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Survey of the Risk Management Methods, Techniques and Software Used Most Frequently in Occupational Health and Safety

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ABSTRACT

Throughout modernity, increasing emphasis on knowledge, digitization and information technology has fueled the emergence of new methods of organizational management. In several fields, digital technologies have proven indispensable for facilitating and improving operations as well as business development. Companies that recognize this are now acquiring software even for risk management, notably for work-related injuries and illnesses, a persistent and particularly complicated problem because of its multidisciplinary nature and entanglement with human behavior. Despite their undeniable contribution to the progress made so far, conventional methods are not entirely adequate for managing the unpredictability characterizing occupational health and safety (OHS) risks. The aim of this study is to provide an overview of the current use of software in OHS risk management, based on a survey of the advantages and limitations of the most widely used tools. Our findings reveal that such tools are intended primarily for use in construction and chemical processing, the industries in which OHS is taken most seriously. They are found nevertheless to hold promise as solutions to OHS risk management problems encountered in a wide variety of small and medium-sized businesses.

1. INTRODUCTION

Due to the complexities and unpredictable side effects of new industrial technologies, processes and work methods implemented worldwide over the past three decades, occupational health and safety (OHS) has become an unavoidable issue in modern business management [1]. The threshold of acceptability of OHS risks has decreased in many economic sectors as general awareness of consequences has increased and legislation has been strengthened. In order to comply with new regulations, employers must implement concrete measures that promote OHS within their organizations [2]. Taking OHS risks into account is now considered profitable for the economic development of businesses, industries and nations, even though much work still needs to be completed in order to correct the persistent misconceptions surrounding this notion [3].

The need for more effective risk management has incited the OHS community to develop and adapt suitable tools and techniques [3-5]. Such tools provide support particularly for risk identification, evaluation and prioritization in order to enlighten decisions relating to prevention. At the same time, organizations are now acquiring OHS management systems that provide a more rational framework for implementing preventive measures. Even though several such tools allow systematic identification of situations at risk, offer means of bringing these under control and have been adopted in numerous organizations, work-related injuries and illnesses remain commonplace [6]. Because of the diversity of the settings in which they are used, risk management methods and techniques are numerous. Their development reflects particular situations, the risks associated with these, and the type of information available in the organizations concerned [7]. Some may be considered simplistic and therefore perhaps less effective, while other more complex techniques might be more effective. Experts have long been attempting to develop decision-aid tools or to adapt existing ones to fit the specifics of OHS risk management [2-4].

Several software-based methods have been developed to facilitate and accelerate the risk management task by reducing processing time and providing access to different sources of information. Such software is also highly diversified, addressing specific contexts and sometimes even limited initially to specific risks (economic, financial, project, etc.). In most cases, these products have not been designed for simultaneous evaluation of all potential risks, especially not of OHS risk, due to the complexity of the latter.

The present article provides a survey of methods, techniques and software that could be used to manage and overcome the constraints inherent in OHS risks. In addition to discussing their content and functioning, we examine the advantages and limitations associated with their use in the field, insofar as we have been able to ascertain from an extensive review of the literature on OHS risk management.

This article is organized as follows: The research problem is described in section 2. The details of the research methodology are provided in section 3. The results of the literature review are discussed in section 4. The results and limitations of the research are discussed in section 5, followed by a conclusion.

2. RESEARCH PROBLEM

The research is focused on the four elements shown in Figure 1. We begin with the problem of occupational injuries and illnesses. Next, we put OHS risk management into perspective. We then discuss the various problems associated with OHS risk management tools. We conclude with an examination of OHS risk management software.

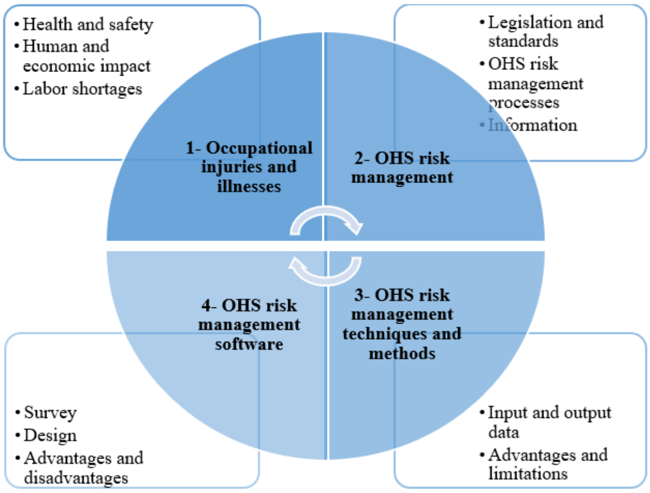

Figure 1. The principal elements of the research problem

2.1 Occupational injuries and illnesses

The statistics show that the incidence of occupational injuries and illnesses has decreased over the past two decades. However, the problem of workplace safety persists [6]. It is recognized that the impact of work-related infirmity is major, not only for the victims but also for businesses and communities [8]. In 2011, the cost of work-related infirmity to Québec society was estimated at about $4.84 billion [9]. According to the International Labor Organization, the total cost of occupational injuries and illnesses worldwide is equal to about 4% of the world total gross domestic product [10].

