# User Safety Performance Evaluation from Complex Systems Design Phases: Application to Arduous Working Conditions

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*Abstract*— **Considering user requirements in the design of production systems is a necessity imposed by directives and standards. However, in spite of standards application by companies, many user health problems still happen. So, it becomes a goal of companies to design machines and install manufacturing systems to improve the safety performance of their artefacts. In this paper, we propose to collect data and information concerning the difficult/harsh working conditions when using the artefacts (machine or system) in order to evaluate them from the conception phase to propose new more ergonomic systems/machines. To do this, we analyzed a system used by our partner company and completed our method, which is already proposed in the literature. The application hardness evaluation is presented in the article to demonstrate and evaluate the advantages and limitations of the proposed method.**

***Keywords- Arduous working conditions; Design method; Performance evaluation; User safety.***

## I. INTRODUCTION

Since January 1st, 2015, in France, the “Pénibilité de travail”, (meaning, in English: difficult/harsh working conditions, arduous working conditions) has been included in the calculation of pension rights system. The related labor code is [1], taken from the European framework directive of June 12th, 1989. In the rest of the paper, we used “arduous working conditions” and not “Job penibility” as noted in [2]. This had three effects:

*1)* The first consists in establishing an inventory of working conditions in the existing production workshops.

*2)* The second, for works subject to arduous working condition tasks, it implements preventive measures to eliminate or reduce the arduous working conditions risk.

*3)* The third, for companies designing machines and installing manufacturing systems, is to take this difficulty into account when designing these systems.

The objective of this paper is to propose a method to formulate and evaluate ergonomic information (particularly related to arduous working conditions) and to use it in the design process. We know that the design from a technical point of view [3][4] is no longer sufficient to design an efficient system [5][6]. In this sense, the concept of integrated prevention has been defined and presented in numerous articles [7]-[13].

To be able to design a system that can be used in companies with a minimum level of ergonomic and safety risks authorized by law and standards, we propose to measure and evaluate the arduous working conditions during the use phase to estimate this for the design phase of a new complex manufacturing systems in an Industry 4.0 context [14].

### *A. Field data and method followed*

In the unique safety document of each company, it is recommended to specify points such as the following:

- Risk assessment per workstation.
- Safety cards for the workstations.
- User safety data card.
- Assessment of musculoskeletal disorders for each workstation.
- Noise assessment for each workstation etc.

The question dealt with in this article is to identify and evaluate, based on good industrial practices, the information to be fed back in order to integrate the best ergonomic specifications in design, particularly related to arduous working conditions. For this, we used the DMAIC method: Define, Measure, Analyze, Improve and Control the preventive measures to be taken into account from the design stage. This method is applied on an existing system with two objectives, i.e., the first one is improving the design of future similar systems. The second one is to propose an approach that meets the conditions of use of such types of systems. For this, we have followed the following steps:

- Define the state of the art of the ergonomics and safety conditions of all workstations in the workshop.
- Choose and implement measurement tools and methods to measure and manage risk factors.
- Look for means and solutions to eliminate or reduce the risks exceeding the thresholds.
- Provide an assessment of the six factors increasing the arduous working conditions of work presented in the next section.

 

### *B. Components of the arduous working conditions*

The Labor code stipulates that: it is necessary to eliminate any exposure of the worker to one or more occupational risk factors likely to leave permanent, identifiable and irreversible traces on his/her health. Since July 1st, 2016, L4121-3-1 [15] entered into force and ten risk factors were identified as the origin of the increase in arduous working conditions with their regulatory thresholds. The 10 risk factors associated with arduous working conditions are the following:

- Manual handling of loads
- Painful postures or forced positions
- Mechanical vibrations
- Activities carried out in a hyperbaric environment (high pressures)
- Hazardous chemicals, including dust and fumes
- Extreme temperatures
- Noise
- Night work and work in successive alternating teams
- Repetitive work

These ten factors are classified into three categories:

1) *Marked physical constraints*
2) *Aggressive physical environment*
3) *Certain working rhythms*

In Section 2, the method of integrating to use information from the first phase of the design is illustrated. In Section 3, we develop our work on the identification, measurement, evaluation and integration of arduous working conditions in design and present the results obtained. In the last section, we conclude and present some perspectives.

