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Critical success factors in the development and implementation of special purpose industrial tools: An ergonomic perspective

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Abstract

The variety of different manual tasks performed in industry is infinite. In many circumstances, these tasks are carried out under difficult conditions with ergonomic concerns about the postures, force or repetitions involved. These tasks are sometimes performed using a dedicated special purpose tool, often developed by the workers themselves. These special tools are generally task-oriented only, with very little consideration of basic ergonomics. Therefore, in many cases, the design of a new or improved special purpose tool is one of the solutions that could enhance the ergonomics of the performed task.However, developing and implementing a new or improved tool is not an easy assignment and the ergonomist could face many unexpected challenges and pitfalls. This paper discusses the pitfalls that could compromise these ergonomic interventions and the critical success factors that should be considered. The main difficulties that could arise during such a project include the poor understanding of the user's needs, the hidden constraints related to the requirements of the task to be performed, the construction and testing of the prototypes, and the users' resistance to change.Critical success factors related to worker participation, needs and constraints analysis, and the implementation of prototypes,are presented. Examples from industrial projects involving the development and implementation of special purpose tools areused to support the discussion. This paper should provide some guidance in this particular field of applied ergonomics.

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*Keywords:*Manual tools; Ergonomics; Design; Implementation; Pitfalls; Success factors

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1. Introduction

The variety of different manual tasks performed in industry is infinite. In many circumstances, these tasks are carried out under difficult conditions, with ergonomic concerns about the postures, force or repetitions involved. In some cases, no special tool is used to accomplish the task. In other cases, the tasks are performed using a dedicated special purpose tool, often developed by the workers themselves. These “homemade” tools are generally task-oriented only, with very little consideration of basic ergonomics. Therefore, in many cases, the design of a new or improved special purpose tool is one of the solutions that could enhance the ergonomics of the performed task.

However, developing and implementing sucha new or improved tool is not an easy assignment and the ergonomist could face many unexpected challenges. Based on past experience, the main difficulties that could arise during such a project are described in section 2. The critical success factors that should be considered during the main steps of the development and implementation of such toolsare presented in section 3. Examples from industrial projects involving the development and implementation of special purpose tools are used to support the discussion.

2. Ergonomic problems and hand tool design: Challenges and pitfalls

2.1. Challenges and pitfalls related to the workers’ support for the new tool development project

Even if workers are aware of the risks associated with their work technique or their actual tools, they often appreciate their simplicity and their effectiveness. In fact, “homemade” tools are often considered by workers as being very adapted to the task, despite their ergonomic deficiencies. Workers are therefore sometimes disinclined to change, particularly if this could have an impact on the simplicity or rapidity of task performance. An example of such a tool is presented in Figure 1. This tool, used for a residue cleaning task in an aluminum plant, consisted of a simple metal rod equipped with a handle. Despite the many musculoskeletal disorders of the back and elbows reported by workers using this tool, they were reluctant to change, considering its simplicity and its effectiveness.

Fig. 1. (a) Cleaning task (b) Simple tool used

Also, workers do not necessarily share the idea that the implementation of a new tool is the solution to an ergonomic problem. Sometimes, the task is particularly difficult and the workers want the task to be mechanized or eliminated. Yet the technical, organizational or financial constraints may be such that the company does not consider these alternatives. While the idea of a new tool can seem an interesting solution, the workers might not share this viewpoint and could be reluctant to support the project.

2.2. Challenges and pitfalls relatedto the workers’ participation in the project

In a development project for a new more ergonomic work tool, the workers’ active and direct participation is essential. Even when the workers support the project, obtaining their real participation in the project can sometimes

be difficult. Certain steps require group meetings and activities that cannot be carried out at the same time as production activities. Sometimes, the production requirements and the company's limited resources can make these activities difficult by limiting the workers' direct participation.The participation of foremen, production engineers and occupational health and safety managers is definitely relevant, but never replaces the input of the workers themselves.

2.3. Challenges and pitfalls related to the understanding of the users' needs

A poor understanding of the user's needs and of the hidden constraints related to the requirements of the task to be performed is certainly one of the main factors for failure of adapted tool development projects. As previously mentioned, the work technique or the actual tools are often characterized by their simplicity and effectiveness, even if this effectiveness is often obtained at the expense of ergonomics.

