SAFETY SCIENCE Monitor

Issue 1 2007

Article 2

VOL 11

INDUSTRIAL MACHINE SAFETY: DO THE EXPERTS SEE THE SAME RISKS?

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March 22, 2005

ABSTRACT

Abstract - Theoretically known, the process to assess the risks associated with industrial machinery calls for many approaches or different tools. Although there is an international standard (ISO 14121) on the subject, interpretation or application of this standard can vary depending on the users or domains of application. In order to obtain a picture of the coherence in the interpretation of this standard, a survey was made with recognized experts about the risk components analysis phase. From ten hazardous situations around industrial machines, seventeen experts gave their perception of the four risk components (hazard, hazardous situation event, hazardous event and harm). The results of this survey were analysed on the angle of the cohesion of the language used in reference to a pre-established glossary and on the angle of the identification of the risks presented by the ten risk situations.

Test results showed that the notions associated to the basic risk components suggested by the standard are usable and used in the most part (from 57% to 73% of the answers). However certain notions seem to be used more in conformity to the standard: they are notions associated to hazardous event and harm. The methodology used for this inquiry could be used in a broader scale research in the domain of cohesion and sturdiness of the methods and the tools used to do risk analysis associated with industrial machinery.

Key words: risk identification, survey, risk components, industrial machinery.

1. INTRODUCTION

Theoretically, even if the steps to be taken in a process to assess the risks associated with industrial machines are known, the large number of tools proposed or used for these analyses shows that there is no single and universal approach. In fact, and as Main (i) and Pérusse (ii) noted, there are many methods and tools proposed for carrying out part or all of such a process.

In the preparation of specific research to compare methods and tools for analyzing the risks associated with industrial machines, no systematic methodology was identified for comparing the results of a risk analysis according to controlled parameters and by eliminating the potential biases posed by the situations to be analyzed.

For reference purposes, a European international standard (ISO 14121) (iii) that has existed for close to five years has established the principles for analyzing the risks associated with industrial machines. When this standard was revised, an survey was carried out to establish how the experts on this standard's review committee (iv) define in practice the aspects that constitute the risks associated with industrial machines. In fact, even if the content of the standard is supposed to reflect a certain consensus among the experts, validation of the application of this consensus in practice will confirm or refute the use made of the aspects contained in the standard.

2. HYPOTHESES

According to ISO 14121, the process of assessing the risks associated with industrial machines is carried out according to the general diagram shown in Figure 1 and whose definitions (in the exact terms and language of the original document) in the different steps are the following:

- Risk assessment: "the overall process of risk analysis and risk evaluation" (ISO 12100-1, 3.13) (v);
- Risk analysis: "combination of the limits of the limits of the machine, hazard identification and risk estimation" (ISO 12100-1, 3.14) (v);
- Hazard identification: "The essential step in any risk assessment of machinery is the systematic identification of possible hazards, hazardous situations and hazardous events during all phases of the machine life cycle" (ISO 14121, 6) (iv);
- Risk estimation: "defining likely severity of harm and probability of its occurrence" (ISO 12100-1, 3.15) (v);
- Risk evaluation: "judgement, on the basis of risk analysis, of whether the risk reduction objectives have been achieved" (ISO 12100-1, 3.16) (v).

