☐ Risk assessment
☐ Machinery
☐ Industry

THEMATIC PROGRAM: INTEGRATED PROJECTS ON RISK ASSESSMENT TOOLS FOR INDUSTRIAL MACHINERY

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In front of the diversity of the methods and tools for assessment of the risks associated with industrial machinery and the divergence of results sometimes observed (inter and intra – operators), it has been undertaken to analyze in depth the characteristics of the methods and tools proposed in the literature or used in the industries through a thematic program of research projects. The proposed projects will deal with the theoretical and practical aspects of methods and tools for assessing the risks associated with industrial machines as well as the training currently given in this field. The analyzed methods and tools as well as the related training strategies will be compared between them. Experiments based on the same hazardous situations will then allow a comparison of the results. Recommendations will be produced in the form of practical technical guides relating to the choice and use of tools for assessing the risks associated with industrial machines in addition to the training required to use them. Finally, in a subsequent phase of this thematic program, a project will be proposed for following up the practices followed in Québec industries for assessing the risks associated with industrial machines. This paper presents the main questions and the research projects proposed to bring answers. The state of the current situation of the projects will be exposed too.

OCCUPATIONAL HEALTH AND SAFETY ORIGIN AND ISSUE

In order to reduce hazardous situations at the origin of machine–related accidents, machines must be designed or modified by integrating means of risk reduction. Without carrying out a specific and rigorous risk assessment process, it is difficult to choose optimal means of risk reduction.

In order to train professionals in such a process, training sessions on machine risk assessment has been developed and presented. A specific project [1] has made it possible to train intermediaries who in turn presented this training in local companies. More than 560 people were thus contacted during the 16 awareness-raising sessions presented by the project's intermediaries.

Beyond the interest that this training raised and the analysis of this training which demonstrates that many participants transfer certain aspects of this training in their practice [2], questions were also raised during this training. In fact, it emerged that the needs of local companies, mainly small and medium enterprises (SME), can vary significantly and that one method or one tool used successfully in one plant does not necessarily correspond to the needs in another plant. It is likely that the diversity of tool alternatives available to carry out the risk estimation phase is due to the different needs from one plant to the next.

In the field of risks associated with the machines themselves, excluding lockout procedures, few specific directives are available to local companies for analyzing these risks, which are generally of a mechanical nature. Only a few large corporations have invested the necessary resources to develop systematic methods for analyzing the risks associated with hazardous machines; however, it is difficult to directly access these methods which are often considered as essential for the company's internal management strategy and therefore of a confidential nature.

Faced with a great diversity, prevention practitioners who want to carry out an analysis of the risks associated with hazardous machines, are unequipped to choose and apply an optimal method that produces useful results with a minimum of effort; these choices are even more difficult for SME, which have few or no resources in this field.

CURRENT KNOWLEDGE ON THE SUBJECT

Past studies revealed that there can be significant differences between different subgroups in the results of a risk assessment process carried out using the same machine (including the identification and estimation of the risks) from one group to another in estimating the risk index of some of the machine's activities or sub-activities [3]. A certain variability in the results can be considered "natural" according to Parry [4], and therefore tolerable, but too great a dispersion may eventually lead to a poor estimation of the means of risk reduction.

In the different European countries, experts interested in risk assessment processes arrive at the same observation:

« The methods used in the different European countries for assessing a machine's risks, when these methods exist, may lead to different, and even contradictory results. In some cases, they may potentially require, for a given machine, different levels of safety...» [5].

Abrahamsson [5] also seriously challenges the problem of the validity of existing tools by stressing that the latter often are perceived by potential users as not very credible or unusable.

These questions in the face of the validity of risk assessment tools are rather recent, even if the last few years have produced a significant increase in the tools available in America and Europe, suggesting that these tools give reliable and valid results. Our experience forces us to challenge this suggestion because many variables can influence the appropriate estimation of the risk indices of each of a machine's activities or sub-activities.

Very little research seems to have concentrated on validating one or more risk assessment tools in the field of machine safety, while attempting to identify the variables that can influence the proper estimation of a machine's risk indices. For example, Abrahamsson [6] attempted to validate various risk assessment tools in different contexts and particularly in the context of work in contact with chemicals; however, his research was focused exclusively on the analysis of the variables related to the risk assessment tool (the model and its parameters,...) without analyzing other variables that can modulate a proper estimate of a machine's risks (variable originating from prior training, variables originating from individual characteristics of person doing the analysis, ...).

