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Yuvin Chinniah
Bruno Agard

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Bureaux de Montréal :
Université de Montréal
C.P. 6128, succ. Centre-ville
Montréal (Québec)
Canada H3C 3J7
Téléphone : 514 343-7575
Télécopie : 514 343-7121

Bureaux de Québec :
Université Laval
2325, de la Terrasse, bureau 2642
Québec (Québec)
Canada G1V 0A6
Téléphone : 418 656-2073
Télécopie : 418 656-2624

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An Improved Occupational Health and Safety Estimation Tool for Manufacturing Systems

Afrooz Moatari Kazerouni[1], Yuvin Chinniah[1], Bruno Agard[1,2]

[1] Department of Mathematics and Industrial Engineering, École Polytechnique de Montréal, P.O. Box 6079, Station Centre-ville, Montréal, Canada H3C 3A7

[2] Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation (CIRRELT)

Abstract. Unlimited number of hazards can be found in almost any workplace. Millions of workers die, are injured or fall ill every year as a result of these workspace hazards. Industrial machines are often involved in these occupational accidents. Because of regulatory compliance, the possible high cost in terms of human suffering and lost production, a business should place particular emphasis on safety measures. Generally, any improvement to safety of a situation or machine begins with a risk estimation which is used to examine the hazards associated with any situation or machine. There are a large number of techniques proposed for risk estimation and recent studies have revealed serious flaws in risk estimation tools.

The main objective of this paper is to develop an improved risk estimation tool which not only is general enough to be applied to a manufacturing systems instead of specific machines or tools, but also this tool is a first step towards the integration of OHS into facility planning models. The proposed tool is developed according to the characteristics of 31 risk estimation tools. The tool is then applied to 20 test risk scenarios representing different hazardous situations. The results were compared with the ones from the other risk estimation tools in order to evaluate the performance of the improved tool. Outcomes confirmed the improved ability of the proposed tool to estimate risk as compared to the other risk estimation tools.

Keywords. Occupational health and safety (OHS), risk estimation tools, manufacturing systems.

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* Corresponding author: Bruno.Agard@cirrelt.ca

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1 Introduction

Global market competition has driven improvements of production systems in the manufacturing companies. These improvements steer performance factors including production capacity, work in process, and cost efficiency (Neumannr, Kihlberg et al. 2002). Nevertheless, manufacturing industry is one of the most dangerous branches in light of the frequency of occupational accidents (Silvestri, De Felice et al. 2012). Hence, health and safety at work is one of the most significant areas of action of the European Union's social policy as well as in USA. Work related injuries can compromise industrial competitiveness (Arne 1994; Hendrick 1996) due to the costs related to labour turnover, absenteeism, spoiled and defective goods, while reducing productivity (Andersson 1992). Besides, occupational health and safety (OHS) and work quality are closely related in the manufacturing context, i.e. improving employee performance and efficiency of work systems (Erdinc and Yeow 2011). OHS contributes to product conformity, since this field ensure that conditions necessary for thoroughly carrying out work tasks are met (De Oliveira Matias and Coelho 2002). The Occupational Safety and Health Administration (OSHA) the European Committee for Standard (CEN), and the International Organization for Standardization (ISO) define the recommended exposure limits in the workplace to reduce work related injuries and outline employers' responsibilities to protect their employees' safety and health (Mutlu and Ozgormus 2012).

Major accidents are not the only incidents impacting on companies; numerous features can reflect a potentially dangerous situation. Some of these common features are improper workplace design, ill-structured jobs, mismatch between worker abilities and job demands, adverse environment, poor human-machine system design, and inappropriate management programs. Workplace hazards, poor worker health, mechanical equipment injuries, and disabilities are some of its consequences, which accordingly reduce worker productivity, influence quality, and increase cost (Shikdar and Sawaqed 2003). Therefore, it is important to eliminate or reduce the risk that these hazardous situations cause for the workers.

Risk is an expression of chance that combines frequency and severity of damage from hazards (Carpenter 1995). Risk estimation is the process wherein managers should analyse the potential impacts of the identified risks to the organisation (Lee, Lv et al. 2013). It is traditionally based on collecting and evaluating data on severity of an injury and probability of occurrence of the event. In other words, risk is reduced when a protective action such as change of design, use of safeguard, or application of safe procedure is implemented, that meaningfully reduces severity of injury or probability of occurrence of harm (Etherton 2007).

Furthermore, the most desirable characteristic of a facility layout is the ability to maintain its efficiency over time (Krishnan, Jithavech et al. 2009) while coping with occupational health and safety. Physical arrangement indicates the assignment of departments, machines and equipment to specific locations on the floor, which is addressed as facility layout. Facility layout deals with the selection of most appropriate and effective arrangements in the open continual plane to allow greater working efficiency

(Deb and Bhattacharyya 2003). A physical arrangement of the departments, machines and equipment that minimizes the movement of personnel and material between departments, and thereby decreases material handling costs, increases a system's efficiency and productivity. In practice many more factors need to be considered in addition to minimizing the cost involved in movement between departments and machines. As such, one important factor is providing safe and pleasant environment for personnel (Tompkins 2010).