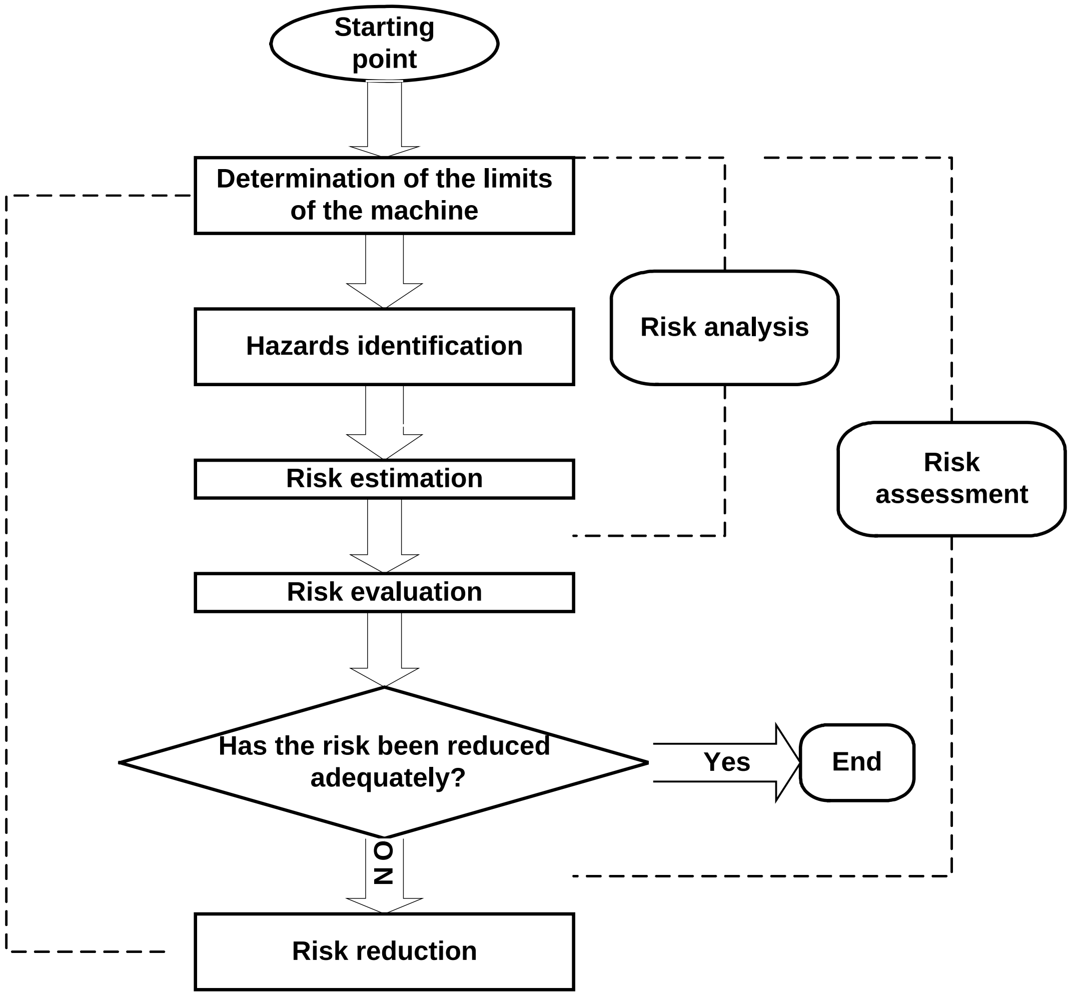

Figure 1: General diagram of the risk assessment process

Even if experts agree that "The benefit of risk assessment comes from the discipline of the process rather than in the absolute validity of the results …" (Annex B of ISO 14121) (iv), the observed dispersion of the results obtained by different observers remains disturbing for people, like preventers, who are responsible for carrying out a risk analysis. To determine a reference level for the dispersion of the risk analysis results, an survey was done with the committee's experts who are helping to update the standard; more precisely, this survey should determine whether these experts have an identical vision of the application of the concepts proposed in this standard. This survey therefore was not based on scientific sampling, but was based instead on an expert opinion approach, analogous to the DELPHI method.

This survey was made just for exploration purpose, with no intend to explain its results. This will be done in future researches which will refer in a more systematical way to other researches related to cognitive psychology.

This survey involved the hazard identification step, referring mainly to the 4 basic components of the risks associated with industrial machines as defined in the standard during revision (iv); these 4 components are defined (in the exact terms and language of the original document) mainly in the general international standard on machine safety (ISO 12100-1, v):

- Hazard: “potential source of harm” (ISO 12100-1, 3.6) (v);
- Hazardous situation: “circumstance in which a person is exposed to at least one hazard. The exposure can immediately or over a period of time result in harm” (ISO 12100-1, 3.9) (v);
- Hazardous event: “event that can cause harm” (ISO 14121, 3.4) (iv);
- Harm: “physical injury or damage to health” (ISO 12100-1, 3.5) (v).

No definition of the terms “origin” and “consequence” have been found in the two ISO standards (v)(iv).

