suspended scaffolds with winds exceeding 40 km/h? |
| F40 | Is it forbidden a single worker to work in suspended scaffolds? |
| F41 | Is it complied with the maximum permissible load (in any kind of scaffold)? |
| F42 | Are the scaffold floors kept clear and cleaned (i.e. tools were not lying on it, it was not muddy or oil was not present)? |
| F43 | Are the scaffolds protected against being hit by lorries, cranes or other vehicles or machines? |
| F44 | Are the scaffolds (of any kind) sufficiently shored up and anchored (fastened solidly to prevent it from toppling over)? |
| F45 | The scaffold (of any kind) loads bearing capacity are correctly posted? |
| F46 | Are the scaffolds inspected by an expert after a storm? |
| F47 | Are the loads correctly distributed across the scaffold (of any kind) platforms? |
| ***Ladders***<br>To what extent: | |
| F48 | Are fixed ladders safely designed and constructed (i.e. not too steep and not too narrow, without: slippery floors, worn floor, not uniform floor, steps with not uniform heights, handrails loose or weak, the distance between the permanent floor and the first rung was greater than the space between two consecutive rungs, rungs slippery by itself and/or landing platforms were missing if the ladder was higher than 3 m)? |
| F49 | Are fixed ladders provided with protection against falling from either side (e.g. robust handrails)? |
| F50 | Are fixed ladders robust enough for the planned efforts? |
| F51 | Are fixed ladders properly fixed to the upper or lower floor (for instance, because it was being built or rebuilt)? |
| F52 | Are the rungs (of all kinds of ladders) kept clear of soiling (such as mud, oil, paint, snow or ice or other slippery material)? |
| F53 | Are conditions such as: wearing shoes with slippery soles, the presence of objects on the ladder, hastily ascending or descending, being distracted or preoccupied with something at the same time, and poor vision, under which workers can lose their balance, be maintained under control? |
| F54 | Are ladders inspected and kept in safe conditions (without weak, broken or missing steps and weak, broken or missing handrails)? |

| Possibility factors affecting Falls (continuation) | |
|---|---|
| ***Portable (or moveable) ladders***<br>To what extent: | |
| F55 | Are portable ladders placed correctly, at an angle of one in four, (one unit of measurement out for every four units up), on and against a material that has a reasonable coefficient of friction and strength and was the step ladder placed on a surface that was not level and/or stable? |
| F56 | Are portable ladders large enough to workers to be able to reach their workplaces? |
| F57 | Are portable ladders equipped with stability devices or tied (or equally effectively secured against movement) at the top? |
| F58 | Is strictly prohibited to place portable ladders on incline or sloping surfaces? |
| F59 | Are ladders with broken or missing rungs or split side rails, tagged and taken out of service? |
| F60 | Are metal ladders inspected for damage or signs of corrosion? |
| F61 | Are portable ladders used only in short-term jobs (not exceeding 30 min and do not require the worker side loads)? |
| F62 | Are portable wood ladders adequate for their purpose, maintained in good condition, and provided with secure footing (i.e. rungs of ladders uniformly spaced and not exceeding 30 cm)? |
| F63 | Do workers assume a correct position on the ladder (not standing on the side of the ladder, feet in the middle, face toward the rungs, using both hands for support, not standing on the ladder whilst shifting or extending, not slipping off the ladder without using the rungs and not hanging onto the side)? |
| F64 | Are areas around the top and bottom of the portable ladder kept clear? |
| F65 | Are portable ladders prohibited from being used in a horizontal position as platforms, runways, or scaffolds? |
| F66 | Are the side rails of the portable ladder extending above the landing (at least 90 cm)? |
| F67 | Is the distance at the base of the open portable ladders 15 cm by each 30 cm high? |
| F68 | Are there warning signs indicating that work was being performed on a ladder? |
| F69 | Are workers aware of the dangers when they are in poor physical condition (sick, weak, nauseous, disabled to some extent, dizzy, vertigo, fatigued, tense or under the influence of drugs, alcohol or medicine, etc.) whilst standing on the ladder? |
| ***Moveable platforms***<br>To what extent: | |
| F70 | Are moveable platforms provided with guard rails and stability devices (e.g. outriggers, locking-out controls) to prevent inadvertent operation? |
| F71 | Are moveable platforms inspected to detect signs of wear and tear in the lifting and hoisting mechanism (cables, chains, hydraulics, etc.)? |
| F72 | Are moveable platforms operation and control devices inspected to detect signs of technical malfunctions and to assure that the control panel is clear (that means the symbols on the control panel cannot be interpreted in several ways and that all parts are visible)? |
| F73 | Are the moveable platforms sufficiently shored up and anchored? |
| F74 | Are the moveable platforms protected against being hit by lorries, cranes or other vehicles or machines? |
| F75 | Are the loads correctly distributed across the moveable platforms (it means that the load is placed in such a way that it can start sliding and/or that it can make the platform unstable)? |
| F76 | Is strictly prohibited to place moveable platforms on incline or sloping surfaces? |

## Annex I.12 - Questions to assess Possibility factors affecting Contact with electricity

| **Possibility factors affecting Contact with electricity**<br>To what extent: | |
|---|---|
| E1 | Is it ensured that the work was properly planned, appropriately supervised, and carried out in a safe way as it is reasonably practicable? |
| E2 | Is electrical equipment's (cables, frames, accessories) revised before being reassembled in a new site? |
| E3 | Does electrical equipment meet all the legal and/or normative requirements? |
| E4 | Are all electrical cords or cables taken out of service when worn or frayed? |
| E5 | Are voltage transmission lines clearly indicated by means of marking and/or signalling? |
| E6 | Is aerial lift equipment's working near energized lines or equipment grounded or barricaded properly and considered as energized equipment or the truck insulated for the work being performed? |
| E7 | Is all electrical equipment free from recognized hazards (insulation defects, e.g.) that may cause death or serious harm? |
| E8 | Are live electrical parts properly guarded against accidental contact? |
| E9 | Are safety distances to the electric network (2 m until 1 kV, 4 m between 1 kV and 60 kV, 5 m to over 60 kV) met? |
| E10 | Are ground fault circuit interrupters properly used to protect employees? |
| E11 | Are all outlet devices correctly and properly matched with load being served? |
| E12 | Is the path to ground from circuits, equipment, and enclosures satisfied so that they are permanent and continuous? |
| E13 | Are there (on site) measures' in place to prevent unauthorised persons from working on installations under tension (e. g. locker keys, supervision and key procedures)? |
| E14 | Are all the electrical extension cords of the three wire types (with ground wire, green wire and yellow wire)? |
| E15 | Are the lamps for general illumination properly protected against breakage? |
| E16 | Are the protection measures against damage for flexible cords and cables satisfactory? |
| E17 | Are all cabinets, cut out boxes, fittings, boxes, panel board enclosures, switches, circuit breakers, through doorways or windows, attached to building surfaces, or concealed behind walls, ceilings, or floors? |
| E18 | All pull boxes, junction boxes and fittings have covers? |
| E19 | Are all electrical equipment's used in hazardous locations intrinsically safe? |
| E20 | Are electric powered tools double-insulated or properly grounded? |
| E21 | Are de-energization tests or other appropriate methods or means applied so that the electric equipment and lines are considered de-energized |
| E22 | Do workers not wear metal objects (rings, watches…) when working with electrical devices? |
| E23 | Are the measures taken so that electrodes removed and electrode holders placed or protected cannot make electrical contact with employees when the holders are left unattended? |
| E24 | Are all disconnecting devices legibly marked to indicate purpose unless located so that purpose is evident? |
| E25 | Are metal ladders not used when working on or near electrical equipment (such as changing light bulbs or fluorescent tubes)? |
| E26 | Is electric power operation tools equipment with proper ground or double insulated? |
| E27 | Is sufficient working space provided to permit safe operation and maintenance of electrical equipment? |
| E28 | Was the electrical energy of the machines or the equipment's (including hand tools) turned off when work was being performed on it (for instance, during maintenance work or failure repairs)? |
| E29 | Are workers aware of the dangers when they are working in the immediate vicinity of voltage transmission lines? |
| E30 | Are workers aware of the dangers of bypassing the electrical protection devices (e. g. residual-current device or ground fault circuit interrupter)? |
| E31 | Are workers aware of the dangers of using tools that were not suitable for electrical works (e.g. using non-insulated screwdrivers) or using it incorrectly (e. g. using low voltage detectors for high voltage)? |
| E32 | Do all electricians wear cotton clothes and use protective equipment's (such as rubber shoes and gloves and mats)? |

## Annex I.13 - Questions to assess Possibility factors affecting Struck by moving vehicle

| Possibility factors affecting Struck by moving vehicle | |
|---|---|
| ***General***<br>To what extent: | |
| S1 | Is ensured that all drivers had (before starting to drive) a special training in order to drive the specific vehicles? |
| S2 | Is ensured that all visiting drivers report to site management before entering the site (to assure that drivers had received proper safety training)? |
| S3 | Is there (where vehicles have to reverse) a trained signaler to assist the vehicle driver? |
| S4 | Are passengers prevented from riding in dangerous positions? |
| S5 | Are flagmen and other workers at risk of being struck by moving vehicle do they wear noticeable garments (red or orange warning garments, reflectorized for working at night)? |
| S6 | Are there proper warning vests made of reflectorized or of high visibility material and to what extent are they being used by employees exposed to vehicular traffic? |
| S7 | Are the necessary measures taken to prevent the parked vehicles from inadvertently moving (using the hand brake, removing the ignition key, putting blocks behind the wheels when this was in fact necessary, etc.)? |
| S8 | Do all vehicles with an obstructed view to the rear have a backup alarm or are they always used with an observer? |
| S9 | Are drivers aware of the dangers (for themselves and for pedestrians) of exit of the vehicle while it had not yet stopped and been properly locked? |
| S10 | Are drivers aware of the dangers of the vehicles with high center of gravity resulting in an increased risk of tipping over? |
| S11 | Are drivers aware of the dangers (for themselves and for pedestrians) of doing other things whilst driving (talking on the telephone, talking with others, adjusting the radio, larking about, etc.) or of being distracted by things in his surroundings (by or loud noise)? |
| S12 | Are drivers aware of the dangers (for themselves and for pedestrians) of reduced visibility by load obstruction, poor weather conditions or insufficient lighting? |
| S13 | Are drivers aware of the dangers (for themselves and for pedestrians) when they are in poor physical condition (sick, weak, nauseous, disabled to some extent, dizzy, vertigo, fatigued, tense or under the influence of drugs, alcohol or medicine, etc.) whilst driving? |
| S14 | Are workers at noisy locations (or when using ear protection, MP3 players or talking on the mobile phone…) aware of the increasing danger of being struck by moving vehicle? |
| S15 | Are workers aware of the dangers of being just in front of or behind a vehicle (for instance, by crossing behind a vehicle to do something with the load or because of being talking with the driver)? |
| S16 | Are workers aware of the dangers of walking in a hurried or stressed manner, tripping or losing their footing at locations where vehicles are driven? |
| S17 | Are workers aware of the dangers of leaving or entering the vehicle, while it was not yet (entirely) brought to a standstill by the driver? |
| S18 | Are workers aware of the dangers of being transported in a vehicle that is not intended for persons (e. g. catching a lift on forklift trucks or running boards of a vehicle)? |

| **Possibility factors affecting Struck by moving vehicle (continuation)** | |
|---|---|
| ***Roads***<br>To what extent: | |
| S19 | Is a traffic plan for the site established (with lines separating vehicles and pedestrian routes, vehicle access points and warning signs, traffic signs and traffic lights in dangerous situations like pedestrian crossings)? |
| S20 | Are vehicle traffic routes suitable for the types and quantity of vehicles that use them (ensure they are wide enough and that floor and road surfaces are kept in good condition) and periodically checked? |
| S21 | Are one-way systems or turning points provided to minimize the need for reversing (to avoid manoeuvre the vehicle within the site)? |
| S22 | Is there space enough to manoeuvrer the vehicles safely (avoiding the vehicle to enter pedestrian zones when being maneuverer)? |
| S23 | Are obstructions (sharp bends, pillars, other vehicles, stacks of material, etc.) removed where possible or otherwise is it make sure they are clearly visible (e.g. providing suitable fixed mirrors at blind corners)? |
| S24 | Is the road surface clean of slippery (due to mud, spilled oil, freezing, snow or because the structure of the road surface is itself slippery)? |
| S25 | Does the speed limit assure that the vehicles could be stopped in time (that depends on both the vehicle (weight…) and the situation (presence of pedestrians, the visibility…)? |
| S26 | Are physical speed restrictions such as speed bumps taken (if necessary)? |
| S27 | Are traffic or warning signs satisfactory? |
| S28 | Is the road surface properly stable to avoid that the vehicle could sink or tip over? |
| S29 | Are supportive structures provided where necessary to prevent collapse and to prevent vehicles from running out of the roadway? |
| S30 | Are roads, runways and manoeuvring areas correctly illuminated (functioning and position of lights to ensure that all surfaces are evenly lit and all potential hazards, e.g. obstructions and spills can be clearly seen)? |
| S31 | Is delimitation and signalization made with retro reflective material? |
| ***Vehicles***<br>To what extent: | |
| S32 | Are vehicles maintained (steering, handbrake and footbrake works properly and tires tread are deep enough) to assure that it is possible to brake on time and steer properly? |
| S33 | Are the vehicles equipped with safety belts? |
| S34 | The vehicles have suitable safety features (lights, acoustic signals, side-turn signal lights, etc.) periodically checked (by a competent worker)? |
| S35 | Are vehicles inspected (by the drivers) at the beginning of each shift to assure that all parts, equipment, and accessories affecting safety operation are free of defects? |
| S36 | Are vehicles securely loaded (the load is properly distributed and does not obstruct or interfere with the ability to see) and without overload (an overloaded vehicle can be difficult to handle)? |