Another more advanced example of research in this field was carried out by Wallstein and al. [7] who clearly showed, because of a carefully validated experimentation method, that "non numerical probability expressions convey vague uncertainties"; he thus showed that the definition of probability in the verbal form is not reliable.

In Europe, in the United States, in Canada and in other parts of the world, tools are proposed by organizations concerned with the safety of industrial machines; some companies have established their own methods and tools of analysis. All these processes are based on the same principles illustrated in *Figure 1*, derived from international standard ISO 12100-1 [8] which identifies two steps in the risk assessment phase: risk analysis and risk evaluation.

Risk analysis consists of three aspects:

- determining the limitations of the machine and its operation,
- identifying hazardous phenomena,
- estimating the risks.

International standard ISO 12100-1 [8] specifies the following definitions:

- "3.13 risk assessment: overall process comprising a risk analysis and a risk evaluation,
- 3.14 risk analysis: combination of the specification of the limits of the machine, hazard identification and risk estimation,
- 3.15 risk estimation: defining likely severity of harm and probability of its occurrence,
- 3.16 risk evaluation: judgment, on the basis of risk analysis, of whether the risk reduction objectives have been achieved".

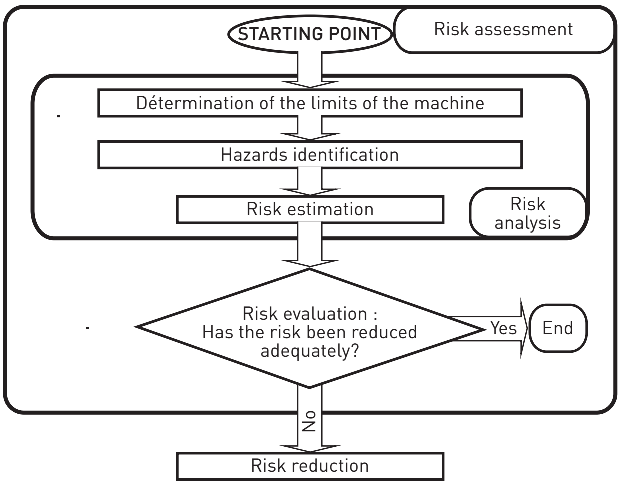
Even if most of the risk analysis methods and tools adapted to hazardous machines relate more or less to this model, they come in very different forms, it is not easy to choose the one best adapted to the needs of each company that wants to be involved in such a process.

In fact, the large number of tools proposed or used for these analyses shows that there is no single and universal approach; as Main [9] and Worsell [10] 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.

A recently finished project [11] has shown the great diversity of the used or proposed methods and tools for risk estimation and evaluation in the domain of industrial machinery.

FIGURE 1

Risk assessment based on standard ISO 12100-1



METHOD

Based on the previous observations, a set of questions has been identified:

- What are the different methods or tools for assessing and estimating the risks associated with hazardous machines used in industry?
- Do these methods or tools provide objective answers about the observed situations?
- What criteria should be used in choosing a method or a tool for assessing or estimating the risks associated with hazardous machines?
- Are the tools for risk estimation theoretically equivalent in their application and in their results?
- What are the determining factors for these tools?
- How must these methods and tools be applied in order to ensure an optimal result in relation to the resources that they require?
- What minimum training is required for optimal use of these methods and tools?
- How can a process for assessing machine risks be integrated into existing analysis processes in companies (ergonomic analysis of workstations, task analysis, ERGO teams, WHMIS, etc.)?
- What kind of link can be made between the risk assessment process and the risk reduction process?

In order to bring answers to these questions, a thematic program of research projects has been set, based on different tools and methods available (standards or guides) and used (internal company procedures) from 275 documents analyzed and classified in a first project [11].

This thematic program has been developed into the following aspects and questions, as the use and result of methods and tools for risk assessment depend on several distinct factors:

- Inventory: Which methods or tools are currently available (or used)? How these tools can be classified? On which base can they be compared? Which ones are the more representative?
- Theoretical aspects: How can the parameters of the tools be compared? How can the results of the tools be compared in the absolute? What could be the difference of results of different tools applied to the same situations?
- Practical aspects: What kind of dispersion of the results can be expected when different users of methods and tools from the same situations? How results obtained from the same users for different situations can be compared? How repetitive judgments will be made by the same users in front of the same situations? What kind of methods and tools are preferred by users? What are their reasons for their choice? Training aspects: What kind of training is necessary for each participant, depending of their role, in a risk assessment team?
- Follow-up of the application of the results of the projects: Once guides have been produced and diffused for application in industries, how are they applied in real life? What should be adapted in the guides to make them more suitable for the users' needs? What link can be done with the general risk analysis methods already existing in industries (safety task analyses, 6 Sigma group, ISO 9000, etc.).

