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Analysis and Classification of the Tools for Assessing the Risks Associated With Industrial Machines

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To assess and plan future risk-analysis research projects, 275 documents describing methods and tools for assessing the risks associated with industrial machines or with other sectors such as the military, and the nuclear and aeronautics industries, etc., were collected. These documents were in the format of published books or papers, standards, technical guides and company procedures collected throughout industry. From the collected documents, 112 documents were selected for analysis; 108 methods applied or potentially applicable for assessing the risks associated with industrial machines were analyzed and classified. This paper presents the main quantitative results of the analysis of the methods and tools.

risk assessment estimation methods tools safety machinery

1. INTRODUCTION

Machine-related hazardous situations have resulted in serious accidents in industries. In order to reduce these hazardous situations, machines must be designed or modified by integrating means of risk reduction. Without doing a specific risk assessment, it is difficult to choose optimized means of risk reduction. The procedures for assessing the risks associated with hazardous industrial machines are generally based on the international standards No. ISO 12100-1:2003 [1] and ISO 14121:1999 [2]. All these procedures are based on the same principles illustrated in Figure 1. In this figure, the risk assessment process is followed by the risk reduction process with an iterative approach (illustrated in broken lines) as defined in the ISO 12100-1:2003 standard. The risk assessment process comes to an end when the risk has been adequately reduced.

In practice, to carry out the risk assessment procedure presented in Figure 1, many methods and tools are available in different forms and produce a variety of results. Tools have been proposed mainly by organizations involved in the safety of industrial machines, in such countries as

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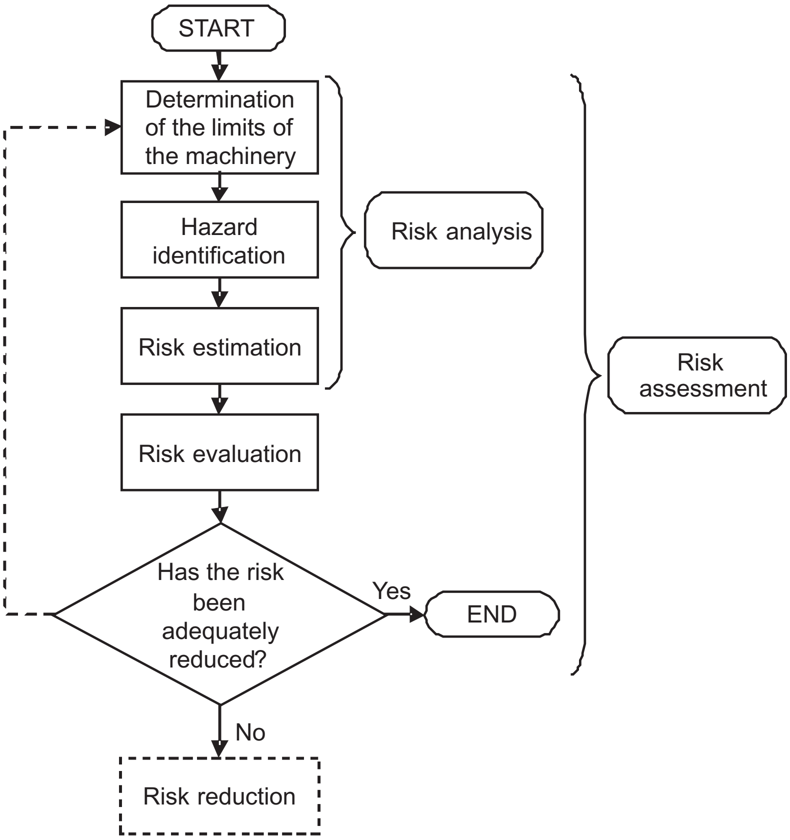

Figure 1. Management of risk assessment.

Canada [3], France [4], Switzerland [5], the UK [6], the USA [7, 8] as well as on the international level [9]. Some companies have also established their own analytical methods and tools. In fact, the large number of tools proposed or used for risk assessment shows that there is no single universal approach. As Main [10] and Worsell [11, 12] noted, there are many methods and tools proposed for carrying out part or all of such a process. Also, new forms of tools for estimating or evaluating the risks associated with industrial machines are regularly being proposed.

Previous studies have revealed that the needs of companies, mainly small and medium-sized enterprises, can vary significantly and that a method or tool used successfully in one plant does not necessarily correspond to the needs in another plant [13]. In particular, it is probable that the diversity of alternatives of tools available for carrying out the risk estimation phase is explained by the different needs from one plant to another. Few studies have been undertaken in order to better understand the application of the risk analysis methods and tools [14, 15, 16, 17]. Therefore, it is not easy to choose the tool best adapted to the needs of each company that wants to be involved in such a process.

A series of research projects was therefore proposed in a thematic program on the methods and tools for assessing the risks associated with industrial machines [18, 19]. These projects will be used to identify, compare and define criteria for using these methods and tools. This paper presents the results of the first project in this series; its objective was to survey and begin the characterization of the methods and tools for risk assessment, particularly the risk estimation and evaluation phases. The aim of this study was therefore to analyze the available bibliography in order to classify the different risk estimation and evaluation methods, to identify the characteristics of each of these methods and tools, and to group them into families where representative examples will be chosen in subsequent projects.