## Annex I.14 - Questions to assess Possibility factors affecting injured by falling/swinging objects

| | |
|---|---|
| **Possibility factors affecting injured by falling/swinging objects** | |
| ***General***<br>To what extent: | |
| Fo1 | Is it ensured that the work was properly planned, appropriately supervised, and carried out in a safe way as it is reasonably practicable (e.g. with letting objects fall in an intentional and a controlled manner such as rubble or debris, into a chute/container)? |
| Fo2 | Was simultaneous activities at the same location properly plan to be carried out in a safe way and are appropriately supervised? |
| Fo3 | Are materials which are stored in tiers stacked, racked, blocked, interlocked, or otherwise, properly secured to prevent sliding, falling or collapsing? |
| Fo4 | Is the storage of materials properly done (are materials stored more than 1,80 m from any hoist way or inside floor opening and more than 3 m from any exterior walls that do not extend above the top of the stored materials)? |
| Fo5 | Is the weight of the loads to move known (if it is not known, it is estimated by multiplying the load volume by the material specific weight)? |
| Fo6 | Are the cranes, lifts and other lift equipment's load bearing capacity correctly posted? |
| Fo7 | Have proper guards been provided to protect employees from falling materials where conveyors pass over areas or aisles? |
| Fo8 | Are all floor openings not used as material drops equipped with a properly secured cover that will support any load which may be imposed? |
| Fo9 | Is any area where material is dropped outside the exterior walls of the structure effectively and properly protected? |
| Fo10 | Is a limited access zone established securely when constructing a masonry wall? |
| Fo11 | Are proper conditions satisfied for all masonry walls over eight feet high (are they braced or supported properly to prevent collapse)? |
| Fo12 | Are inspections made by a competent person as work progresses to detect hazards from weakened or deteriorated floors or walls or loosened materials? |
| Fo13 | Are accessible areas within the swing radius of the rotating superstructure of the crane properly barricaded or protected? |
| Fo14 | Are there (on site) objects poorly maintained, damaged or not properly secured so that parts can break off or release at high wind speeds and be blown away? |
| Fo15 | Is there (on site) objects placed in such a way that they easily could have been taken/were actually taken by the strong winds? |
| Fo16 | Are scaffolders whose height exceeded 30 meters, have an irregular shape or scaffolding whereby more than one working platform was loaded with diagrams for erection? |
| Fo17 | Are workers aware of the dangers of the use of incorrect tools or aids (e.g. decide to lift something manually, whilst it would be better to do so mechanically)? |
| Fo18 | Have all scaffolds footers? |
| Fo19 | Are the danger zones of swinging/hanging loads or in the vicinity of rotating arms or counterweights clearly indicated by means of marking and/or signalling? |
| ***Formwork and concreting***<br>To what extent: | |
| Fo20 | Are all formworks for cast-in-place concrete designed, fabricated, erected, supported, braced, and maintained so that it will support without failure all loads that may be anticipated? |
| F021 | Is inspection of the erected shoring equipment performed (it is inspected immediately, prior to, during and immediately after concrete placement properly satisfied)? |
| Fo22 | Is the inspection of the forms and shores performed properly, considering that the forms and shores are left in place until the employer determines that the concrete can support its weight and superimposed loads? |
| Fo23 | Are precast concrete wall units, structural framing, and tilt up wall panels supported properly to prevent overturning and collapse until permanent connections are made? |
| Fo24 | Do designs and plans include prescribed methods of erection? |
| Fo25 | Are the jacking operations performed properly (for example, are jacking operations synchronized to insure even and uniform lifting)? |
| Fo26 | Are there only those workers required for jacking and to secure slabs permitted under slab during jacking? |

| Possibility factors affecting Struck by moving vehicle (continuation) | |
|---|---|
| ***Mechanical lifting***<br>To what extent: | |
| Fo27 | Are accessible areas within the swing radius of the rotating superstructure of the crane properly barricaded or protected (by measures - for instance, roofs - which prevent objects from falling in a safety zone)? |
| Fo28 | Are danger zones of hanging loads indicated by means of marking and/or signalling? |
| Fo29 | Are workers prohibited to stay in the lifting danger zone while this is not necessary for attaching or loosening loads? |
| Fo30 | Is strictly prohibited to overload (it means that the load is heavier than the equipment's capacity indicated in the load chart) the hoisting equipment (crane, hoist, gantry crane, forklift truck etc.)? |
| Fo31 | Are hoisting equipment’s maintained (hoisting cable, cable guides, winch, drive, operating panel, the levers, switches, instruments/sensors, limiters or indicators/gauges, hoisting arm, loading arm, stabilizers/props, etc.) to assure its good condition (not damaged, worn and properly assembled)? |
| Fo32 | Are the “hoisting gear” (lifting straps, lashing straps, slings, hoisting chains, hoisting hooks, swivels, lifting beams, lifting clamps, hoisting eyes, lifting magnets, cargo slings, latches, etc.) periodically checked (by a competent worker)? |
| Fo33 | Are hoisting equipment’s inspected (by the operators) at the beginning of each shift to assure that all equipment parts and accessories affecting safety operation are free of defects? |
| Fo34 | Do any hooks, rings, oblong links, pear shaped links, coupling links, and other attachments have a rated capacity at least that of the chain? |
| Fo35 | Is assured that the “hoisting gear” is correctly used (it means used in the way that it was made/intended for)? |
| Fo36 | Is assured that cranes and lifts are fixed on solid foundations? |
| Fo37 | Is assured that hoisting equipment was placed on ground that is stable and sufficiently able to support the weight (it means that the surface is strong enough to bear the weight of the equipment’s and expected loads)? |
| Fo38 | Is assured that hoisting equipment that was affixed to a fixed construction (ceiling or another fixed construction) is properly attached to the fixed construction and/or rails? |
| Fo39 | Is assured that props and stabilizers are properly used and placed (i.e. during the lifting the props were not properly used and the stabilizers placed were not properly placed or deployed)? |
| Fo40 | Is assured that loads are correctly stowed and attached (correctly fastened to avoid load instability and/or fall) and correctly disconnected (only when it is in a stable position on the floor or on another surface)? |
| Fo41 | Is assured that bulk and/or small loads are fastened in appropriate devices (e.g. wire mesh containers or pallets)? |
| Fo42 | Is assured that loads are moved at an appropriate speed (not quickly or too suddenly)? |
| Fo43 | Is raised loads kept as close to the ground as possible to prevent tipping and bumping against objects or buildings while travelling? |
| Fo44 | Are Mobile Elevating Working Platforms (MEWP’S) provided with overload blocked devices, guard rails, toe-boards, stability devices (e.g. outriggers, locking-out controls (other than those in the basket) to prevent any inadvertent operation? |
| Fo45 | Are MEWP’S used on firm ground which is free from slopes / holes and the work area checked for localized features, e.g. manholes, service ducts, potholes, etc. (e.g. a hole 75 mm deep caused an overturn), overhead crushing or contact hazards? |
| Fo46 | Are stabilizers and outriggers provided with suitable soleplates for use on soft ground? |
| Fo47 | Are there systems of communication (working properly) between lifting operators and banks men? |
| Fo48 | Is it forbidden to hang loads with winds exceeding 40 km/h, heavy rain or fog (or other weather conditions that can hinder vision or difficult the load control)? |

## Annex I.15 - Questions to assess Possibility factors affecting Cave-ins

| | |
|---|---|
| **Possibility factors affecting Cave-ins**<br>To what extent: | |
| Ci1 | Is it ensured that the work was properly planned, appropriately supervised, and carried out in a safe way as it is reasonably practicable? |
| Ci2 | Is the excavation area properly demarcated and signalized? |
| Ci3 | Do all excavation slopes respect at least the angle of response except for areas where solid rock allows line drilling or presplitting? |
| Ci4 | Are workers aware of the dangers of working in the immediate vicinity of slopes of excavations that have the possibility of becoming unstable due to previous activities/processing work? |
| Ci5 | Is there proper drainage in the bulk mass? |
| Ci6 | Are there (on site) walls tilting (it means a slope of > 90° and can occur, for instance, if excavation is being conducted at the foot of the mass but not above it)? |
| Ci7 | Did all structures become unstable by excavation works (walls, trees, poles…) were they properly anchored? |
| Ci8 | Are all surface encumbrances that may create a hazard removed or supported? |
| Ci9 | Is proper warning system such as barricades, hand or mechanical signals or stop logs used when mobile equipment approaches the edge of the excavation? |
| Ci10 | Are excavation materials kept at least 1 m from the edge of the excavations? |
| Ci11 | Are daily inspections made to the excavation to determine the possibility of cave-ins and are they necessary measures taken to protect employees? |
| Ci12 | Are excavations inspected after any hazard increasing occurrence (e. g. storms)? |
| Ci13 | Are shoring or sloping systems used to support the walls and faces of the excavations sufficient to ensure against cave-ins? |
| Ci14 | Are there ladders properly placed in the excavation? |
| Ci15 | Is vehicle speed properly reduced in roads near excavations (to reduce vibration)? |
| Ci16 | Is pedestrians’ safety on the sidewalks assured by outlining the obstacles and/or forcing pedestrians to walk in the opposite side? |

## Annex I.16 - Questions to assess Possibility factors affecting hit by rolling/sliding/flying object (including awkward or sudden movement)

| **Possibility factors affecting Hit by rolling/sliding/flying object (including awkward or sudden movement)**<br>To what extent: | |
|---|---|
| H1 | Was the work properly planned, appropriately supervised, and carried out in a safe way (e.g. the demolition or assembly of prefabricated structures)? |
| H2 | Simultaneous activities at the same location are properly planned to be carried out in a safe way and appropriately supervised? |
| H3 | Are abrasive wheel grinders provided with safety guards which cover the spindle ends, nut and flange projections? |
| H4 | Are workers working in the vicinity of running machinery from which material or items could fly around, or in the vicinity of persons who use hand tools whereby material could fly around, properly protected (such as eye protection, facial protection or a helmet) for activities with a cutting action (sawing, drilling, planning, turning, honing, etc.) or for other activities whereby there is a risk that objects/parts can fly off (for instance, hammering, the treatment of objects on a lathe, with a drill or saw, whereby the object or the fastener can fly around during the treatment…)? |
| H5 | Are workers aware of the dangers of the use of wrong tools or machine operated incorrectly or tools used in the wrong way (e. g. using metal hammers, whereas a plastic hammer should have been used for that material; using grinding discs that are not suitable for the material to be treated or for the rotational speeds of the machine; using the wrong pliers for holding something firmly; or using a screwdriver as a chisel and vice versa; when a force that is too great is exerted with the tool or if the machine is used for treating something with the wrong setting - speed, angle, direction, force, aid, etc.; wood drill instead of stone drill (for drilling into stone), a hand tool with the wrong size (spanners, pliers))? |
| H6 | Are workers aware of the dangers of outlet valves, hoses or pipes that become clogged and whereby the material that causes the clogging can suddenly release outwards due to pressure build-up? |
| H7 | Are workers aware of the dangers if some material is poorly maintained or damaged, hoses, chains, wires, ropes, cables under tension can suddenly break so that the loose ends could fly around? |
| H8 | Are workers aware of the dangers of wires, cables or ropes that could get caught on something or become entangled getting under pressure or under (mechanical) tension (if these items then suddenly came loose, they could fly around)? |
| H9 | Are workers aware of the dangers of the use of tools or machines in the wrong way (for instance, using a forklift truck to move vehicles; not using tensioners properly, the wrong timing when releasing something under tension or pressure)? |
| H10 | Are objects that could be under pressure or under (mechanical) tension, properly secured (for instance, objects such as flexible hoses, cables, tackles, tail-lifts, binding wire, lashing straps, tensioners, steel wire or springs)? |
| H11 | Are workers aware of the dangers of the use of incorrect tools or aids or hold hand tools incorrectly (e.g. use of the wrong tools, not holding tools in a safe direction; not safely placing tool leads and tubes so that the tool could suddenly shoot out in another direction; not properly holding tools that are being carried, etc.)? |
| H12 | Is ensured that workers receive adequate information on the weight of a load, the centre of gravity or the heaviest side when a package is unevenly loaded? |
| H13 | Are material and equipment that might fall or roll into an excavation kept at least 2 meters from the edge? |
| H14 | Are parked vehicles properly locked? |
| H15 | Are objects and structures near roads protected against collisions or crashes? |
| H16 | Are work areas well lit, dry and clean (especially where loads are moving manually)? |
| H17 | Are objects/materials correctly stacked (including stacks of dissimilar objects) to avoid collapse, topple over and objects falling (e. g stack should not be higher than 3x the width, heavy objects could be stacked on the lower parts of the stack, objects should not exceed the edge of the shelves)? |
| H18 | Are there (on site) objects/materials that could be dragged by the wind? |

| **Possibility factors affecting Hit by rolling/sliding/flying object (including awkward or sudden movement) (continuation)**<br>To what extent: | |
|---|---|
| H19 | Are the surfaces adequate to support the load (e.g. strong enough to bear the weight of the objects, without vibrations caused by passing lorries)? |
| H20 | Are observers kept at a safe distance from work equipment's? |
| H21 | Are all vehicles which are left unattended at night, adjacent to a highway in normal use or a construction site where work is in progress, equipped with lights, reflectors, or barricades to identify the location of the equipment? |
| H22 | Are vehicles securely loaded (ensuring that the cargo is stowed and not beyond the loading box (it is not sticking out) and is not distributed unevenly and it is not too high)? |
| H23 | Are loads in vehicles securely fastened (e.g. tensioning the ratchet strap and the correct lashing angle) by correct devices (for instance not using a drum clamp or using rope with little elasticity instead of a lashing strap)? |
| H24 | Are machines and tools kept in good conditions (to avoid that with normal use parts, such as saw blades, chisels or bits, could have broken or flown around)? |
| H25 | Are the machines and tools inspected (by the users) at the beginning of each shift to assure that they are free of defects? |
| H26 | Are the fastening devices kept in good conditions? |
| H27 | Are the fastening devices inspected (by the users) at the beginning of each shift to assure that they are free of defects? |
| H28 | Are stowing material, connections or couplings that could slip off with normal use inspected (by the users) at the beginning of each shift to assure that they are free of defects (for instance, defective tensioners, cables, lifting straps, hoisting eyes, bolts/screws/nails or tackles)? |
| H29 | Are loads/objects suitable to be moved manually (e.g objects that are too large to be carried, objects with a surface that is too slippery and/or sharp, objects that are too heavy – with more than 27 kg)? |
| H30 | Are there handles (adequate and sufficient) for helping the manual handling tasks? |
| H31 | Are there (on site) objects poorly maintained, damaged or not properly secured so that parts can break off or release at high wind speeds and be blown away? |
| H32 | Are there (on site) objects placed in such a way that they easily could have been taken/were actually taken by the strong winds? |
| H33 | Is strictly forbidden to throw tools or other objects? |

