Safety of machinery: requirement specification based on functional need and work situations analysis

Mahenina Remiel Feno[1] · Patrick Martin[2] · Bruno Daille-Lefevre[1] · Alain Etienne[2] · Jacques Marsot[1] · Ali Siadat[2]

Abstract
This paper describe the ongoing work jointly between INRS and LCFC/ENSAM to take risk prevention into account in the specification drawn up when considering buying or designing work equipment (special machine, individual workstation, assembly line, etc…). The methodology is based on the functional need analysis and the concept of work situations as defined by INRS in their previous research work. The aim is to bring together the "user" and the "designer" in a dynamic of dialogue, in order to define the main work situations and not only the technical system. An overview of the problem is first described, followed by a brief review of methods currently in use. We then describe the different steps involved in the proposed methodology, before examining the results of a case-study application to a milling machine in which the benefits of such an approach and its acceptability by SME/SMIs are assessed.

1 Introduction

The "Integrated prevention" is widely shared by European countries since the 90s (Fig. 1). It consists of applying as early as possible safe design principles in the design process. The aim is to make a preliminary risk analysis in order to get a lower level of risk while designing complete future machine.

Many documents on safety issues (design instructions, guides, standards…) for safe design principles are not yet correctly applied in most companies, especially SME/SMIs. This is actually because the different actors of the design process (designers, project leaders…) are not prevention specialists, and don't have not formal methods and tools [2,3] adapted to perform *a priori* risk assessments. They are limited, on the one hand, to the risk families closest to their field of experience (for example, mechanical), and on the other hand, to carrying out this assessment more often at the end of the project, once all the technical solutions have been defined. Therefore, they can hardly make the right choice in a timely manner without penalizing the project cost or delay. So, the integration of safety in the design process is mainly based on the individual knowledge or experience of designers and they don't follow a formalized way [4]. This fact regarding the whole design process is also verified at the specification stage. Many exchanges with both designers and final users from SME/SMIs have confirmed that requirements about "health safety and ergonomy" are not as detailed as those purely functional. For instance they are amounts to stereotypical sentences like "the equipment should respect regulations and standards …", "should be safe, ergonomic and easy to use …"

As a result, designers generally handle prevention issues from technical requirement at the end of the project when technical solutions chosen reduce sharply the range of feasible safety solutions and implemented measures are mainly corrective to satisfy regulation. We cannot thus consider that this is a real safety integration which takes into account the future activity of the operators, including the "reasonably foreseeable misuse » as it is write on European Directive [5].

✉ Patrick Martin
patrick.martin@ensam.eu

Bruno Daille-Lefevre
bruno.daille-lefevre@inrs.fr

Jacques Marsot
jacques.marsot@inrs.fr

1 Work Equipment Engineering Department, Institut national de recherche et de sécurité (INRS), 1 rue du Morvan, 54519 Vandœuvre-Lès-Nancy Cedex, France