2. METHODS

2.1. Reference Bibliography

From a technical watch that has existed for more than 5 years, bibliographical searches, opportunities after in-plant interventions, and a follow-up similar to standardization work, 275 documents were collected and classified that refer to a greater or lesser extent to concepts associated with industrial risks.

These documents were collected by attempting to find those that are the most representative possible but not on a statistical basis. The consequence of this approach was that some methods or tools were found in several documents. In order to avoid systematic repetitions, the documents produced by a given organization and that contained clearly identical information were eliminated. In some cases, documents originating from the same organization but that presented alternatives were retained. The result is that any interpretation of the quantitative distribution of the methods and tools is somewhat imprecise; however, this distribution was considered as representative for comparison purposes.

2.2. Coding Methodology

The 275 collected documents did not all contain a method or a tool that could be used in a risk assessment process, but all alluded to them in a more or less detailed way. Some documents referred to a specific total or partial risk assessment process that was carried out, while others offered advice or presented guidelines that should be followed during such a process. Therefore, after a preliminary analysis, 112 of the 275 documents were retained and coded in a Microsoft Access relational database. All these documents were published in English (88 documents) or French (24 documents). They were originally published in European countries (Finland, France, Germany, The Netherlands, Poland, Sweden, Switzerland, and the UK: 44 documents), the USA (35 documents), Canada (23 documents), Australia (2 documents), or by international organizations (8 documents). Since some documents referred to several methods or tools, two computer files were defined, with one on the documents themselves, and the other on the methods or tools. The relational database established a link between the methods or tools and all the documents that referred to them.

Coding forms were established for coding the following main information:

- for documents (one form):
  - original designation (title, authors, year, editor, etc.);
  - type of document (standard, technical guide, article, internal company procedure, etc.);
  - origin (company, prevention organization, manufacturer, etc.);
- for methods and tools (10 forms):
  - general designation (name of method or tool, related reference documents);
  - type of application (general, general public, continuous or noncontinuous industrial process, any type of machine, specific machine, military equipment);
  - targeted users (preventionists, designers, managers, occupational health and safety [OHS] consultants, other, unspecified);
  - use of the method or tool (determining the limits, identifying the hazardous phenomena, risk estimation or evaluation or reduction, determining the intervention priorities, unspecified);
  - application and training (application of the method or tool in the real world, training required);
  - stage of use in the life of the machine (design, installation, start-up, operation, adjustment, repair, preventive maintenance, unjamming, unspecified);
  - type of risk level determination tool (matrix, risk graph, numerical operation, nomogram, combination of several types);
  - parameters used (severity, exposure frequency or duration, probability of harm or of the hazardous event, possibility of avoiding the harm, other);

- ranking or weighting of the parameters (name, exact term, qualifier, change threshold, description);
- risk characterization (name of risk level, value, description, action to be taken).

The content of the coding tables was mainly descriptive because the knowledge sought in this project in the coded documents was purely factual in order to produce a summary of knowledge and not to carry out a critical analysis. Some of these tools will be critically analyzed in future projects in the light of the results of their theoretical and practical performances.

Coding was based on specific information contained in the reference documents, i.e., the information was stated in the document (e.g., if it was stated that the method or tool was intended for a specific type of machine) or it was obvious that such was the case (e.g., when it was clear that the method or tool was intended for risk estimation only). Moreover, to ensure the scientific quality of the coding and the rigor of method identification, which could be described in several documents as formal or conceptual alternatives, a double independent coding was done by researchers at Institut National de Recherche et de Sécurité (INRS), France, and at Université du Québec à Trois-Rivières (UQTR), Canada. Once all the relevant documents were coded in two databases, a systematic comparison identified the differences, which were resolved during exchanges and confrontation sessions. The divergence was thus reduced from 36% (before long-distance comparison) to 12% (before final comparison), and a final consensus of all the partners was reached regarding the database. Finally, 108 risk assessment methods or tools potentially usable or used on industrial production machines were coded in the final database.

3. RESULTS

The coded data was initially analyzed to show the distribution of the methods and tools according to the main categories of information coded, based on general or precise questions, which were translated into queries using Microsoft Access and Excel software. The following sections present the main quantitative results for method distribution according to the different fields of analysis on the forms. These results are grouped according to the nature of the original reference documents, the application of the methods or tools, the nature and composition of the methods and tools for risk estimation and/or evaluation, the characteristics of the risk estimation parameters, the number of risk levels for risk evaluation, and the terminology used for the risk estimation.

3.1. Nature of the Original Document

The classification of coded documents according to the type of document is presented in Table 1. Technical guides published by prevention organizations as well as standards were the most common types of documents, representing in total 48.2% of the coded documents (32 and 22 documents, respectively). Documents obtained from companies were important in this study since they demonstrate an appropriation of the existing methods for an actual application often endorsed by companies. However, such documents were difficult to obtain because they were often considered essential for the company's internal management and therefore confidential, which explains the relatively reduced number of documents indexed.

TABLE 1. Distribution of Coded Documents According to the Type of Original Document

	Magazine	Scientific Journal	Other (Book, etc.)	Company Document	Guide	Standard	Detailed Procedure	Software
No.	7	4	21	12	32	22	12	2
%	6.25	3.6	18.8	10.7	28.6	19.6	10.7	1.8

Notes. 112 documents = 100%.