A new tool, no matter how ergonomic, must fulfill the users' basic needs and respond to the constraints imposed by the task. Previous experience shows that even if a new tool is perfectly ergonomic, the fact that it does not meet just one of the requirements can be sufficient for the workers to reject it. While most of these needs and constraints are easy to identify, others are hidden and more difficult to determine. They are found, for example, in unusual situations involving rarer variants of the task.A structured needs analysis involving many observations and individual and group meetings with several workers is therefore an unavoidable starting point for this type of project.

Sometimes, however, the workers' expectations about a new tool can be unrealistic. They want a miracle solution that retains all the advantages of the current tool or technique and that eliminates the ergonomic disadvantages. It then becomes important to establish, with the workers, the relative importance of each of the needs and constraints in order to find the ideal compromise.

2.4. Challenges and pitfalls related to the design and implementation of the new tool

When a tool manufacturer designs a new product, he possesses the expertise, means of manufacture, and the materials necessary for his products. As well, he can easily and rapidly produce several prototypes, which allows him to validate and refine its design in several steps before arriving at the final product. However, in the case of a one-time development of a very specialized tool for a company's specific needs, the means available to the development team are naturally more limited:

- The expertise and financial means available do not always allow the use of all possible options or technologies, and the tools must therefore remain technically simple;
- The means of fabrication are often limited to the basic techniques of mechanical fabrication, thus eliminating, for example, component-molding processes;
- The choice of materials must often be limited to standard materials that are easily accessible in small quantities;
- The number of prototypes that can be produced is generally very limited.

Thus, in addition to the technical aspects inherent in any development project, adapted tools must be designed by taking into account these particular constraints.

Moreover, when a new tool is being introduced, the workers are sometimes disappointed. In principle and on paper, the new tools can seem functional and ergonomic, but when the prototype is in the users' hands, small details can rapidly lead to a less positive perception. The workers may then have a strong reaction to go back to the old methods or the old tools. This situation is generally unavoidable and the designer must always expect to have to deal with it.

3. Critical success factors

The main steps in the development and implementation of special purpose industrial tools and the critical success factors that should be considered during these steps are presented in this section.In all these steps, the workers' active participation is essential. A participatory ergonomic approach, as recommended by numerous authors, must be favored [1][2][3]. At least two experienced workers should be part of the project team. This involvement must be voluntary, and it is preferable if the chosen workers are known for their leadership and open-mindedness. The direct involvement of the operations manager (foreman, team leader, etc.) is also necessary. In addition to the ergonomist who pilots the project, the team can also use the expertise of an engineer or a technician who understands the different prototype fabrication options.

3.1. Establishing the relevance of the development project for a special purpose industrial tool

For the reasons presented in section 2.1, the development of a new tool to solve a particular ergonomic problem should only be considered when other approaches are impossible to put into practice or have proven ineffective. So, before deciding to initiate such a project, one must first consider the other potential solution scenarios. As in any occupational health and safety prevention procedure, prevention of hazards at the source must be the first option to be considered. Possible options include:

- Eliminating the task or certain parts of the task that make it difficult;
- Reducing the loads, effort, repetition or pace;
- Improving posture by reconfiguring the workstation.

Also, the work technique or the tools used by the workers generally represent only one aspect of the problem and therefore offer only one solution scenario. The use of an Ishikawa diagram[4]to identify all of the problem's contributing factors is a technique that is proving very effective in properly understanding the entire context. With this technique, the workers participate in the analysis of the problem and it ensures a shared awareness of the relative constraints of the potential solutions. It also reduces the requirements or expectations regarding a new tool, by identifying alternative measures that will help reduce the ergonomic hazards. In the ergonomic evaluation project for the aluminum plant cleaning task presented in Figure 1, this technique identified several risk reduction options: improvement of work methods, optimization of the production sequence, improvement of surface preparation, etc. A new more ergonomic cleaning tool was then designed as a complement to these measures.

These initial steps provide a better understanding of the general context and promote worker support for the special tool development project. They are therefore crucial for a good start and the success of a project.