## II. INTEGRATION METHOD TO USE SYSTEM INFORMATION IN DESIGN PROCESS

Considering the present methodologies' hysteresis and cost of the Human Factors and Ergonomics (HF/E) integration in the design phase, Sun et al. [6] attempt to develop a time saving, economic and standard approach for designers to integrate the HF/E from the early design phase. We use, in this work, the method proposed by Sun et al. in [6]. Based on the feedback from the field, the final objective is to demonstrate and analyze the feasibility of the method of integration to use information from the first phase of the design.

In [16][17], the authors presented rich state of the art containing the integration of human and ergonomic factors in the different phases and design processes. The key to achieving this integration is to understand the design, whose main goal is to get a product / system that matches the use and user requirements from the point of view, ease of use, user safety, reliability and efficiency in the workstation [18] [19].

Sun et al. in [20] proposed a systematic method taking into account related information to use. Sun et al. in [6] improved the first proposition by integrating the three-level "function-task-behavior" framework (Figure 1) and based on the simultaneous design of the product / system and its manual usage (Product manual).

The safety documents use in industries contain very little information on the evaluation of use under the conditions required by European directives. Many users do not rely on these documents in the day-to-day use of their machine [21].

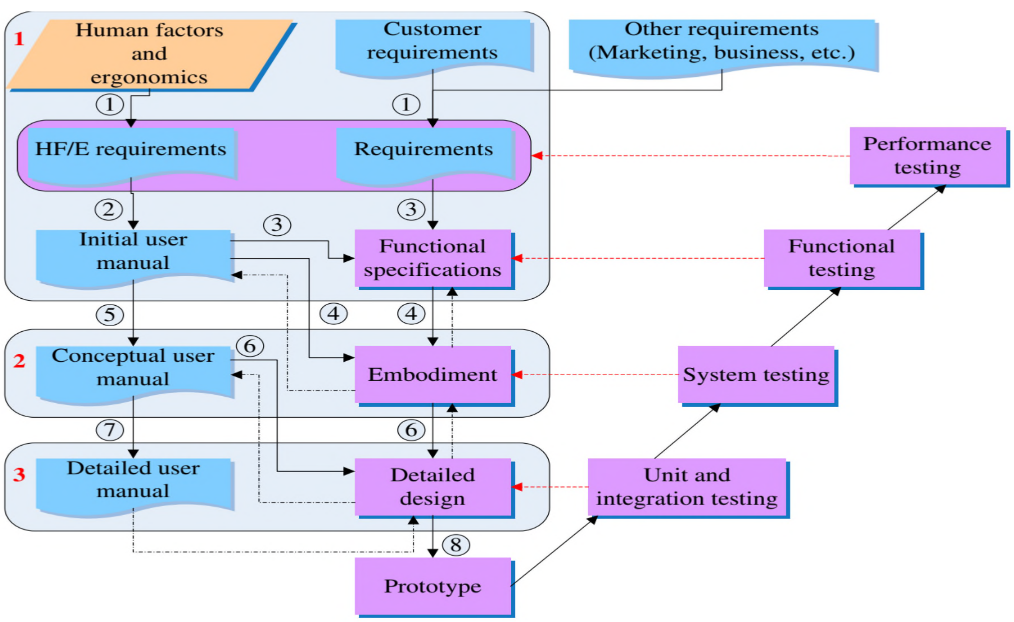


Figure 1. The Methodology proposed by [20]

In this method, the designer defines the initial product manual which directs the functional specifications and the mode of realization of the manual functions according to the requirements of the use. At this level, the designer defines the tasks to perform the functions provided for in the specifications. He distinguishes between the tasks performed by the product (system/machines) as technical tasks, and the tasks performed by the user as socio-technical tasks. At the

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second level, the initial product manual will be detailed to give a conceptual product manual which is the guideline of the detailed design. At this level, the designer will propose the structure that fulfills the technical functions compatible with the socio-technical (manual) tasks to be performed by the user.

Finally, at the third level, after having completed the detailed design of the structure, the designer refines the tasks performed by the user and those to be carried out by the technical structure after having completed the detailed design of the structure. Then, he analyzes the interaction between user behavior and system behavior in order to check the overall performance of the system (machine) and its user.

It was noted that the guideline of the method is to avoid bad interactions between the system (machine) and its user. Overall, all interactions that cause an ergonomic problem, or adversely affect the safety and health of the user should be eliminated.

However, Sun did not present how this product manual could be defined, served and evaluated on the three levels listed below, nor from what data and information.