## Annex I.17 - Questions to assess Possibility factors affecting contact with machinery/equipment moving parts (including trapped between objects)

| | |
|---|---|
| **Possibility factors affecting Contact with machinery/equipment moving parts (including trapped between objects)** | |
| ***General***<br>To what extent: | |
| M1 | Do equipment's and machinery comply with the applicable use specifications and safety regulations (i. e. bears a CE marking)? |
| M2 | Were equipment's and machinery not modified after purchase? |
| M3 | Have equipment's and machinery emergency stop devices within reach and properly functioning? |
| M4 | Do all circular saws have an exhaust hood or a guard to prevent accidental contact with the saw blade? |
| M5 | Are rotating or moving parts of equipment properly guarded (i. e contact with the moving parts could not still occur) to prevent contact with worker's body parts? |
| M6 | Are machinery guards kept in place and in working order? |
| M7 | Are saw guards checked to assure they are not wedged up thereby leaving an unguarded lower portion of the blade? |
| M8 | Are work rests and tongue guards properly set? |
| M9 | Are hand tools and other equipment regularly inspected for safe condition (including visual inspection each day for defects or obstructions prior to use)? |
| M10 | Are handles wedged tightly in the heads of all tools? |
| M11 | Are impact tools free of mushroomed heads? |
| M12 | Are welding and cutting operations shielded by non-combustible or flameproof screen whenever practicable? |
| M13 | Are all employees who are performing any type of welding, cutting, or heating protected by suitable eye protective equipment? |
| M14 | Are power tools, belts, gears, shaft, pulleys, sprockets, spindles, drums, fly wheels, and chains properly guarded? |
| M15 | Are portable circular saws equipped with guards above and below the base or shoe? |
| M16 | Are power saws and similar equipment provided with safety guards? |
| M17 | Are tools used with the correct shield, guard, or attachments recommended by the manufacturer? |
| M18 | Are power actuated tools left unloaded until they are ready for immediate use? |
| M19 | Are tools stored in a dry, secure location where they won't be tampered with? |
| M20 | Are gears on the hoisting machine well-guarded? |
| M21 | Are machines moving parts still moving (e. g. continuing to turn) after the machine had been switched off? |
| M22 | Are workers aware of the dangers of bypass the physical safeguard (physical safeguard' refers to equipment that prevents people from touching the moving parts such as screens, hoods, optical screens, etc.)? |
| M23 | Are workers aware of the dangers of intentionally come within reach of a machine's moving parts (for instance, in order to straighten something out, remove something, clean something, etc.)? |
| M24 | Are workers aware of the dangers of wearing something or holding something so that the machine could 'grab' (e. g. loose-fitting clothing, long hair or wearing gloves near rotating parts)? |
| M25 | Are (machine/equipment moving parts) danger zones clearly indicated by means of signs? |
| M26 | Was the electrical energy, pressure and (mechanical) tension of the machines or the equipment's (including hand tools) turned off when work was being performed on it (for instance, during maintenance work or failure repairs)? |
| M27 | Are technical measures taken against unintentional start-up of the machine (such as: removing fuses, locking/blocking handles and switches, etc.) whilst cleaning, maintaining or repairing? |

| Possibility factors affecting Contact with machinery/equipment moving parts (including trapped between objects) (continuation) | |
|---|---|
| ***Hand Tools***<br>To what extent: | |
| M28 | Are hand tools properly protected (safeguards, locks against unintentional start-up, locks against continued turning after switching off and other accessories for the safe use of the tool)? |
| M29 | Are hand tools equipped with the appropriate and properly mounted handles (with a shape able to provide sufficient grip) and kept in good condition (not soiled, worn or damaged)? |
| M30 | Do all portable circular saws have a guard above the base plate and a guard below the base plate that will automatically and instantly return to the covering position when the saw is withdrawn from the work? |
| M31 | Are tool handles free of splits and cracks? |
| M32 | Could or did the hand tool and/or the cords/tube of the hand tool get caught somewhere? |
| M33 | Are hand tools correctly adjusted (e. g. correct rotational speed)? |
| M34 | Are the heads of chisels or punches grounded periodically to prevent mushrooming? |
| M35 | Are frames of all arc welding and cutting machines grounded properly? |
| M36 | Are electric, pneumatic or hydraulic hand tools not immediately stopped moving when the operating button is released? |
| M37 | Are workers aware of the dangers of working materials (of the object/work piece) insufficiently suited for working with the hand tool (material too hard, material with defects - e.g. knots in wood, presence of objects in the material that do not belong to it - nails in a piece of wood)? |
| M38 | Are workers aware of the dangers of using the hand tool in an unsafe position (e. g. at a wrong angle so that the tool kicks back - when sawing, honing or milling)? |
| ***Hand Tools (cont.)***<br>To what extent: | |
| M39 | Are workers aware of the dangers of the use of electric, pneumatic and/or hydraulic hand tools (including high-pressure sprayers), hand tools under mechanical or other tension not properly protected against unintentional start-up or activation of the tool (e. g. situations in which locks are not used, switches are not blocked, the tool's power has not been shut off)? |
| M40 | Are workers aware of the dangers of the use of hand tool not in a good condition (e. g. hand tools whose safety features - such as self-braking grinding discs, safeguards, etc. - are missing or not functioning properly or if the grips/handles are slippery)? |
| M41 | Are workers aware of the dangers of working with hand tools whilst doing something else at the same time (e. g. carrying or putting away another object/tool, using another hand tool, using a telephone, drinking coffee, etc.)? |
| M42 | Are workers aware of the dangers of working with hand tools in workplaces not orderly (i.e. insufficient visibility/lighting, very noisy, extreme temperatures or slippery and/or messy floors)? |
| ***Trapped between objects***<br>To what extent: | |
| M43 | Are locations where objects, machines or obstacles were placed too closely to each other so that workers could be trapped if the objects or machines started moving clearly indicated by means of marking and/or signalling? |
| M44 | Are locations that could become unsafe if objects or machines inadvertently started moving clearly indicated by means of marking and/or signalling? |
| M45 | Are there (on site) poorly designed handles/grips (of machines, doors, lids, etc.) so that when in use a hand/fingers could become trapped? |
| M46 | Are hinged objects (such as doors, manhole covers or engine covers) that were not properly secured (e. g. by mechanisms for preventing the object from closing/opening suddenly or too quickly)? |
| M47 | Are there (on site) work with machines or vehicles with which loads are moved and was operators view of the road obstructed (by, for instance, the load on the vehicle) or insufficient due to poor weather, insufficient lighting, obstacles or because the vehicle has many blind spots? |
| M48 | Are loads properly fastened so to avoid that it started inadvertently to move? |
| M49 | Are workers aware of the dangers of body parts (such as heads, arms or legs) of passengers or of the driver were partially or fully protruding from the vehicle? |
| M50 | Are workers aware of the dangers of being transported in a vehicle that is not intended for persons (e. g. in a cargo space)? |

## Annex I.18 - Questions to assess Possibility factors Lost buoyancy in water due to the activity

| **Possibility factors Lost buoyancy in water due to the activity**<br>To what extent: | |
|---|---|
| Lw1 | Was the work in the vicinity of water properly planned, appropriately supervised, and carried out in a safe way? |
| Lw2 | Are the falling gradients near the water (near the banks of rivers, canals, along ditches or ponds) edges properly protected (e. g. fences)? |
| Lw3 | Are roads in the vicinity of water properly protected? |
| Lw4 | Are workers aware of the dangers when they are in poor physical condition (sick, weak, nauseous, disabled to some extent, dizzy, vertigo, fatigued, tense or under the influence of drugs, alcohol or medicine, etc.) whilst working in the vicinity of water? |
| Lw5 | Are workers aware of the dangers of reduced visibility due to fog, downpours or darkness whilst working in the vicinity of water? |
| Lw6 | Are workers aware of the dangers of the circumstances (wind, waves, current, etc.) that could make the floating object capsize or sink as a result? |
| Lw7 | Are workers aware of the dangers of standing on a slippery surface and/or one with obstacles whilst working in the vicinity of water? |
| Lw8 | Are workers in the vicinity of water or other fluids within reach of objects that could start moving, rolling or swinging against them (e. g. hanging and/or swinging loads or lashing cables, ropes, anchor chains or banging booms)? |
| Lw9 | In the vicinity of water or other fluids are workers working in floating objects that were not suitable for floating (e. g. due to poor physical condition)? |
| Lw10 | Floating objects are properly loaded (load correctly distribution and not overloading)? |
| Lw11 | Workers working in floating objects are sufficiently experienced (e. g. ability to move on a strong current)? |
| Lw12 | Are there cables, structures, nets or other objects (such as other floating objects) present on water that could trap/entangle floating objects? |
| Lw13 | Are workers working in the vicinity of water able to swim competently? |

## Annex I.19 - Questions to assess Possibility factors affecting fire or explosion (including confined spaces)

| **Possibility factors affecting Fire or explosion (including confined spaces)** | |
|---|---|
| ***General***<br>To what extent: | |
| FE1 | Was the work properly planned, appropriately supervised, and carried out in a safe way (e.g. work in confined spaces)? |
| FE2 | Are all flammable and combustible liquids stored and handled in approved and proper containers and portable tanks? |
| FE3 | Are flammable, combustible and explosives stored in appropriated conditions? |
| FE4 | Are explosives not in use kept in a locked magazine? |
| FE5 | Are necessary safety conditions satisfied for motor vehicles transporting explosives (are they always attended)? |
| FE6 | Are smoking matches, open flame lamps and other fires, flames or heat producing devices, and sparks prohibited in or near flammables and explosive magazines while flammables or explosives are being handled, transported, or used? |
| FE7 | Is equipment (other tools or aids such as rubber shoes or textile cloths) used in flammable or combustible atmospheres sufficiently conductive or earthed to avoid created static electricity? |
| FE8 | Are oxygen cylinders and fittings kept away from oil and grease? |
| FE9 | Are cylinders secured (and caps in place) when transporting or storing compressed gas cylinders? |
| FE10 | Are all compressed gas cylinders secured in an upright position at all times (including when transported by power vehicles)? |
| FE11 | Is insured that cylinders, full or empty, are never used as rollers or supports? |
| FE12 | Are torches inspected for leaking shut off valves, hose couplings, and tip connections at the beginning of each shift? |
| FE13 | Has mechanical ventilation system sufficient capacity to keep the concentration of flammable vapours within safe limits? |
| FE14 | Are drums, containers, or hollow structures which have contained explosive or flammable substances not outdate, poorly maintained, damaged or left open? |
| FE15 | Are drums, containers, or hollow structures which have contained explosive or flammable substances either filled with water or thoroughly cleaned of such substances, ventilated and tested before welding, cutting, or heating? |
| FE16 | Are workers aware of the dangers of smoking in the immediate vicinity of flammable or combustible atmospheres? |
| FE17 | Are workers aware of the dangers of hot surfaces that have not been sufficiently cooled, present in the immediate vicinity of flammable substances? |
| FE18 | Are workers aware of the dangers of wearing clothes soiled with grease, oil or another flammable substance when in the vicinity of oxygen and heat sources? |
| ***Confined spaces***<br>To what extent: | |
| FE19 | Are measurements (of substances, such as oxygen, toxic or flammable gases) in confined spaces taken before workers entered the space and regularly taken during a longer stay (30 minutes or more)? |
| FE20 | Are measurements (of substances, such as oxygen, toxic or flammable gases) in confined spaces regularly taken (30 minutes or more) when activities (such as using solvents, working with combustion engines or burners, or carrying out welding activities) being carried out, could create hazardous vapours? |
| FE21 | Are all hazardous substances removed from confined space when work stops (even in meal breaks)? |
| FE22 | Are workers aware of the dangers of working in confined spaces? |

# Annex II

## Annex II.1 – Questionnaire for elicitate expert opinions

Dear madam/sir

I am a doctoral student in safety risk assessment in the New University of Lisbon (Portugal).

An appropriate Risk analysis RA is an essential component of the safety risk management process in organizations. If the framework for RA is inadequate and/or not applied effectively, it impacts on the wider process and results in an ineffective use of resources.

Estimate the possible severity consequences of a work accident are done by safety experts perceptions causing discrepancies between assessments made by different safety experts.

This work aims to develop severity functions (on the safety risk assessment scope), based on biomechanical knowledge for injury criteria and on predictors that can be elicited by observable or existing data on site, to allow determining the severity of occupational accidents on construction industry, and consequently improve occupational risks assessment quality.

In order to address the project goals, I have developed the attached questionnaire, which I would be grateful if you complete. The survey should take about 15 minutes to complete.

I believe the topic of my PhD research brings an important contribution to enhancing the quality of safety risk assessment and management, in both theory and practice. Your responses form an essential part of my research and hence will contribute to advances in safety risk assessment and management.

All survey information will be kept strictly confidential and I will assume all responsibilities for any conclusions derived from the analysis of the survey data.

Thank you for your valuable assistance

Abel Pinto

PhD student, New University of Lisbon

**Questionnaire**

This questionnaire, are inserted in the investigation for my doctorate thesis entitled Development of a Fuzzy Qualitative Risk Assessment Model applied to construction industry. It aims understand the way by that companies analyzed risk factors related to Safety and evaluate the new developed model QRAM.

FOR SAMPLE WAS SELECTED A GROUP OF SAFETY EXPERTS WITH 10 OR MORE YEARS OF EXPERIENCE ON OCCUPATIONAL SAFETY IN CONSTRUCTION INDUSTRY.

THIS QUESTIONNAIRE IS **STRICTLY CONFIDENTIAL.** WILL NOT RESULT REFERENCES TO ANY COMPANIES OU INDIVIDUALS. PLEASE REPLY CORRECT AND STRICT.

For any additional clarification, please contact ABEL PINTO by abel.fnpinto@gmail.com.