To take into account a more detailed breakdown of the hazards, as mentioned for example by Noyes and Gouriveau (vi) who also propose a “causes–consequences relationship”, the hazards can also be considered from an “origin–consequences” breakdown, as also appeared in annex A of the standard under revision (ISO 14121, Tables A. 1, A. 2 and A. 4) (iv).

Two basic questions were therefore asked:

1. Are all hazardous situations identified in all cases by all the expert observers?
2. Are all the identified hazardous situations described in the same way in all cases by all the expert observers?

3. METHODOLOGY

3.1 Survey Process

At one of the work meetings of the international committee in January 2004, seventeen experts, from 10 countries, on the committee filled out a questionnaire while ten photographs of hazardous activities showing ten activities associated with industrial machines were presented. The questionnaire was ten pages in length, with each page including a photograph of a hazardous activity and four spaces to be filled out for the four components of the hazard (hazardous phenomenon, hazardous situation, hazardous event and harm). A brief verbal description of the activity shown on the photograph accompanied each picture; the participants had five minutes to complete each page of the questionnaire, and the photograph was changed at the end of five minutes. The completed questionnaires were collected at the end of the approximate one-hour period and were coded for later analysis.

The 10 photographs of hazardous activities showed the following activities:

- Activity no. 1: Visiting an old sawmill
- Activity no. 2: Freeing a log in a debarking machine
- Activity no. 3: Changing tools on a numerically controlled lathe
- Activity no. 4: Freeing a log on a conveyor
- Activity no. 5: Manual lathe
- Activity no. 6: Changing an electrical motor
- Activity no. 7: A working passing beside a wrapper

- Activity no. 8: Adjustment of cutters on a packing machine
- Activity no. 9: Cleaning under a paper machine
- Activity no. 10: Greasing of an edger in a sawmill

An example of a questionnaire illustrating a hazardous activity is presented in Figure 2:

Task: Cutters adjustment on a packing machine

Hazard:

Hazardous situation:

Harmful event:

Harms:

Figure 2: One page of the questionnaire

The photographs illustrating the ten hazardous activities were chosen for their ease of comprehension from many photographs of hazardous situations taken in different production industries in Québec and elsewhere over more than 15 years. Some of these photographs are also being used in various training on machine safety; however, none of the experts who participated in the survey had seen these photographs beforehand.

3.2 ANALYSIS TOOLS

3.2.1 Reference glossary

A reference glossary was developed to define the terms or groups of terms that had to be considered as belonging to one of these four components. This glossary was bilingual since the basic survey was conducted in English, and was created from annex A (iv) of the standard during its revision, from the quick reference on machine safety produced by the CSST(vii). This latter document was chosen because it represents the consensus of a task force consisting mainly of CSST inspectors. In this glossary, two other components of hazards were identified, namely the origin and the consequence, because this breakdown is also used in the two reference documents. Approximately 370 terms and groups of terms were thus identified and translated based on need (French and English).

For some terms not specifically listed in the references, coding rules were based on the definitions previously indicated or by grouping the terms from different categories. For example, an action (coded C for consequence; example: cut) on one part of the body that specifies the part of the body involved (example: cut on finger) was coded D for harm.

3.2.2 Coding

All the terms listed by the experts on the survey forms, after potential correction and translation, were entered in tables with four main columns corresponding to the four components of the hazard (hazard, hazardous situations, hazardous events, harm).

From the glossary developed, all the terms or groups of terms were classified according to eight different types:

- Hazard (P); example: “revolving gears”
- Hazardous situation (S); example: “The worker is standing on the conveyor”
- Hazardous event (E); example: “The robot is starting”
- Harm (D); example: “Foot injuries”
- Origin (O); origin: “Stability”
- Consequence (C); consequence: “Crushing”
- Reference to a means of risk prevention or reduction (R); example: “is not wearing hearing protection”
- Uncodable according to the glossary (?); example: “‘unfortunate’ initiative without risk assessment by the operator”.