Methods of identifying hazards and estimating risks can take many forms. Each method offers a different perspective, with its differing strengths and weaknesses. Depending on the system design of the company and the user interactions with it, one or more methods can be used to estimate risks. Therefore, which particular method best suits for risk estimation, would depend on the application. Besides, models for solving the layout problems do not directly include safety issues; thus the occupational health and safety features, in terms of exposure to risk factors for work-related injuries, are rarely investigated in facility planning. In most literature, health and safety issues are considered only from the ergonomic point of view and facilities layout design is rarely included. However, other factors such as safety of material handling systems, machines, environmental concerns, etc. are also important. Facility planners, thus, lack a tool that will integrate OHS as one of the variables to optimize in addition to traditional elements.

In an attempt to address this gap in the literature, the present study focuses on developing a risk estimation tool that not only covers every risk parameters that are required to assess OHS in a company, but also is general and independent of the situation. The proposed tool is intended to be an integrative framework that serves as a reference for the development of preventive actions, so it can be applicable to all types of companies.

The proposed risk estimation tool can be integrated into facility planning models, in order to better meet the OHS requirements in companies. Therefore, the purpose of the safety analysis is to ensure that the risks which could be a potential source of harm, damage of property and degradation of the environment in the workplace, are sufficiently minimized by addressing every relevant safety issues through safe layout design of a facility.

The research methodology was based on a sample of risk estimation tools that had been formed in a previous study, comparing their characteristics, and consequently identifying the parameters that the improved tool must include. Additionally, risk scenarios, also developed in a previous study, were assessed using the proposed tool, and the obtained results were compared with the ones from other risk estimation tools.

The outcome of this research is a risk estimation tool which includes some of the desirable traits, in terms of the architectures and parameters of risk estimation tools, as identified in a previous study. The tool uses a numerical approach in that the risk value is calculated. Such an approach is believed to facilitate the integration of OHS and facility planning criteria. The tool thus provides guidelines to base preventive action in any type of companies, with the aim being to reduce occupational accidents and their consequent human and economic losses when designing a facility layout.

2 Risk Estimation

High risk is defined as a combination of grave severity and significant probability of occurrence of potential injuries (Etherton 2007). Generally, improving the safety of a workplace initiates with risk assessment which is a series of steps to examine the hazards. The process includes a risk analysis, followed by a risk evaluation. Risk analysis usually consists of three stages, namely determining the limitations, hazard identification and estimating the risk.

Methods of identifying hazard and estimating risk take many forms. Wassell (2008) presented a coherent and concise description of current methods for risk identification, describing their limitations. Etherton (2007) reviewed risk assessment concepts and methods which reside in linking current risk theory to machine system risk assessment, as well as exploration of how various risk estimation tools translate into decisions on industrial machine system design and use. Anderson (2005) explored the applied risk analysis techniques used during the development and application of industrial machines. The discussed method is used to define the hazards, apply a quantitative value to the hazards, evaluate the applied quantitative value with consistent benchmarks, record the justifying steps or that the estimated residual risk is below the established benchmark. The report by Parry (1986) describes underlying principles and philosophy of hazard identification techniques, their usage and limitations. It reviewed various techniques that are available for identifying hazards associated with the processing, storage and handling of dangerous substances, namely: HAZOP, Checklists, FMEA, Fault Tree Analysis, Event Tree Analysis and Cause-Consequence Analysis.

2.1 Risk Estimation Tools

Previous researches and literature reviews demonstrate that there are different tools and methods for estimating risk in companies and it is not an easy task to choose the tool the best adapted to the needs of each company. As noted by Main (2004), Worsell and Wilday (1997) and Worsell and Ioannides (2000), there are many methods and tools proposed for carrying out part or all of such a process. Paques, Perez et al. (2005) analysed 108 methods and tools for estimating the risks associated with industrial machines and in different sectors such as military, nuclear and aeronautics industries. Chinniah, Gauthier et al. (2011) researched to theoretically compare the performances of tools in estimating risks and to evaluate whether they estimate the risks uniformly. Gauthier, Lambert et al. (2012) studied differences in the results of using different risk estimation tools, in the same hazardous situations, involving dangerous machinery. Abrahamsson (2000) attempted to analyse various quantitative risk estimation tools particularly in the occupational exposure to hazardous substances. His research focused exclusively on analysis of various types of uncertainty associated with the tools.

These tools can be classified according to different criteria. The most notable aspects are addressed in Chinniah, Gauthier et al. (2011) as diversity in the nature of each risk estimation tool, how to describe and define each parameter, the number of parameters, how to calculate, quantify and qualify the risk, how to classify or evaluate the final result, etc. Risk assessments are performed for consumer products, industrial machinery and in occupational settings. Industries such as robotics, machine tooling, packaging machinery, elevators, medical devices, aviation and semiconductors have incorporated the process into standards and guidelines. Risk assessment also appears in cross-industry applications such as process controls, control of hazardous energy (lockout/tag-out), environmental and food (Main 2004).

Risk estimation tools allow risks from various hazardous situations to be qualified or quantified in order to allow high-risk situations be quickly distinguished from low-risk situations (Etherton 2007). Qualitative tools use at least two parameters. One always represents severity of harm, where the other represents probability of occurrence of that harm. Quantitative tools attempt to estimate the frequency of a specific hazardous event. It is important to recognize that even traditional safety analyses must deal with frequencies, though, unlike in quantitative risk estimation, these probabilities are not quantified. The ratings or values that come from any risk estimation tool are relative rather than absolute. Therefore, risks that estimated using one tool cannot be directly compared to those estimated using another tool (ISO14121 2004).