In Québec, as in all industrialized countries, employers are facing the problem of labor shortages. Several factors are contributing to this problem, including aging population and declining birthrates [11, 12]. The Québec society of certified human resources counsellors (CRHA) deplores persistent negligence with regard to OHS and wellbeing in the workplace [11]. The importance of prevention and OHS risk analysis remains underappreciated. Stricter OHS legislation and improved preventive measures have led to reductions of certain so-called traditional risks. However, changes in work organization as well as new technologies and work methods have contributed to the emergence of new risks. Meanwhile, modern societies are quickly becoming less and less tolerant of OHS risks [13]. These conditions are making necessary the adoption of new forms of prevention and innovative OHS risk management solutions.

2.2 Management of OHS risks

OHS risk management is the cornerstone of effective prevention of occupational injuries and illnesses. In Québec, OHS risk management is a legal obligation of the employer, the goal of the legislation being to eliminate risks at the source [14]. "Risk management is a preventive activity that draws upon a wide range of means in order to reduce or eliminate the risk of a damaging situation occurring and to limit the damage when the situation does occur" [15]. In order to achieve this, a multitude of risk management systemic process models have been proposed for the proactive identification of hazards and the application of corrective measures based on the capabilities of the organization [16]. According to Pinto et al. [17, 18], risk appreciation consists of systematic utilization of the information available, in order to identify and evaluate risks and thus make the best decisions. However, the information is generally vague, uncertain and coming from a variety of disciplines of technical, sociological or managerial nature [19, 20]. Furthermore, "OHS risk management is a process conducted by humans collaborating with humans in order to analyze complex situations created by interactions of humans with their environment" [19]. These aspects make OHS risk management very complicated and necessitate robust methods in order to avoid making poor decisions.

2.3 OHS risk management methods and techniques

OHS legislation prescribes the use of methods and techniques designed to identify, control and eliminate OHS risks (LSST, art. 51.5) [18]. The CNESST [21] recommends that businesses use, in their practice of OHS risk management, tools proven to be effective as decision aids. Pinto et al. [17] suggest that to be considered reliable, a risk appreciation tool must provide for systematic utilization of all available information that may be deemed relevant to identifying and evaluating hazards. Some OHS risk management tools do allow users to carry out exhaustive identification of hazards and realistic analysis of risks and thus to minimize incoherence [19, 22, 23]. Their usefulness in a wide variety of settings has been demonstrated in several published studies [5, 24, 25]. However, they have several limitations in terms of the range of applicability, difficulty of implementation and the quality (reliability) of the results [22, 25-27].

2.4 OHS risk management software

Applications of information technologies have now infiltrated practically all aspects of our lives. Organizations have not escaped from this reality, and many software apps are being designed to facilitate data and knowledge management [28]. Risk management is a major component of the process of ensuring the performance of an organization or increasing its profitability, and many experts are devoted to the development of software designed specifically for OHS and prevention. In spite of this, research shows that most of the commercially available risk management software is poorly adapted to use for OHS purposes [29, 30]. There is no doubt that practitioners in the field of prevention would benefit enormously from new software better adapted to managing OHS.

3. METHODOLOGY

The focus of this study is conventional methods and techniques of risk management as well as the software most widely used for the purposes of OHS. A systematic review of the OHS risk management literature was chosen as the research methodology (Figure 2).

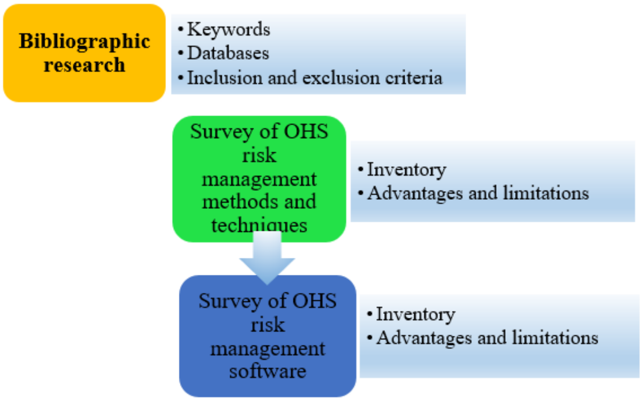

Figure 2. The steps of the research methodology

3.1 Bibliographic research

We began by identifying the keywords to be used in order to retrieve suitable documents in the databases Scopus and Google scholars, which cover the journals in which most articles relating to OHS are published. The principal keywords were drawn from the following expressions (in English and French): OHS risk management; OHS risk evaluation; advantages and disadvantages (limitations, drawbacks) of OHS management tools; OHS risk management software and OHS risk management evaluation.

A preliminary list of documents of all types on the subject of risk management methods and techniques was obtained (journal articles, theses, standards, websites) without selective criteria. Priority was given to documents dealing with OHS risk appreciation. In the case of references to software, only review articles, conference papers and reports produced by organizations responsible for prevention, such as the IRSST (Québec), INRS (France) and EU-OSHA (Europe), were retained. Software developed by third parties was not considered, because of its commercial nature and the unreliability of literature written for promotional purposes.

Using the keywords in the software context resulted in the retrieval of some documents having no connection to our research problem or even to our field of study, for example, project risk management software [31], information security software [32], computerized integrated management systems and automated obstacle avoidance support systems for construction sites [33]. Only computer-based tools relating to the various steps of the OHS risk management process were retained. In addition, articles containing the keywords but no in-depth discussion of the associated concepts of interest were also excluded. Finally, software developed before the year 2000 was disregarded in order not to include outdated technologies.

3.2 Survey of OHS risk management methods and techniques

The published research on methods and techniques of OHS risk management was reviewed in order to obtain a portrait of current practices. These were then compiled in order to identify their respective advantages and limitations with regard to range of application, ease of use and effectiveness (certainty and objectivity). This provided a frame of reference for evaluating the software discussed in the literature.