**YOUR RESPONSE IS VERY IMPORTANT THANKS.**

**Q1 – EXPERT DATA**

**1. Occupation: ______________________________________________________**

**2. Experience in the current position: _____ years**

**3. Experience in the industry: _____ years**

**4. Are you involved with:**

☐ Developing RA

☐ Implementing RA

☐ Evaluating RA

## Q2 – Company Data

**1. Dimension:**

Micro (<= 10 workers) □ Small (11 a 50 workers) □ Average (51 a 200 workers) □

Big (> 200 workers) □

**2. Type of building works:** (In this issue you can choose multiple answers)

Buildings (residences, factories…) □ Infrastructures (including roads) □ Bridges, Viaducts…□

Sea or Rail Works □ Other □Which?______________________

## Q3 – Safety Climate on Construction Occupational Risk Analysis

**1. Usually take into account Safety Climate factors on ORA (Occupational Risk Analysis):**

Yes □ No □ Sometimes □

**2. If your answer was YES, what type of factors you usually include:**

Safety Rules and Procedures □ Workers' Involvement □ Personal Appreciation of Risk □

Workers' Competence □ Safe Work Behavior □ Management Commitment □

Leadership and Supervisory Environment □ Communication and Participation □

Supportive Environment □ Safety planning □ Work Pressure □ Safety management □

Other □Which?_______________________________________________________________

**3. If your answer was No, why you usually don't include this type of factors:**

Are not determinants □ Information is not reliable □ There are no information □

Is very time consuming □ I don't know any methodology that including these kind of factors □

Methodologies (that include this kind of factors) are not reliable □

Other □Which?_______________________________________________________________

**4. If your answer was Sometimes, why you usually don't include this type of factors in ORA:**

Only after an accident □ Information is not always available □ Sometimes there is no time □

Other □Which?_______________________________________________________________

## Q4 – SAFETY CLIMATE ON QRAM

**1. You agree that the presented set of factors allows to characterize properly Safety Climate on Construction Sites:**

Strongly Approved □ Approved □ Undecided □ Disapproved □ Strongly Disapproved □

**1.2 Could you, please, explain your answer:________________________________________**

**2. How considers the set of safety climate factors usability, in terms of:**

**2.1 Effectiveness (the ability of users to complete a ORA using the method, and the expected quality of the output)**

Strongly Approved □ Approved □ Undecided □ Disapproved □ Strongly Disapproved □

**2.2 Efficiency (the level of resources consumed)**

Strongly Approved □ Approved □ Undecided □ Disapproved □ Strongly Disapproved □

**2.3 Satisfaction (users' subjective reactions)**

Strongly Approved □ Approved □ Undecided □ Disapproved □ Strongly Disapproved □

**2.4 Could you, please, explain your answer:________________________________________**

**3. How considers the usability, about time spent:**

Quick to apply (a pair of hours) □ Slow to apply (one or more days) □

**3.1 Could you, please, explain your answer:______________________________________**

## Q5 – Severity on QRAM

**1. You agree that the presented set of functions allows to characterize properly Severity on Construction Sites:**

Strongly Approved □ Approved □ Undecided □ Disapproved □ Strongly Disapproved □

**1.2 Could you, please, explain your answer:_______________________________________**

**2. How considers the severity functions usability, in terms of:**

**2.1 Effectiveness (the ability of users to complete a ORA using the method, and the expected quality of the output)**

Strongly Approved □ Approved □ Undecided □ Disapproved □ Strongly Disapproved □

**2.2 Efficiency (the level of resources consumed)**

Strongly Approved □ Approved □ Undecided □ Disapproved □ Strongly Disapproved □

**2.3 Satisfaction (users' subjective reactions)**

Strongly Approved □ Approved □ Undecided □ Disapproved □ Strongly Disapproved □

**2.4 Could you, please, explain your answer:_______________________________________**

**3. How considers the usability, about time spent:**

Quick to apply (a pair of hours) □ Slow to apply (one or more days) □

**3.2 Could you, please, explain your answer:_____________________________________**

## Q6 – POSSIBILITY ON QRAM

**1. You agree that the presented set of factors allows to characterize properly work accidents possibility on Construction Sites:**

Strongly Approved □ Approved □ Undecided □ Disapproved □ Strongly Disapproved □

**1.2 Could you, please, explain your answer:_______________________________________**

**2. How considers the set of possibility factors usability, in terms of:**

**2.1 Effectiveness (the ability of users to complete a ORA using the method, and the expected quality of the output)**

Strongly Approved □ Approved □ Undecided □ Disapproved □ Strongly Disapproved □

**2.2 Efficiency (the level of resources consumed)**

Strongly Approved □ Approved □ Undecided □ Disapproved □ Strongly Disapproved □

**2.3 Satisfaction (users' subjective reactions)**

Strongly Approved □ Approved □ Undecided □ Disapproved □ Strongly Disapproved □

**2.4 Could you, please, explain your answer:_______________________________________**

**3. How considers the usability, about time spent:**

Quick to apply (a pair of hours) □ Slow to apply (one or more days) □

**3.3 Could you, please, explain your answer:_______________________________________**

**Q7 – SAFETY BARRIERS ON QRAM**

**1. You agree that the presented set of factors allows to characterize properly the effectiveness of safety barriers on Construction Sites:**

Strongly Approved □ Approved □ Undecided □ Disapproved □ Strongly Disapproved □

**1.2 Could you, please, explain your answer:__________________________________________**

**2. How considers the set of safety barriers usability, in terms of:**

**2.1 Effectiveness (the ability of users to complete a ORA using the method, and the expected quality of the output)**

Strongly Approved □ Approved □ Undecided □ Disapproved □ Strongly Disapproved □

**2.2 Efficiency (the level of resources consumed)**

Strongly Approved □ Approved □ Undecided □ Disapproved □ Strongly Disapproved □

**2.3 Satisfaction (users' subjective reactions)**

Strongly Approved □ Approved □ Undecided □ Disapproved □ Strongly Disapproved □

**2.4 Could you, please, explain your answer:__________________________________________**

**3. How considers the usability, about time spent:**

Quick to apply (a pair of hours) □ Slow to apply (one or more days) □

**3.4 Could you, please, explain your answer:________________________________________**

**Q8 – QRAM RESULTS**

**1. You agree that the QRAM results characterize properly the risk level on Construction Sites:**

Strongly Approved □ Approved □ Undecided □ Disapproved □ Strongly Disapproved □

**1.2 Could you, please, explain your answer:__________________________________________**

**THANK YOU FOR COMPLETING THIS QUESTIONNAIRE.**

## Annex II.2 – Results from case 1 safety climate assess

| Safety Climate Factors | Analyst assessment (Semantic term) |
|---|---|
| Related to workers | |
| Safety Rules and Procedures | |
| Written work procedures match the way tasks are done in practice | Inadequate |
| Written work procedures are technically accurate and adequate sources of safety information | Inadequate |
| Written work procedures are complete and easy to read and understand | Inadequate |
| Written work procedures are always available whenever needed be consulted | Inadequate |
| Workers can easily identify the applied procedure for each job | Inadequate |
| Rules enforce the use of personal protective equipment whenever necessary | Inadequate |
| Rules require detailed work plans from subcontractors or self-employed individuals | Inadequate |
| The definition of responsibilities and accountabilities is quite adequate | Inadequate |
| Workers' Competence | |
| In this site: | |
| Workers received adequate training to perform theirs jobs safely | Low Adequate |
| Workers use, keep, inspect and test the appropriate personal protective equipment as indicated | Inadequate |
| Workers know and correctly use relevant safety procedures | Inadequate |
| Workers appropriately report incidents and accidents | Low Adequate |
| Workers take general precautions to avoiding the dangers of workplace hazards | Inadequate |
| Workers identify and communicate potentially hazardous situations | Low Adequate |
| Workers apply appropriate work practices to reduce exposures to hazards | Inadequate |
| Safe Work Behavior | |
| In this site: | |
| Safety plays an effective role in preventing accidents | Low Adequate |
| Safety makes it possible to get the job done | Low Adequate |
| Safety is not restrictive and superficial | Low Adequate |
| Safety helps to increase workers productivity | Adequate |
| Safety contributes to workers work satisfaction | Adequate |
| Safety inspires workers to work more safely | Low Adequate |
| Safety has a positive influence on morale | Adequate |
| Workers have proud to take part of it | Adequate |
| Workers are proactive behavior in removing workplace safety hazards | Adequate |
| **RELATED TO MANAGEMENT** | |
| **Management Commitment** | |
| Management: | |
| clearly considers safety to be equally as important as production | Low Adequate |
| expresses concern if safety procedures are not adhered to | Low Adequate |
| acts decisively when a safety concern is raised | Low Adequate |
| acts quickly to correct safety problems | Adequate |
| commitment to safety is visible (e.g. by usage of PPEs) | Low Adequate |
| praises site employees for working safely | Low Adequate |
| disciplines site employees for working unsafely | Low Adequate |
| considers a person's safety behavior when moving/promoting people | Low Adequate |
| requires each manager to help improve safety in his/her department | Low Adequate |
| uses any available information to improve existing safety rules | Adequate |
| gives safety personnel the power they need to do their job correctly | Almost Adequate |
| clearly communicates and continues to bring safety information to site employees' attention at all levels within the site | Low Adequate |
| operates an open-door policy on safety issues | Low Adequate |
| encourages feedback from site employees on safety issues | Low Adequate |
| undertakes campaigns to promote safe working practices | Inadequate |
| provides a sufficient budget for safety on site | Inadequate |

| **Safety Climate Factors (continuation)** | **Analyst assessment (Semantic term)** |
|---|---|
| Supervisory Action Towards Safety | |
| Supervisors: | |
| have positive safety behavior | Very Adequate |
| usually engages in regular safety talks | Low Adequate |
| welcome reporting safety hazards/incidents | Adequate |
| are a good resource for solving safety problems | Adequate |
| not allow working around safety procedures even to meet important deadlines | Low Adequate |
| value workers ideas about improving safety even when significant changes to working practices are suggested | Low Adequate |
| say a “good word” to workers that pay special attention to safety | Low Adequate |
| make sure that workers receive all the equipment needed to do the job safely | Low Adequate |
| discusses how to improve safety with workers | Low Adequate |
| listen to and acts upon feedback from site employees | Low Adequate |
| communicate lessons from accidents to improve safety performance | Inadequate |
| appropriately reports incidents, accidents, and/or illnesses | Low Adequate |
| wear the personal protective equipment even if it is uncomfortable | Very Adequate |
| **RELATED TO SAFETY ENVIRONMENT** | |
| **Communication and Participation** | |
| Site safety policy and objectives are clearly communicate to site employees’ at all levels within the site | Inadequate |
| Workers participate in hazard identification, risk assessment, determination of risk controls (safety barriers) and personal protective equipment’s choice | Inadequate |
| Workers and subcontractors are consulted and involved in the ongoing review of safety | Inadequate |
| Workers and subcontractors are consulted and involved in accident investigation | Low Adequate |
| Workers and subcontractors participate in work planning | Inadequate |
| Communication with the supervisors regarding safety matters is easy | Low Adequate |
| There is a fluent communication embodied in periodic and frequent meetings, campaigns or oral presentations to transmit principles and rules of action | Inadequate |
| Information systems made available to affected workers prior to modifications and changes in production processes or job positions | Inadequate |
| When starting in new job position worker provided written information about procedures and correct way of doing tasks | Inadequate |
| Written circulars elaborated and meetings organised to inform workers about risks associated with their work and how to prevent accidents | Inadequate |
| Information flow (e.g. policy, procedures, vertical andhorizontal channels, scheduled and unscheduledmeetings) are used in support of various types ofdecision-making processes | Inadequate |
| **Supportive Environment** | |
| Subcontractors safety records are inspected before awarding contracts | Inadequate |
| Coworkers adopt a no-blame approach to highlight unsafe work behavior | Low Adequate |
| Coworkers often remind each other on how to work safely | Low Adequate |
| Coworkers believe it is their business to maintain a safe workplace environment | Low Adequate |
| Coworkers always offer help when needed to perform the job safely | Low Adequate |
| Coworkers endeavor to ensure that individuals are not working by themselves under risky or hazardous conditions | Low Adequate |
| Coworkers maintain good working relationships | Adequate |
| Coworkers ensure that the workload is reasonably balanced among their selves | Low Adequate |

| **Safety Climate Factors (continuation)** | **Analyst assessment (Semantic term)** |
|---|---|
| **Safety planning** | |
| Does safety started at design stage | Inadequate |
| Construction schedule is reasonable | Adequate |
| Safety is a primary consideration when determining site layout | Low Adequate |
| Chances of being involved in a site accident are quite large, due to unsafe conditions | Adequate |
| Operating site conditions may hinder one's ability to work safely | Almost Adequate |
| Detecting potential hazards is not a major aim of the site planning exercise | Low Adequate |
| Working with defective equipment is not allowed under any circumstances | Low Adequate |
| Potential risks and consequences are identified prior to execution | Low Adequate |
| Weather (and soil conditions) are considered in work planning | Low Adequate |
| Training includes effective skills practice for normal work and skill practices for emergencies | Inadequate |
| **Work Pressure over Safety** | |
| There are sufficient "thinking time" to enable workers to plan and carry out their work to an adequate standard | Adequate |
| There are enough workers to carry out the required work | Adequate |
| Workers consider that is necessary depart from safety requirements for production's sake | Low Adequate |
| Workers perceive that operational targets conflict with some safety measures | Low Adequate |
| Workers consider that is normal to take shortcuts at the expense of safety | Low Adequate |
| Workers tolerate minor unsafe behaviors performed by coworkers | Adequate |
| Workers consider that is not acceptable to delay periodic inspection of plant and equipment | Low Adequate |
| Management is strict about working safely when work falls behind schedule | Low Adequate |
| Supervisors refuse to ignore safety rules when work falls behind schedule | Low Adequate |
| **Safety Management System** | |
| Periodic checks are conducted on execution of prevention plans and compliance level of regulations | Inadequate |
| Systematic inspections conducted periodically to ensure effective functioning of the whole system | Inadequate |
| Accidents and incidents are reported, investigated, analysed and recorded | Low Adequate |
| External evaluations (audits) are periodically conducted of validity and reliability of prevention management system | Inadequate |
| Personal protective equipment use is monitored to identify problem areas | Inadequate |
| Are ensure daily housekeeping at all workplaces | Adequate |
| After using, tools and small machinery are stored in a correct place | Almost Adequate |
| Safety devices on machines are maintained in good operating | Almost Adequate |
| Marking and sign-posting of all risks and relevant safety information | Inadequate |