3.2. Application of the Methods and Tools

Tables 2–5 detail the distribution of methods and tools according to their application conditions. Table 2 presents the classification of the 108 methods and tools in relation to the targeted user. The total percentage is greater than 100% because 16.7% of the methods are intended for several types of individuals. A significant proportion of the methods and tools were intended for designers, among others, which is consistent with the requirements of Standard No. ISO 14121:1999 which "give guidance for decision during the design of machinery" (p. iv) [2]. However, for one third of the methods, the targeted users were not specified.

The distribution of the methods and tools in relation to the utilization objective as defined in the ISO 14121:1999 standard [2] (determination of the limits of the machine, hazard identification, risk estimation, etc.; see Figure 1) is presented in Table 3. The total percentage is greater than 100% because of the 108 coded methods, 38% combine identification, estimation and evaluation; 58.3% combine estimation and evaluation and 66.6% combine identification of hazardous phenomena and risk estimation. The objective "determining intervention priorities" was added because it was explicit for 29 of the 108 methods or tools (26.8%).

It is should be mentioned that 105 of the 108 methods (97%) were used for estimating and/or evaluating risks. For the three other methods, the estimation and/or evaluation approach was used for other purposes, e.g., to determine intervention priorities.

Table 4 presents the distribution of methods and tools in relation to the machine's lifecycle phases (design, installation, start-up, etc.) to which they apply. Sixteen point seven percent of the methods apply to several phases of the machine, and 11.1% of these apply to three phases or more. For example, 4.6% of the methods apply to the design and operating phase, and 7.4% involve the operating, repair and preventive maintenance phases. The majority of the methods (55.6%) do not specify the phases of the lifecycle to which the methods apply.

TABLE 2. Targeted Users of Method and Tools

	Preventionists	Designers	Managers	OHS Consultants	Others	Not Specified
No.	14	37	22	3	36	36
%	13.0	34.2	20.4	2.8	33.3	33.3

Notes. OHS—occupational health and safety; 108 methods and tools = 100%.

TABLE 3. Utilization Objectives for the Methods or Tools

	Determination of Limits of Machinery	Hazard Identification	Risk Estimation	Risk Evaluation	Risk Reduction	Determining Intervention Priorities	Not Specified
No.	18	83	95	74	47	29	1
%	16.7	76.8	88.0	68.5	43.5	26.8	1.0

Notes. 108 methods and tools = 100%.

TABLE 4. Distribution of the Methods and Tools According to the Machine's Lifecycle Phases

	Design	Installation	Start-up	Operation	Adjustment	Repair	Preventive Maintenance	Unjamming	Not Specified
No.	31	6	6	19	5	15	13	4	60
%	28.7	5.6	5.6	17.6	4.6	13.9	12.0	3.7	55.6

Notes. 108 methods and tools = 100%.

TABLE 5. Distribution of Methods and Tools According to the Types of Application

	General	General Public	Continuous Industrial Process	Noncontinuous Industrial Process	All Types of Machines	Specific Machine	Military Equipment	Not Specified
No.	16	4	12	15	39	9	6	30
%	14.8	3.7	11.1	13.9	36.1	8.3	5.6	27.8

Notes. 108 methods and tools = 100%.

Table 5 presents the distribution of methods in relation to the type of application. Fifteen point seven percent of the methods apply to several types of applications. When we combine the "general" type (16 methods) with the "all types of machines" type (39 methods) and with those with a "not specified" application (30 methods), we conclude that 78.7% of the analyzed methods or tools may be applied to a wide variety of situations.

All these tables reveal the diversity of the types of documents analyzed: the people for whom they are intended, the utilization objectives for the methods, the phases in the life of the machine, and finally the types of applications.

3.3. Nature and Composition of the Methods and Tools for Risk Estimation and/or Evaluation

Considering that 97% (105 out of 108) of the methods or tools were intended for risk estimation and/or evaluation, further analyses were done in order to classify these methods or tools according to their specific characteristics. Since risk is the combination of the probability of occurrence of harm and the severity of that harm [2], these methods or tools used different approaches to determine risk using the following parameters: matrix, risk graph, numerical operation, nomogram, or a combination of several types.

A risk matrix is a multidimensional table for combining any class of severity of harm with any class of probability of occurrence of that harm. Table 6 presents an example of a risk matrix (see Main [10] for more examples of the different types of risk determination methods or tools). The end result is a qualifying word or figure for the estimated risk of each of the identified hazardous situations. A risk graph has a tree structure that is generally worked from left to right. Each node of the tree represents one parameter (such as severity, probability of occurrence, exposure, possibility of harm avoidance). Each parameter has two or three classes; each class is represented by a branch from that node. Some methods use numerical (mathematical) operations (addition, multiplication, etc.) with or without formal weighting of each parameter to estimate the risk. The objective weighting of each parameter can be included in the notation (or through coefficients in the calculation formula) from a score assigned to the parameters. Finally, some methods use a graphical representation called a nomogram that uses scaled lines arranged in such a way that by connecting known values on two separate lines, an unknown value can be read at the point of intersection with another line.