3.3 Survey of OHS risk management software

Software was identified using the following procedure: The first step was the compilation of documents dealing in some way with OHS risk management software. These were grouped into three categories, namely 1) software used in chemical processing, 2) software used in construction, and 3) software used in other settings. The second step consisted of noting the following information: name, OHS risk management process step to be aided, corresponding method or technique, problem to be solved, problem-solving technique used, advantages and finally the limitations. The advantages and limitations were either identified directly in the document or surmised from the tool design criteria and requirements. The third step was devoted to grouping the advantages and limitations of all of the software according to range of application, ease of use and effectiveness (certainty and objectivity).

4. RESULTS

4.1 OHS risks and risk management

Risk is a concept associated with many fields and is inherent in human activity. Hubbard [34] defined risk as the combination of the probability of the occurrence of an event and the magnitude of its potential for causing loss or catastrophic failure. For an organization, risk is the combination of the probability and the seriousness of the impact of an event that may occur in its operations. An undesirable OHS event is the occurrence of a work-related infirmity that may affect the health or physical integrity of a worker. This definition is the same as the one adopted in OHSAS standard 18001 (replaced by ISO 45001), which defines it as "*a combination of the probability of occurrence of one to several harmful events or exposures to such events and the seriousness of the personal injury or loss of health that this (these) event(s) or exposures may cause*" [35]. According to this same standard, a hazard is defined as "*a source, situation, or act or any combination of these elements, having the potential to cause harm to a person or to the person's health.*" Regardless of the sector in which an organization operates, OHS risks arise from interaction between humans and the work environment (machinery, chemicals, etc.). Interdependent risks may also arise, such as electrical, physical, chemical, ergonomic, biological, psychosocial, etc.

OHS risk management is a process by which policies and procedures are applied systematically to routine activities in order to guarantee a safe work environment [34, 36]. The present study reveals that the literature relating to risk management is replete with models and processes intended for standardization purposes [16, 36, 37]. Various organizations and experts have provided guidelines for designing more flexible and effective risk management processes. However, there is practically unanimous agreement that the risk management process is iterative. Standard ISO 31000 [36] recommends a process based on five steps. The step of establishing the organizational setting consists of gathering the necessary information, such as the definition of the objectives and scope of the risk management process and understanding of the structure and various activities of the organization. The risk identification step consists of recognizing possible hazardous situations that could pose a threat to worker health and safety. The probabilities of occurrence of undesirable events and their potential impact are estimated in the risk analysis step. In the evaluation step, the organization ranks the risks by level of unacceptability. The final step is treatment, in which corrective actions are implemented in order to eliminate the risks or reduce their impact to acceptable levels. The organization must ensure the effectiveness of its corrective measures on a continual basis. Effective communication and coordination must be ensured throughout the process in order to make the risk management initiative successful. Risk is often evaluated by estimating its two principal variables [38]:

- The seriousness of the damage: characterized by injuries and the extent to which human health is affected.
- The probability of occurrence of the damage: what could happen and how likely, based on observation.

According to Moulet [38], evaluation of the probability of occurrence of damage is based on estimation of secondary variables:

- Exposure, which describes the dangerousness of the situation;
- The possibility of avoiding the damage;
- The possibility of avoiding the dangerous event, by preventive measures.

The goal of management is to eliminate or at least reduce the risk to an acceptable level. Evaluation of risk acceptability is based on criteria pre-defined by the organization. These must be compliant with regulations, law and the applicable standards. However, criteria set forth in legislation represent only minimal requirements, and organizations must go further. In-house criteria must be defined at the outset of the risk management process and must be reviewed continually. For the purposes of definition, numerous factors need to be taken into consideration, including prevention policy, technical feasibility and the resources available [39].

Appreciation is the foundation of the risk management process [24]. Underlying the choice of preventive actions, this step is generally followed by a systematic analysis of the feasibility of decisions. Cost-benefit, cost-effectiveness and multi-criteria analyses are suitable methods for this purpose [40]. Researchers and experts have focused their efforts on the development and improvement of risk appreciation tools [17, 22, 40, 41]. In the case of OHS risk, the goal of appreciation is to provide support for decisions relating to the prevention of injuries and illnesses in the workplace [42]. Several researchers emphasize the necessity of using systematic and systemic methods and tools in order for hazard identification and evaluation to reflect reality and support decisions that are based on all available information and hence unbiased [17, 24, 43]. However, risk appreciation is very complicated and fraught with uncertainties and will likely remain a formidable challenge for some time [44].

4.2 Survey of OHS risk management methods and techniques

The use of recognized, adapted and proven techniques of risk appreciation is crucial in OHS risk management [45]. Since the same principles of management have been applied to a variety of risks (financial, operational, professional, etc.), methods and tools such as job safety analysis (JSA), HAZard and OPerability study (HAZOP) and fault tree analysis (FTA) are being used for OHS, even though they are only somewhat applicable. Other tools have been adapted from engineering and especially from quality engineering, for example *analyse des modes de défaillance, de leurs effets et de leur criticité* (AMDEC) [5].

Data and information on OHS risks are often imprecise, incomplete and inherently uncertain [16, 20, 25]. In order to make them usable, expert judgments are often brought to bear [46]. Examination of the literature has revealed a multitude of basic methods and techniques that have been used to appreciate OHS risks. Tixier et al. [23] have compiled a list of 62 tools that can be used in support of at least one of the three steps of the risk appreciation process. They found a tool to be suitable to use as long as it provided means of data input (e.g. descriptions of hazards), a calculation model and presentation of results.