## Annex II.3 – Results from case 1 falls work accidents possibility assess

| Work accidents Possibility Factors | Analyst assessment (Semantic term) |
|---|---|
| **Falls** | |
| **General** | |
| To what extent the work (at height) was properly planned to be carried out in a safe way (especially work on or near fragile roof surfaces, on a roofs and store floors being built or demolished or erecting/dismantling/altering scaffolding) and properly supervised? | Adequate |
| To what extent were simultaneous activities at the same location properly planned to be carried out in a safe way and appropriately supervised? | Adequate |
| To what extent are floor openings and storey floor edges properly protected? | Adequate |
| To what extent are the wall openings with 1.20 m or more above ground properly protected? | Very Adequate |
| To what extent the means to access to workplaces at height are adequate and properly protected? | Adequate |
| To what extent the working surfaces provide sufficient grip (refers to surfaces that were not made or designed to climb onto, walk on or provide support)? | Adequate |
| To what extent are form and scrap lumber with protruding nails and all other debris kept clear from work areas, passageways, and stairs? | Adequate |
| To what extent are work platforms adequate and robust enough (to resist to wind and to forces exerted by falling objects or by workers when using hand-operated tools) and protected by guardrails (top railings at least 1 meter above the working platform, foot rails at no less than 15 cm and intermediate rails so that no openings are greater than 47 cm, around the perimeter)? | Adequate |
| To what extent is assured that working platforms are not overloaded and the loads correctly distributed? | Adequate |
| To what extent proper measures are taken so that employees working at a height greater than 1.20 m are protected from falling? | Adequate |
| To what extent are lighting levels adequate (functioning and position of lights to ensure that all floor areas and wall opening areas are evenly lit and all potential hazards, e.g. obstructions, stairways, runways and spills can be clearly seen)? | Almost Adequate |
| To what extent are the workplaces maintained clean and tidy, with floors and access routes kept clear of slippery (due to mud, wetness, moisture, oil, grease, powder, insufficient drainage, freezing, snow or ice…) and obstacles were workers could slip or trip? | Very Adequate |
| To what extent the working floors are not uneven and/or unstable (it means that the surface was on level, there were not loose or unstable floor parts, wrinkled carpets, etc) or have dangerous thresholds or steps? | Very Adequate |
| To what extent is strictly prohibited to stay at height while this was not necessary for carrying out tasks? | Almost Adequate |
| To what extent is strictly prohibited to talking on the telephone during work at height? | Almost Adequate |
| To what extent are workers aware of the dangers of lose their balance when using hand tools (e. g. lipping, tripping, taking a wrong step, being bumped by someone and consequently losing the balance)? | Inadequate |

| Work accidents Possibility Factors | Analyst assessment (Semantic term) |
|---|---|
| **Falls (continuation)** | |
| **Portable (or moveable) ladders** | |
| To what extent are portable ladders large enough to workers to be able to reach their workplaces? | Strongly Adequate |
| To what extent are ladders with broken or missing rungs or split side rails, tagged and taken out of service? | Inadequate |
| To what extent are metal ladders inspected for damage or signs of corrosion? | Low Adequate |
| To what extent are portable ladders used only in short-term jobs (not exceeding 30 min and do not require the worker side loads)? | Inadequate |
| To what extent do workers assume a correct position on the ladder (not standing on the side of the ladder, feet in the middle, face toward the rungs, using both hands for support, not standing on the ladder whilst shifting or extending, not slipping off the ladder without using the rungs and not hanging onto the side)? | Adequate |
| To what extent are areas around the top and bottom of the portable ladder kept clear? | Adequate |
| To what extent are portable ladders prohibited from being used in a horizontal position as platforms, runways, or scaffolds? | Adequate |
| To what extent is the distance at the base of the open portable ladders 15 cm by each 30 cm high? | Strongly Adequate |
| To what extent are there warning signs indicating that work was being performed on a ladder? | Inadequate |
| To what extent are workers aware of the dangers when they are in poor physical condition (sick, weak, nauseous, disabled to some extent, dizzy, vertigo, fatigued, tense or under the influence of drugs, alcohol or medicine, etc.) whilst standing on the ladder? | Inadequate |

## Annex II.4 – Results from case 1 contact with electricity work accidents possibility assess

| Work accidents Possibility Factors | Analyst assessment (Semantic term) |
|---|---|
| **Contact with electricity** | |
| To what extent is it ensured that the work was properly planned, appropriately supervised, and carried out in a safe way as it is reasonably practicable? | Low Adequate |
| To what extent are electrical equipments (cables, frames, accessories) revised before being reassembled in a new site? | Low Adequate |
| To what extent does electrical equipment meet all the legal or normative requirements? | Strongly Adequate |
| To what extent are all electrical cords or cables taken out of service when worn or frayed? | Low Adequate |
| To what extent is all electrical equipment free from recognized hazards (insulation defects, eg) that may cause death or serious harm? | Adequate |
| To what extent are live electrical parts properly guarded against accidental contact? | Strongly Adequate |
| To what extent are leakage circuit breakers properly used to protect the workers? | Very Adequate |
| To what extent are all outlet devices correctly and properly matched with load being served? | Very Adequate |
| To what extent is the path to ground from circuits, equipment, and enclosures satisfied so that they are permanent and continuous? | Adequate |
| To what extent are there (on site) measures in place to prevent unauthorised persons from working on installations under tension (e. g. locker keys, supervision and key procedures)? | Inadequate |
| To what extent are all the electrical extension cords of the three wire types (with ground wire, green wire and yellow wire)? | Adequate |
| To what extent is the protection of the lamps for general illumination against breakage proper and satisfactory? | Low adequate |
| To what extent are the protection measures against damage for flexible cords and cables satisfactory? | Inadequate |
| To what extent are all cabinets, cut out boxes, fittings, boxes, panel board enclosures, switches, circuit breakers, through doorways or windows, attached to building surfaces, or concealed behind walls, ceilings, or floors? | Low adequate |
| To what extent are electric powered tools and equipment’s double-insulated or properly grounded? | Very Adequate |
| To what extent are tests or other appropriate methods or means applied to assure that the electric equipment and lines are considered de-energized? | Inadequate |
| To what extent do workers not wear metal objects (rings, watches…) when working with electrical devices? | Inadequate |
| To what extent are all disconnecting devices legibly marked to indicate purpose unless located so that purpose is evident? | Inadequate |
| To what extent are metal ladders not used when working on or near electrical equipment (such as changing light bulbs or fluorescent tubes)? | Inadequate |
| To what extent is sufficient working space provided to permit safe operation and maintenance of electrical equipment? | Strongly Adequate |
| To what extent was the electrical energy of the machines or the equipment’s (including hand tools) turned off when work was being performed on it (for instance, during maintenance work or failure repairs)? | Adequate |
| To what extent are workers aware of the dangers of bypass the electrical protection devices (e. g. residual-current device or ground fault circuit interrupter)? | Inadequate |
| To what extent are workers aware of the dangers of using tools that were not suitable for electrical works (e.g. using non-insulated screwdrivers) or using it incorrectly (e. g. using low voltage detectors for high voltage)? | Inadequate |

## Annex II.5 – Results from case 1 injured by falling/swinging objects work accidents possibility assess

| Work accidents Possibility Factors | Analyst assessment (Semantic term) |
|---|---|
| **Injured by falling/swinging objects** | |
| To what extent is it ensured that the work was properly planned, appropriately supervised, and carried out in a safe way as it is reasonably practicable (e.g. with letting objects fall in an intentional and a controlled manner such as rubble or debris, into a chute/container)? | Low Adequate |
| To what extent was simultaneous activities at the same location properly plan to be carried out in a safe way and are appropriately supervised? | Low Adequate |
| To what extent are materials which are stored in tiers either stacked, racked, blocked, interlocked, or otherwise, properly secured to prevent sliding, falling, or collapsing? | Low Adequate |
| To what extent is the storage of materials properly done (are materials stored more than 1,80 m from any hoist way or inside floor opening and more than 3 m from any exterior walls that do not extend above the top of the stored materials)? | Adequate |
| To what extent is the weight of the loads to move known (if it is not known, it is estimated by multiplying the load volume by the material specific weight)? | Inadequate |
| To what extent are the cranes, lifts and other lift equipment's load bearing capacity correctly posted? | Adequate |
| To what extent is any area where material is dropped outside the exterior walls of the structure effectively and properly protected? | Very Adequate |
| To what extent are inspections made by a competent person as work progresses to detect hazards from weakened or deteriorated floors or walls or loosened materials? | Adequate |
| To what extent are workers aware of the dangers of the use of incorrect tools or aids (e.g decide to lift something manually, whilst it would be better to do so mechanically)? | Inadequate |

## Annex II.6 – Results from case 1 hit by rolling/sliding/flying object (including awkward or sudden movement) work accidents possibility assess

| Work accidents Possibility Factors | Analyst assessment (Semantic term) |
|---|---|
| **Hit by rolling/sliding/flying object (including awkward or sudden movement)** | |
| To what extent was the work properly planned, appropriately supervised, and carried out in a safe way (e.g the demolition or assembly of prefabricated structures)? | Low Adequate |
| To what extent were simultaneous activities at the same location properly planned to be carried out in a safe way and appropriately supervised? | Adequate |
| To what extent are abrasive wheel grinders provided with safety guards which cover the spindle ends, nut and flange projections? | Strongly Adequate |
| To what extent are workers working in the vicinity of running machinery from which material or items could fly around, or in the vicinity of persons who use hand tools whereby material could fly around, properly protected (such as eye protection, facial protection or a helmet) for activities with a cutting action (sawing, drilling, smoothing, turning, honing, etc.) or for other activities whereby there is a risk that objects/parts can fly off (for instance, hammering, the treatment of objects on a lathe, with a drill or saw, whereby the object or the fastener can fly around during the treatment…)? | Adequate |
| To what extent are workers aware of the dangers of the use of wrong tools or machine operated incorrectly or tools used in the wrong way (e. g. using metal hammers, whereas a plastic hammer should have been used for that material; using grinding discs that are not suitable for the material to be treated or for the rotational speeds of the machine; using the wrong pliers for holding something firmly; or using a screwdriver as a chisel and vice versa; when a force that is too great is exerted with the tool or if the machine is used for treating something with the wrong setting - speed, angle, direction, force, aid, etc; wood drill instead of stone drill (for drilling into stone), a hand tool with the wrong size (spanners, pliers))? | Inadequate |
| To what extent are workers aware of the dangers of the use of incorrect tools or aids or hold hand tools incorrectly (e.g use of the wrong tools, not holding tools in a safe direction; not safely placing tool leads and tubes so that the tool could suddenly shoot out in another direction; not properly holding tools that are being carried, etc.)? | Inadequate |
| To what extent are work areas well lit, dry and clean (especially where loads are moving manually)? | Adequate |
| To what extent are objects/materials correctly stacked (including stacks of dissimilar objects) to avoid collapse, topple over and objects falling (e. g stack should not be higher than 3x the width, heavy objects could be stacked on the lower parts of the stack, objects should not exceed the edge of the shelves)? | Adequate |
| To what extent are the surfaces adequate to support the load (e.g strong enough to bear the weight of the objects, without vibrations caused by passing lorries)? | Strongly Adequate |
| To what extent are observers kept at a safe distance from work equipment's? | Low Adequate |
| To what extent are machines and tools kept in good conditions (to avoid that with normal use parts, such as saw blades, chisels or bits, could have broken or flown around)? | Adequate |
| To what extent are the machines and tools inspected (by the users) at the beginning of each shift to assure that they are free of defects? | Low Adequate |
| To what extent are loads/objects suitable to be moved manually (e.g objects that are not too large to be carried, objects with a surface that is not slippery and/or sharp or objects that nor exceed 27 kg)? | Very Adequate |
| To what extent are there handles (adequate and sufficient) for helping the manual handling tasks? | Inadequate |
| To what extent is strictly forbidden to throw tools or other objects? | Low Adequate |

## Annex II.7 – Results from case 1 contact with machinery/equipment moving parts (including trapped between objects) work accidents possibility assess

| **Work accidents Possibility Factors** | **Analyst assessment (Semantic term)** |
|---|---|
| **Contact with machinery/equipment moving parts (including trapped between objects)** | |
| **General** | |
| To what extentequipments and machinery comply with the applicable use specifications and safety regulations (i. e. bear a CE marking)? | Strongly Adequate |
| To what extent were equipments and machinery not modified after purchase? | Very Adequate |
| To what extent have equipments and machinery emergency stop devices within reach and properly functioning? | Strongly Adequate |
| To what extent are machinery guards kept in place and in working order? | Very Adequate |
| To what extent are hand tools and other equipment regularly inspected for safe condition (including visual inspection each day for defects or obstructions prior to use)? | Low Adequate |
| To what extent are impact tools free of mushroomed heads? | Very Adequate |
| To what extent are power tools, belts, gears, shaft, pulleys, sprockets, spindles, drums, fly wheels, and chains properly guarded? | Very Adequate |
| To what extent are tools used with the correct shield, guard, or attachments recommended by the manufacturer? | Low Adequate |
| To what extent are power actuated tools left unloaded until they are ready for immediate use? | Low Adequate |
| To what extent are tools stored in a dry, secure location where they won't be tampered with? | Low Adequate |
| **Hand Tools** | |
| To what extent are hand tools equipped with the appropriate and properly mounted handles (with a shape able to provide sufficient grip) and kept in good condition (not soiled, worn or damaged)? | Very Adequate |
| To what extent are tool handles free of splits and cracks? | Very Adequate |
| To what extent are workers aware of the dangers of working materials (of the object/workpiece) insufficiently suited for working with the hand tool (material too hard, material with defects - e.g. knots in wood, presence of objects in the material that do not belong to it - nails in a piece of wood)? | Inadequate |
| To what extent are workers aware of the dangers of using the hand tool in an unsafe position (e. g. at a wrong angle so that the tool kicks back - when sawing, honing or milling)? | Inadequate |
| To what extent are workers aware of the dangers of the use of electric, pneumatic and/or hydraulic hand tools (including high-pressure sprayers), hand tools under mechanical or other tension not properly protected against unintentional start-up or activation of the tool (e. g. situations in which locks are not used, switches are not blocked, the tool's power has not been shut off)? | Inadequate |
| To what extent are workers aware of the dangers of the use of hand tool not in a good condition (e. g. hand tools whose safety features - such as self-braking grinding discs, safeguards, etc - are missing or not functioning properly or if the grips/handles are slippery)? | Inadequate |
| To what extent are workers aware of the dangers of working with hand tools whilst doing something else at the same time (e. g. carrying or putting away another object/tool, using another hand tool, using a telephone, drinking coffee, etc.)? | Inadequate |
| To what extent are workers aware of the dangers of working with hand tools in workplaces not orderly (i. e. insufficient visibility/lighting, very noisy, extreme temperatures or slippery and/or messy floors)? | Inadequate |
| To what extent are there (on site) poorly designed handles/grips (of machines, doors, lids, etc.) so that when in use a hand/fingers could become trapped? | Low Adequate |