2 Laboratoire de Conception Fabrication Commande, Arts et Métiers ParisTech, 4 rue Augustin Fresnel, 57078 Metz, France

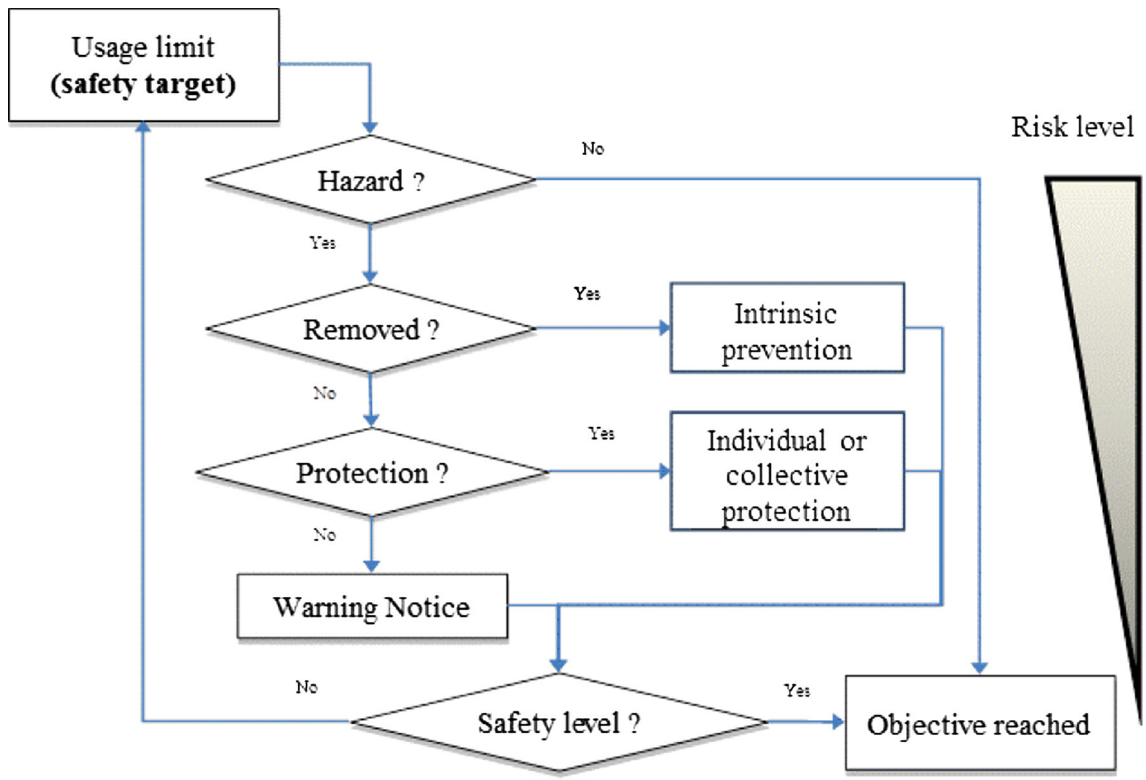

Fig. 1 Risk reduction process according to Risk reduction process according to NF EN ISO 12100 [1]

So in order to answer to this problem, the following methodology has been developed in the frame on our joint laboratory between INRS and Arts et Métiers focused on integrated safety. The objective is to involve stakeholders in a dynamic of dialogue to define together all the necessary informations to implement safe design principles at the very beginning of the design phase (during the functional specification).

The "Integrated prevention" is a specific point of view of the paradigms of concurrent engineering or collaborative engineering or integrated design [6–9]. These paradigms are not only dedicated to technical application but also to human aspects [10] which is the context of this work. For this goal it is necessary to use different complex and heterogeneous design tools (requirements, tables, data bases, models, rules, engineering /CAD/CAM softwares…) for the different phases of the product life cycle. They allow to formalized the need and knowledge of the different actors (user, designer, manufacturer, maintenance service…) who share the documents and have to interact and collaborate. More this collaborative/interactive engineering have to be efficient (project management, information consistency, relevant information,…) in order to save time, cost and avoid defects or accidents. In this context, this paper is related to the specification phase of the design process where the user and the designer collaborate in order to precise the product requirements in terms of safe uses (the working situation) and to get precise, complete and consistent information. This interactive engineering between actors who have their own point of view and have to share it for designing the best product/machine, is developed with a specific and structured methodology based on dedicated and structured questionnaire, data base, link between objects and data processing for identification of potential hazards.

2 State of the art

This paper focuses on the early stage of the design process called "specification", where the need, use during all the life cycle about the future work equipment are clearly identified. These specifications are supposed to contain health, safety and ergonomics informations.

Although "integrated prevention" is widely studied by the scientific community, a few research works concern this specification stage. In fact, whether it is about engineering or human science, these works mainly deal with the whole design process [4,11,12] and associate tools [13–15] or specifically the designers' activities [16–18]. Martin et al. [19] also pointed out the fact that engineering design research works focused essentially on mass production product and less on special machines. They also confirmed that specification stage has been studied less than other stages of the design process.

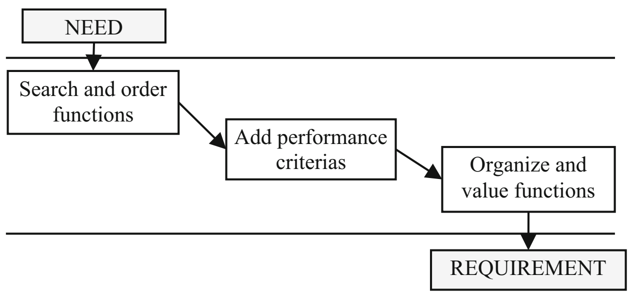

Fig. 2 The main steps of need functional analysis

Some papers concerning safety integration at the specification stage recommend considering health, safety and ergonomics as design objectives that should be specified in the requirement document. So requirements should go beyond classical standards on safety and have to take into account of the predictable use of the working equipment by analyzing the activities of the operators on similar equipment and production activities [11,20–22]. In fact these real activities are different from the nominal ones.