RESULTS AND DISCUSSION

The thematic program of projects is proposed as the results of this method. *Figure 2* shows the estimated planning of activities and links between the different projects of this thematic program.

FIRST PROJECT: REASONED REVIEW OF THE TOOLS FOR ASSESSING THE RISKS ASSOCIATED WITH INDUSTRIAL MACHINES

Content of the project

This first project of the thematic program is now completed [11]. Its objective was to analyze the available literature in order to classify the different risk estimation and evaluation tools and to prepare the selection of those that propose the most representative methods and tools for subsequent testing; more precisely, it involved identifying the specific features of each of these methods and tools or types of tools.

In this project, 275 documents describing methods and tools for assessing the risks associated with industrial machines or other sectors such as nuclear, military, aeronautics, 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 and coded in a relational database; the detailed coding for the documents was based on origin and use; the detailed coding for the methods and tools was based on type of risk level determination tool, parameters used, graduation or weighting of the parameters, risk characterization, type of application, expected use of the method or the tool, stage of use in the life of the machine.

Finally, 108 risk estimation or evaluation methods or tools potentially usable or used on industrial production machines were coded in the database and analyzed to show their distribution.

Results of the project

The most notable aspect of the analysis lies in the diversity at all levels: diversity in the types of analyzed documents, the people for which they are intended, the utilization objectives for the methods and life phases of the machine, and the types of applications. The very nature of each method and tool to estimate or evaluate the risks presents also a great diversity: the way to describe and to define each parameter, the number of parameters, the way to determine or to qualify the risk, the way to classify or evaluate the final result, etc.

However, this observed diversity does not prevent the definite identification of the general trends on the structure of the methods and tools studied.

The classification of methods and tools based on type shows a high majority of tools (53.7%) that use a matrix presentation to determine the level of risk.

The "severity" parameter is present in all the methods and tools studied, but based on a graduation that can vary from 2 thresholds (4% of the cases) to 10 thresholds (2% of the cases), most of them using 4 thresholds (43% of the cases). A majority (71.3%) express severity in a detailed qualitative way.

The "exposure" parameter is used in various ways, either in a single way (18 cases or 16.7%) or broken down into other sub-parameters (56 cases or 51.8%). This parameter is generally expressed semi quantitatively (39.2%) or in a detailed qualitative way (35.1%).

The "Probability of harm" and "probability of a hazardous event occurring" parameters are used together in 54.6% of the tools and methods; they are generally expressed in a detailed qualitative way (53.6%).