Additionally, the method proposes some steps to analyze functions in tasks, then to characterize these tasks by identifying who does it, when, using what tools, on which part of system, etc. This method is a top-down method that begins from client, marketing, user and others possible requirements without any specific focus on how these requirements could be identified, set out and evaluated to know if they could be integrated in the design processes. Here in particular, we considered how to do that for the arduous working conditions that could appear during the use of the artifact (system or machine).

## III. Taking into Account the Arduous Working Conditions from the Design Phase

First of all, we defined the criteria considered in our study:

- Meet the legal obligation, according to the article L4121-3-1 of the French Labor Art (Code).
- Preserve the health and safety of workers: the need to assess occupational risks does not only result from the observation of the large number of work accidents and occupational diseases, but also results from prevention of their occurrence from the design phase.
- Contribute to improving the performance of the system: The important consequences from the human point of view integration from design. This allows reducing direct and indirect costs.
- Improve and strengthen social relations: participatory prevention approaches make it possible to promote exchanges between user and designer.

Then, after having gathered the data necessary for a good approach from a legislative point of view, we identify the factors of arduous working conditions in the workshop of our partner company. We have identified existing workstations similar to the future workstation in which the system subject to the design will be implanted and installed. On each workstation, we observed and analyzed the working conditions in comparison with the work evaluation required in the unique safety document.

- Only the workstation operator has knowledge of the actual work. His/her active participation is the main key to the success of our process.
- Observation of workstations and especially dialogue with operators is, therefore, essential to extract information about their manner to use the system.
- These make it possible to consider the actual work of the operators, to visualize, to objectify and to assess the risks of arduous working conditions.
- In spite of standards application, the significant and intolerant risks presented in Table 1 were identified.

In order to respect the confidentiality imposed by the partner company, only two items are considered in Table 1.

TABLE I. Identified Risks

| | **Significant Risks** |
|---|---|
| **Raw Material Flow** | Thermal environment |
| | Noise |
| | Energy |
| | Fire explosions |
| | Contact with other users |
| | Awkward postures |
| | Driving equipment |
| | Mechanical Vibration |
| | Manual handling |
| **Milling Workshop** | Noise |
| | Awkward postures |
| | Manual handling |
| | Working Organization |
| | External intervention |
| | Mechanical vibrations |
| | Hazardous chemical material |

In comparison with the arduous working condition factors, the following risks are selected. In the following, we limit our observations to the factors related to the arduous working conditions that appeared in 2016. In the partner company only, the following factors were identified. The other factors do not exist in this business. For example, there is only one work shift and no night shift.

TABLE II. Risks Related To Arduous Working Conditions

| | **Significant Risks** |
|---|---|
| **Raw Material Flow** | Noise |
| | Awkward postures |
| | Mechanical Vibration |
| | Manual handling |
| **Milling Workshop** | Noise |
| | Awkward postures |
| | Manual handling |
| | Mechanical vibrations |
| | Hazardous chemical product |

### A. *Evaluation of arduous working conditions factor during raw material flow:*

The raw material flow is used to receive, store and debit material either for subcontractors or for internal production orders. The following arduous working conditions factors are evaluated:

*1) Noise:* The sources of noise are saws and the machine that manufactures perforating blades. Personal protective equipment used to reduce exposure to noise is earplugs.

*2) Awkward postures:* Presence when pushing material onto the conveyor because it is very high in relation to the user.

*3) Mechanical vibration:* Exposure to vibration comes from the manual saw, but rarely comes into contact while cutting operation.

*4) Manual handling:* When transporting the material to a shipping pallet or to the saw, the operator has to push the long rods of material onto the forklift which is not very suitable because a lot of effort is needed to move the materials. For pushing the material onto the conveyor, this is very difficult due to the poor condition of the conveyor.

### B. *Evaluation of arduous working conditions factor in milling workshop:*

In the milling workshop we observed certain factors identical to those observed in the raw material flow, but which do not have the same origins and their evaluations are different:

*1) Noise:* The combination of running machines presents a high exposure, to the point of raising one's voice to speak with a person a meter away. Personal protective equipment, ear plugs, are present.

*2) Awkward postures:* The material is stored on trolleys at a height close to the ground. The operator must bend to pick up the parts and certain measuring tools are placed at a height which implies restrictive positions.