2.1 Need functionnal analysis (NFA)

The functional analysis is one of the methodological tools which can support the specification stage. It was created in the 40s by General Electric to deal with economic and strategic challenge and requires a multidisciplinary approach to ask about the real expectations of users regarding a product or service.

The purpose is to take an inventory, characterize and order in a hierarchy, all the functional needs (Fig. 2) which should be expressed in term of finality and not technical solutions. This methodology is standardized [23], and widely spread, taught and well known for the machinery designers and also integrated in design software.

On the theoretical point of view, NFA should identify exhaustively the expected functionalities of the future work equipment during the different steps of its lifecycle (setup, production, maintenance, dismantling).

On one hand, some papers underline the benefits of the functional analysis towards the prevention of risks because of its pluridisciplinary approach [24], on the other hand, some describe its limits about the ability to specify different contexts of use and future user activities [25].

2.2 Working situation model (MOSTRA)

MOSTRA resulted from INRS previous research work about safety integration in design [26]. The objective of this model is to help designers in taking into account different contexts of use and future user activities. It allows showing, in the frame of a database model information (Fig. 3), the relevant parameters which describe the working situation. The concept of working situations systemic has been described by Guillevic [27] and uses entities which are involved in work safety. It allows to take into account of information and elements related to the situation in which the system is going to be exploited. Moreover this model allows registering process history and all modifications brought to system during its design. The knowledge retained can be re-using for later design.

Manufacturing systems are an organized set of mechanical and electronical devices (components, sub-components, tooling, auxiliary, PLC, sensors…) implemented together to create products and services. This system, when it is used in several phases of life cycle (assembly, use, set-up, maintenance, disassembly…) defines a working situation. It needs one or several human operators, to supervise, control it or to realize precise tasks. These components based on technical solutions and the work organization can engender Dangerous phenomenon (Hazard). This concept characterizes any cause able to provoke injury or damaging to health of the operator or even a third party entering the working situation zone for a system configuration, in a dangerous zone at a defined instant. Risk for the operator (injury, health damage, ergonomics...) is a combination of probability and the level of the possible damage.

A specificity of this model is to have a specific structure with no specific input or preferred output data [28]. For instance the technical designer could firstly input the "Technical solutions" objects when the safety manager would prefer the "Risk" objects. So this model cannot manage by itself during the design process and it is necessary to use it in connection to classical design tools in order to exploit it.

3 Specification methodology for safe design

As previously defined, the objective of this research work is to bring the binomial "user/designer" to define necessary informations to integrate safe design principles in the specification stage. The methodology relevance which is developed is assured by the logical use of these tools and the data consistency provided by MOSTRA. To do so, the link between work situations model and the identified functions with NFA is developed in order to access to the risk assessment.

3.1 NFA and safety requirements

It is possible to integrate safety requirements in the functional analysis at three levels which can lead to different results, as following:

- At the level of **global constraints**: as enacted by EN 1325-1 [23], FNA brings the working group to define