Majority of qualitative risk estimation tools are either risk matrices or risk graphs. A risk matrix is a multidimensional table allowing the combination of any class of severity of harm with any class of probability of occurrence of harm (Clemens 2000). Many research studies have tackled risk matrix structure to introduce their risk estimation tools; e.g. BT, Kazer, Raafat Matrix, and Wells SCRAM presented in Worsell and Wilday (1997), as well as US CPSC, HSE Construction, and Australia Environment, presented in Main (2004).

A risk graph has a tree structure, configured from left to right (ANSI/RIA-R15.06 1999). Two examples of applying the risk graph structure in risk estimation tools are MEP Risk Graph (Worsell and Wilday 1997) and the one presented by CSST (2006).

Quantitative risk estimation tools can be addressed as numerical scoring tools and quantified risk assessment (QRA). Quantified risk estimation tools mathematically calculate the probability of a specific outcome occurring during a specific duration of time (Etherton 2007). Numerical scoring tools have two to four parameters that are broken down into a number of classes, similar to risk matrices and risk graphs. However instead of a qualitative term, different numerical values are associated with the classes (Manuele 2001). An application of numerical scoring tool is SUVA, presented by Bollier and Meyer (2002).

2.2 Risk Estimation Parameters

Differences in the number of parameters, types of parameters, number of levels, and definitions of the parameters significantly contributed to the diversities in the identified risk estimation tools.

ISO/IEC Guide 51:1999 interpreted as risk being made up of two parameters, severity and probability, which form the basis of techniques for risk estimation, popular in evaluating workplace risks (ISO/IEC-Guide51 1999). ISO 14121 states that the probability of occurrence of harm was, itself, made up of a number of parameters. These are frequency and duration of exposure, probability of occurrence of hazardous event, and possibility to avoid or limit the harm (ISO14121 2004).

1) Severity of harm. It is a function of the objective of protection (i.e. human, property or environment) in relation with the severity, i.e., slight, serious or fatal and it does affect one person or several.

Harm may also occur to property or the environment. Therefore, the severity of harm can be estimated by taking into account:

- severity of injuries or damage to health; e.g. slight, serious, or death
- the extent of harm; e.g. one or several persons

2) Probability of occurrence of harm. It can be estimated by:

    a) Exposure of persons to the hazard
        - the need for accessing the hazard zone; e.g. for normal operation correction of malfunction, maintenance or repair
        - nature of access; e.g. manual feeding of materials
        - time spent in the hazard zone
        - number of persons requiring access
        - frequency of access

    b) Occurrence of a hazardous event
        - reliability and statistical data
        - accident history
        - history of damage to health
        - risk comparison

    c) Technical and human possibilities of avoiding or limiting the harm
        - different persons (type of persons involved and their practical experience in operating the machinery) who can be exposed to the hazards; e.g. skilled, or unskilled
        - how quickly the hazardous situation could lead to harm; e.g. suddenly, quickly, or slowly
        - any awareness of risk; e.g. by general information, information for use, by direct observation, or through warning signs and indicating devices on the machinery
        - the human ability of avoiding or limiting harm; e.g. reflex, agility, possibility of escape
        - practical experience and knowledge; e.g. knowledge of the machinery, similar machinery, or absence of experience

The risk assessor is required to select the probability of occurrence of harm and the severity of harm from a fixed number of levels. There are generally three or four levels for each parameter (Charlwood, Turner et al. 2004). Chinniah, Gauthier et al. (2011) have defined equivalent scales for the parameters as well as their risk levels in risk estimation tools. The definitions explained in their research have been used in this paper and elaborated in Section 4.2.2.

3 Research Methodology

This paper focuses on presenting a risk estimation tool which can be employed for appraising risk in general and not specific to a situation. The methodology consists of following stages:

1. Using previous studies on risk estimation tools as the starting point.
2. Applying desirable traits of these tools in terms of number of risk parameter levels and definitions.
3. Studying numerical tools (5 out of 31) to design an equation for calculating the risk value.
4. Testing the proposed tool by applying it to risk scenarios.
5. Evaluating the proposed tool by verifying how it performs compared to other tools; i.e. ranking of scenarios from lowest to highest. Ranks established in previous study, based on average results of each scenario when applied 31 tools, are used.

4 Proposition of the Improved Risk Estimation Tool

In this section, the phases for developing the proposed risk estimation tool are discussed. Summary of tools with similar characteristics is presented. The approach for identifying risk scenarios is deliberated, and the equation for calculating the risk value is modelled.

4.1 Similarity of Other Tools

Various risk estimation tools were studied in order to identify their characteristics such as the risk parameters, number of risk levels, equation and the approach they follow to assess risk. These tools were mainly adapted from Chinniah, Gauthier et al. (2011) and Gauthier, Lambert et al. (2012), in which the authors analysed 31 qualitative and quantitative tools that follow ISO 14121-1: 2007 guidelines.