In general, risk appreciation tools have undeniable advantages. They can be used to identify the various elements of the accident process (dangerous situations, risk factors, undesirable events and potential consequences) in a structured manner and from a systemic perspective. For exhaustive identification of all such elements, tools with some complementarity are generally used, such as *analyse préliminaire des risques*-AMDEC (APR-AMDEC), APR-HAZOP, HAZOP-layer of protection analysis (HAZOP-LOPA) and *méthode organisée systémique d'analyse des risques*-AMDEC (MOSAR-AMDEC) [47]. These facilitate communication by sharing relevant OHS-related information [48]. Finally, risk appreciation methods in the literature are generally grouped into three main categories, namely qualitative, quantitative and hybrid (qualitative-quantitative).

4.2.1 Quantitative tools

The purpose of a quantitative tool is to assign a numerical value to a level of risk [22] generally using probabilistic and/or statistical techniques [16, 25]. Several tools of this sort have been proposed in the literature, such as event tree analysis (ETA), Monte Carlo simulations [20, 49], the proportional risk assessment technique (PRAT), decision matrix risk assessment (DMRA) and quantitative assessment of domino scenarios (QADS) [22]. Quantitative tools are used frequently in numerous industrial fields, especially in those that demand more specification of the results [25]. They are based on mathematical models that are generally amenable to support by software.

4.2.2 Qualitative tools

The purpose of qualitative tools is to obtain an estimate of the level of risk based on expert judgments [22]. They are generally modelled in the form of matrices and are the single most popular type of tool because of their simplicity. Closer analysis nevertheless shows that they represent only 28% of all of the tools used in risk management [22]. Qualitative tools are not suitable for use in high-risk industrial installations, but they do give good results in non-industrial environments [22]. The literature contains frequent references to several types such as checklists, APR, AMDEC and failure tree or event tree analysis [48]. Risk acceptance criteria are generally set at numerical values, even though the results of a qualitative analysis themselves are not numerical. This represents a major challenge for experts who are invited to compare adjectives (serious, very serious, etc.) to figures expressing limits of exposure to chemical irritants and pollutants.

Table 1. Advantages and limitations of OHS risk management tools

Aspect		Qualitative tools	Quantitative tools
Scope	Advantages	- Applicable in a variety of situations and industrial fields. - Easily customized for analysis of new situations.	- May provide the level of total risk of a business and aid the setting of prevention goals. - Allow evaluation of the probability of failure of various safety devices. - Provides a relevant evaluation of high-impact and low-probability risks. - Products of specific needs.
	Limitations	- Quality of the analysis depends on the reliability of the data. - Not suitable for settings in which rare events may cause huge damage.	- Quality of the analysis depends on the reliability of the data. - Probability theory neglects the flow of knowledge (temporal aspect of data flow).
Ease of use	Advantages	- Quickness and simplicity of use. - New users are easily trained. - Easy and simple presentation of the results.	- Facilitate sharing and concerted effort among a variety of analysts. - Facilitate the choice of risk acceptability level. - Allow easy ranking of risks.
	Limitations	- Incoherent use of risk matrices. - Practitioner bias of decisions. - Quality of results depends on analyst experience and expertise.	- Time-consuming; require many human resources. - Difficulty of modeling and quantifying effectively risks involving multiple uncertain and interdependent factors.
Effectiveness (certainty and objectivity)	Advantages	- Adaptation to specific needs is possible.	- Results may be more reproducible if methodologies and databases are standardized. - The level of detail facilitates understanding of the process and leads to better decisions. - Options for risk reduction may be compared.
	Limitations	- Quality of the analysis depends on the data and information available. - Results are difficult for outsiders to understand. - Risk evaluations are subjective. - Difficulty of standardizing event frequency and seriousness. - Process quality influenced by the person conducting the analysis.	- Quality of the analysis depends on the data and information available. - Results obtained in probabilistic terms are difficult to express in plain language. - Only qualified analysts can make appropriate judgments regarding the effects of specific uncertainties on decision-making.

4.2.3 Hybrid tools

Hybrid tools or techniques (e.g. human error analysis (HEA), human failure event analysis (HFEA), FTA, ETA, HAZOP-LOPA, etc.) combine features of the preceding two families of risk management resources and can be very complex, since they have been developed specially in response to a particular need or problem, which prevents their broader use [22]. At the time of a study by Marhavilas et al. [22], these tools were mentioned somewhat less often in the literature. They represented only 7% of the total number found in our search. Their intention is to improve the risk management process by offering the advantages of quantitative and qualitative tools.

4.2.4 Advantages and limitations

Researchers have focused their efforts on the development of new risk management tools and approaches better adapted to the work setting under study. Even so, the resulting offerings continue to have limitations, as discussed in several articles [16, 22, 25, 27]. Evaluation of these tools is generally focused on three aspects, namely, 1) the extensiveness of the supporting studies and the number of situations that can be treated effectively, 2) the quality of the results while decreasing subjectivity and uncertainty, and 3) the cost, the time and the skills required for their use.

Table 1 lists the advantages and limitations of the quantitative and qualitative tools [22, 27, 48] that will be used below as the basis for evaluating OHS risk management software (section 4.3). The advantages and limitations identified are described further in literature other than the references cited up to this point. In the OHS field, qualitative risk management tools have received the most attention and detailed analysis in the literature. This justifies the large number of advantages and drawbacks that have been compiled in this category.