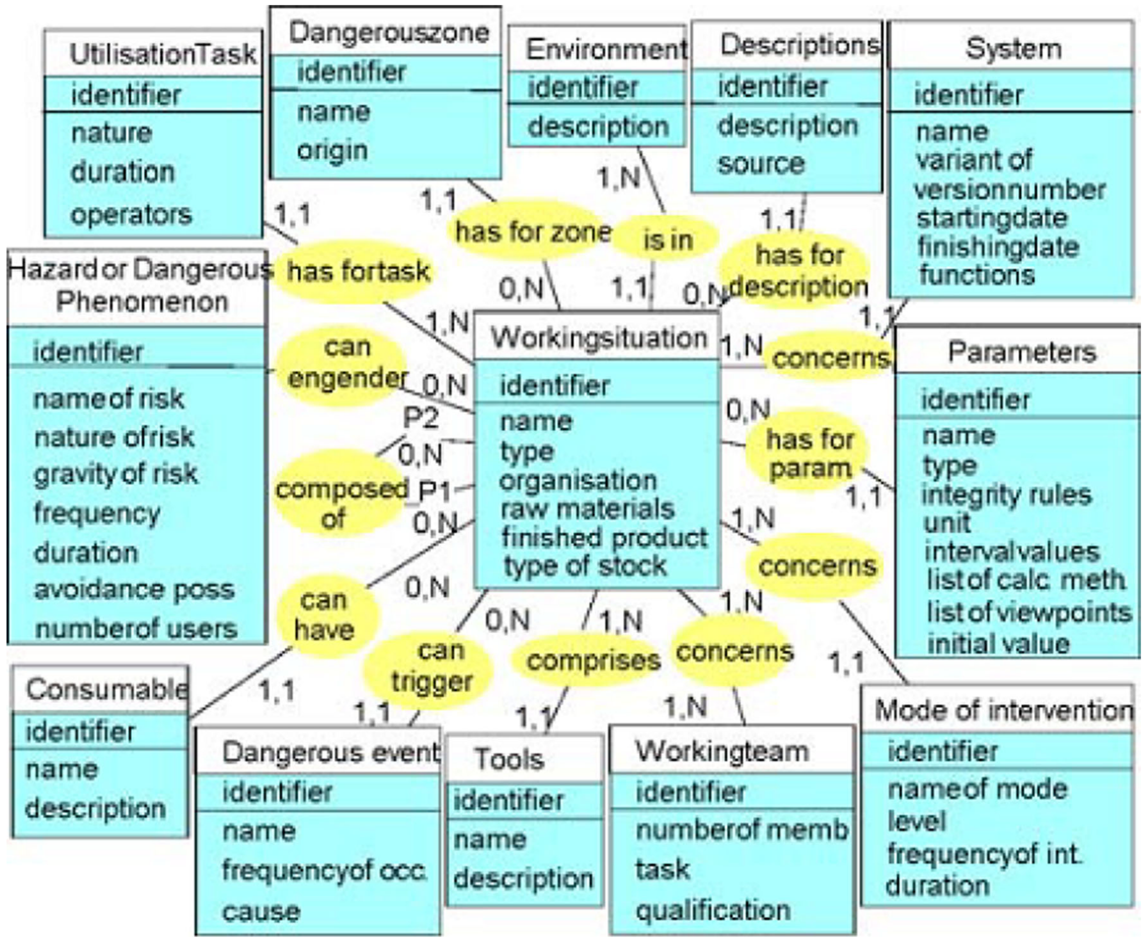

Fig. 3 Simplified view of MOSTRA [14]

global constraints which contain explicitly safety requirements and effective standards to conform too. Although this is necessary, it is not detailed enough and can lead the designer to develop the prevention apart from the technical and functional requirement, which we want to avoid.

- As a **function**: the second level to integrate prevention is to express as a specific function. The INRS worked in that way in many industrial projects to design work equipment, in order to deal with prevention issues [29]. This approach is relevant only when the objective is to design a safety-related system. This is mostly the case when the industrial need is to implement protective device or safeguards. Except this scenario, this approach leads designers to specify the prevention independently from the functional requirement.
- As **performance criteria** of function: the purpose of this level is to identify all the parameters which have a direct impact on safety. In other words, to specify that each function should be safe through these criteria's. The functional decomposition of the system is then used to define the future user tasks on the work equipment. Therefore this task analysis will facilitate the risk assessment according to the EN 12100 methodology [1].

For our purpose we select this last approach because it deals better with the objectives of the integrated prevention principles. By this way, health, safety and ergonomics issues are imbricated into the functional decomposition of the future work equipment and not expressed independently anymore. In fact the binomial "user/designer" needs to be guided to provide complete picture for a design task. Although, they naturally give the foundation to focus design efforts, there are other important criteria that the user may not even detect, such as safety issues. Otto and Wood [30] had defined them as *latent specification* (the customer do need them, but they do not think to clearly express them).

To do so, we need to ask for each function, what are the possible work situations and which entities are taking part. It is then necessary to split the second stage of FNA method ("Add performance criteria"—cf. Fig. 2) in two different phases: **description** and **characterization**.

3.2 Description step

This is the central step of the proposed approach. Its purpose is to collect and transcribe all the predictable use, including latent ones, of the future work equipment. They will constitute the input data for MOSTRA model.

Although there are various techniques based on the ergonomic approach to collect these data (interviews, observation, and task analysis, questionnaire, focus group, etc…) [31], this phase is often undone because it is perceived by project managers as too long or too difficult to undertake. Therefore, we propose a structured and easy-to-use questionnaire to carry out this description phase function by function. We retain the "5Ws and an H" tool, which is often used in industrial problem solving [32,33]. The stakeholders (designers and end-users) must answer "What", "Who", "Where", "When", "Why" and "How" each function is accomplished. This tool is an intuitive, descriptive and imaginative tool.

This description phase needs to be carried out by a team work (designers, users, project leader…) with the help of a structured and easy to use questionnaire to gather all informations, including the latent ones. It is necessary to check whether it is more interesting to:

- Directly uses MOSTRA links to build the questionnaire and gather informations about work situations such as "Environment", "User task", "Work team", etc.
- Use the tool "5Ws and an H" in order to answer "What", "Who", "Where", "When", "Why" and "How" the function is realized. This technique could be an easy way to describe work situation because it uses basic question generating prompts answers provided by the natural language.