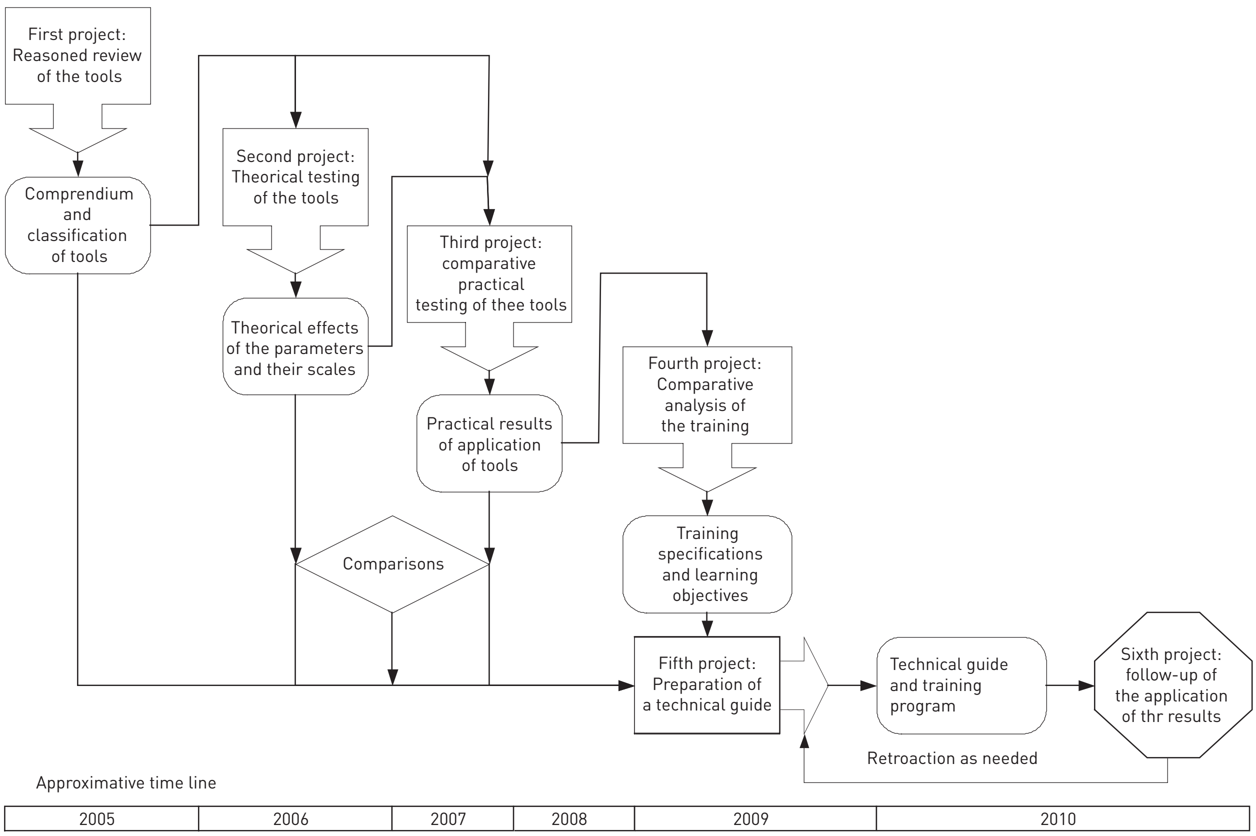
Conclusion of the project

It is interesting to note that the general theoretical basis of all the tools and methods analyzed is the same because they almost always refer to the general concept of risk as a combination of consequences (or harm) with a probability of an event or exposure.

The "severity" parameter is used in all the methods. Severity is therefore a parameter considered as unavoidable for estimating the risks associated with machines. However, a parameter such as the "possibility of avoidance" is used in only 16.7% of the methods. As well, parameters such as the "probability of harm occurring" (24% of the methods use it), and the "probability of the hazardous event occurring" (30.5% of the methods), are also not widely represen-

FIGURE 2

Estimated planning of activities and links between the different projects of the thematic program



ted. Since these parameters are used in ISO 14121 [12], it will be interesting to understand why they are so little used.

Regarding the parameters and the type of used tools, this project has found that 82% of the methods use between 2 and 5 risk levels, and 49.1% of the methods use 2-parameters matrix methods. Only 4.6% of the methods and tools use a matrix presentation with more than two parameters. This tends to show that for reasons of simplicity and method appropriation by companies, it is perhaps more judicious to have simple methods that are easy to use, rather than complex methods.

The comparison of the results of risk estimation made with different tools presents several obstacles, mainly due to the variation of the parameters' nature and numbers, in scoring the parameters, in the way to calculate the final result and in the wording used to qualify the results.

SECOND PROJECT: THEORETICAL TESTING OF THE TOOLS FOR ESTIMATING OR EVALUATING THE RISKS ASSOCIATED WITH INDUSTRIAL MACHINES

Content of the project

The project will be undertaken to analyze and compare the theoretical performances of some of the methods or tools for estimating or evaluating the risks associated with hazardous machines that have been identified and studied during the previous project [11].

The methodology of this project presents five main stages:

Selection of methods or tools to be used for the research:

As the number of identified methods or tools (108), identified and analyzed during the previous project, is too high, a selection of the ones to keep for analysis (likely between 10 to 20) will be made, among the 108 identified and analyzed during the previous project PR 99-434 [11].

Definition of equivalence scales for the selected method

Considering the great diversity of tools, the comparison of the between the results of the theoretical application of each tool will represent the main difficulty of this project. This will be managed using equivalence scales defined for each parameter of each selected method.

The risk estimation tools (or risk evaluation tools in some cases) will be compared using equivalence scales based on the different parameters that they involve, the way that these parameters are expressed, and the way that the final result of the estimation (or evaluation) is obtained.

The parameters used will be the following:

- severity of the harm,
- probability of damage, exposure, hazardous event or other,
- exposure to the hazard,
- possibility of avoiding the hazard or the accident.