TABLE 6. Example of a Risk Matrix

Probability of Occurrence of Harm	Severity of Harm		
	Slightly harmful	Harmful	Extremely harmful
Highly unlikely	Trivial	Tolerable	Moderate
Unlikely	Tolerable	Moderate	Substantial
Likely	Moderate	Substantial	Intolerable

The classification of methods and tools according to the type of risk determination is presented in Figure 2. The majority of the tools (58; 53.7%) use a matrix form to define risk. Of these 58 methods and tools that use a matrix presentation, 51 use only two parameters to determine the level of risk. However, 7 of the 11 risk graphs documented use more than two parameters to define the risk. This could be explained by the fact that it is more practical to combine several parameters in a risk graph rather than by a matrix with several dimensions. Nevertheless, since risk graphs can be converted into matrices by a simple modification of the graphical representation, practically two thirds of the methods could be used in matrix form.

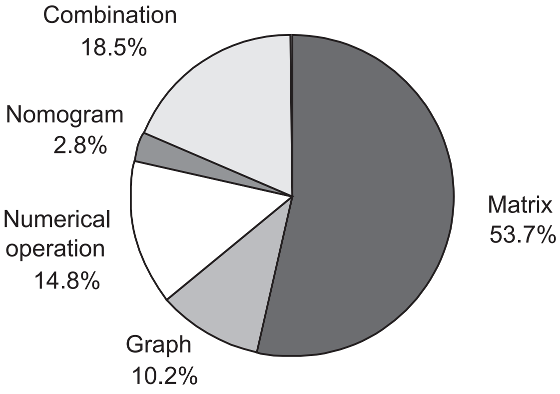

Figure 2. Distribution of methods and tools according to the type of risk level determination tool.

Many methods or tools use other parameters besides severity of harm to further describe the probability of occurrence of harm. Table 7 presents the distribution of the parameters used, and Figure 3 presents the distribution based on the number of parameters used by each method or tool analyzed. The 108 methods and tools mentioned use formally defined parameters varying in number from 1 to 5, with a majority using two parameters (61 methods, 56.4%), one being severity of harm (or consequence). Of these 61 methods with two parameters, 11 use the probability of occurrence of harm, 14 use the probability of the hazardous event, and 26 use an unspecified frequency and/or probability parameter as the second parameter. Also noted was that the three exposure parameters as well as the parameter "possibility of avoiding harm" are rarely used in methods with fewer than three parameters. In some cases, other parameters were mentioned, without being explicitly defined.

TABLE 7. Distribution of Methods and Tools According to the Parameters Used

	Severity of Harm	Exposure Frequency	Exposure Duration	Exposure Frequency and/or Duration	Frequency and/or Probability Not Specified	Probability of Harm	Probability of Hazardous Event	Possibility of Avoiding Harm	Other
No.	108	20	6	20	32	26	33	18	42
%	100.0	18.5	5.6	18.5	29.6	24.1	30.6	16.7	38.9

Notes. 108 methods and tools = 100%.

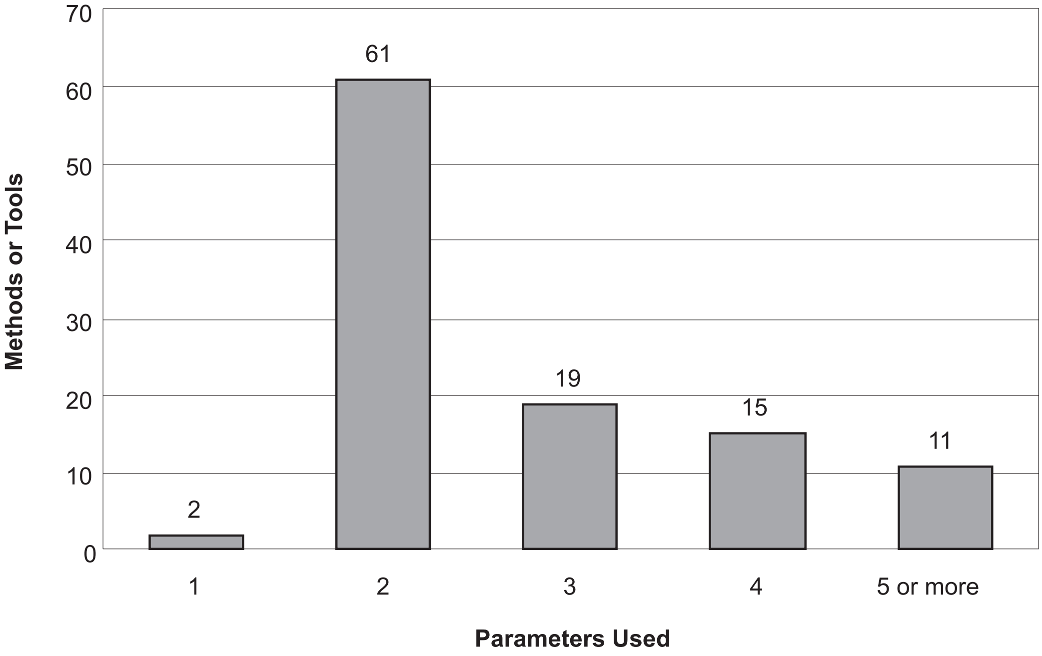

Figure 3. Number of parameters by methods and tools analyzed.