An exploratory test has been carried out to compare these approaches. We choose a case study about band saw machines for food industry and formed two study groups. Each group is composed by two technical designers and one ergonomist having the same level of knowledge on the case study. They are asked to specify four functions (F1: set-up the blade, F2: remove the blade, F3: cutting meat, F4: cleaning the machine) with both questionnaires.

The first team started with F1 function and the "5W's and an H" questionnaire, while the second one started with the MOSTRA based questionnaire. Then, the running order of the functions was also defined to detect the possible influence of an approach on the other one (Table 1).

The first result of this comparative analysis is based on each participant opinion. Five of the six group members confirmed that they could easily provide information with the "5W's and an H" methodology.

The second result is based on the content of the analysis. The answers of the "5Ws and H" questionnaire overlap with those of the MOSTRA, which means, there are as many identified criteria with both questionnaires that doesn't appear in the other one. Besides, all key parameters that best describe the concerned function have been identified with the "5Ws and an H" methodology.

Table 1 Rolling out of working sessions

Team	Methods and functions			
Team 1	"5W's and an H"		MOSTRA	
	F1	F2	F3	F4
Team 2	MOSTRA		"5W's and an H"	
	F1	F3	F2	F4

We then recommend using first the "5W's and H" for this description step, MOSTRA based questionnaire is used during the characterization one. The following chart (cf.

Table 2) has been defined to stream the group discussion to achieve our objectives.

In this chart, we use the initial concepts of NFA by putting the "5W's and an H" questions in the criteria column and the corresponding answers to the value column (performance criteria level).

The first question (Why) places the function in its context. The following ones enable us to define whether the function is acting on a product or a system component (What), and if it need a manual or automatized task (Who).

The standard categories for searching and decomposing functional specifications (such as geometry, kinematics, forces, material, signals, assembly, transport, operation, cost…) are now integrated in each type of the "5W's and an H" questions.

3.3 Characterization step

The objective of this step of the NFA is to define performance criterias that characterize each previously identified entity. Our hypothesis is that health, safety and ergonomics aspects will be identified through these criteria. If, this step can be carried out by an individual work of the designers, the results must be shared and validated by the teamwork working on the previous step.

According to the NFA method, each performance criteria should be measurable, testable or verifiable at each following step of the development process [30] . To do so, it is necessary to:

- Firstly associate one or several MOSTRA object to each description according to what it characterizes. A mapping between "5W's and an H" and MOSTRA objects was established for this (Table 3). The MOSTRA based questionnaire allows to complete and to verify the coher-

Table 2 Functional specification guide (description step)

Criteria	Questionnaire	Value
Why function description?	What is the objective of the function?	Upper level function
	What reasons is the function for?	To solve any issue concerning the production process
What is the function acting on?	What physical element is the function acting on ?	Raw material, finished good, consumable, machine element
	What physical element is the function acting on ?	Procedures, bill of operation, task, organisation
Who does intervene to realize the function?	Who or what are taking part to realize the function?	Operator, team, designers, maintenance agent
		Machine or machine element
Where does the function take place?	In which area is the function taking place?	Working area, around the machine, workshop
	What are the influencial environment?	Temperature, noise, ray, humidity
When does the function take place?	At which stage of the process do we realizethe function?	Specific part of the process the whole operation
	At what frequency, flow rate, bucket, duration, cycle time?	User tasks informations
How is the function realized and in what conditions?	Which are the possible machine configuration?	Manual, automatic
	What are the intervention mode?	Posture, visibility, accessibility, procedure
	Does the task need complementary equipments ?	Necessary tools
	What are sources of energy at stake?	Nature, power supply

Table 3 Mapping between 5Ws and MOSTRA (§7 gives the abbreviation definitions)

5Ws	MOSTRA
What	Consumable (C)
	System (S)
Who	Work Team (WT)
	System (S)
Where	Environment (EV)
When	User Task (UT)
How	Tool (T)
	Intervention Mode (IM)
	Functioning Mode (FM)

ence of the data with regard to the concerned function (Table 4).

- Secondly, define links between previously identified objects, according to the MOSTRA structure. These associations allow identifying the main working situations where the function is effective. Every situation is specific and corresponds to intended use as well as "reasonably foreseeable misuse ».