## Annex II.8 – Results from case 1 fire or explosion work accidents possibility assess

| Work accidents Possibility Factors | Analyst assessment (Semantic term) |
|---|---|
| **Fire or explosion** | |
| To what extent was the work properly planned, appropriately supervised, and carried out in a safe way (e.g. work in confined spaces)? | Low Adequate |
| To what extent are all flammable and combustible liquids stored and handled in approved and proper containers and portable tanks? | Adequate |
| To what extent are flammable, combustible and explosives stored in appropriated conditions? | Adequate |
| To what extent are workers aware of the dangers of smoking in the immediate vicinity of flammable or combustible atmospheres? | Inadequate |
| To what extent are workers aware of the dangers of hot surfaces that have not been sufficiently cooled, present in the immediate vicinity of flammable substances? | Inadequate |

## Annex II.9 – Results from case 2 safety climate assess

| Safety Climate Factors | Analyst assessment (Semantic term) |
|---|---|
| **Related to workers** | |
| **Safety Rules and Procedures** | |
| Written work procedures match the way tasks are done in practice | Adequate |
| Written work procedures are technically accurate and adequate sources of safety information | Adequate |
| Written work procedures are complete and easy to read and understand | Adequate |
| Written work procedures are always available whenever needed be consulted | Almost Adequate |
| Workers can easily identify the applied procedure for each job | Adequate |
| Rules enforce the use of personal protective equipment whenever necessary | Strongly Adequate |
| Rules require detailed work plans from subcontractors or self-employed individuals | Strongly Adequate |
| The definition of responsibilities and accountabilities is quite adequate | Adequate |
| **Workers' Competence** | |
| In this site: | |
| Workers received adequate training to perform theirs jobs safely | Very Adequate |
| Workers use, keep, inspect and test the appropriate personal protective equipment as indicated | Adequate |
| Workers know and correctly use relevant safety procedures | Adequate |
| Workers appropriately report incidents and accidents | Very Adequate |
| Workers take general precautions to avoiding the dangers of workplace hazards | Very Adequate |
| Workers identify and communicate potentially hazardous situations | Adequate |
| Workers apply appropriate work practices to reduce exposures to hazards | Adequate |
| **Safe Work Behavior** | |
| In this site: | |
| Safety plays an effective role in preventing accidents | Adequate |
| Safety makes it possible to get the job done | Very Adequate |
| Safety is not restrictive and superficial | Very Adequate |
| Safety helps to increase workers' productivity | Very Adequate |
| Safety contributes to workers work satisfaction | Very Adequate |
| Safety inspires workers to work more safely | Very Adequate |
| Safety has a positive influence on morale | Very Adequate |
| Workers have proud to take part of it | Very Adequate |
| Workers are proactive behavior in removing workplace safety hazards | Very Adequate |
| **Related to management** | |
| **Management Commitment** | |
| Management: | |
| clearly considers safety to be equally as important as production | Adequate |
| expresses concern if safety procedures are not adhered to | Very Adequate |
| acts decisively when a safety concern is raised | Very Adequate |
| acts quickly to correct safety problems | Very Adequate |
| commitment to safety is visible (e.g. by usage of PPEs) | Very Adequate |
| praises site employees for working safely | Strongly Adequate |
| disciplines site employees for working unsafely | Very Adequate |
| considers a person's safety behavior when moving/promoting people | Very Adequate |
| requires each manager to help improve safety in his/her department | Strongly Adequate |
| uses any available information to improve existing safety rules | Adequate |
| gives safety personnel the power they need to do their job correctly | Low Adequate |
| clearly communicates and continues to bring safety information to site employees' attention at all levels within the site | Very Adequate |

| Safety Climate Factors (continuation) | Analyst assessment (Semantic term) |
|---|---|
| **Management Commitment (continuation)** | |
| operates an open-door policy on safety issues | Adequate |
| encourages feedback from site employees on safety issues | Adequate |
| undertakes campaigns to promote safe working practices | Low Adequate |
| provides a sufficient budget for safety on site | Very Adequate |
| **Supervisory Action Towards Safety** | |
| Supervisors: | |
| have positive safety behavior | Very Adequate |
| usually engages in regular safety talks | Very Adequate |
| welcome reporting safety hazards/incidents | Adequate |
| are a good resource for solving safety problems | Very Adequate |
| not allow working around safety procedures even to meet important deadlines | Adequate |
| value workers ideas about improving safety even when significant changes to working practices are suggested | Adequate |
| say a "good word" to workers that pay special attention to safety | Adequate |
| make sure that workers receive all the equipment needed to do the job safely | Very Adequate |
| discusses how to improve safety with workers | Adequate |
| listen to and acts upon feedback from site employees | Low Adequate |
| communicate lessons from accidents to improve safety performance | Adequate |
| appropriately reports incidents, accidents, and/or illnesses | Adequate |
| wear the personal protective equipment even if it is uncomfortable | Very Adequate |
| **Related to safety environment** | |
| **Communication and Participation** | |
| Site safety policy and objectives are clearly communicate to site employees' at all levels within the site | Very Adequate |
| Workers participate in hazard identification, risk assessment, determination of risk controls (safety barriers) and personal protective equipment's choice | Adequate |
| Workers and subcontractors are consulted and involved in the ongoing review of safety | Very Adequate |
| Workers and subcontractors are consulted and involved in accident investigation | Very Adequate |
| Workers and subcontractors participate in work planning | Low Adequate |
| Communication with the supervisors regarding safety matters is easy | Adequate |
| There is a fluent communication embodied in periodic and frequent meetings, campaigns or oral presentations to transmit principles and rules of action | Adequate |
| Information systems made available to affected workers prior to modifications and changes in production processes or job positions | Adequate |
| Written circulars elaborated and meetings organised to inform workers about risks associated with their work and how to prevent accidents | Strongly Adequate |
| Information flow (e.g. policy, procedures, vertical andhorizontal channels, scheduled and unscheduledmeetings) are used in support of various types ofdecision-making processes | Very Adequate |
| **Supportive Environment** | |
| Subcontractors safety records are inspected before awarding contracts | Very Adequate |
| Coworkers adopt a no-blame approach to highlight unsafe work behavior | Very Adequate |
| Coworkers often remind each other on how to work safely | Adequate |
| Coworkers believe it is their business to maintain a safe workplace environment | Very Adequate |
| Coworkers always offer help when needed to perform the job safely | Very Adequate |
| Coworkers endeavor to ensure that individuals are not working by themselves under risky or hazardous conditions | Very Adequate |
| Coworkers maintain good working relationships | Very Adequate |
| Coworkers ensure that the workload is reasonably balanced among their selves | Very Adequate |

| Safety Climate Factors (continuation) | Analyst assessment (Semantic term) |
|---|---|
| **Safety planning** | |
| Does safety started at design stage | Strongly Adequate |
| Construction schedule is reasonable | Very Adequate |
| Safety is a primary consideration when determining site layout | Very Adequate |
| Chances of being involved in a site accident are quite large, due to unsafe conditions | Very Adequate |
| Operating site conditions may hinder one's ability to work safely | Almost Adequate |
| Detecting potential hazards is not a major aim of the site planning exercise | Very Adequate |
| Working with defective equipment is not allowed under any circumstances | Very Adequate |
| Potential risks and consequences are identified prior to execution | Very Adequate |
| Weather (and soil conditions) are considered in work planning | Strongly Adequate |
| Training includes effective skills practice for normal work and skill practices for emergencies | Strongly Adequate |
| **Work Pressure over Safety** | |
| There are sufficient "thinking time" to enable workers to plan and carry out their work to an adequate standard | Adequate |
| There are enough workers to carry out the required work | Strongly Adequate |
| Workers consider that is necessary depart from safety requirements for production's sake | Very Adequate |
| Workers perceive that operational targets conflict with some safety measures | Very Adequate |
| Workers consider that is normal to take shortcuts at the expense of safety | Adequate |
| Workers tolerate minor unsafe behaviors performed by coworkers | Very Adequate |
| Workers consider that is not acceptable to delay periodic inspection of plant and equipment | Very Adequate |
| Management is strict about working safely when work falls behind schedule | Adequate |
| Supervisors refuse to ignore safety rules when work falls behind schedule | Adequate |
| **Safety Management System** | |
| Periodic checks are conducted on execution of prevention plans and compliance level of regulations | Adequate |
| Systematic inspections conducted periodically to ensure effective functioning of the whole system | Very Adequate |
| Accidents and incidents are reported, investigated, analyzed and recorded | Very Adequate |
| External evaluations (audits) are periodically conducted of validity and reliability of prevention management system | Very Adequate |
| Personal protective equipment use is monitored to identify problem areas | Adequate |
| Are ensure daily housekeeping at all workplaces | Adequate |
| After using, tools and small machinery are stored in a correct place | Strongly Adequate |
| Safety devices on machines are maintained in good operating | Strongly Adequate |
| Marking and sign-posting of all risks and relevant safety information | Very Adequate |

## Annex II.10 – Results from case 2 falls work accidents possibility assess

| Work accidents Possibility Factors | Analyst assessment (Semantic term) |
|---|---|
| **Falls** | |
| **General** | |
| To what extent the work (at height) was properly planned to be carried out in a safe way (especially work on or near fragile roof surfaces, on a roofs and storey floors being built or demolished or erecting/dismantling/altering scaffolding) and properly supervised? | Adequate |
| To what extent were simultaneous activities at the same location properly planned to be carried out in a safe way and appropriately supervised? | Very Adequate |
| To what extent are the means to access to workplaces at height are adequate and properly protected? | Very Adequate |
| To what extent the working surfaces provide sufficient grip (refers to surfaces that were not made or designed to climb onto, walk on or provide support)? | Adequate |
| To what extent are form and scrap lumber with protruding nails and all other debris kept clear from work areas, passageways, and stairs? | Very Adequate |
| To what extent are work platforms adequate and robust enough (to resist to wind and to forces exerted by falling objects or by workers when using hand-operated tools) and protected by guardrails (top railings at least 1 metre above the working platform, foot rails at no less than 15 cm and intermediate rails so that no openings are greater than 47 cm, around the perimeter)? | Very Adequate |
| To what extent is assured that working platforms are not overloaded and the loads correctly distributed? | Adequate |
| To what extent proper measures are taken so that employees working at a height greater than 1.20 m are protected from falling? | Adequate |
| To what extent are lighting levels adequate (functioning and position of lights to ensure that all floor areas and wall opening areas are evenly lit and all potential hazards, e.g. obstructions, stairways, runways and spills can be clearly seen)? | Almost Adequate |
| To what extent are the workplaces maintained clean and tidy, with floors and access routes kept clear of slippery (due to mud, wetness, moisture, oil, grease, powder, insufficient drainage, freezing, snow or ice…) and obstacles were workers could slip or trip? | Very Adequate |
| To what extent the working floors are not uneven and/or unstable (it means that the surface was on level, there were not loose or unstable floor parts, wrinkled carpets, etc) or have dangerous thresholds or steps? | Very Adequate |
| To what extent is strictly prohibited to stay at height while this was not necessary for carrying out tasks? | Almost Adequate |
| To what extent is strictly prohibited to talking on the telephone during work at height? | Almost Adequate |
| To what extent are workers aware of the dangers of lose their balance when using hand tools (e. g. lipping, tripping, taking a wrong step, being bumped by someone and consequently losing the balance)? | Very Adequate |

| Work accidents Possibility Factors | Analyst assessment (Semantic term) |
|---|---|
| **Falls (continuation)** | |
| **Ladders** | |
| To what extent are fixed ladders safely designed and constructed (i.e. not too steep and not too narrow, without: slippery floors, worn floor, not uniform floor, steps with not uniform heights, handrails loose or weak, the distance between the permanent floor and the first rung was greater than the space between two consecutive rungs, rungs slippery by itself and/or landing platforms were missing if the ladder was higher than 3 m)? | Very Adequate |
| To what extent are fixed ladders provided with protection against falling from either side (e.g. robust handrails)? | Strongly Adequate |
| To what extent are fixed ladders robust enough for the planned efforts? | Strongly Adequate |
| To what extent are fixed ladders properly fixed to the upper or lower floor? | Adequate |
| To what extent are the rungs (of all kinds of ladders) kept clear of soiling (such as mud, oil, paint, snow or ice or other slippery material)? | Adequate |
| To what extent are conditions such as: wearing shoes with slippery soles, the presence of objects on the ladder, hastily ascending or descending, being distracted or preoccupied with something at the same time, or poor vision, under which workers can lose their balance, be mantained under control? | Very Adequate |
| To what extent are ladders inspected and kept in safe conditions (without weak, broken or missing steps and weak, broken or missing handrails)? | Very Adequate |
| Portable (or moveable) ladders | |
| To what extent are portable ladders placed correctly, at an angle of one in four, (one unit of measurement out for every four units up), on and against a material that has a reasonable coefficient of friction and strength and was the step ladder placed on a surface that was not level and/or stable? | Very adequate |
| To what extent are portable ladders large enough to workers to be able to reach their workplaces? | Strongly Adequate |
| To what extent is strictly prohibited to place portable ladders on incline or sloping surfaces? | Adequate |
| To what extent are ladders with broken or missing rungs or split side rails, tagged and taken out of service? | Very Adequate |
| To what extent are metal ladders inspected for damage or signs of corrosion? | Very Adequate |
| To what extent are portable ladders used only in short-term jobs (not exceeding 30 min and do not require the worker side loads)? | Adequate |
| To what extent do workers assume a correct position on the ladder (not standing on the side of the ladder, feet in the middle, face toward the rungs, using both hands for support, not standing on the ladder whilst shifting or extending, not slipping off the ladder without using the rungs and not hanging onto the side)? | Adequate |
| To what extent are areas around the top and bottom of the portable ladder kept clear? | Adequate |
| To what extent are portable ladders prohibited from being used in a horizontal position as platforms, runways, or scaffolds? | Adequate |
| To what extent is the distance at the base of the open portable ladders 15 cm by each 30 cm high? | Strongly Adequate |
| To what extent are there warning signs indicating that work was being performed on a ladder? | Inadequate |
| To what extent are workers aware of the dangers when they are in poor physical condition (sick, weak, nauseous, disabled to some extent, dizzy, vertigo, fatigued, tense or under the influence of drugs, alcohol or medicine, etc.) whilst standing on the ladder? | Very Adequate |