It is important also to recognize limitations associated with the lag behind technological progress, as noted by Pinto et al. [17], regarding:

- Support of system complexity
- Continuous changes in legislation
- Emerging forms of human error
- Injuries/illnesses associated with poor control of information rather than energy.

4.3 Survey of OHS risk management software

The current complexity and evolution of the internal and external environments of businesses is making the management of OHS-related information more complicated. Progress in information technology has improved control of managerial processes, thus allowing operation at an increased pace as well as overall improvements in performance [28]. However, other disadvantages are starting to emerge, especially problems relating to data security and losses having huge potential for causing harm to organizations.

The computerization of business managerial processes worldwide has ushered in, among other things, the development of risk management software. In their critique of the integrated risk management tools in the construction industry, Dikmen et al. [30] asserted that risk management is essential for attaining goals, but considered the tools used at that time to be non-systemic, that is, inadequate for managing a diversity of risk typologies. They proposed the use of an information model based on five modules, combined with risk identification, analysis and formal continual management processes. This meant primarily computerization based on specific modeling of information.

In order to eliminate risk management activities that do not fit into any systemic approach, integrated management models that cover the entire life cycle of a project were proposed more than a decade ago [50]. Implementing a software-based information system with support for all decisions in order to integrate all relevant aspects of a project (including risk management) had been considered even earlier [51]. However, most of the software did not support OHS risks or required huge investments as well as specialists to adapt it to OHS. Such decision-aid tools have been of great assistance to OHS analysts, especially for calculations. However, in no case was the cost ever justified, in view of the poor quality of the results obtained, due to the complexity of OHS risks [48, 52].

Research on the uses of various applications of information technology with the aim of developing new OHS risk management tools in construction (considered to be one of the most dangerous industrial sectors) is focused on applications of online databases, virtual reality, 4D computer-aided design, geographic information systems, building information modeling, anomaly detection/warning and others [53]. This has led to the design of much software intended to facilitate the automated use of risk management methods and techniques. One feature of these apps is easier access to databases and a variety of sources of essential information [29]. Nunes and Simões-Marques [54] have suggested that the focus of such software needs to be quite specific and that there are two possible reasons for the absence of this characteristic. One is that conventional Boolean-based software programming is poorly adaptable to the inherent complexity and imprecision of the data and knowledge used in OHS risk appreciation processes. The other is that there are no universal rules for OHS risk appreciation. These challenges require innovative solutions that are methodical, flexible and better adapted to OHS standards and regulations solutions.

The principal advantages to be gained from using risk management software are ease of access to information, the possibility of collaboration and greater responsiveness of the decision-making process [55]. This is the case especially for prevention initiatives in small or medium-sized businesses, thanks to the Internet. Multi-criteria searches allow filtering of data that otherwise would be overwhelming. Another aspect cited is the dynamic nature of the software, which allows easy adaptation of risk management to changing environments within organizations [55].

In the course of the present study, several software products applicable to OHS risk management were identified. Originating in a broad range of industrial sectors including design, these tools call upon a variety of computer modeling techniques and technologies. At the outset, three concepts need to be defined in order to clarify how the different tools function and what types of information are being discussed in this article. These concepts are data, information and knowledge. In the context of knowledge management, the term 'data' refers to facts and figures that relate to some specific measurement or description (e.g. age) but are not structured and provide no additional information to the manager [56]. By themselves, data have no meaning, but once interpreted and associated with a specific context, they become 'information' and acquire a meaning understood by the manager. The same data in two different settings will give two different pieces of information. In contrast, knowledge is information that corresponds to skills and understanding that have been acquired as a result of learning or experience. Knowledge exists explicitly as documents, policies and procedures and implicitly as individual know-how [57].

4.3.1 Software used in the chemical processing industries

Chemical processing is an industry fraught with dangers. As Bhopal illustrated so tragically, an accident in a chemical plant can affect not only the personnel directly exposed but also the surrounding community and environment. The two principal causes of accidents in such settings are poor appreciation of OHS risks and the lack of adequate risk management tools capable of generating sufficient information [58]. One of the most effective and most widely used tools in the chemical processing industry is HAZOP. However, its implementation is tedious and requires patience. For a typical chemical process, a team of 5 to 8 experts needs up to 8 weeks to complete an OHS risk analysis [58, 59]. The chemical processing industry spends annually about $5 billion USD on various activities relating to OHS risk management [59]. Specialists are searching constantly for ways of decreasing the time and cost and thereby improving the effectiveness of the risk management process.

a) Process hazard analysis suite (PHASuite)

The terminology used by OHS risk management practitioners varies widely from one country or region to the next and even among organizations and colleagues. Jargon systems abound in this field, a problem alleviated by software thanks to the ease with which information is exchanged. Efforts to adopt a data model that encompass all terms referring to OHS risk management concepts (and thereby facilitate communication between stakeholders) date back more than 10 years. PHASuite is a software package for automating the management of knowledge and risk analysis [60]. Based on an open architecture in which knowledge is represented explicitly and information is shared with peripheral systems, this tool is provided with a dictionary of defined terms in order to simplify the choice of a common terminology convenient for all. Expert experience is allowed to play a preponderant role in the analysis by refining and modifying the process in order to facilitate the identification of cause/effect relationships. Past experience also facilitates identification of risks associated with new situations. A reasoning technique based on cases entered into the system imitates human thought in order to benefit maximally from experience. This technique relies on retrieval of similar cases and reuse of the associated information to solve the new problem and evaluate the suitability of the proposed solution as well as on the input of new cases for analyses of future OHS risks.