As described above, MOSTRA model have a circled structure with neither a specific input nor a prefered output data. In our case, the entry point is necessarily the "Function". The structure used to define the working situations is illustrated by

Figure 4. The second level contains the work situations, the third one can be either user tasks or systems, and the last one contains the other informations such as work team, consumable, tools, intervention and functioning mode.

- The final step is to add quantitative or qualitative value to each criterion. They can be either predifined attribute of the Mostra UML model (task name, duration, work team, intervention mode) or specific parameters (initial/final state, speed…).

This step contributes to feed the risk analysis which should be carried out iteratively according to NFA progress. Within the framework of this study we used the method IDAR® developed by the CETIM [34]. This method, based on the EN12100 approach, has specifically a user centered and human safety oriented analysis, which fits with our objectives.

3.4 Expected results

The expected outcome of the proposed approach is the ability to identify prevention criteria through the characterization of the system functions.

Table 4 Illustration of a functional chart—industrial application

Function: to receive and to place parts to manufacture from uphill machine line to the milling unit

Criteria	Value	MOSTRA object
WHAT	Geometry : deformable and non rectilinear part	C
	Maximum dimensions : $(2 \times 200) \times 20 \times 12000$ (Width, Thickness, Length)	C
	Minimum dimension : compatibility with the existing conveyor and clamping system	S, C
	Maximum weight : about 750 kg (62 kg/m)	C
	Surface finition : no slippery parts for good grip	C
	Stability of parts : homogeneous part with easily identifiable center of gravity	C
	Room temperature	EV
	Initial state : parts positioned on the conveyor	C, S
	Final state : machining position	C
	Precision of the placement ± 2 mm	C
WHO	Machine : long parts (automatic configuration)	S, C, FM
	Operator : short parts (manual command configuration)	WT, C, FM
	Operator : short and long parts for the clamping system	WT, C, UT
WHERE	From the uphill conveyor to the manufacturing area of the milling machine	S
WHEN	Before the milling cycle	UT
HOW	Machine: long parts:automatically positioned by the uphill conveyor according to the entered command.	S, C, FM
	Operator: short parts: manually positioned by the operator (on sight) on the conveyor up to the position of the laser dead stop and the clamping system.	WT, C, UT, S
	Need visibility from the milling control panel while positioning manually to see the parts through the conveyor of uphill machine line and the laser dead stop	UT, FM, S
	Accessibility of the operator to the milling control panel during manual operations	UT, S
	Operator position : standing in front of the control panel with visibility for the positioning	WT, IM, UT
	Automatic mode : 1 m/s	FM, UT
	Manual mode : < 0.5 m/s	FM, UT
	No handling from the operator	S, UT

As a result, the time required for functional need and risk analysis will be reduced by combining tasks that are common to both methodologies.

Moreover, the criteria identified using this approach might also be used initiate the risk analysis process recommended by the "Machinery" directive and its corresponding standard [1].

4 Industrial application

In order to evaluate the relevance and acceptability of the approach, we intend to apply the proposed methodology to several industrial cases in SME/SMIs companies.

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Function 1 (F1)
    |_Work situation 1 (WS1)
          |_User task 1 (UT1)
                |_Work team 1 (WT1)
    |_Mode of intervention 1 (MI1)
          |_User task 2 (UT2)
          |_System 1 (S1)
                |_Functioning mode1 (FM1)
          |_System 2 (S2)
    |_Work situation 2 (WS2)
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Fig. 4 Data structure used to define the working situations

This first industrial test-case we performed was in partnership with a company that designs and manufactures both specialized and standard machines with several optional functions (drilling, stamping, and sawing machining transfer line) for working with steel beams.

The company has recently developed a product line by adding a milling unit to an existing machining transfer line. The unit will be used both independently and with the machine line, depending on the customer's activities.

It was decided that the requirements for this new functionality would be drawn up a posteriori using the proposed methodology. The objective was to determine whether the industrial partner would have reconsidered any of technical solutions they had implemented in the original design.

4.1 Need functional analysis (NFA)

With the aid of TDC NEED© software, which is used to support the NFA, we were able to reconstruct the functional tree for the new milling unit. This highlighted certain issues, for instance the importance of the set-up phase compared to other phases (e.g., production or maintenance). Furthermore, certain functions could be placed in a different phase and the tree could be validated. Among a generic list of functions, two of them were analyzed through the case study and are discussed in detail below.

4.2 Description step ("5W's and an H")

The TDC Need software was configured for designing the "5Ws and an H" based questionnaire in such way that the different questions could be placed in the *criteria* column and the description in the *value* column. The question responses are summarized in the second column of Table 2.