*3) Manual handling:* Loads are carried regularly from the trolley to the workstation. For very heavy parts, an electric bridge is available to move them. Handling is also present when changing tools.

*4) Mechanical Vibrations:* The sources of vibration to which the operator may be exposed are all the machines that operate in the workshops.

*5) Hazardous chemical agents:* The products to which operators are most exposed are cutting oils and some grinding glues that will be identified later.

## IV. Assessment of Risks Related to Arduousness

In order to be able to assess the arduous working conditions by factors, it is necessary to put in place some tools to collect the data and compare it with the exposure thresholds defined by the standards. Next, we detail the evaluation carried out for each factor.

### A. *Awkward postures*

Awkward or strenuous postures are defined as forced positions of the joints of the human body. When there are situations with duration and intensity there is a risk of arduousness. We meaasured the different postions illustraited in Figure 2 and defined by standards as awkward postures.

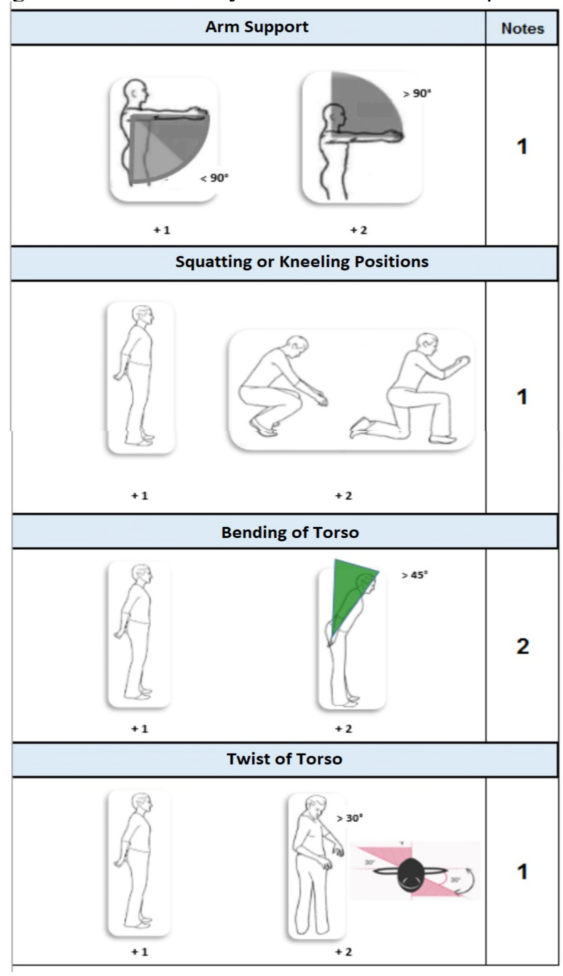


Figure 2. Different positions evaulated in Milling workshop

For each task done by the operator on each machine, we applied the following stepes

- Identified the angles of the position that exceeds the thresholds allowed by standards.
- Then, we timed the time of each task done in an awkword posture. These represent approximately 15% of the time spent on to do the machine setting-up tasks.
- For each awkward posture, we gave a grade as indicated in Figure 2.
- Evaluate the exposition time per year as a function of time and note.

Unfortunately, our industrial partner refused to communicate the final results of this evaluation.

### *B. Noise evaluation*

We should remember that the exposure threshold is set by standards at 81 decibels (A) over a reference period of 8 hours, either a number of 120 "shocks" per year at 135 decibels (C). Article R. 4431-2 of the Labor Code prohibits companies from exposing employees to more than 87 dB (A). Thus, to analyze and diagnose exposure to arduous working conditions, a flowchart makes it possible to exclude or not the factor for each position (Figure 3).