The way that the parameters are defined may take the five following forms, as a result of the previous project PR 99 343 [11]:

- qualitative,
- detailed qualitative,
- semi quantitative,
- quantitative,
- hybrid.

Equivalence scales will be established for each parameter of each tool selected for analysis. Equivalence of the parameters will be easy to achieve for the parameters defined quantitatively or semi-quantitatively, as defined in a previous paper [11].

For the parameters defined qualitatively or pseudo-quantitatively, an equivalence table of the qualifiers used in natural language will be established and used, according to the bases that other researchers have used or tested [12, 14, 15]. Preliminary tests showed that such equivalences tables could efficiently traduce the results from one method to another. Table 1 shows an example of equivalence table for severity of harm between four different estimation/evaluation tools.

Once equivalence scales or tables have been established for each parameter *(severity of the harm, probability of damage, exposure, hazardous event or other, exposure to the hazard, possibility of avoiding the hazard or the accident)*, comparison will be made for each parameter of the same nature for all the analyzed tools. However, it is possible that multiple equivalence tables will be required to translate one of the parameters of all selected tools. In this case, sub-classifications or clusters will be created and treated separately for the rest of the thematic program. This should not affect the overall outcome of the research.

Comparison of the theoretical results of the use of these tools

The possible results of the risk estimation tools will be theoretically compared using the equivalence model on a representative selection of the risk estimation and evaluation tools. This analysis will show the effect of the number of parameters and their scales on the possible results (theoretical equivalence of the tools), as some researchers have already done in a more specific context [16].

Once equivalences have been established between the different tools for analysis, a systematic comparison of the results will be done with all the possible values of the parameters in order to detect mainly the intrinsic biases of each risk calculation tool analyzed.

Application of the tools on reference situations

The selected and analyzed tools for risk estimation and evaluation tools will then be applied to 10 to 20 reference machine situations chosen for their diversity and their representativeness of real situations. The risk estimation process will also be carried out in order to identify the differences in the results obtained with certain risk estimation tools, depending on whether they are used before or after introducing risk reduction measures.

This project will consist mainly on defining criteria for selection and analysis of existing methods and tools exposed in documents (collected in the previous project). The definition of the criteria and classification of elements will be done by the whole research team. Once this is defined, all these research operations will be done in double by separated smaller teams in order to reduce risks of errors in coding, classifying, analyzing, interpreting or calculating the data; the results of these operations will be compared to obtain a consensus among the research teams.

Expected results of the project

The conclusions of these analyses will help in producing theoretical recommendations in the final guide on tools

TABLE I

Example of equivalence scale of severity of harm

Equivalence SEVERITY	Tool A Severity	Tool B Severity of the Damage	Tool C Severity (Se)	Tool D Severity (Se)
S1	S1 Minor Injury (Normally reversible or requiring first aid only).	V : Very slight (Injury without loss time)	Se = 1 Scratches, bruises which are cured by a first aid or similar.	G1 Slight injury (normally reversible); Examples: Scratches, bruises, laceration, slight injury requiring first aid.
S1		IV : Slight (Injury with loss time)		
S3	S2 Major Injury (Normally irreversible or requiring more than first aid).	III : Moderate (Slight disability)	Se = 2 More severe scratches, bruises, stabbing, which require medical attention from professionals.	G2 Severe injury (normally irreversible including death); Examples: broken or torn limb; serious injury requiring stitches, MSD, death, etc.
S4		II : Serious (Severe disability)	Se = 3 Normally irreversible injury. It will be slightly difficult to continue work after healing.	
S5		I : Very Serious (Death)	Se = 4 Irreversible injury in a way that it will be very difficult to continue work after healing, if possible at all.	

for estimating and evaluating the risks associated with machines available or used in industries. These conclusions will also be used to establish the scientific bases of the subsequent steps in the thematic program.

THIRD PROJECT: COMPARATIVE PRACTICAL TESTING OF TOOLS FOR ESTIMATING OR EVALUATING THE RISKS

Content of the project

This project will analyze and compare the practical performances of the tools for estimating or evaluating the risks associated with hazardous machines that will have been identified, selected and tested on a theoretical aspect and for which equivalence scales have been defined in the previous project.

In this project, designated populations will be trained to the use of the tools for estimating or evaluating the risks associated with hazardous machines; then they will be exposed to the same hazardous situations on industrial machinery and asked to apply the tools. The results of the applications of the tools will be compared under different aspects: ease of use, cohesion or dispersion of results, etc. The opinion of the exposed populations regarding the tests and the used tools will be collected and analyzed. At this stage, the number of exposed population is not yet defined. The results of previous projects and the available resources at the time of the project will have a great influence on the number of the exposed populations.