4.3 Characterization step (MOSTRA)

Using the mapping table between MOSTRA and "5Ws and an H" (Table 3), the different entities involved in the function were linked to MOSTRA objects (last column of Table 3). For instance, the first WHO description involved a system component (S): the milling unit, a consumable (C): long parts, and a functioning mode (FM): automatic configuration.

The next step defined how these elements interact. Two kinds of link existed:

- Links between the same types of object such as hierarchical link (system) or succession link (tasks).
- Links between different types of object involved in the same Working Situation (WS). For example, the WHO question allowed us to define three main WS :
  - WS1 (automatic positioning for long parts), defined by the interactions between UT1 (placing parts), S4 (conveyor of the line), FM2 (automatic mode) and C1 (long parts).
  - WS2 (manual positioning for short parts), defined by the interactions between UT1 (placing parts), WT1 (operator), FM1 (manual mode) C2 (short parts) and IM1 (standing posture)
  - WS3 (manual command of the clamping system for both short and long parts), defined by the interactions between UT5 (clamping), S2 (clamping system), WT1 (operator), C1 (long parts), C2 (short parts) FM1 (Manual mode) and IM1 (standing posture).

The data structure is described in the functional tree, as shown below (Fig. 5).

After repeating this for all functional needs, the requirements were returned to the industrial partner, focusing on the two functions as previously described. Discussions and the comments on the methodology made by the industrial partner are detailed in the next section.

5 Discussions

5.1 About technical solutions

The following lines describe the implemented solutions concerning the studied function: *to receive and to place parts to manufacture from uphill machining transfer line to the milling unit*. According to the part length, two operating modes were initially defined by the industrial partner: manual and automatic.

By answering to "5W's and an H" questions, the same designers discovered that the technical solutions retained for these two operating modes are not completely satisfactory from the safety point of view.

For the short part, the operator needs to command and visualize the parts positioning at the same time. The current location of the control panel should lead to uncomfortable position.

In addition, the transferring wheels were designed for parts longer than 300 mm. But when answering to the "what" question, it was said that some customers realized shorter parts (250 mm). So this working situation make the operator do maintain parts manually with a risk of hand crushing between the part (25 kg) and the transferring wheels.

Another safety point highlighted by the proposed approach concerns the possible interactions during the loading/unloading phase.

For safety reasons, and according to the machinery Directive, the industrial partner planned to forbid the access to the conveyor during the machine is running.

Receive and place parts to manufacture from uphill machining transfer line to the milling unit.

|_ **WS1:** Automatic positioning for long parts

|_ **UT1**: Placing parts

|_ **C1**: Long parts

|_ **S4**: Conveyor of the line

|_ **FM2**: Automatic mode

|_ **WS2**: Manual positioning for short parts

|_ **UT1**: Placing parts

|_ **WT**: Operator

|_ **IM1**: Standing posture

|_ **C2**: Short parts

|_ **FM1**: Manual mode

|_ **WS3:** Manual command of the clamping

|_ **UT5**: Clamping the parts

|_ **C1**: Short parts

|_ **C2**: Long parts

|_ **S2**: Clamping system

|_ **WT**: Operator

|_ **IM1**: Standing posture

|_ **C1**: Long parts

|_ **C2**: Short parts

|_ **FM1**: Manual mode

Fig. 5 Structure of main work situations

By questioning "When" for the function “loading/unloading”, it quickly appeared that the end-user will make this operation within the production time : the machine is running in an automatic mode during several minutes and don’t need the intervention of the operator. This way of working recovers from what the Machinery Directive calls “reasonably foreseeable misuse” which has also to be taken into account by the designer: it was not the case in the initial design. As the preparation zone is closer to the conveyor, its access is also forbidden by the safety device. Then, it seems obvious that someday, it will be bypassed in the future due to productivity requirements.

5.2 About the industrial test

The first opinion of the technical manager about the methodology is positive because it pointed out unsafe work situations that was not identifying in the previous design.

The initial risk analysis has been realized by the industrial partner at the end of the project. Results were only organizational and corrective measures. Neither the potential activity of users nor the potential contexts of use were taken into account.

The mechanical designer deduces the need to spend more time on this NFA. This aspect was taken into account in the proposed methodology. Indeed, in order to optimize the design duration, we propose to combine a maximum of tasks between functional and risk analysis. In any case, a correct functional and risk analysis needs time and it is now widely recognized that this time is not lost but it is an investment for the next steps of the design.

The last point concerns comments made by the designers during the NFA but not directly address to this method. If, in the theoretical point of view, the work equipment should be considered only as a set of functional needs during the whole NFA, in practical, designers always think about technical principles in advance and cannot ignore previously implemented solutions.