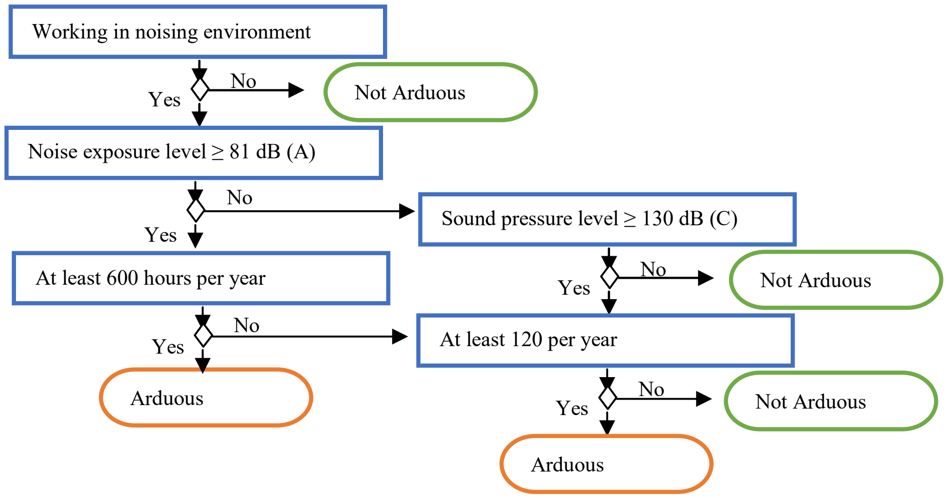


Figure 3. Flowchart for the noise factor

As soon as the environment is observed to be noisy, the sound intensity must be quantified. Here, we decided to find out about personal exposure to noise. To assess the noise and collect the necessary data, we used an Expositimeter to measure the intensity perceived by the operator. It is more accurate for measuring personal exposure to noise as operators move around a lot. It is necessary to map the entire production workshop to have usable data over time if there is no change in the location of the workstations.

### *C. Evaluation of mechanical vibrations*

The 2016 reform requires cumulating the levels of vibration transmitted to the hands and arms with those transmitted to the whole body and comparing it to a threshold of 450 hours per year.

After identifying the positions exposed to vibrations, we quickly noticed that most machines exceed the threshold of 2.5 m / s² for vibrations felt in the hands and arms, where the Milling presents the greatest exposure compared to the other workstations. To assess this factor, we followed the same process by identifying the positions that cause vibrations. Then, it was necessary to determine the exposure times and compare the result with the exposure thresholds.

We noted the duration of exposure by timing the tasks performed by the different operators. The measurements are taken over a normal working week (not too busy and without layoffs). The maximum duration per day is 23 minutes which represents 15% of the time on a working time of 8:30 am. The overall duration of use of some machines does not exceed the thresholds per person exposed because several operators use it.

TABLE III. OVERALL DURATION OF USE

| In hours | Warehouse Trolley | Assembly Trolley | Milling |
|---|---|---|---|
| Averages / Day | 1.26 | 0.18 | 0.16 |
| Provisional accumulation/Year | 285.51 | 39,54 | 35.12 |
| Max | 1.90 | 0,53 | 0.31 |
| Min | 0.50 | 0.01 | 0.00 |

### *D. Evaluate hazardous chemical products*

The chemical risk assessment required a great deal of investigation with the search for a way to assess and standardize an approach with chemical products. The assessment is based on the ND 2233 method and is a common language for doctors, CARSAT, and the labor inspectorate. The steps followed for the assessment of this factor are as follows:

*1)* Inventory of used chemical products and their location in workshops, workstations and tasks.

*a)* List all the products in the chosen software with their hazard statements.

*b)* Investigate their use by operators.

*2)* Comparison with ERP data to know the quantities used and ordered of each item codes.

*3)* Select the chemical products containing the hazard statements falling under the regulations on arduous working conditions.

*4)* Evaluate the duration of exposure for the products concerned and compare them to the exposure thresholds.

The products concerned are the products labelled as dangerous chemical, or emitted in the processes. To identify the products named to be eligible for the arduousness, we proceeded by funnel effect. The products with the terms of arduousness are identified and the inventory and classification by workstation and by machine made it possible to locate them.

Once the affected products were identified, we quantified the duration of exposure for each operator (times of use, duration and frequency of each exposure). By timing the operators working, we obtained an exposure time greater than the regulatory threshold of 150 hours / year. Products exceeding the thresholds are identified. These products are used for several tasks which multiply the total exposure time.

We obtain the following exposure times per operator (Table IV):

TABLE IV. EXPOSURE TIME TO CHEMICALS PRODUCT

| | Exposure Hour/Year |
|---|---|
| Product 1 | 125.32 |
| Product 2 | 323.76 |
| Product 3 | 131.95 |

For products exceeding the thresholds, risk prevention means should be considered. Personal protective equipment is mandatory so that the operator is the least exposed. This includes a diving suit and a specific suit. For each of these products, exposure conditions must be reduced and prevention improved by redesigning systems in avoiding adding doors or boxing the machine which decrease the visibility and the accessibility of the operators. In Figure 4, we show an extract of our results (not clearly shown due to the confidentiality of data).