The 31 tools were studied in details and narrowed down to five tools. They estimate risk in a pseudo-quantitative way. These tools, which arithmetically associate risk parameters in their risk estimation approach, are presented in Table 1.

Table 1 Summary of the five risk estimation tools

Tool	Parameters (#levels)	Risk calculation equation
BT (Worsell and Ioannides 2000)	- Potential to cause harm (3) - Likelihood to cause harm (3)	Risk = Hazard * Likelihood
Company A	- Severity (3) - Probability of occurrence of a hazardous event (3) - Frequency of exposure to hazard (3)	Risk = Severity + Probability + Frequency
SUVA (Bollier and Meyer 2002)	- Severity (5) - Probability of occurrence of harm (5) - Frequency and duration of exposure to hazard (5) - Probability of occurrence of a hazardous event (5) - Technical/human possibilities to avoid/limit harm (3)	Risk ~ F (Severity ; Probability of harm) Probability of harm = Frequency and duration + 2* Probability of hazardous event + Avoidance
NORDIC (Mortensen 1998)	- Severity (4) - Probability of occurrence of harm (4) - Frequency of exposure to hazard (5)	Risk ~ F (Severity ; Probability of harm) Probability of harm = Frequency + Probability of hazardous event +

	- Probability of occurrence of a hazardous event (5) - Technical/human possibilities to avoid/limit harm (3)	Avoidance
Gondar (Design 2000)	- Severity (3) - Probability of occurrence of harm (3)	Risk = Severity * Probability of harm

The five tools, introduced in Table 1, are not the only risk estimation tools that exist to estimate risk in a quantitative way; however they are well-known tools which are considered in this research. Four out of the five tools are introduced in literature, namely: BT (Worsell and Ioannides 2000), SUVA (Bollier and Meyer 2002), NORDIC (Mortensen 1998), and Gondar (Design 2000). The fifth tool had taken from the risk estimation procedure applied in a company, which is referred as Company A in this paper.

The parameters and their risk levels, used in assessing risk, are discussed for each tool. Additionally, the approach taken for arithmetically calculating the risk value is presented in this table.

4.2 Improved Risk Estimation Tool

For developing the improved risk estimation tool, risk parameters and their respective levels for assessing risk scenarios were chosen. Two parameters of severity (S) and probability of occurrence of harm (Ph) are the main measures of risk; while four measures are used to compute probability of occurrence, namely:

- Frequency of exposure to the hazard (Exf)
- Duration of exposure to the hazard (Exd)
- Probability of occurrence of a hazardous event (Pe)
- Technical and human possibilities of avoiding or limiting the harm (A)

The literature appears to usually use three measures where frequency and duration are considered as one risk parameter of "exposure of persons to the hazard" (e.g. Mortensen (1998), ANSI/RIA-R15.06 (1999), ISO14121 (2004)). This research is based on the four-parameter categorisation. This would result in an elaborated evaluation of risk for the scenarios; thus having a more detailed and reliable risk estimation tool. Moreover, risk levels for each of the five parameters are defined.

4.2.1 Improved Risk Estimation Definition

The improved risk estimation model was developed based on the identified parameters. The mathematical relations between the parameters as well as the weight assigned to each parameter were adjusted according to the approach taken in the five selected tools. The equation was developed as below:

Risk value (R) *= Severity of harm (S) * Probability of occurrence of harm (Ph)*

Probability of occurrence of harm (Ph) *= Frequency of exposure to the hazard (Exf) + Duration of exposure to the hazard (Exd) + 2* Probability of occurrence of a hazardous event (Pe) + Possibility of avoidance (A)*

The proposed equation is a combination of approaches seen and includes all risk parameters highlighted in ISO 12100. Using the equation, the risk value for each scenario is calculated. Risk is calculated by multiplying the qualitative value for severity of harm (S) and probability of occurrence of harm (Ph). This function is similar to the approach used in BT and Gondar tools.

In order to calculate the value of probability of occurrence of harm (Ph), similar approach applied in SUVA, NORDIC, and Company A was employed. Four parameters of frequency of exposure to the hazard (Exf), duration of exposure to the hazard (Exd), probability of occurrence of a hazardous event (Pe), and possibility of avoidance (A) are summed up. In this function the weight for the 'Pe' value is considered twice more than the other parameters. The reason is that the likelihood of occurrence of a hazardous event, which depends on a determinate of the technical standard of safety and activity, has a higher rank than the other parameters (Bollier and Meyer 2002).

4.2.2 Improved Risk Estimation Parameters and Levels

Since the proposed risk parameters are qualitatively scaled, in order to be transformed to quantitative measures, a rating system is used. Quantitative values were assigned to the levels of each risk parameter as their rates. These values are based on the 1 to 5 rating scales, where 1 indicates the lowest and 5 is the highest importance of risk. The number of levels for each parameter has been determined from the equivalent scales as explained in Chinniah, Gauthier et al. (2011). The equivalent scales were formed by considering all the 31 tools and by matching their individual levels against one another. It is believed that the improved tool would effectively discriminate among different parameter levels and offer the desirable granularity if its five risk estimating parameter have similar number of levels as identified in Chinniah, Gauthier et al. (2011). These parameters, their risk levels, and the corresponding quantitative values are presented in following paragraphs.