Then, during the NFA, designers expressed technical issues based on return of experiment like prohibited or recommended technical solutions, potential hazards. In order to don’t forget these information, it was decided to add a new column called “Alert point” which contains three types of information:

- Potential incoherence or contradiction between functional requirements,
- Potential hazards,
- Solution principles: prohibited usage or range of applications.

5.3 About the methodology

The methodology proposed is based on concepts and tools (NFA, structured questionnaire, data base) which are well known by the designer, he can appropriate them easily. This methodology can be used for any kind of product or machine. At the beginning, it is necessary to build the working situation model with the relevant parameters which are to be fulfill, this model is generic for the application cases of the company (for example special machine). For need functional analysis, a commercial software can be used in order to get functional tree or it can be develop by the company based on its knowledge and application domain, in the same way structured questionnaire can be built by the company. The methodology implementation is based on working group where the actors interact for fulfilling the data base and tables with the help of the software's developed. The result of the data processing allows getting requirements which take into account of hazards at the very beginning of the design process, approved by all the group members. Used of data base of safety standards and directives can also be used in order to help the working group. Perhaps methodology implementation, as deep functional analysis, can seem to be a loss of time, but this time is won at the end of the design process even during use phase, where modifications have to be done on the product / machine. The approach allows a direct interaction between the user(s) and the designer (s) in real time by the exchanges in the frame of the working group.

6 Conclusion and prospects

The aim of this research work is to bring the binomial "user/designer", to define necessary information (intermediary objects [35]) for integrating safety requirements in the specification stage. Our hypothesis is to integrate safety requirements as performance criteria of each function and not as specific functions or global requirements, in other words, to specify that each function should be safe. By this way, health, safety and ergonomics issues are imbricated into the functional decomposition of the future working equipment and not expressed independently anymore. For this, we propose to use:

- firstly the need functional analysis which is classically used to identify all functions of a future product (working equipment in our case),
- secondly, an intuitive and descriptive tool like "5W's and an H" to define, for each function, the usage based criteria, which include safety ones,
- thirdly, the working situation model MOSTRA to organize and capitalize all these data. This model was specifically developed to support safety integration at the design stage.

In addition to the specific benefits of the classical functional analysis (saving time on the following steps of the design process, possibility to capitalize analysis results…), the proposed approach create a common basis for both NFA and risk analysis, which saves from doing again some part of the two analysis.

The first industrial application of this approach gives relevant results: unsafe work situations that were not identifying in the previous design by the industrial partner were pointed out.

However, this first case study allowed validating only the potential benefits from the designer point of view. Indeed, the data was mainly provided by the designers and few from the final user. Then, another industrial case study is under way to validate this approach with both points of view: manufacturer and end-user companies.

The mapping between the different softwares allow to proposed a virtual environment. More integration between the different tools, safety data and product model developed during the embodiment design have to undertake. To apply the methodology need interactivity between the actors.

7 General terms

- *MOSTRA* Work situation (**WS**) Model.
- *NFA* Need Functional Analysis.
- *Functional requirement* statements of the specific performance of a design, i.e., what the product should do [17].
- *System* (*S*) The whole or part of the work equipment which represents the machine(s) in the work situation.
- *User Task* (*UT*): any activity necessary for obtaining the result set by the working system. I.e. the tasks to be carried out by the machine(s) or the user(s) in the work situation.
- *Working Team* (*WT*) any group of people responsible for installing, operating, setting, maintaining, cleaning, repairing or transporting a machine. The term represents users who take part in the work situation.
- *Consumable* (*C*) any consumable material necessary to carry out the task that is the subject of the design (raw materials, cutting blade, cords etc.)
- *Tool* (*T*) any tool necessary for carrying out the task that is the subject of the design (screwdriver, ruler, stroboscope etc.).
- *Environment* (*EV*) all the physical, chemical, biological, organizational, social and cultural elements that surround a work situation inside its working area.
- *Intervention Mode* (*IM*) one of the system–user interactions, i.e. the procedures allowing the user to carry out the tasks.
- *Functioning Mode* (*FM*) different possible states or configuration of the system during a given task. (E.g. normal operation, setting point, maintenance, malfunctioning etc.)
- *Hazard* (*H*) one of the risks that exist in the zone created by the technical solution chosen.
- *Hazard zone* (*HZ*) part of the area in the system liable to engender risks for the user.
- *Hazardous event* (*HE*) an event liable to be created by one or several users (during production, troubleshooting, etc.) either accidentally or intentionally.

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