A very important step in the design of OHS risk management software is acquisition of the relevant technical knowledge. To begin with, the PHAsuite knowledge base was constructed from existing knowledge in the chemical processing field. This base was then updated as experience was acquired from analysis of more than a dozen industrial processes. The base is thus enriched each time a new analysis is conducted. A graphic interface called Knowledge Builder allows modification and improvement of the base as well as avoidance of errors [60]. The results of the analysis are produced in the final step, in which information (introduced manually or automatically) must be represented such that the system can use them to carry out the HAZOP analysis. Petri networks represent chemical processes. A two-layer system of reasoning (Petri network and safety model) built on the knowledge base is used to complete the process [60]. The results generated by the system generally include the following information: (1) the location of the deviation; (2) the equipment involved; (3) deviation name; (4) deviation type; (5) consequences; (6) causes; (7) where the causes occurred and where the consequences will occur; (8) protective measures to be implemented, and (9) recommendations. Most of the information is presented as text. The results are recorded in a database, thus allowing PHAsuite to produce documents automatically and to report the results of analyses.

Zhao et al. [60] summarize the characteristics and advantages of the system as follows: (1) appropriate representation of the HAZOP analysis procedure for chemical processes; (2) support of abstraction and analysis at several levels of the process; (3) integration of general knowledge of the system as well as experience; (4) learning capacity and (5) ease of implementation of concrete solutions. From the application perspective, this system can: (1) improve the quality of the HAZOP analysis; (2) gain time and save HAZOP analysis effort and (3) integrate data from other software.

b) LEADER (HAZOP-LOPA)

HAZOP is a qualitative risk evaluation tool, meaning that the evaluation is subjective and depends on the experience of the evaluators. This is a source of incoherence and makes decision-making less effective [58]. For this reason, HAZOP is often combined with quantitative or semi-quantitative tools (ETA, FTA and LOPA). Dangerous scenarios are thus identified using HAZOP, and a tool such as LOPA is then used to evaluate the effectiveness of the means implemented to prevent the scenario from arising [61]. Although integration of HAZOP and LOPA for risk appreciation purposes can be achieved manually, the process is complicated and tedious. The quality of the results may suffer from the omission of important information.

One software product developed to facilitate OHS risk management is called LEADER [62]. With this tool, deviations identified using HAZOP are recorded in a database that compiles hazards and protective measures in order to propose LOPA scenarios automatically. To calculate the resulting level and hence acceptability of the OHS risk, analysts use each LOPA spreadsheet to attribute appropriate values or credits to each attenuating measure. If the risk remains unacceptable, additional measures can be proposed and tested. However, even with the software, advanced expertise is required in order to apply the LOPA rules in an appropriate and coherent manner.

c) PetroHAZOP

The performance of a prevention system improves over time with the increase in the number of cases analyzed and recorded in the knowledge base. However, as the numbers of records increases, retrieval of cases becomes more difficult. One way of facilitating retrieval is to group them into a subordinated ensemble, in which each case is represented by indices at four levels in a hierarchical tree [59]. At the first level, cases are classified in terms of the equipment involved and its design parameters. At the second level, each ensemble is divided according to the materials contained in the equipment and their parameters. At the third and fourth levels, the software attributes to each ensemble the conditions of usage and flow. The system includes a main module containing an algorithm for calculating the similarity between cases, in order to retrieve those closest to reality as aids for the current analysis.

d) HASILT

This relatively recent product combines HAZOP, LOPA, Safety Requirements Specification (SRS) and safety integrity level (SIL) software [58]. HASILT is in effect an intelligent integration framework combining primarily the strong points of HAZOPsuite, HazardReview and LEADER (HAZOP-LOPA). In addition, it uses the human knowledge model to analyze new problems by drawing on past experience. The underlying hypothesis is that a similar case means a similar deviation in a similar process, a similar SRS and a similar SIL validation [58]. This facilitates risk management and allows experts to come up with better-targeted responses.

The HASILT architecture is composed of basal sub-systems (HAZOP, LOPA and SRS study and SIL validation) and auxiliary sub-systems, that is, report generation, action follow-up, user and process safety information management, an equipment database and instrumentation diagrams (e.g. pipe and instrumentation diagram or P&ID). It thus includes a knowledge base and extensible generic data libraries. Through the learning system, results obtained are stored for use in other risk analysis tasks. This software possesses a help menu that provides personalized advice. The example of a case study of a hexane storage reservoir taken from the CCPS document (2001) showed that HASILT gave very satisfactory results [58].

e) Fault tree analysis software

Fault trees are used to identify hazards and their consequences by arranging elements into logical sequences that could lead to an undesirable event. Probabilistic approaches to risk evaluation require data on the reliability of system components. However, such data are not always available or of adequate quality. To overcome subjectivity in OHS risk management, estimations of probability can be expressed as a quantity represented by a fuzzy set and characterized by a membership function [20].

Software based on this principle features an improved version of a computer-assisted systematic fault tree methodology proposed earlier [20]. In the case of chemical processing, the fault tree may be very complex and difficult to analyze. The algorithm provides aid in constructing the tree and allows better-integrated consideration of the subjectivity that characterizes human judgment. The tool can be used to perform sensitivity analyses and to estimate the improvement index of a problematic situation.