In some instance the used terms were not placed in the appropriate reserved space for the four components of the hazard (hazard, hazardous situations, hazardous events, harm) or were not classified as above:

- “Cut” (Consequence, in accordance with the glossaries) was indicated as Hazard;
- “Shearing” (Consequence, in accordance with the glossaries) was indicated as Hazard;
- “Fingers severing risks” (Harm, in accordance with the glossaries) was indicated as Hazard;
- “Untimely start-up of the machine” (Hazardous event, in accordance with the glossaries) was indicated as Hazardous situation;
- “Bypassed protections” (Protection, in accordance with the classification for coding) was indicated as Hazardous event;
- “Drawing in” (Consequence, in accordance with the glossaries) was indicated as Harm.

3.3 Analysis of Results

The results are presented using two complementary approaches in order to answer the two basic questions.

To answer the question whether all the experts describe the hazardous activities in the same way, for each of the ten photographs, the terms were counted in relation to the use of the eight types (P, S, E, D, O, C, R, ?) and also by indicating in which space of the form each term or group of terms had been placed. Table 1 below shows, for each of the hazardous activities, the distribution of terms placed in the spaces reserved for hazard and for hazardous situations based on the eight types or codes of terms used:

Table 1: Terms used to describe hazard and situations

	Hazard									Hazardous situation								
Activity	P	S	E	D	O	C	R	?	Number of terms used	P	S	E	D	O	C	R	?	Number of terms used
1	19	0	0	1	0	11	2	2	35	1	13	5	1	1	1	2	0	24
	54%	0%	0%	3%	0%	31%	6%	6%		4%	54%	21%	4%	4%	4%	8%	0%	
2	21	3	5	0	2	11	0	0	42	1	21	7	0	0	0	1	0	30
	50%	7%	12%	0%	5%	26%	0%	0%		3%	70%	23%	0%	0%	0%	3%	0%	
3	34	0	12	1	1	8	0	0	56	4	21	11	0	0	0	2	0	38
	61%	0%	21%	2%	2%	14%	0%	0%		11%	55%	29%	0%	0%	0%	5%	0%	
4	40	4	8	1	0	9	1	0	63	9	28	8	0	1	1	1	3	51
	63%	6%	13%	2%	0%	14%	2%	0%		18%	55%	16%	0%	2%	2%	2%	6%	
5	21	2	2	0	0	11	1	0	37	1	17	6	0	0	0	0	0	24
	57%	5%	5%	0%	0%	30%	3%	0%		4%	71%	25%	0%	0%	0%	0%	0%	
6	29	0	5	4	2	4	0	0	44	2	25	1	0	2	0	3	0	33
	66%	0%	11%	9%	5%	9%	0%	0%		6%	76%	3%	0%	6%	0%	9%	0%	
7	14	0	7	1	0	9	1	0	32	0	18	0	0	0	0	0	0	18
	44%	0%	22%	3%	0%	28%	3%	0%		0%	100%	0%	0%	0%	0%	0%	0%	
8	14	1	0	2	0	12	0	0	29	1	18	1	0	0	0	1	0	21
	48%	3%	0%	7%	0%	41%	0%	0%		5%	86%	5%	0%	0%	0%	5%	0%	
9	24	2	0	0	1	9	3	2	41	2	20	3	0	0	0	3	4	32
	59%	5%	0%	0%	2%	22%	7%	5%		6%	63%	9%	0%	0%	0%	9%	13%	
10	25	0	5	0	1	10	0	0	41	4	17	3	1	1	0	1	0	27
	61%	0%	12%	0%	2%	24%	0%	0%		15%	63%	11%	4%	4%	0%	4%	0%	
Total	241	12	44	10	7	94	8	4	420	25	198	45	2	5	2	14	7	298
	57%	3%	10%	2%	2%	22%	2%	1%		8%	66%	15%	1%	2%	1%	5%	2%	

P = Hazard;
S = Hazardous situation;
E = Hazardous event;
D = Harm ;
O = Origin ;
C = Consequence ;
R = Reference to a means of risk prevention or reduction;
? = Uncodable according to the glossary

By combining the results of the ten hazardous activities analyzed, hazard were identified in 57% of the cases by terms listed as descriptors of hazard (P), and in 22% by terms listed as descriptors of consequences (C). Also, hazardous situations were identified in 66% of the cases by terms listed as descriptors of hazardous situations (S), and in 15% by terms listed as descriptors of hazardous events (E).