3.4. Characteristics of the Risk Estimation Parameters

Table 8 presents the number of thresholds (number of levels, qualitative or quantitative, that can be used to score a given parameter) for each of the analyzed parameters. This number of thresholds could not always be identified for certain methods or tools or when the parameter was expressed continuously, e.g., for use in a numerical operation. Those cases are indicated as not applicable in Table 8. Shaded cells in the table indicate the highest proportion for each parameter or group of parameters. For the majority of parameters, the number of thresholds is between three and five. An additional analysis demonstrated that there was no significant correlation between the number of thresholds specified for each parameter for a given method: each parameter in the same method generally has a number of thresholds different from the others.

For the 108 methods and tools analyzed, 305 different terms have been assigned to the used parameters. In 288 cases in which the parameters were defined explicitly, the definition mode could be qualified: qualitative, detailed qualitative, semiquantitative, quantitative, or hybrid as per the definition given below:

- qualitative—assigning a score (number or letter) from words without values or explanation, thus a choice cannot be made with a minimum of objectivity and repetition (e.g., for probability of harm: 1—*highly unlikely*, 2—*unlikely*, 3—*likely*);
- detailed qualitative—assigning a score (number or letter) from qualitative data using words; these words serve as benchmarks or

TABLE 8. Variation in the Number of Thresholds for Each Parameter

Parameter	No. of Mentions	No. of Parameter Thresholds										
		1	2	3	4	5	6	7	8	9	10	n/a
Severity of harm	108	0	4	24	46	20	8	2	0	1	2	1
	100%	0.0%	3.7%	22.2%	42.6%	18.5%	7.4%	1.9%	0.0%	0.9%	1.9%	0.9%
Exposure frequency	20	0	2	6	2	4	2	2	0	0	0	2
	100%	0.0%	10.0%	30.0%	10.0%	20.0%	10.0%	10.0%	0.0%	0.0%	0.0%	10.0%
Exposure duration	6	0	1	3	0	0	0	0	0	0	0	2
	100%	0.0%	16.7%	50.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	33.3%
Exposure frequency and/ or duration	20	0	6	3	3	3	0	3	0	0	0	2
	100%	0.0%	30.0%	15.0%	15.0%	15.0%	0.0%	15.0%	0.0%	0.0%	0.0%	10.0%
Summary: 3 exposure parameters	46	0	9	12	5	7	2	5	0	0	0	6
	100%	0.0%	19.6%	26.1%	10.9%	15.2%	6.5%	10.9%	0.0%	0.0%	0.0%	13.0%
Probability of harm	26	0	1	6	7	7	3	0	0	0	0	2
	100%	0.0%	3.8%	23.1%	26.9%	26.9%	11.5%	0.0%	0.0%	0.0%	0.0%	7.7%
Probability of a hazardous event	33	0	1	7	3	13	3	2	0	0	1	3
	100%	0.0%	3.0%	21.2%	9.1%	39.4%	9.1%	6.1%	0.0%	0.0%	3.0%	9.1%
Summary: 2 probability parameters	59	0	2	13	10	20	6	2	0	0	1	5
	100%	0.0%	3.4%	22.0%	16.9%	33.9%	10.2%	3.4%	0.0%	0.0%	1.7%	8.5%
Possibility of avoiding harm	18	0	11	1	0	2	0	0	0	0	1	3
	100%	0.0%	61.1%	5.6%	0.0%	11.1%	0.0%	0.0%	0.0%	0.0%	5.6%	16.7%
Frequency and/or probability not specified	32	0	0	6	5	12	6	1	0	1	0	1
	100%	0.0%	0.0%	18.8%	15.6%	37.5%	18.8%	3.1%	0.0%	3.1%	0.0%	3.1%
Other parameters	42	0	6	12	2	2	1	3	0	0	1	15
	100%	0.0%	14.3%	28.6%	4.8%	4.8%	2.4%	7.1%	0.0%	0.0%	2.4%	35.7%
Summary: all parameters	305	0	32	68	68	63	23	13	0	2	5	31
	100%	0.0%	10.5%	22.3%	22.3%	20.7%	7.5%	4.3%	0.0%	0.7%	1.6%	10.2%

Notes. Shaded cells indicate highest proportion.

points of comparison (e.g., for severity of harm: harmful—lacerations, burns, concussion, serious sprains, minor fractures, deafness, dermatitis, asthma, work-related upper limb disorders, ill-health leading to permanent minor injury);

- semiquantitative—assigning a score (number or letter) from quantitative data using words and numbers serving a benchmarks. (e.g., for probability of a hazardous event: frequent—likely to occur immediately or within less than one year);
- quantitative—direct use of the quantitative data applicable to the parameter (e.g., for probability of a hazardous event: estimate the likelihood of the event occurring in terms of frequency per year);
- hybrid—two types of notation are used to define the thresholds or values of a single parameter (e.g., some thresholds or levels of the parameter are defined using a qualitative approach and others are defined using a detailed qualitative approach).