## Annex II.11 – Results from case 2 contact with electricity work accidents possibility assess

| Work accidents Possibility Factors | Analyst assessment (Semantic term) |
|---|---|
| **Contact with electricity** | |
| To what extent is it ensured that the work was properly planned, appropriately supervised, and carried out in a safe way as it is reasonably practicable? | Very Adequate |
| To what extent are electrical equipments (cables, frames, accessories) revised before being reassembled in a new site? | Very Adequate |
| To what extent does electrical equipment meet all the legal or normative requirements? | Strongly Adequate |
| To what extent are all electrical cords or cables taken out of service when worn or frayed? | Adequate |
| To what extent is all electrical equipment free from recognized hazards (insulation defects, eg) that may cause death or serious harm? | Very Adequate |
| To what extent are live electrical parts properly guarded against accidental contact? | Adequate |
| To what extent are leakage circuit breakers properly used to protect the workers? | Very Adequate |
| To what extent are all outlet devices correctly and properly matched with load being served? | Very Adequate |
| To what extent is the path to ground from circuits, equipment, and enclosures satisfied so that they are permanent and continuous? | Adequate |
| To what extent are there (on site) measures in place to prevent unauthorised persons from working on installations under tension (e. g. locker keys, supervision and key procedures)? | Almost Adequate |
| To what extent are all the electrical extension cords of the three wire types (with ground wire, green wire and yellow wire)? | Strongly Adequate |
| To what extent is the protection of the lamps for general illumination against breakage proper and satisfactory? | Adequate |
| To what extent are the protection measures against damage for flexible cords and cables satisfactory? | Adequate |
| To what extent are all cabinets, cut out boxes, fittings, boxes, panel board enclosures, switches, circuit breakers, through doorways or windows, attached to building surfaces, or concealed behind walls, ceilings, or floors? | Low adequate |
| To what extent are electric powered tools and equipment's double-insulated or properly grounded? | Very Adequate |
| To what extent are tests or other appropriate methods or means applied to assure that the electric equipment and lines are considered de-energized? | Adequate |
| To what extent do workers not wear metal objects (rings, watches…) when working with electrical devices? | Inadequate |
| To what extent are all disconnecting devices legibly marked to indicate purpose unless located so that purpose is evident? | Inadequate |
| To what extent are metal ladders not used when working on or near electrical equipment (such as changing light bulbs or fluorescent tubes)? | Inadequate |
| To what extent is sufficient working space provided to permit safe operation and maintenance of electrical equipment? | Strongly Adequate |
| To what extent was the electrical energy of the machines or the equipment's (including hand tools) turned off when work was being performed on it (for instance, during maintenance work or failure repairs)? | Adequate |
| To what extent are workers aware of the dangers of bypass the electrical protection devices (e. g. residual-current device or ground fault circuit interrupter)? | Very Adequate |
| To what extent are workers aware of the dangers of using tools that were not suitable for electrical works (e.g. using non-insulated screwdrivers) or using it incorrectly (e. g. using low voltage detectors for high voltage)? | Very Adequate |

## Annex II.12 – Results from case 2 struck by moving vehicle work accidents possibility assess

| Work accidents Possibility Factors | Analyst assessment (Semantic term) |
|---|---|
| **Struck by moving vehicle** | |
| General | |
| To what extent is ensured that all drivers had (before starting to drive) a special training in order to drive the specific vehicles? | Adequate |
| To what extent is ensured that all visiting drivers report to site management before entering the site (to assure that drivers had received proper safety training)? | Adequate |
| To what extent is there (where vehicles have to reverse) a trained signaler to assist the vehicle driver? | Low Adequate |
| To what extent are passengers prevented from riding in dangerous positions? | Very Adequate |
| To what extent are flagmen and other workers at risk of being struck by moving vehicle do they wear noticeable garments (red or orange warning garments, reflectorized for working at night)? | Very Adequate |
| To what extent are there proper warning vests made of reflectorized or of high visibility material and to what extent are they being used by employees exposed to vehicular traffic? | Very Adequate |
| To what extent are the necessary measures taken to prevent the parked vehicles from inadvertently moving ( (using the hand brake, removing the ignition key, putting blocks behind the wheels when this was in fact necessary, etc)? | Very Adequate |
| To what extent do all vehicles with an obstructed view to the rear have a back up alarm or are they always used with an observer? | Very Adequate |
| To what extent are drivers aware of the dangers (for themselves and for pedestrians) of exit of the vehicle while it had not yet stopped and been properly locked? | Very Adequate |
| To what extent are drivers aware of the dangers of the vehicles with high center of gravity resulting in an increased risk of tipping over? | Very Adequate |
| To what extent are drivers aware of the dangers (for themselves and for pedestrians) of doing other things whilst driving (talking on the telephone, talking with others, adjusting the radio, larking about, etc.) or of being distracted by things in his surroundings (by or loud noise)? | Very Adequate |
| To what extent are drivers aware of the dangers (for themselves and for pedestrians) of reduced visibility by load obstruction, poor weather conditions or insufficient lighting? | Very Adequate |
| To what extent are drivers aware of the dangers (for themselves and for pedestrians) when they are in poor physical condition (sick, weak, nauseous, disabled to some extent, dizzy, vertigo, fatigued, tense or under the influence of drugs, alcohol or medicine, etc.) whilst driving? | Very Adequate |
| To what extent are workers at noisy locations (or when using ear protection, MP3 players or talking on the mobile phone…) aware of the increasing danger of being struck by moving vehicle? | Very Adequate |
| To what extent are workers aware of the dangers of being just in front of or behind a vehicle (for instance, by crossing behind a vehicle to do something with the load or because of being talking with the driver)? | Very Adequate |
| To what extent are workers aware of the dangers of walking in a hurried or stressed manner, tripping or losing their footing at locations where vehicles are driven? | Very Adequate |
| To what extent are workers aware of the dangers of leaving or entering the vehicle, while it was not yet (entirely) stopped? | Very Adequate |
| To what extent are workers aware of the dangers of being transported in a vehicle that is not intended for persons (e. g. catching a lift on forklift trucks or running boards of a vehicle)? | Very Adequate |

| Work accidents Possibility Factors | Analyst assessment (Semantic term) |
|---|---|
| **Struck by moving vehicle (continuation)** | |
| **Roads** | |
| To what extent is a traffic plan for the site established (with lines separating vehicles and pedestrian routes, vehicle access points and warning signs, traffic signs and traffic lights in dangerous situations like pedestrian crossings)? | Low Adequate |
| To what extent are vehicle traffic routes suitable for the types and quantity of vehicles that use them (ensure they are wide enough and that floor and road surfaces are kept in good condition) and periodically checked? | Adequate |
| To what extent are one-way systems or turning points provided to minimize the need for reversing (to avoid maneuver the vehicle within the site)? | Adequate |
| To what extent is there space enough to maneuver the vehicles safely (avoiding the vehicle to enter pedestrian zones when being maneuvered)? | Low Adequate |
| To what extent are obstructions (sharp bends, pillars, other vehicles, stacks of material, etc) removed where possible or otherwise is it make sure they are clearly visible (e.g providing suitable fixed mirrors at blind corners)? | Low adequate |
| To what extent is the road surface clean of slippery (due to mud, spilled oil, freezing, snow or because the structure of the road surface is itself slippery)? | Low Adequate |
| To what extent does the speed limit assure that the vehicles could be stopped in time (that depends on both the vehicle (weight…) and the situation (presence of pedestrians, the visibility…)? | Adequate |
| To what extent are physical speed restrictions such as speed bumps taken (if necessary)? | Adequate |
| To what extent are traffic or warning signs satisfactory? | Low Adequate |
| To what extent is the road surface properly stable to avoid that the vehicle could sink or tip over? | Very Adequate |
| To what extent are supportive structures provided where necessary to prevent collapse and to prevent vehicles from running out of the roadway? | Very Adequate |
| To what extent are roads, runways and maneuvering areas correctly illuminated (functioning and position of lights to ensure that all surfaces are evenly lit and all potential hazards, e.g. obstructions and spills can be clearly seen)? | Adequate |
| To what extent is delimitation and signalization made with retro reflective material? | Adequate |
| Vehicles | |
| To what extent are vehicles maintained (steering, handbrake and footbrake works properly and tyres tread are deep enough) to assure that it is possible to brake on time and steer properly? | Very Adequate |
| To what extent are the vehicles equipped with safety belts? | Very Adequate |
| To what extent the vehicles have suitable safety features (lights, acoustic signals, side-turn signal lights, etc) periodically checked (by a competent worker)? | Very Adequate |
| To what extent are vehicles inspected (by the drivers) at the beginning of each shift to assure that all parts, equipment, and accessories affecting safety operation are free of defects? | Adequate |
| To what extent are vehicles securely loaded (the load is properly distributed and does not obstruct or interfere with the ability to see) and without overload (an overloaded vehicle can be difficult to handle)? | Very Adequate |

## Annex II.13 – Results from case 2 injured by falling/swinging objects work accidents possibility assess

| Work accidents Possibility Factors | Analyst assessment (Semantic term) |
|---|---|
| **Injured by falling/swinging objects** | |
| **General** | |
| To what extent is it ensured that the work was properly planned, appropriately supervised, and carried out in a safe way as it is reasonably practicable (e.g with letting objects fall in an intentional and a controlled manner such as rubble or debris, into a chute/container)? | Very Adequate |
| To what extent was simultaneous activities at the same location properly plan to be carried out in a safe way and are appropriately supervised? | Very Adequate |
| To what extent are materials which are stored in tiers stacked, racked, blocked, interlocked, or otherwise, properly secured to prevent sliding, falling, or collapsing? | Adequate |
| To what extent is the storage of materials properly done (are materials stored more than 1,80 m from any hoist way or inside floor opening and more than 3 m from any exterior walls that do not extend above the top of the stored materials)? | Adequate |
| To what extent is the weight of the loads to move known (if it is not known, it is estimated by multiplying the load volume by the material specific weight)? | Almost Adequate |
| To what extent have proper guards been provided to protect employees from falling materials where conveyors pass over areas or aisles? | Inadequate |
| To what extent arethe cranes, lifts and other lift equipment's load bearing capacity correctly posted? | Adequate |
| To what extent are inspections made by a competent person as work progresses to detect hazards from weakened or deteriorated floors or walls or loosened materials? | Adequate |
| To what extent are accessible areas within the swing radius of the rotating superstructure of the crane properly barricaded or protected? | Low Adequate |
| To what extent are there (on site) objects poorly maintained, damaged or not properly secured so that parts can break off or release at high wind speeds and be blown away? | Adequate |
| To what extent are there (on site) objects placed in such a way that they easily could have been taken/were actually taken by the strong winds? | Adequate |
| To what extent are workers aware of the dangers of the use of incorrect tools or aids (e.g decide to lift something manually, whilst it would be better to do so mechanically)? | Adequate |
| To what extent have all scaffolds footers and the shoring devices exceed the ground level in at least 15 cm? | Adequate |
| To what extent are the danger zones of swinging/hanging loads or in the vicinity of rotating arms or counterweights clearly indicated by means of marking and/or signaling? | Low Adequate |
| Formwork and concreting | |
| To what extent are all formworks for cast-in-place concrete designed, fabricated, erected, supported, braced, and maintained so that it will support without failure all loads that may be anticipated? | Very Adequate |
| To what extent is inspection of the erected shoring equipment performed (it is inspected immediately, prior to, during and immediately after concrete placement properly satisfied)? | Adequate |
| To what extent is the inspection of the forms and shores performed properly, considering that the forms and shores are left in place until the employer determines that the concrete can support its weight and superimposed loads? | Adequate |
| To what extent are precast concrete wall units, structural framing, and tilt-up wall panels supported properly to prevent overturning and collapse until permanent connections are made? | Adequate |
| To what extent do designs and plans include prescribed methods of erection? | Adequate |
| To what extent are the jacking operations performed properly (for example, are jacking operations synchronized to insure even and uniform lifting)? | Adequate |
| To what extent are there only those workers required for jacking and to secure slabs permitted under slab during jacking? | Adequate |

| Work accidents Possibility Factors | Analyst assessment (Semantic term) |
|---|---|
| **Injured by falling/swinging objects (continuation)** | |
| **Mechanical lifting** | |
| To what extent are accessible areas within the swing radius of the rotating superstructure of the crane properly barricaded or protected (by measures - for instance, roofs - which prevent objects from falling in a safety zone)? | Low Adequate |
| To what extent are danger zones of hanging loads indicated by means of marking and/or signaling? | Inadequate |
| To what extent are workers prohibited to stay in the lifting danger zone while this is not necessary for attaching or loosening loads? | Low Adequate |
| To what extent is strictly prohibited to overload (it means that the load is heavier than the equipment's capacity indicated in the load chart) the hoisting equipment (crane, hoist, gantry crane, forklift truck etc.)? | Adequate |
| To what extent are hoisting equipment's maintained (hoisting cable, cable guides, winch, drive, operating panel, the levers, switches, instruments/sensors, limiters or indicators/gauges, hoisting arm, loading arm, stabilizers/props, etc) to assure its good condition (not damaged, worn and properly assembled)? | Very Adequate |
| To what extent are the "hoisting gear" (lifting straps, lashing straps, slings, hoisting chains, hoisting hooks, swivels, lifting beams, lifting clamps, hoisting eyes, lifting magnets, cargo slings, latches, etc) periodically checked (by a competent worker)? | Adequate |
| To what extent are hoisting equipment's inspected (by the operators) at the beginning of each shift to assure that all equipment parts and accessories affecting safety operation are free of defects? | Adequate |
| To what extent do any hooks, rings, oblong links, pear-shaped links, coupling links, and other attachments have a rated capacity at least that of the chain? | Adequate |
| To what extent is assured that the "hoisting gear" is correctly used (it means used in the way that it was made/intended for)? | Very Adequate |
| To what extent is assured that cranes and lifts are fixed on solid foundations? | Very Adequate |
| To what extent is assured that hoisting equipment was placed on ground that is stable and sufficiently able to support the weight (it means that the surface is strong enough to bear the weight of the equipment's and expected loads)? | Adequate |
| To what extent is assured that loads are correctly stowed and attached (correctly fastened to avoid load instability and/or fall) and correctly disconnected (only when it is in a stable position on the floor or on another surface)? | Adequate |
| To what extent is assured that bulk and/or small loads are fastened in appropriate devices (e.g. wire mesh containers or pallets)? | Almost Adequate |
| To what extent is assured that loads are moved at an appropriate speed (not quickly or too suddenly)? | Very Adequate |
| To what extent are raised loads kept as close to the ground as possible to prevent tipping and bumping against objects or buildings while travelling? | Almost Adequate |
| To what extent are there systems of communication (working properly) between lifting operators and banks men? | Almost Adequate |
| To what extent is it forbidden to hang loads with winds exceeding 40 km/h, heavy rain or fog (or other weather conditions that can hinder vision or difficult the load control)? | Very Adequate |