Table 2 below shows for each of the hazardous situations, the distribution of terms placed in the spaces reserved for the hazardous event and for harm based on the eight types or codes of terms used:

Table 2: Terms used to describe the hazardous events and harm

	Hazardous event									Harm								
Activity	P	S	E	D	O	C	R	?	Number of terms used	P	S	E	D	O	C	R	?	Number of terms used
1	0	0	16	0	0	1	1	0	18	0	0	0	23	0	6	0	1	30
	0%	0%	89%	0%	0%	6%	6%	0%		0%	0%	0%	77%	0%	20%	0%	3%	
2	0	1	25	0	0	4	1	0	31	0	0	0	36	0	3	0	0	39
	0%	3%	81%	0%	0%	13%	3%	0%		0%	0%	0%	92%	0%	8%	0%	0%	
3	0	2	35	1	6	0	0	0	44	0	0	1	38	0	19	0	0	58
	0%	5%	80%	2%	14%	0%	0%	0%		0%	0%	2%	66%	0%	33%	0%	0%	
4	3	1	42	1	0	3	0	2	52	5	0	1	40	0	7	0	1	54
	6%	2%	81%	2%	0%	6%	0%	4%		9%	0%	2%	74%	0%	13%	0%	2%	
5	3	2	19	1	0	1	4	1	31	0	0	0	27	0	8	0	0	35
	10%	6%	61%	3%	0%	3%	13%	3%		0%	0%	0%	77%	0%	23%	0%	0%	
6	2	4	23	4	0	2	0	0	35	0	0	1	30	0	2	0	0	33
	6%	11%	66%	11%	0%	6%	0%	0%		0%	0%	3%	91%	0%	6%	0%	0%	
7	4	0	17	0	0	1	3	0	25	0	0	0	16	0	11	0	0	27
	16%	0%	68%	0%	0%	4%	12%	0%		0%	0%	0%	59%	0%	41%	0%	0%	
8	2	2	17	0	0	2	2	2	27	0	0	0	23	0	4	0	0	27
	7%	7%	63%	0%	0%	7%	7%	7%		0%	0%	0%	85%	0%	15%	0%	0%	
9	2	2	23	0	0	1	2	2	32	1	1	0	20	0	12	1	1	36
	6%	6%	72%	0%	0%	3%	6%	6%		3%	3%	0%	56%	0%	33%	3%	3%	
10	4	1	18	0	0	3	2	0	28	0	0	0	24	0	14	0	0	38
	14%	4%	64%	0%	0%	11%	7%	0%		0%	0%	0%	63%	0%	37%	0%	0%	
Total	20	15	235	7	6	18	15	7	323	6	1	3	277	0	86	1	3	377
	6%	5%	73%	2%	2%	6%	5%	2%		2%	0%	1%	73%	0%	23%	0%	1%	

By combining the results of the ten hazardous activities analyzed, hazardous events were identified in 73% of the cases by the terms listed as descriptors of hazardous events (E). Also, harm was identified in 73% of the cases by terms listed as descriptors of harm (D), and in 23% by terms listed as descriptors of consequences (C).

For comparison purposes, Table 3 indicates overall the number of times that terms relating to the eight types were used, regardless of the space on the form where they appeared.

Table 3: Overall distribution of the 8 types of coded terms

		Number of terms or groups of terms coded by type							
		P	S	E	D	O	C	R	?
Space used on the form	P	241	12	44	10	7	94	8	4
	S	25	198	45	2	5	2	14	7
	E	20	15	235	7	6	18	15	7
	D	6	1	3	277	0	86	1	3
	Total	292	226	327	296	18	200	38	21
	1418	20.6%	15.9%	23.1%	20.9%	1.3%	14.1%	2.7%	1.5%
	Total	P, S, E and D combined				O	C	R	?
		1141				18	200	38	21
		80.5%				1.3%	14.1%	2.7%	1.5%

Also, the distribution of the classification error for the 4 main components of risk is as follows:

- 12.9% of the terms coded as hazardous phenomenon were placed in a space other than that reserved for this aspect on the form;

- 26.7% of the terms coded as hazardous situation were placed in a space other than that reserved for this aspect on the form;
- 15% of the terms coded as a hazardous event were placed in a space other than that reserved for this aspect on the form;
- 3.5% of the terms coded as harm were placed in a space other than that reserved for this aspect on the form.