Table 9 indicates the distribution of the methods and tools based on the nature and mode of definition of the parameters (shaded cells indicating highest proportion). Very few methods use quantified parameters to define the risk. In fact, the majority of the parameters are defined in a detailed qualitative way. However, the exposure duration and the possibility of avoiding harm are distinguished by their qualitative approach, while the exposure frequency is most often defined in

TABLE 9. Distribution and Definition of the Mentioned Parameters

Parameter	Total No. of Mentions	Total No. of Explicit Definitions	Definition of Parameter				
			Qualitative	Detailed Qualitative	Semiquantitative	Quantitative	Hybrid
Severity	108	108	23	77	14	1	7
			21.3%	71.3%	13.0%	0.9%	6.5%
Exposure frequency	20	18	2	4	14	0	2
			11.1%	22.2%	77.8%	0.0%	11.1%
Exposure duration	6	5	3	1	1	0	0
			60.0%	20.0%	20.0%	0.0%	0.0%
Exposure frequency and/or duration	20	19	6	7	6	1	1
			31.6%	36.8%	31.6%	5.3%	5.3%
Summary: 3 exposure parameters	46	42	11	12	21	1	3
			22.2%	28.5%	50.0%	2.4%	7.1%
Probability of harm	26	24	8	11	5	0	0
			33.3%	45.8%	20.8%	0.0%	0.0%
Probability of a hazardous event	33	32	8	19	7	0	2
			25.0%	59.4%	21.9%	0.0%	6.3%
Summary: 2 probability parameters	59	56	16	30	12	0	2
			28.6%	53.6%	21.4%	0.0%	3.6%
Possibility of avoiding harm	18	17	11	6	0	0	0
			64.7%	35.3%	0.0%	0.0%	0.0%
Frequency and/or probability not specified	32	32	10	14	8	0	0
			31.3%	43.8%	25.0%	0.0%	0.0%
Other parameters	42	33	8	17	8	2	2
			24.2%	51.5%	24.2%	6.1%	6.1%
Summary: all parameters	305	288	79	156	63	4	14
			27.4%	54.2%	21.9%	1.4%	4.9%

Notes. Shaded cells indicate highest proportion.

a semiquantitative way. It is interesting to note that these three parameters are also among those found the least frequently in the methods studied, with a representation of 5.6% for the exposure duration, 16.7% for the possibility of avoiding harm, and 18.5% for the exposure frequency (cf. Table 7).

Looking at Tables 7, 8, and 9, one notes that the severity parameter is present in all the methods and tools studied, but is based on a ranking that can vary from 2 thresholds (3.7% of the cases) to 10 thresholds (1.9% of the cases), with most of them using 4 thresholds (42.6% of the cases). A majority (71.3%) express severity in a detailed qualitative way. Severity is therefore a parameter considered as unavoidable in estimating machine-related risks. The exposure parameters are used in various ways (see “Summary: 3 exposure parameters” in Table 9). When they are explicitly defined, these parameters are often expressed semiquantitatively (50.0%). The probability of harm or probability of hazardous event parameters are used in 59 of the 108 tools and methods; they are generally expressed in a detailed qualitative way (53.6%). However, the possibility of avoiding harm parameter is used in only 16.7% of the methods. This parameter is generally expressed in a qualitative way (64.7%).

It is interesting to note that 32 of the 108 methods use an unspecified frequency and/ or probability parameter. This information is of concern because the fact of not explicitly specifying the frequency or probability data that is used to define the risk can lead to significant discrepancies from one case to another. For example, the probability of harm is generally clearly lower than that of a hazardous event, with the latter not necessarily leading to harm.

Other parameters were mentioned in 38.9% of the cases; these parameters are very heterogeneous because they make use of 40 different terms or expressions. These parameters are mostly expressed in a detailed qualitative way (51.5%).

3.5. Number of Risk Levels for Risk Evaluation

Figure 4 presents the distribution of methods in relation to the number of risk levels used during the evaluation. These levels are used to assign priorities to the risk reduction measures. The number of levels for defining the risk varies from 2 to 12. The most common values are 3 (32 methods), 4 (29 methods), and 5 levels (21 methods). One notes that 75.9% of the methods use between 3 and 5 risk levels. At the even more detailed level of the analyzed tools and methods,