1) Severity of harm (S)

Severity of harm is defined as hazard in term of potential to cause harm. The likely effect of a hazard can be rated as in Table 2.

Table 2 Severity of harm

Severity of harm (S)	**Rank**
Slight injuries (bruises) requiring no first aid or injuries requiring first aid but without lost time	1
Injuries requiring more than first aid (medical assistance) and with lost time or when there is irreversible harm and slight disability but able to return to same job	2
Serious disability, able to return to work but perhaps not to the same job	3
Permanent disability and can no longer work	4
Single or multiple deaths	5

2) Probability of occurrence of harm (Ph)

It is estimated by four parameters. These parameters and their risk levels are addressed in Table 3-6.

A. Frequency of exposure to the hazard (Exf)

Table 3 Frequency of exposure to the hazard

Frequency of exposure to the hazard (Exf)	Rank
Frequency less than once per year	1
Annual frequency	2
Monthly frequency	3
Weekly frequency	4
Daily frequency to several times per hour (continuous)	5

B. Duration of exposure to the hazard (Exd)

Table 4 Duration of exposure to the hazard

Duration of exposure to the hazard (Exd)	Rank
< 1/20 of work time	1
1/10 of work time (45 min per 8 hour shift)	2
1/5 of work time (90 min per 8 hour shift)	3
half of work time (1/2) (4 hours per 8 hour shift)	4
continuous during work time	5

C. Probability of occurrence of a hazardous event (Pe)

Table 5 Probability of occurrence of a hazardous event

Probability of occurrence of a hazardous event(Pe)	Rank
Negligible	1
Rare	2
Possible	3
Probable	4
Frequent	5

D. Technical and human possibilities to avoid or limit the harm (A)

Table 6 Technical and human possibilities to avoid or limit the harm

Technical and human possibilities to avoid or limit the harm (A)	Rank
Easy	1
Probable	2
Possible with certain conditions	3
Improbable	4
Impossible	5

These parameters are used to model the improved risk estimation tool. The quantitative values assigned to the risk levels facilitate numerating the risk value which gives an easier perspective to assess the risk scenarios.

4.2.3 Evaluation Procedure

With the purpose of evaluate risk values, five risk categories were defined. Since the maximum number that can be obtained from the equation is 125 and the minimum is 1, the range of risk ranks were divided to 5 equal categories starting from 1 to 125. Risk categories were assigned to the corresponding range as follow:

- If the risk value is a number between 1 and 25, it is a very low risk scenario.
- If the risk value is a number between 26 and 50, it is a low risk scenario.
- If the risk value is a number between 51 and 75, it is a medium risk scenario.
- If the risk value is a number between 76 and 100, it is a high risk scenario.
- If the risk value is a number between 101 and 125, it is a very high risk scenario.

4.2.4 Improved Risk Estimation Model

To outline the phases for assessing the OHS in a company, according to the improved risk estimation tool, the following steps should be followed for each hazardous scenario. This model not only specifies the OHS deficiencies, but also guides facility planners about the safety improvements they need to consider when designing a new layout.

Step 1: For each hazardous situation, identify the qualitative risk level for each of the five risk parameters.

Step 2: Identify the quantitative value (1-5) corresponding to the risk levels identified in Step 2.

Step 3: For each hazardous situation, calculate the risk values:

Risk value (R) *= Severity of harm (S) * Probability of occurrence of harm (Ph)*

Probability of occurrence of harm (Ph) *= Frequency of exposure to the hazard (Exf) + Duration of exposure to the hazard (Exd) + 2* Probability of occurrence of a hazardous event (Pe) + Possibility of avoidance (A)*

Step 4: For each risk scenario, identify the corresponding interval for the risk value (Table 7).

Table 7 Risk value evaluation

Ranks	Risk Category
1-25	very low
26-50	low
51-75	medium
76-100	high
101-125	very high

5 Validation of the Risk Estimation Tool

The improved risk estimation tool was applied to hazardous situations in order to compare the obtained risk values when applying different tools to the same hazardous scenario. 20 scenarios of different hazardous situations were used to evaluate the proposed tool. Figure 1 demonstrates an example of one of these hazardous situations.

Scenario R **Thermal Hazard**	
Activity	Cutting out thermo-formed panel.
Hazard	Elevated temperature of cut panel (60 °C).
Hazardous situation	Worker in the proximity of the panel.
Hazardous event (choose and define one specific hazardous event)	Worker is in extended contact with the panel.
Probability of occurrence of hazardous event (considering training, experience, reliability of safety and non safety components, safeguards, supervision, defeating of safety devices, procedures…)	The worker is experienced in undertaking this task. The cuts and the tools necessary for this task need to be as close as possible to the panel and done while the panel is still hot.
Possible harm	Recurrent light burns.
Exposure information	On average 5 hours a day during an 8 hour shift.
Avoidance information (considering information on time and speed, warnings, escape route, training, experience, …)	The worker is experienced and aware of the danger. The nature of the work makes it difficult to avoid the contact with the hot panel. The worker is not wearing protective gloves.

Figure 1 Example of a hazardous situation – retrieved from Chinniah, Gauthier et al. (2011)

In the analysis by Chinniah, Gauthier et al. (2011), firstly, the average risk for the scenarios was computed. Then, scenarios were classified in terms of risk levels from low-risk to high-risk scenarios (A to T) according to the average of risk values obtained from 31 risk estimation tools.