To answer the question whether all the experts do identify all the hazardous situations for each of the ten hazardous activities, each hazardous phenomenon that was identified by any of the experts was identified separately and the number of times that the experts mentioned it was counted. Table 4 indicates the number of times that a hazardous phenomenon was mentioned for each hazardous activity. One notes that between three (activity 1) and eight hazard (activities 3, 4., 5 and 9) were identified for each photograph examined. A total of 331 hazard were mentioned by the 17 experts for the ten photographs examined.

Table 4: Identification of hazard by the experts

Activity	Experts who identified the hazard	Number of the hazardous phenomenon							
		1	2	3	4	5	6	7	8
1	Number	17	1	1	0	0	0	0	0
	Percentage	100%	6%	6%	0%	0%	0%	0%	0%
2	Number	16	6	4	2	1	0	0	0
	Percentage	94%	35%	24%	12%	6%	0%	0%	0%
3	Number	15	14	11	2	2	1	1	2
	Percentage	88%	82%	65%	12%	12%	6%	6%	12%
4	Number	16	12	7	7	4	4	2	1
	Percentage	94%	71%	41%	41%	24%	24%	12%	6%
5	Number	11	8	6	3	2	1	1	1
	Percentage	65%	47%	35%	18%	12%	6%	6%	6%
6	Number	13	10	7	2	2	2	2	0
	Percentage	76%	59%	41%	12%	12%	12%	12%	0%
7	Number	16	6	3	2	0	0	0	0
	Percentage	94%	35%	18%	12%	0%	0%	0%	0%
8	Number	16	3	1	1	1	0	0	0
	Percentage	94%	18%	6%	6%	6%	0%	0%	0%
9	Number	13	8	4	3	3	2	1	1
	Percentage	76%	47%	24%	18%	18%	12%	6%	6%
10	Number	17	5	2	1	1	1	0	0
	Percentage	100%	29%	12%	6%	6%	6%	0%	0%
Total	Number	150	73	46	23	16	11	7	5
	Percentage	45%	22%	14%	7%	5%	3%	2%	2%

Table 5 below shows the number of hazard identified by each expert for each hazardous activity; one notes that between one and five hazard were identified individually by the experts for each photograph examined.

Table 5: Number of hazard identified per expert and per hazardous activity

Activity	Experts who identified the hazard	Number of hazard identified by one expert				
		1	2	3	4	5
1	Number	16	0	1	0	0
	Percentage	94%	0%	6%	0%	0%
2	Number	7	7	3	0	0
	Percentage	41%	41%	18%	0%	0%
3	Number	1	3	12	0	1
	Percentage	6%	18%	71%	0%	6%
4	Number	1	2	9	4	1
	Percentage	6%	12%	53%	24%	6%
5	Number	6	8	2	0	1
	Percentage	35%	47%	12%	0%	6%
6	Number	6	4	5	1	1
	Percentage	35%	24%	29%	6%	6%
7	Number	10	4	3	0	0
	Percentage	59%	24%	18%	0%	0%
8	Number	13	3	1	0	0
	Percentage	76%	18%	6%	0%	0%
9	Number	7	4	4	2	0
	Percentage	41%	24%	24%	12%	0%
10	Number	9	6	2	0	0
	Percentage	53%	35%	12%	0%	0%
Total	Number	75	41	42	7	4
	Percentage	44%	24%	25%	4%	2%

4. DISCUSSION

4.1 Description of the hazardous activities

From the results in Tables 1 and 2, it seems clear that the experts consulted do not rigorously describe the hazardous activities in the same way. However, trends can be identified and conclusions drawn. First, terms recognized as descriptors of hazardous events are most often used, since 73% of the answers mention them in the reserved space. In the same way, it can be concluded that rather uniform vocabulary is used to describe the harm since 73% of the answers in the space reserved for harm use terms that are associated with harm in the reference glossary.