Particular care will be taken to select the hazardous situations used for experiments. This selection will be done by taking into account the taxonomic difficulties associated with the description of the risk's components and parameters, as identified in general [17]. This will be the main challenge of the project and will require the active input of psychology specialists.

The exposed populations will be selected carefully among people who participate or will participate to a process of risk assessment of industrial machinery; it is expected that their main function can be:

- operation (machine operator or helper)
- maintenance (electrician, mechanic, adjuster, cleaner, etc.)
- management (foreman, staff, human resource, etc.)
- occupational Health and Safety (OHS professional, partial or full time, union or company representatives, etc.)
- design (in house or external consulting engineer, in some cases maintenance staff, etc.)

Consideration should be given to the passed and personal experiences of the exposed populations (age, working years, participation to OHS committees, past training, etc.). The organization of the tests will have to take into account that usually the risk assessment results are obtained by consensus in teams. These precautions are necessary to take into account the results of researches which have shown the subjectivity of experts analyzing occupational accidents, in order to avoid or at least reduce the «self-serving bias» [18].

Expected results of the project

The comparison of results of the tests will allow to confirm or infirm the results of the theoretical experiments made in the previous project. Analysis of variance will show the range of dispersion which can be expected for different tools and hopefully help to select the more reliable ones. This will directly conduct to recommendation for selection and application of the tools.

Fourth project: Comparative analysis of the training associated with machine risk assessment

Content of the project

This project will compare different training in methods for assessing the risks associated with hazardous machines in order to define the key parameters and to make recommendations to the organizations likely to offer this type of training.

Information on existing training programs on industrial machinery risk assessment presented in different countries will be collected.

Data and evaluation methods for training program on risk assessment have been already made available in a previous study [1]. It will be necessary to adapt this evaluation model in order to include information relative to the exposed populations, such as, but not limited to:

- links with previous knowledge,
- interactions between participants,
- participants expertise and variability,
- active participation,
- required and developed competencies,
- initial contextualization and number of re-contextualizations,
- similarity between contextualization presented during training and those of experimentation,
- knowledge organization in long term memory,
- knowledge construction (declarative, procedural and conditional).

Expected results of the project

Based on the used evaluation model, conclusions and recommendations will be made for future training programs on industrial machinery risk assessment. This could be done under the format of competencies and learning objectives which could provide recommendations on the specific elements to be incorporated into training.

Fifth project: Preparation of a technical guide on the choice of methods and tools and the related training

Content of the project

This project is the outcome of the thematic programming, and will synthesize and transfer the results of the preceding phases into practice.

Expected results of the project

The objective of this project is to prepare a technical guide including training material for potential users (OSH practitioners and designers of machinery), to facilitate the choice and application of machine risk estimation and evaluation methods. This technical guide will be inspired on other documents of the same nature previously published by the Institut de recherche Robert-Sauvé en santé et en sécurité du travail of Quebec (IRSST) [see i, ii]. The detailed content of this guideline will be defined once the results of the previous projects are known.

At this stage, it is not possible to predict if new methods and tools will be created (meta-method) based on existing or if the recommendations will apply only on existing tools which have been extensively tested during the projects.

Sixth project: Follow-up of the application of the results of the projects

Content of the project

A final project will deal with the follow-up and evaluation of the outcomes of the application of the results of the previous studies. This could be done by interviews and visits of industries who have started risk assessments and collecting their feedback, using tools which have already been used in other previous projects [22]. It is currently very difficult to describe the used tools in details because they will depend very much of the detailed objectives of this project and their applications. A selection and adaptation will be made among general tools such as interviews, observations, statistics analysis, etc." This project will also take into consideration of a research just finished on the same kind of matter [22].

Expected results of the project

This project will allow to appreciate the change in companies' culture and the results of introducing risk assessment of risk associated with industrial machinery on accident.

CONCLUSION

From these researches, OSH practitioners and designers of machinery will have access to precise theoretical and practical information on the methods and tools for assessing the risks associated with hazardous machines. OSH practitioners will be in a position to select or recommend to industries the best appropriate methods and tools. Designers of machinery will be in a position to select and use the more appropriate method and tool for their needs.

A better knowledge of methods and tools available for assessing and estimating risks associated with industrial machinery will be made available.

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