4.3.2 OHS risk evaluation software used in construction

On construction sites, the nature of the tasks and the work environment changes as the project advances [24, 63, 64]. Levels of risk fluctuate with changes in physical surroundings, the work carried out and the work crews [24, 64]. These factors add complexity to the OHS risk management process. One common practice is to carry out the entire process at each passage to a new phase of the project. This can be onerous in terms of human resources and cost. In any case, risk identification is never exhaustive [64].

a) Risk assessment model (RAM)

Injuries in the construction sector are often associated with work at heights, in cramped spaces or under other conditions that exacerbate workload [24]. RAM is an OHS risk appreciation software product based on construction site accident historical data. It is divided into three main sections: a worksheet for data entry (project duration, activities and trades practiced, types of potential accidents, etc.), data-processing algorithms, and a result display sheet on which risks are ranked for each activity to enlighten hazard identification and elimination [24].

The relative level of risk associated with each activity is quantitated in terms of the frequency of occurrence of accidents and the seriousness of the resulting damage. In order to estimate seriousness, the authors combined indicators of person-days lost, injuries sustained and indemnifications paid out [24].

b) MDE software product line

Software product line development proposes a combined and flexible approach to OHS risk management based on model-driven engineering [63]. Ever-increasing software development time and costs to meet increasing user demands has led designers to search for means of improving their productivity. One innovation in this area is the product-line approach, in which a family of related products is designed with built-in adaptability to a variety of variables rather than designing a specific application for each situation. These variables may take into consideration the regulatory and legal framework, which changes from one country or cultural context to the next [65]. This would be of obvious benefit to OHS risk managers. A case study is presented in which the legal framework is a variable. Legal obligations in the realm of OHS change with the scale of the business, the sector of activity, the definition of what constitutes a construction site, etc. MDE-SPL software can be an effective tool for a multinational corporation with production operations in several countries or regions [63].

c) ToolSHeD software

Reducing work-related injuries and illnesses in the construction business by eliminating risks at the design stage is considered as a national priority. In order to achieve this goal, a system of knowledge management in the form of an interactive Web application called ToolSHeD has been proposed [66]. This software provides support to designers who have insufficient training in OHS. It is a prototype of an OHS risk management decision-aid Web application based on the tree scheme method developed by Toulmin [67]. In its initial form, the tool was limited to processing the risk of falls at construction sites, considered to be the most serious type of workplace accident.

ToolSHeD reproduces the knowledge of the OHS experts that participated in its development. It appears to be quite effective as a tool for guiding modifications of design characteristics judged as high-risk. The designer enters data on variables that have an incidence on the risk of falls, and the tool carries out the evaluation based on an integrated model to produce a ranking of factors as low, moderate or high risk.

d) Construction hazard assessment with spatial and temporal exposure (CHASTE)

CHASTE is a tool developed to reduce the frequency of work-related accidents on construction sites by systematic management of a variety of OHS risks beginning at the project planning stage. Its function is based on the assumptions that risk is the resultant of interference with work crews and that its level varies throughout the project [64, 68]. It supports the routine construction task safety analysis tool known as construction job security analysis or CJSA, which was used to develop a knowledge base for defining a set of important risk management elements used in the implementation of CHASTE [64]. The importance of developing a knowledge base for each country and region is emphasized, since local factors including legislation and culture influence the results. Data from Microsoft Project, Microsoft Access and AutoCAD are compatible with CHASTE. However, this tool does not appear to tolerate the dynamism of construction projects very well.

e) RA_X software

An expert system based on fuzzy logic for enhanced processing of complex and imprecise data has been proposed for risk analysis in construction companies [54]. The program is built around a knowledge base drawn from the literature and containing a list of potential risks. The main advantage of this tool is its ability to combine objective and subjective data using various fuzzy logic operators. The user enters various types of quantitative and qualitative data characterizing his work situation. The tool provides explanations to facilitate comprehension of the results obtained and also recommends risk-reducing safety measures.

4.3.3 OHS software for other industries

In addition to construction and chemical processing, other industrial settings have benefitted from software designed specifically for their OHS concerns.

a) Human factors workbench (HFW)

A software platform called HFW supports a set of four tools for preventing work-related accidents due to human error in gas-processing plants. The aim of this product is to prevent human error more effectively and at lower cost [69].

b) On-line interactive risk assessment (OiRA)

A product of EU-OSHA, the application OiRA is reputed to support any OHS risk management process practiced in small to medium-sized businesses in a variety of industrial and service sectors. Differences in legislation from one country to the next place limits on the sectors of applicability of this tool. EU-OSHA indicates the sectors in which its use is in compliance with local legislation. The main purpose of this product is to sensitize small and medium-sized businesses to the importance of carrying out reliable OHS risk management as means of decreasing the number of injuries and improving wellbeing in the work environment and hence productivity.

c) Computer image generation for job simulation (CIGJS)

Computer-generated images can facilitate analysis of the safety of tasks in the workplace. Based on virtual images, animations and an interactive 3D environment designed to simulate worker activity in interaction with a particular environment, the CIGJS tool developed by Patrucco et al. [45] is suitable also for training company staff.

4.3.4 Advantages and limitations

Researchers have focused their efforts on the development of new software better adapted to the work setting of interest. The persistent limitations of these products have been discussed in several studies [20, 58-60, 62, 63]. Table 2 lists some of the advantages and limitations mentioned in association with the software cited in this article. These are described in greater detail in literature other than the references cited above.