The following sections discuss how the proposed tool in this research would appraise risk for scenarios and where it stands comparing to the other risk estimation tools.

5.1 Estimating Risk for Scenarios

The 20 risk scenarios were evaluated by the proposed tool (Figure 2). For each scenario, the qualitative values of S, Exf, Exd, Pe, and A were determined. Thereafter, the corresponding quantitative values were associated. The risk value was calculated for each scenario using the equation: R=S*(Exf+Exd+2*Pe+A). Moreover, based on the five risk categories, corresponding interval for the risk values were identified.

Figure 2 outlines these analyses. Applying this tool, the overall risk average for the scenarios is 38.9% with the standard deviation of 23.3.

SCENARIOS	S	Ph				Risk Value
		Exf	Exd	Pe	A	R=S*(Exf+Exd+2*Pe+A)
S	5	5	1	1	4	60
G	2	5	1	3	1	26
A	1	5	1	4	3	17
B	2	5	1	2	2	24
R	2	5	5	5	4	48
N	3	4	1	4	3	48
O	5	4	1	1	2	45
E	2	3	1	1	3	18
H	1	5	1	5	5	21
M	4	4	1	2	2	44
K	3	3	2	1	3	30
L	5	3	1	2	3	55
I	2	5	3	2	1	26
P	2	5	5	4	4	44
J	3	5	5	2	1	45
F	1	5	3	2	5	17
C	1	5	5	1	2	14
D	1	5	5	5	4	24
T	5	5	5	4	5	115
Q	3	5	3	4	3	57

Corresponding Interval for the Risk Value				
1-25 very low	26-50 low	51-75 medium	76-100 high	101-125 very high
		x		
	x			
x				
x				
	x			
	x			
	x			
x				
x				
	x			
	x			
		x		
	x			
	x			
	x			
x				
x				
x				
				x
		x		

Figure 2 Estimating risk for scenarios

As an example, for scenario R (Figure 1), the "severity of harm" is considered to be injuries requiring more than first aid (medical assistance) and with lost time, therefore ranked as 2 in the table. For the "frequency of exposure to the hazard", scenario R indicates continues frequency which is ranked as 5. Similarly for the "duration of exposure to the hazard", the duration is considered continues with the rank of 5. The "probability of occurrence of a hazardous event" is frequent and ranked 5; while the "possibility of avoidance" appears to be improbable with the rank of 4.

Consequently the risk value is calculated as: $R_{\text{Scenario R}} = 2*(5+5+(2*5)+4) = 48$.

Whereas the corresponding interval for the value of 48 is the risk category of low.

5.2 Evaluation of the Improved Tool

In order to evaluate the proposed tool, the sequence of scenarios, based on their risk values, is evaluated and shown in Figure 3. The risk values are rounded to their upper bounds, while their equivalent percentage values are used for the sequence comparisons. These values are:

- Ranks between 1 and 25 ~ 20%
- Ranks between 26 and 50 ~ 40%
- Ranks between 51 and 75 ~ 60%
- Ranks between 75 and 100 ~ 80%
- Ranks between 100 and 125 ~ 100%

As an example, for scenario R, the risk value is calculated as 48. This value is in the range from 26 to 50 which is equal to 40%.

20	20	20	20	20	20	20	40	40	40	40	40	40	40	40	40	60	60	60	100
A	B	C	D	E	F	H	G	I	J	K	M	N	O	P	R	L	Q	S	T
0	0	0	0	0	0	1	1	0	0	0	1	1	1	1	2	5	1	0	0

Figure 3 Sequence of scenarios for the proposed tool

The risk values for the scenarios should follow the A to T order or be close to that. The sequence of scenarios is compared by counting the number of intervals (distances) between the current position of scenarios and where their actual letter (A to T) must be situated. If a scenario is considered to have a lower risk, the number is coloured red, otherwise in black.

For our proposed tool, scenarios H, M, N, O, P, and R are the ones that are considered to have lower risks than expected. This fact can utter the proposed tool being a low estimating tool. Based on the report by Chinniah, Gauthier et al. (2011), a low estimating tool has an average risk lower than the overall average for the scenarios (48.8%). With the average of 38.9%, the proposed tool in this paper is indeed a low estimating tool.

Figure 3 also represents scenario G, L, and Q being considered more risky than they truly are. However, this would not be problematic when assessing risk in real life.

5.3 Comparing Sequence of Scenarios

The sequence of scenarios for the proposed tool was compared with the ones from the five selected tools. This comparison is displayed in Figure 4. Chinniah, Gauthier et al. (2011) has categorized scenarios, in terms of risk values, as low (A to C), mid-low (D to J), mid-high (K to P) and high (Q to T). This was done according to the number of times that a scenario was evaluated to have the lowest or highest risk values. Similar categorization is applied in this research.

For each of the five tools as well as the proposed tool, scenarios were sorted based on increase of risk value. Thereafter, the sequence of scenarios was compared to the original order of A to T. Number of intervals between their current and original positions are counted. Sum of these differences was calculated for both being considered a lower and higher risky scenario.