## Annex II.14 – Results from case 2 cave-ins work accidents possibility assess

| Work accidents Possibility Factors | Analyst assessment (Semantic term) |
|---|---|
| **Cave-ins** | |
| To what extent is it ensured that the work was properly planned, appropriately supervised, and carried out in a safe way as it is reasonably practicable? | Very Adequate |
| To what extent is the excavation area properly demarcated and signalized? | Adequate |
| To what extent do all excavation slopes respect at least the angle of response except for areas where solid rock allows line drilling or presplitting? | Adequate |
| To what extent are all electrical cords or cables taken out of service when worn or frayed? | Adequate |
| To what extent is there proper drainage in the bulk mass? | Very Adequate |
| To what extent are all surface encumbrances that may create a hazard removed or supported? | Very Adequate |
| To what extent is proper warning system such as barricades, hand or mechanical signals or stop logs used when mobile equipment approaches the edge of the excavation? | Low Adequate |
| To what extent are excavation materials kept at least 1 m from the edge of the excavations? | Strongly Adequate |
| To what extent are daily inspections made to the excavation to determine the possibility of cave-ins and are they necessary measures taken to protect workers? | Very Adequate |
| To what extent are excavations inspected after any hazard increasing occurrence (e. g. storms)? | Very Adequate |
| To what extent are shoring or sloping systems used to support the walls and faces of the excavations sufficient to ensure against cave-ins? | Strongly Adequate |
| To what extent are there ladders properly placed in the excavation? | Adequate |
| To what extent is vehicle speed properly reduced in roads near excavations (to reduce vibration)? | Low Adequate |
| To what extent is pedestrians' safety on the sidewalks assured by outlining the obstacles and/or forcing pedestrians to walk in the opposite side? | Almost Adequate |

## Annex II.15 – Results from case 2 hit by rolling/sliding/flying object (including awkward or sudden movement) work accidents possibility assess

| Work accidents Possibility Factors | Analyst assessment (Semantic term) |
|---|---|
| **Hit by rolling/sliding/flying object (including awkward or sudden movement)** | |
| To what extent was the work properly planned, appropriately supervised, and carried out in a safe way (e.g the demolition or assembly of prefabricated structures)? | Very Adequate |
| To what extent were simultaneous activities at the same location properly planned to be carried out in a safe way and appropriately supervised? | Adequate |
| To what extent are abrasive wheel grinders provided with safety guards which cover the spindle ends, nut and flange projections? | Strongly Adequate |
| To what extent are workers working in the vicinity of running machinery from which material or items could fly around, or in the vicinity of persons who use hand tools whereby material could fly around, properly protected (such as eye protection, facial protection or a helmet) for activities with a cutting action (sawing, drilling, smoothing, turning, honing, etc.) or for other activities whereby there is a risk that objects/parts can fly off (for instance, hammering, the treatment of objects on a lathe, with a drill or saw, whereby the object or the fastener can fly around during the treatment…)? | Very Adequate |
| To what extent are workers aware of the dangers of the use of wrong tools or machine operated incorrectly or tools used in the wrong way (e. g. using metal hammers, whereas a plastic hammer should have been used for that material; using grinding discs that are not suitable for the material to be treated or for the rotational speeds of the machine; using the wrong pliers for holding something firmly; or using a screwdriver as a chisel and vice versa; when a force that is too great is exerted with the tool or if the machine is used for treating something with the wrong setting - speed, angle, direction, force, aid, etc; wood drill instead of stone drill (for drilling into stone), a hand tool with the wrong size (spanners, pliers)? | Very Adequate |
| To what extent are workers aware of the dangers if some material is poorly maintained or damaged, hoses, chains, wires, ropes, cables under tension can suddenly break so that the loose ends could fly around? | Very Adequate |
| To what extent are workers aware of the dangers of wires, cables or ropes that could get caught on something or become entangled getting under pressure or under (mechanical) tension (if these items then suddenly came loose, they could fly around)? | Very Adequate |
| To what extent are workers aware of the dangers of the use of tools or machines in the wrong way (for instance, using a forklift truck to move vehicles; not using tensioners properly, the wrong timing when releasing something under tension or pressure)? | Very Adequate |
| To what extent are objects that could be under pressure or under (mechanical) tension, properly secured (for instance, objects such as flexible hoses, cables, tackles, tail-lifts, binding wire, lashing straps, tensioners, steel wire or springs)? | Very Adequate |
| To what extent are workers aware of the dangers of the use of incorrect tools or aids or hold hand tools incorrectly (e.g use of the wrong tools, not holding tools in a safe direction; not safely placing tool leads and tubes so that the tool could suddenly shoot out in another direction; not properly holding tools that are being carried, etc)? | Adequate |
| To what extent is ensured that workers receive adequate information on the weight of a load, the center of gravity or the heaviest side when a package is unevenly loaded? | Almost Adequate |
| To what extent are material and equipment that might fall or roll into an excavation kept at least 2 meters from the edge? | Adequate |
| To what extent are parked vehicles properly locked? | Very Adequate |
| To what extent are objects and structures near roads protected against collisions or crashes? | Low Adequate |
| To what extent are work areas well lit, dry and clean (especially where loads are moving manually)? | Adequate |
| To what extent are work areas well lit, dry and clean (especially where loads are moving manually)? | Adequate |

| **Work accidents Possibility Factors** | **Analyst assessment (Semantic term)** |
|---|---|
| **Hit by rolling/sliding/flying object (including awkward or sudden movement) (continuation)** | |
| To what extent are objects/materials correctly stacked (including stacks of dissimilar objects) to avoid collapse, topple over and objects falling (e. g stack should not be higher than 3x the width, heavy objects could be stacked on the lower parts of the stack, objects should not exceed the edge of the shelves)? | Adequate |
| To what extent are the (on site) objects/materials that could be dragged by the wind properly tied? | Very Adequate |
| To what extent are the surfaces adequate to support the load (e.g. strong enough to bear the weight of the objects, without vibrations caused by passing lorries)? | Adequate |
| To what extent are observers kept at a safe distance from work equipment's? | Low Adequate |
| To what extent are vehicles safely loaded (ensuring that the cargo is stowed and not beyond the loading box (it is not sticking out) and is not distributed unevenly and it is not too high)? | Adequate |
| To what extent are loads in vehicles safely fastened (e.g. tensioning the ratchet strap and the correct lashing angle) by correct devices (for instance not using a drum clamp or using rope with little elasticity instead of a lashing strap)? | Adequate |
| To what extent are machines and tools kept in good conditions (to avoid that with normal use parts, such as saw blades, chisels or bits, could have broken or flown around)? | Adequate |
| To what extent are the machines and tools inspected (by the users) at the beginning of each shift to assure that they are free of defects? | Adequate |
| To what extent are the fastening devices kept in good conditions? | Adequate |
| To what extent are the fastening devices inspected (by the users) at the beginning of each shift to assure that they are free of defects? | Adequate |
| To what extent are stowing material, connections or couplings that could slip off with normal use inspected (by the users) at the beginning of each shift to assure that they are free of defects (for instance, defective tensioners, cables, lifting straps, hoisting eyes, bolts/screws/nails or tackles)? | Adequate |
| To what extent are loads/objects suitable to be moved manually (e.g. objects that are not too large to be carried, objects with a surface that is not slippery and/or sharp or objects that nor exceed 27 kg)? | Adequate |
| To what extent are there handles (adequate and sufficient) for helping the manual handling tasks? | Adequate |
| To what extent are there (on site) objects poorly maintained, damaged or not properly secured so that parts can break off or release at high wind speeds and be blown away? | Adequate |
| To what extent are there (on site) objects placed in such a way that they easily could have been taken/were actually taken by the strong winds? | Adequate |
| To what extent is strictly forbidden to throw tools or other objects? | Adequate |

**Annex II.16 – Results from case 2 contact with machinery/equipment moving parts (including trapped between objects) work accidents possibility assess**

| **Work accidents Possibility Factors** | **Analyst assessment (Semantic term)** |
|---|---|
| **Contact with machinery/equipment moving parts (including trapped between objects)** | |
| **General** | |
| To what extent equipment's and machinery comply with the applicable use specifications and safety regulations (i. e. bears a CE marking)? | Strongly Adequate |
| To what extent were equipment's and machinery not modified after purchase? | Very Adequate |
| To what extent have equipment's and machinery emergency stop devices within reach and properly functioning? | Strongly Adequate |
| To what extent are machinery guards kept in place and in working order? | Very Adequate |
| To what extent are hand tools and other equipment regularly inspected for safe condition (including visual inspection each day for defects or obstructions prior to use)? | Adequate |
| To what extent are impact tools free of mushroomed heads? | Very Adequate |
| To what extent are welding and cutting operations shielded by no combustible or flameproof screen whenever practicable? | Adequate |
| To what extent are all employees who are performing any type of welding, cutting, or heating protected by suitable eye protective equipment? | Very Adequate |
| To what extent are power tools, belts, gears, shaft, pulleys, sprockets, spindles, drums, fly wheels, and chains properly guarded? | Very Adequate |
| To what extent are tools used with the correct shield, guard, or attachments recommended by the manufacturer? | Low Adequate |
| To what extent is power actuated tools left unloaded until they are ready for immediate use? | Low Adequate |
| To what extent are tools stored in a dry, secure location where they won't be tampered with? | Low Adequate |
| To what extent is power actuated tools left unloaded until they are ready for immediate use? | Low Adequate |
| To what extent are tools stored in a dry, secure location where they won't be tampered with? | Low Adequate |
| To what extent are gears on the hoisting machine well guarded? | Adequate |
| To what extent are machines moving parts still moving (e. g. continuing to turn) after the machine had been switched off? | Very Adequate |
| To what extent are workers aware of the dangers of bypass the physical safeguard (physical safeguard' refers to equipment that prevents people from touching the moving parts such as screens, hoods, optical screens, etc.)? | Adequate |
| To what extent are workers aware of the dangers of intentionally come within reach of a machine's moving parts (for instance, in order to straighten something out, remove something, clean something, etc.)? | Very Adequate |
| To what extent are workers aware of the dangers of wearing something or holding something so that the machine could 'grab' (e. g. loose-fitting clothing, long hair or wearing gloves near rotating parts)? | Very Adequate |
| To what extent are (machine/equipment moving parts) danger zones clearly indicated by means of signs? | Very Adequate |
| To what extent was the electrical energy, pressure and (mechanical) tension of the machines or the equipments (including hand tools) turned off when work was being performed on it (for instance, during maintenance work or failure repairs)? | Very Adequate |
| To what extent are technical measures taken against unintentional start-up of the machine (such as: removing fuses, locking/blocking handles and switches, etc) whilst cleaning, maintaining or repairing? | Almost Adequate |

| Work accidents Possibility Factors | Analyst assessment (Semantic term) |
|---|---|
| **Contact with machinery/equipment moving parts (including trapped between objects) (continuation)** | |
| **Hand Tools** | |
| To what extent are hand tools properly protected (safeguards, locks against unintentional start-up, locks against continued turning after switching off and other accessories for the safe use of the tool)? | Strongly Adequate |
| To what extent are hand tools equipped with the appropriate and properly mounted handles (with a shape able to provide sufficient grip) and kept in good condition (not soiled, worn or damaged)? | Very Adequate |
| To what extent are tool handles free of splits and cracks? | Very Adequate |
| To what extent could or did the hand tool and/or the cords/tube of the hand tool get caught somewhere? | Almost Adequate |
| To what extent are hand tools correctly adjusted (e. g. correct rotational speed)? | Adequate |
| To what extent are the heads of chisels or punches grounded periodically to prevent mushrooming? | Adequate |
| To what extent are frames of all arc welding and cutting machines grounded properly? | Very Adequate |
| To what extent are electric, pneumatic or hydraulic hand tools not immediately stopped moving when the operating button is released? | Very Adequate |
| To what extent are workers aware of the dangers of working materials (of the object/workpiece) insufficiently suited for working with the hand tool (material too hard, material with defects - e.g. knots in wood, presence of objects in the material that do not belong to it - nails in a piece of wood)? | Very Adequate |
| To what extent are workers aware of the dangers of using the hand tool in an unsafe position (e. g. at a wrong angle so that the tool kicks back - when sawing, honing or milling)? | Very Adequate |
| To what extent are workers aware of the dangers of the use of electric, pneumatic and/or hydraulic hand tools (including high-pressure sprayers), hand tools under mechanical or other tension not properly protected against unintentional start-up or activation of the tool (e. g. situations in which locks are not used, switches are not blocked, the tool's power has notbeen shut off)? | Very Adequate |
| To what extent are workers aware of the dangers of the use of hand tool not in a good condition (e. g. hand tools whose safety features - such as self-braking grinding discs, safeguards, etc - are missing or not functioning properly or if the grips/handles are slippery)? | Very Adequate |
| To what extent are workers aware of the dangers of working with hand tools whilst doing something else at the same time (e. g. carrying or putting away another object/tool, using another hand tool, using a telephone, drinking coffee, etc.)? | Very Adequate |
| **Trapped between objects** | |
| To what extent are locations where objects, machines or obstacles were placed too closely to each other so that workers could be trapped if the objects or machines started moving clearly indicated by means of marking and/or signaling? | Almost Adequate |
| To what extent are there (on site) poorly designed handles/grips (of machines, doors, lids, etc.) so that when in use a hand/fingers could become trapped? | Low Adequate |
| To what extent are hinged objects (such as doors, manhole covers or engine covers) that were not properly secured (e. g. by mechanisms for preventing the object from closing/opening suddenly or too quickly)? | Strongly Adequate |
| To what extent are there (on site) work with machines or vehicles with which loads are moved and was operators view of the road obstructed (by, for instance, the load on the vehicle) or insufficient due to poor weather, insufficient lighting, obstacles or because the vehicle has many blind spots? | Very Adequate |
| To what extent are loads properly fastened so to avoid that it started inadvertently to move? | Adequate |
| To what extent are workers aware of the dangers of body parts (such as heads, arms or legs) of passengers or of the driver were partially or fully protruding from the vehicle? | Very Adequate |
| To what extent are workers aware of the dangers of being transported in a vehicle that is not intended for persons (e. g. in a cargo space)? | Adequate |