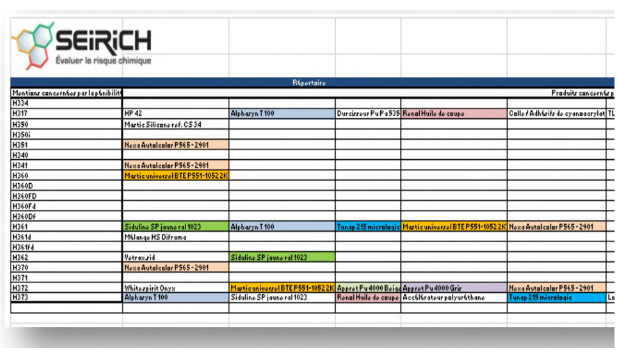


Figure 4. An extract of the evaluation of chimical factor

## V. DISCUSSION

Our objective was to identify, through this field study, the data, parameters, factors, etc. necessary to take into account the arduous working conditions from the design phase. The data collected during this field study is richer than the data considered in the method proposed by Sun et al. in 2018. Indeed, Sun's method focused on the data for tasks to be done by users that 1) has been deemed necessary to define how the functions requested by the customer will be carried out and 2) those necessary for a safe use of the system. He took into account the factors: the duration of the task, who does the task (machine or operator), the order of the operating procedures as well as the structure of the task (a task can be broken down into sub-tasks, down to an elementary level).

On the other hand, the field data made it possible to establish the need to know the nature of the materials treated (chemical, wood, metals, etc.). But also, we were able to establish the work organization (a task that can be carried out by a single operator, it can be distributed over several operators and in several time frames).

Also, the thresholds imposed by the legislations are not sufficiently considered in the method employed by Sun. Indeed, the concepts of risk assessment are based on the product of a risk indicator calculated as a function of hazardous phenomena, exposure time, frequency of exposure and severity [22].

Once these safety parameters are identified, they have to be taken into account by the designer. Some methods could be used, like the ones proposed in [23] and [24], on the integration of safety user parameters in the design process. In both these works, the authors proposed a framework to consider standard data about user safety and some classical known parameters about hazardous situation, but not about Arduous Working Conditions.

Taking our results in consideration in the design process could influence the designer decision. For example, instead of trying to change the cheap technical solution that fulfills the function, but has very high level of vibration by another one (which may be more expensive, but cause less vibration), the designer could keep the first solution too. He/she can either automate some of the manual tasks to avoid or minimize human intervention and, therefore, minimize exposure time. Or he/she could specify in the documents provided to the user client that it is necessary to avoid having a single operator working on this machine all the time or for longtime and that it would be good to alternate two operators during the work time.

Our industrial partner is a constructor of paper machines. We did our analysis for them at a workshop of one of their clients. Their objective was to optimize the performance of their artefact in improving not only the user safety by reducing the dangerous conditions and dangerous zones in very short term (operating term) [24], but also, by considering the very long-term dangerous factors, like those of arduous working conditions. Our work helped them evaluate these factors for the next generation of machines.

## VI. CONCLUSION AND PERSPECTIVES

We can see that the integration of human factors in the design of products, machines, systems has become more and more important in order to improve the final performance of the designed system. Many proposed methods are constantly improving to comply with regulations, but also go further than standards. In this article, we first defined the framework of this work by

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assessing the arduous working conditions to comply with the labor code in order to be able to estimate it from the design phase. For this, we based the work on a method proposed in the literature to determine the data to be sought after in the field at the user workshop and potentially integrate it in the design of future similar systems. These works have shown that the method takes into account most technical and use data. However, we did not find in literature any method considering the data concerning the arduous working conditions and, in particular, the factors of which have recently changed. So, we identified and evaluated some arduous working conditions factors in existing systems. Then, we proposed to the designer to integrate them in his/her design process and refine his/her decisions and choices. We found that considering the materials used and the organization of work in the design is possible and makes compliance with standards easier. In future work, we will propose an evaluation of the identified relevant parameters. Also, other areas will be analyzed in other contexts of use to propose a global and more complete approach in order to provide designers with a method considering all field data related to use conditions, but also propose a method to integrate the identified parameters into the design process.

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