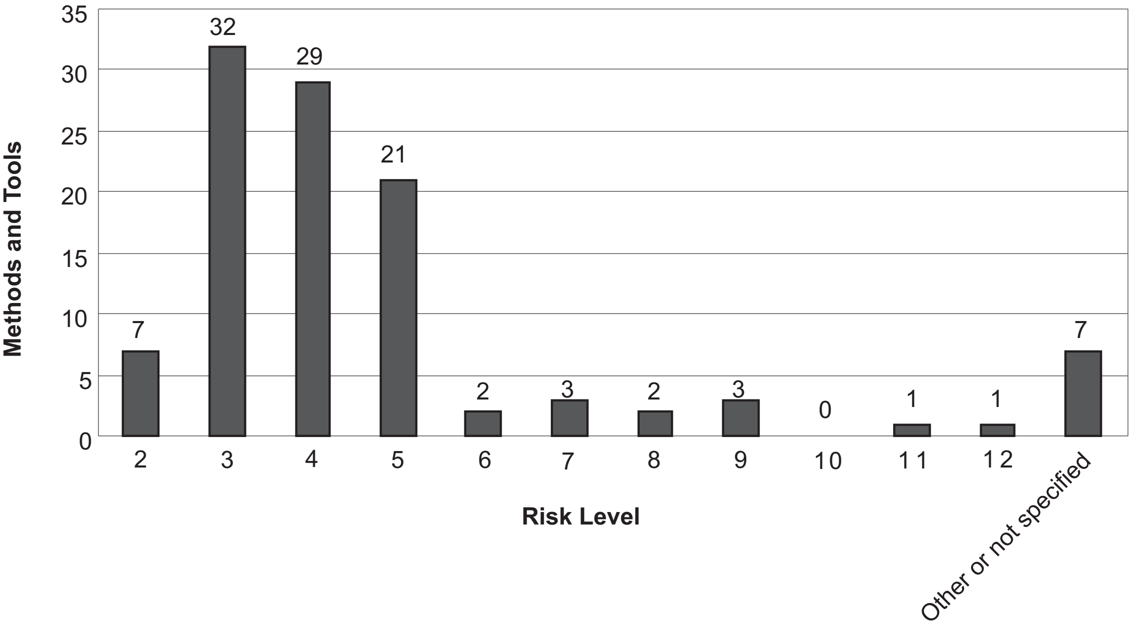

Figure 4. Distribution of methods and tools according to the number of risk levels for risk evaluation.

45 of the 58 documented matrices use 3, 4 or 5 risk levels.

3.6. Terminology Used for the Risk Estimation

For each parameter used, the exact term assigned was compiled. Due to the variety of terms used and the volume of results, only the names found for the severity parameter (Table 10) and for the exposure frequency parameter (Table 11) are presented here.

TABLE 10. Terminology Used and Distribution for the Severity Parameter

Name Used	No. of Mentions
Gravité—sévérité—severity	38
Consequence(s)—*conséquence(s)*	13
Gravité du dommage—severity of harm	11
Consequence—impact—effect	5
Severity of injury	5
Hazard severity	4
Severity of consequences	3
Gravité des dommages potentiels—severity of potential harm	2
Possible severity of injury (harm)	2
25 other terms used individually	1

Notes. Words in italic were taken directly from documents in French.

TABLE 11. Terminology Used and Distribution for the Exposure Frequency Parameter

Name Used	No. of Mentions
Frequency of exposure—exposure frequency—*fréquence d'exposition*	7
Frequency	3
Exposure—*exposition*	2
Fréquence d'exposition aux phénomènes dangereux—frequency of exposure to hazard	2
Frequency of access, of approach	2
Fréquence d'exécution de la tâche—frequency of task execution	1
Potentiel relié à la fréquence de l'activité (PFA)—potential related to the frequency of the activity	1
Exposition (fréquence de survenue de l'événement danger—exposure (frequency of occurrence of the hazardous event)	1
Exposure to hazard	1

Notes. Words in italic were taken directly from documents in French.

One hundred and twenty-five different terms were used to describe or to qualify the risk levels. Of them, 14 basic expressions for risk estimation and 9 basic expressions for risk evaluation were used several times. Twenty-five other terms without any particular meaning (1, 2, 3, A, B, C, etc.) were used solely for classification purposes. Finally, 77 various other estimation or evaluation terms or expressions were mentioned only once. The classification of the expressions used to qualify the result of risk estimation or the result of risk evaluation is presented in detail in Table 12.

TABLE 12. Terminology Used and Distribution for the Name of the Risk Levels

Name Used for Result of Risk Estimation	No. of Mentions
Extremely high	4
Very high	9
High	34
Serious	5
Substantial	4
Important	3
Possible	5
Medium (M)	20
Average	4
Moderate	6
Low (L)	29
Slight	2
Very low	3
Name Used for Result of Risk Evaluation	**No. of Mentions**
Negligible	5
Unacceptable	9
Intolerable	4
Critical	2
Undesirable	2
Tolerable	3
Acceptable with management review	3
Acceptable without review	2
Broadly acceptable	2
Acceptable	4

Notes. Twenty-five other classification terms (1, 2, 3, A, B, C, etc.) were mentioned several times (2–13 times); 77 various other terms for estimation or evaluation were mentioned only once.

4. DISCUSSION

The most notable aspect of the result analysis is in the diversity at all levels: diversity in the types of documents analyzed, the people for whom they are intended, the utilization objectives for the methods and life phases of the machine, and finally the types of applications. There is also great diversity in the nature of each risk estimation or evaluation method and tool: how to describe and define each parameter, the number of parameters, how to calculate and qualify the risk, how to classify or evaluate the final result, etc. However, this observed diversity does not prevent a definite identification of the general trends in the structure of the methods and tools studied.

4.1. Diversity of the Documents and Tools Analyzed and Their Use

The classification of documents according to their varied origins provides a rather broad picture of the methods and tools analyzed; it seems that it is easier for a potential user to obtain documents in the form of a guide or a standard. These documents describe methods and tools whose destination and use are expressed explicitly or implicitly:

- the targeted end-user public, although not specified in 33.3% of the cases, is rather diverse;
- the utilization objectives are almost always defined or at least identifiable;
- the phases of the lifecycle of the machines for which the methods and tools are intended are rather imprecise. When these phases are specified, the design phase is most often mentioned. The fact that the design phase is dominant is explained in part by the sources used, which are basically design guides and standards. These results suggest that the majority of the methods are relatively versatile and can be used for risk analysis in several contexts;
- the type of application for the methods and tools is mainly focused on machines, without specifying the particular type of machine. Considering that more than two thirds of the methods do not limit their application to specific cases, these results suggest once again that the majority of the methods are relatively versatile in their application to the analysis of machine risks.