Color-codes in Figure 4 demonstrate if scenarios are located within their original four categories of low to high risks. In this research, if a scenario is not in its original location, but still within its original risk category, it is not considered as a critic when evaluating performances of the tools.

The comparison demonstrates that sequence of scenarios for our proposed tool is very similar to the original order of A to T. Disregarding the misplacement of some of the scenarios within their risk categories, only scenarios R and L are critically dislocated. Scenario R, with 2 intervals difference, is considered a Mid-High instead of High risk scenario. Indeed, this scenario is deliberated as having lower risk than it actually has, which could make the evaluation censorious. However, the misplacement is only marginal and can be overlooked.

Scenario L is considered more risky than it is, when being located in High risk category instead of Mid-High. Although this can withdraw the required attention from more risky scenarios to such scenarios as L, here, the interval difference is nevertheless low and not criticizing performance of the proposed tool.

Comparing the values for Sum of Differences, it is much less for the proposed tool than the other five selected tools. The value indicates the difference from the original scenario order of A to T, therefor, the lower the better.

TOOLS	LOW			MID-LOW							MID-HIGH						HIGH				SUM of differences	
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	Lower	Higher
Improved	20	20	20	20	20	20	20	40	40	40	40	40	40	40	40	40	60	60	60	100		
	A	B	C	D	E	F	H	G	I	J	K	M	N	O	P	R	L	Q	S	T		
	0	0	0	0	0	0	1	1	0	0	0	1	1	1	1	2	5	1	0	0	**7**	**7**
BT	50	16.7	50	50	50	33.3	50	50	50	50	50	50	83.3	83.3	50	83.3	83.3	50	83.3	100		
	B	F	A	C	D	E	G	H	I	J	K	L	O	R	M	N	P	Q	S	T		
	1	4	2	1	1	1	0	0	0	0	0	0	2	4	2	2	1	1	0	0	**11**	**11**
Company A	26.7	93.3	86.7	73.3	73.3	66.7	93.3	80	86.7	86.7	73.3	80	80	80	80	86.7	93.3	100	80	93.3		
	A	F	D	E	K	H	L	M	N	O	S	C	I	J	P	B	G	Q	T	R		
	0	4	1	1	6	2	5	5	5	5	8	9	4	4	1	14	10	1	1	2	**44**	**44**
SUVA	33.3	66.7	66.7	33.3	66.7	33.3	33.3	33.3	66.7	66.7	66.7	66.7	66.7	66.7	100	66.7	100	66.7	66.7	100		
	A	D	F	G	H	B	C	E	I	J	K	L	M	N	P	R	S	O	Q	T		
	0	2	3	3	3	4	4	3	0	0	0	0	0	0	1	2	2	3	2	0	**16**	**16**
NORDIC	66.7	100	100	33.3	100	100	66.7	66.7	100	100	100	100	100	100	100	100	100	100	100	100		
	D	A	G	H	B	C	E	F	I	J	K	L	M	N	O	P	Q	R	S	T		
	3	1	4	4	3	3	2	2	0	0	0	0	0	0	0	0	0	0	0	0	**11**	**11**
Gondar	83.3	33.3	50	83.3	50	50	83.3	83.3	50	50	50	50	33.3	83.3	50	83.3	83.3	83.3	83.3	100		
	B	M	C	E	F	I	J	K	L	O	A	D	G	H	N	P	Q	R	S	T		
	1	11	0	1	1	3	3	3	3	5	10	8	6	6	1	0	0	0	0	0	**31**	**31**

Figure 4 Comparison of the sequence of scenarios

In order to better understand standing of the proposed tool, Sum of Differences for the scenarios being considered less risky, are compared for the improved tool and 31 other tools. This comparison is illustrated in Figure 5. The first row of the Figure 5 demonstrates the tool presented in this paper as well as the 31 tools which are referred to with a number and can be found in Gauthier, Lambert et al. (2012).

TOOL #	44	35	48	46	41	66	7	89	Improved RA	3	17	33	57	BT	NORDIC
LOW (DIFFERENCE)	0	1	1	1	2	4	5	6	7	7	10	10	10	11	11

TOOL #	94	85	19	6	58	45	SUVA	55	24	34	114	10	Gondar	69	49	Com A	91
LOW (DIFFERENCE)	12	13	13	14	15	16	16	19	21	22	30	30	31	32	42	44	46

Figure 5 Position of tools

All the eight tools that are positioned before the proposed tool have risk matrix structure. Although this cannot necessarily indicate the risk matrix tools being more precise than the proposed risk estimation tool; because tools such as BT, SUVA, and Gondar which are positioned later in the sequence are also risk matrix tools. Moreover, risk graph tools (e.g. tool 19 and 91) and numerical scoring tools (e.g. SUVA and tool 53) appear later in the sequence than the improved tool.

5.4 Correlation Analysis

Correlation analysis was carried out to determine degree of relationship between the proposed risk estimation tool and the five selected tools. This analysis would specify the extent to which changes considered in the structure of the proposed tool is associated with other risk estimation tools.

In this regards, the average risk value of assessing 20 scenarios for the 31 tools, as well as for the improved tool were calculated. The analysis was conducted among the 32 tools with a confidence level of $\alpha=0.05$ and 30 degrees of freedom. Null hypothesis states:

H0. There is a correlation between the structures of the improved and other risk estimation tools.