There is less unanimity in the experts' descriptions of the hazardous situations since only 66% of the terms used in the boxes reserved for hazardous situations are terms associated with hazardous situations in the reference glossary. The other terms used to describe hazardous situations are terms describing hazardous events (15%), and to a lesser extent those used to describe hazard (8%).

Hazard are described in an even less unanimous way, since only 57% of the terms used in the boxes reserved for hazard are terms associated with hazard in the reference glossary. The other terms used to describe hazard are terms that describe consequences (22%), and to a lesser extent those used to describe hazardous events (10%).

Overall, the 4 types of main terms (P: hazard, S: hazardous situations, E: hazardous events, and D: harm) are used respectively in 21%, 16%, 23% and 21% of the 1418 descriptors used (see table 3). "Origin" type terms were not extensively used (1.3%). Terms defined as "consequence" type according to the reference glossary were used in 14% of the cases, mainly to describe harm (23% of the harm descriptors) and hazard (22% of the descriptors of hazard).

In 2.7% of the cases, the experts referred to a lack of means of protection or to defective means of protection. Finally, only 1.5% of the responses could not be coded by referring to the basic glossary.

In general, it can therefore be concluded that the four concepts proposed as risk components (Hazardous phenomenon, Hazardous situation, Hazardous event, and Harm) were used by the experts to express their vision of the risks associated with the ten photographs presented. However, since the terms were not always in the box reserved for the risk component identified, it can be concluded that there may still be some confusion in the type of identification of each component of the risk, particularly for the concept of hazardous situation (26.7% classification error).

Finally, a fifth concept (consequence) was used in a non-negligible proportion of cases (14.1%), even though this concept was not normatively defined.

4.2 Identification of hazard

In examining Tables 4 and 5, it seems clear that all the experts did not identify the same number or the same hazard for all the photographs showing the ten hazardous activities.

The nature of the hazardous situation clearly influenced the number of hazard that the experts identified since certain photographs noticeably revealed fewer hazard than others. For example, only one expert identified more than one hazardous phenomenon on photograph number one, and only four experts identified more than one hazardous phenomenon on photograph number eight; however, on some photographs (activities 3, 4, 5 and 9), eight hazard were identified. Some photographs (activities 3 and 4) clearly showed three hazard that were identified in more than half of the opinions expressed by the experts.

5. CONCLUSION

Event if the experts in the analysis of risks associated with industrial machines came from 10 different countries, the survey showed that the concepts associated with the basic risk components proposed in ISO 14121 can effectively be used and are extensively used. However, some concepts seem to be used more in compliance with the standard: these are the concepts associated with hazardous events and harm; in contrast, the descriptions of concepts of hazardous situations and hazardous phenomenon complied less with the standard. Some experts used a non-standardized concept, the consequence, in a significant way. It would be interesting to investigate why the experts used this concept rather than the four components of risk proposed in the standard.

Analysis of the data collected also showed that although many hazard were identified, they were not identified by only one person; this observation supports the general recommendation that a team and not just one person should carry out any analysis of the risks associated with industrial machines. This observation also shows that the identification of hazard and, by extension, the risks associated with industrial machines may vary greatly, depending on who identifies them. Formal research should also be carried out to identify the parameters that the experts use in their risk identification.

This survey showed that several experts see certain pictures, representing hazardous situations in a context of industrial production machines, from the same viewpoint, while others are not unanimous in their viewpoints.

The feasibility and methodology of a picture selection process were established for use in later research on the methods and tools for analyzing the risks related to industrial machines. Some of the pictures used in this survey will be chosen and used in future phases of the research in order to compare the results of the analysis of the risks associated with industrial production machines. It would be particularly interesting to carry out analogous surveys by presenting the same hazardous situations to different groups of different origins (H&S professionals, students, plant personnel, etc.) and to compare the results with those of the experts.

The methodology used to analyze this survey's results, involving a reference glossary, could also be used to analyze the result of risk assessment processes carried out in industrial environments.

This experiment must be considered as only an exploratory activity, without any objective of justification or explanation, even if the relative dispersion of the results goes toward the same conclusions drawn by other researchers in the domain of cognitive psychology applied to work related accidents (viii, ix, x, xi). A more systematical link with current researches in this domain will be established.

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