4.2. The Major Families of Methods and Tools

Through the diversity of coded tools, six major families of methods and tools can nevertheless be identified for future research. These families were grouped for the following reasons:

1. a two-parameter matrix: the most common type (51 methods; 47.2%);
2. a matrix with more than two parameters: an alternative to the previous type (7 methods; 6.5%);
3. a risk graph: a rather common method of representing matrices (11 methods; 10.2%);
4. a numerical operation: a rather common calculation method different from matrices (16 methods; 14.8%);
5. a nomogram: an original calculation method, although not very common (3 methods; 2.8%); therefore, no conclusions can be drawn;
6. a combination: a rather common combined calculation method (20 methods; 18.5%).

By grouping the previously presented data, a typical portrait of the most common methods can be drawn:

- the method allows risk estimation and/or evaluation;
- the method is relatively versatile in terms of phases of the lifecycle of the machine for which it can be used, and in terms of the type of machine that it targets;
- the method is presented in the two-parameter matrix form;
- the method uses the severity parameter with either the probability of harm parameter, or the probability of the hazardous event parameter, or an unspecified frequency and/or probability parameter;

- these parameters are expressed on a detailed qualitative scale of three to five thresholds;
- the method expresses the risk on a scale from three to five levels.

4.3. Diversity in Terminology

The terms used are very diverse in how they describe in general and in detail the methods and tools as well as how they qualify the risk for estimation or evaluation purposes. It is difficult to provide explanations for these variations beforehand; several factors are probably the cause:

- first, the relative newness of the standards that apply to the assessment of the risks associated with industrial machines; e.g., the work relating to Standard No. EN 1050:1997 [20], which led to ISO 14121:1999 [2], dates from approximately 20 years ago;
- second, the phenomenon of "appropriation" of methods and tools may have led each "new" designer or group of designers of methods or tools to introduce his or their own vocabulary or concepts, without attempting to make the terminology uniform with an existing outside terminology; a beneficial effect of this factor is exactly the appropriation by the interested parties of the methods or tools developed internally; these methods and tools therefore are more likely to be followed and applied if their development was guided by future users and not imposed from the outside with a foreign terminology;
- third, differences in the needs felt about each industrial installation may have led to the use of slightly different concepts with "local" usage vocabularies;
- finally, the lack of visibility of reference documents (standards, laws, guides, etc.) did not facilitate the dissemination of common scientific knowledge; this phenomenon was probably made worse by the almost total lack of school or university training in this field.

4.4. Prospects for Future Research Projects

From the six major families of risk estimation and evaluation methods and tools, probably two examples of each will have to be selected in order to subject them to theoretical and practical tests to compare the results. By classifying them according to how the parameters are defined (qualitative, detailed qualitative, semiquantitative, quantitative, or hybrid), methods or tools can be chosen for testing in order to answer the following questions:

- What is the most precise theoretical way of defining a parameter?
- Does a more precise theoretical definition lead to a better convergence of the results (interoperator variability)?
- Does a more precise theoretical definition lead to a better coherence of the results for the same user (intraoperator variability)?

With a judicious choice of methods and tools, future experiments should provide answers to these as well as other questions. Classification of the different coded methods and tools will be used as a basis for choosing characteristic examples for their theoretical and practical testing in subsequent thematic programming projects on the analysis of the risks associated with industrial production machines. The detailed selection criteria will be defined within each project in relation to their respective objectives and means.

5. CONCLUSION

In the initial analysis, it is interesting to note that when the theoretical basis is mentioned either implicitly or explicitly in the document, it almost always refers to the general concept of risk as a combination of consequences (or harm) with a probability of an event or exposure. The general theoretical basis of all the tools and methods analyzed is therefore the same.

In the detailed analysis of each tool, we note that the "severity" parameter is used in all the methods. Severity is therefore a parameter considered as unavoidable in estimating the risks associated with machines. However, a parameter such as the possibility of avoiding harm is used in very few of the methods. As well, parameters such as the probability of harm, and the probability of a hazardous event are also not greatly represented. Since these parameters are used in Standard No. ISO 14121:1999 [2], in its original European version No. EN 1050:1997 [20] as well as in its updated version, it will be interesting to understand why they are so seldom used.

- Is there a dissemination problem with ISO 14121:1999 [2]?
- Are machine risk parameters poorly understood or poorly expressed?
- Is there a training or knowledge dissemination problem?

Also, can the great diversity of terms and expressions used be interpreted as a lack of standardization or even as a sign of appropriation of the concepts of the standard by method developers and tool designers? The great diversity in how the parameters are defined and in how risk is calculated leads to the same question. For the potential end user of a risk calculation result, the variety of vocabulary may be an obstacle when a final decision has to be made following risk evaluation.

This tends to show that for purposes of simplicity and method appropriation by companies, it is perhaps more judicious to have simple easy methods, rather than complex methods. With complex methods, the person carrying out the risk analysis has difficulty choosing the values for the different parameters involved in the risk analysis.

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