Even though, all 31 tools were used in the correlation analysis, this paper only argues similar behaviours among the five selected tools and the proposed one. Therefore, Figure 6 summarizes the results of correlation analysis between the improved risk estimation tools and the other five.

To determine the likelihood that the correlation coefficient values are occurred by chance, the “Critical Value Table for Pearson’s Correlation Coefficient” was used (Siegle 2009). Correlation coefficient values above 0.349 would indicate a statistically significant relationship between the respective risk estimation tools.

	Improved RA	*BT*	*SUVA*	*Gondar*	*Company A*	*NORDIC*
Improved RA	1.000	0.704	0.650	0.382	0.393	0.359

Figure 6 Correlation analysis

Results show that all the correlation coefficient values are above 0.349 for every tool. Hence there is a significant relation among the proposed tool and the five selected ones; therefore H0 is accepted.

In this analysis, the values higher than 0.6 are assumed to indicate high correlation (red-coloured in Figure 6) and the ones below 0.6 indicate moderate correlation. Correlations between the proposed tool and BT as well as SUVA are high (0.704 and 0.65 respectively). In support of these results, the risk estimation in BT is done by multiplying the severity and likelihood of harm, which is the same methodology as in the improved tool. In SUVA, probability of harm is calculated by summing up parameters of: frequency and duration, probability of hazardous event, and avoidance. These parameters are similar to the one applied in the proposed tool. Moreover, SUVA assigns the weight of 2 for the “probability of hazardous event” parameter, which is similar to the approach taken for the improved tool.

None of the selected tools use all the five parameters that are included in the improved tool. However, NORDIC is the most similar one in terms of the risk parameters used. In regards to the risk levels assigned to each parameter, NORDIC and SUVA use the same number of levels (5) for the “probability of occurrence of a hazardous event” and the “frequency of exposure to hazard” as in the improved tool. Also for the “severity” parameter, the number of risk levels (5) in SUVA is the same as in the proposed tool.

These would justify the high correlations exist between the improved tool and the five selected ones; taking into account that the proposed tool is an improvement to these tools. Therefore, the proposed tool in this paper is a better risk estimation tool.

6 Discussion and Conclusion

Different methods exist for assessing risk and it may not be an easy task to choose the tool that best adapt to the needs of each company. The research work presented in this paper addressed the occupational health and safety issues by presenting an improved tool for risk estimation. It proposes a new approach for risk estimation which can have a general use for a wide range of industrial contexts. The objectives of developing this tool were to propose a quantitative tool which estimates better and more precise than the already existing tools. Specifically, the approach is intended to support the implementation of OHS criteria during layout design of a plant. Moreover, the tool does not concentrate on specific features of OHS; e.g. not only machine safety or ergonomics. Every subject of OHS can be covered when applying this tool.

Indeed, the improved tool function with a similar theoretical foundation as most of the other currently used tools; e.g. risk matrix tools. One benefit of this tool is that even though a thorough theoretical foundation is used, it does not necessitate the analysts to understand the underlying theory.

Five risk parameters are defined for assessing hazardous scenarios in this tool; i.e. severity of harm, frequency of exposure to the hazard, duration of exposure to the hazard, probability of occurrence of a hazardous event, and the technical and human possibilities of avoiding or limiting the harm. These risk parameters are defined and differentiated carefully; for example, the “frequency” and “duration” of exposure are considered as two separate parameters in the risk estimation approach.

Moreover, levels of risk for each parameter are defined precisely in a way that subjectivity in deciding on the levels of parameters is minimized. This helps to avoid disagreements among the analysts, while producing more consistent results. In this regards, five levels of risk were used for each parameter where no gap or discontinuity exists among the levels. It not only supports having a tool which is consistent with the majority of risk estimation tools, but also the number of levels are enough for not tending to overestimate risk.

In addition, the risk estimation approach is pseudo-quantitative which make it simple to incorporate into quantitative analyses. The risk estimation equation has taken into account differences between the degrees of importance of the parameters by assigning weights to them. This helps avoiding that one parameter overly influences the risk level.

In this paper 20 risk scenarios were assessed based on the five risk parameters. Results were used to calculate the risk value based on the developed risk estimation model. The obtained value was evaluated for assigning the low-high degree of risk for each scenario. Furthermore, performance of the improved tool was compared with the other risk estimation tools. Analyses showed that the proposed tool has indication of being a low estimating tool. The sequence of scenarios for the improved tool is very close to their original order of A to T. Furthermore, the Sum of Differences of considering a scenario less risky than its real status, is much less for the improved tool than most of the other evaluated tools.

Future research will aim to propose a methodology by which facility planning models and risk estimation tools can be integrated together in order to better meet the safety requirements of companies. In this concern, a facility layout problem can be formulated as a mathematical model while considering OHS issues as the constraints of the model. Therefore, the proposed tool in this paper can be used as the safety side of the integrated tool. By this means, safety issues would be considered as an important factor as cost, closeness, material flow, flexibility, or material handling system concerns, in the facility layout problems. Moreover, the research can be enriched by appraising the proposed tool in real case studies. This can support validating the practicality of tool in regards to its generality and independency of the situation.

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