Table 2. Advantages and limitations of OHS risk management software

Aspect	Advantages	Limitations
Scope (range of application)	- Complementarity of methods (may support several situations) - May be integrated into other software programs - May be used for OHS education and training purposes	Practically none, in principle
Ease of use	- User-friendly - Faster due to automated calculation - Automatic generation of reports and schematic diagrams - May provide interpretations and recommendations - Facilitates sharing and collaboration - Easy conversion of schemas and tables to text - Easy access (internet and intranet) - Results are modifiable - Can take the legal aspects into consideration	- Maintenance and updates - Data access problems - Confidentiality uncertain - Requires considerable training - Help menus are often not helpful (especially in free software). - Resistance to change from individuals used to using conventional tools
Effectiveness (certainty and objectivity)	- Presentation is adequate - Estimation of risk may combine several factors - Artificial intelligence techniques can be incorporated - Results are obtained in real time - Learning aids are provided	- Does not include thresholds of risk acceptance - Not bug-free - Does not monitor for erroneous data entry

5. DISCUSSION AND LIMITATIONS OF THIS STUDY

Taking OHS into account has become a major issue for any organization operating in a complex environment. This new reality lies behind the evolution of several essential elements and concepts of OHS risks and risk management that now require clearer definition and deconstruction, as we propose in this article.

Our review of the literature shows that a reliable approach to OHS risk management is one that is based on methods and techniques recognized as being capable of enlightening decisions by processing a wide variety of information. This review amounts to a survey of the most commonly used methods and techniques of OHS risk management. The advantages and limitations of these tools are summarized in tabular form (Table 1) to provide a framework of reference for evaluating the suitability of OHS decision-aid software in different workplace settings. It needs to be pointed out here that these advantages and limitations were identified entirely from our examination of the studies retrieved by our search and that few of these studies are focused on any particular sector or field of activity, be it industrial or service, private or public. Furthermore, the diversity and the large number of tools available do not allow easy identification of the advantages and limitations of each. The latter were therefore grouped into families, depending on the qualitative or quantitative nature of the method or technique.

We then focused on a representative sample of software products used to manage OHS risks and that can be divided into two categories of classification. The first category groups more sophisticated software designed primarily for the industries that face the greatest risks, namely chemical processing and construction. These tools were developed to ensure exactness and reliability throughout the risk management process. They draw upon advanced techniques such as knowledge bases, artificial intelligence, etc. The second category contains software that is less sophisticated and designed for use in small to medium-sized companies and in industries where the risks are associated with consequences of a more limited nature. The primary purpose of these tools is to overcome the problem of the lack of qualified OHS human resources by providing minimal basic support for the risk management process. The design of most of these software products is based on evolving knowledge bases that require regular data collection in the field.

The present study reveals that software can support several risk typologies, including human factors. However, the use of such products in the OHS field is not yet very widespread, possibly because of their high cost or intellectual property component. In the case of small to medium-sized business, software based on cloud-computing technology appears to hold promise, especially when it is accessible for free. An additional table (Table 2) is provided in which the advantages and limitations of the best examples of these software products are summarized. Among their advantages are speed of calculation and ease of access in some cases, and in other cases practicality, quality of results and multifactorial analysis capability. On the other hand, their limitations depend directly on the relevance or usefulness of the method or technique supported. Software tools may support several complementary methods and hence a greater variety of advantages. However, no software covers all OHS risk typologies, especially not in complex high-risk installations. This may be possible to some extent in small businesses and low-risk activities.

The most important aspect of any risk management process is the quality of the results, that is, the ability to process uncertainty in order to make the most enlightened decisions. However, there are no reliable data on the quality of the results obtained using the software examined. Our analysis is surmised mostly from what the designers claim the products do. Furthermore, the list of surveyed products is not exhaustive, since our evaluation covered only those mentioned in scientific publications. It is well known that many organizations develop their own software for managing OHS risks. Few of these products have been studied by or even shared with the scientific community. Finally, another aspect omitted from our evaluation of the software products is in relation to cost. The articles retrieved in our search are silent on this important piece of information.

It is important to emphasize that this systematic review is based on a literature search using keywords. This procedure retrieved publications that mention methods, techniques or software combined directly or indirectly with the expression “occupational health and safety” or OHS. The search therefore did not make any distinction between occupational safety (type 1 risk) and disaster safety (type 2 risk). Methods such as HAZOP, LOPA and SIL were designed primarily for process safety (type 2) in the chemical industry, and their application to OHS was not likely ever intended.

Since this is the first study to focus on the contribution of software products to OHS risk management in general, many complementary studies can be envisioned in which organizations would collaborate by allowing researchers to gather reliable data that are truly representative of actual workplace realities. For this purpose, we propose to survey organizations in order to learn to what extent software is used in their OHS risk management practices, to evaluate their satisfaction with the results obtained and to identify the obstacles to more widespread use of these tools.

6. CONCLUSION

Based on a search of the scientific literature, it is safe to say that a wide variety of decision-aid software products exist that are applicable to the management of OHS risks. These tools are based on various design concepts and are used in a variety of industrial sectors and settings. In most cases they have been developed to support various conventional methods and techniques of risk management.

The chemical processing and construction industries are the most often targeted by developers of OHS risk management software, the justification being the seriousness of the potential consequences of almost any accident in a chemical plant and the still appalling numbers of construction-related accidents recorded each year. The design of most of these software tools is based on evolutionary knowledge bases, which require regular collection of data in the field. This study shows that software may support several risk typologies, including human factors. However, wider use of such products is slow to develop, possibly because of high costs or intellectual property issues. In small to medium-sized businesses, software based on cloud-computing technology appears to hold promise, especially given the accessibility of some tools free of charge.

In spite of its limitations, the study undertaken here could incite various practitioners to experiment with software-based OHS risk management decision-aid tools designed for their particular type of workplace setting and perhaps thereby bring about overall positive changes in the culture of accident prevention within their organizations.

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