3.2. Analyzing needs and constraints

Understanding the needs and constraints associated with the use of a special tool is determinant in the project's success or failure;the project must therefore include a structured ergonomic and functional analysis. This procedure naturally begins with observations of the task for several workers (men and women, with varied levels of experience and ideally within different working teams) and in varied production contexts. Not only do individuals have different approaches, but work teams also have their own ways of doing things and their particular constraints that can impact the use of the tools. When possible, individual interviews with certain workers can complete these observations.

One approach that is also very effective for identifying needs and constraints is the holding of a focus group with the workers. The leader prepares a list of discussion topics and invites the workers to express their needs. Eventually, the discussions develop into exchanges between the workers themselves, challenging their viewpoints on their needs and constraints. The information that emerges during these exchanges is often very rich in data relevant to the project.

When a tool is already being used, the analysis must also focus on identifying its positive and negative points, as its users perceive them. The positive aspects of the actual tool must be carefully considered: the users will expect to find them in the new tool.

In drawing up the list of needs and constraints, besides the ergonomic aspects, certain points must be paid particular attention, mainly the rapidity of deployment of the tool, its effectiveness for the task to be performed, its versatility for the different production situations, its strength and durability, and finally, its ease of maintenance, as for example for sharpening or for replacing wear parts.

These needs and constraints are then translated into specifications, which, insofar as possible, must be expressed quantitatively. For example, when users want a tool to be easily activated, the maximum activation force (in lbs-forceor Newtons)that the tool must fulfill must be determined. It may be useful to gather this information in a project specificationsdocument that lists the requirementsand quantitative targets associated with each of them. Figure 2presents some of the specifications (a) produced in the context of development of a (b) new toolthat facilitates the stripping of the small electrical wires used in telecommunications systems. The technical specifications defined in this document made it possible to more accurately establish the needs and constraints that the new tool should meet. This particular tool was patented.

Functions	Specifications	Target values
Frees the thumb and index finger	Length of the neck	20 mm max.
Allows the insertion of the short wires	Length of the stripping slot	6 mm
Operates easily	Length of cutting movement	12 mm
	Activation force	3.5 N max.
Is light	Weight	250 g max.
Is held comfortably in the hand	Length of handle	110 mm
	Diameter of branches of handle	12 mm
…	…	…

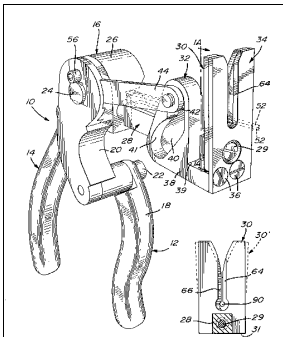

Fig. 2. (a) Specifications (b) Special tool for wire stripping

3.3. Identifying the ergonomic characteristics to be considered

Regarding the tool's ergonomic aspects, the basic principles presented in the literature must naturally be taken into consideration [5][6][7], particularly:

- Posture of the upper limbs (hands, wrists, arms) when using the tool;
- Posture of the back when using the tool;
- Use with one or two hands;
- Shape and dimensions of the handles;
- Use by right-handed and left-handed people;
- Use by people with different anthropometric characteristics;
- Weight of the tool and the position of its center of gravity;
- Required activation force or the effort associated in performing the task with the tool;
- Vibrations or impacts transmitted by the tool.

Previous experience showed that handle design was very important in the users' perception of the new tool. Since the handle is their first contact with the tool, its design must be addressed with care [8]. Previous tests on different handles with the users could avoid errors that could affect their perception of the tool. Figure 3presents a tool prototype for transporting people in wheelchairs easily on stairs. In this project, significant effort went into determining the ideal configuration of the handles to meet the needs of the workers involved.

Fig. 3. (a) Prototype of an aid for transporting wheelchairs (b) Configuration of the upper handles

When a tool is already being used by workers, it can sometimes be advantageous to keep the same handle in the new tool. Even if the handle isn't ergonomically perfect, it offers the advantage of providing a familiar point of reference for the users, which can facilitate the adoption of the new tool.

As for the efforts required to use the tool (activation force, efforts required to complete the task, weight of the tool), it is important to quantify the targeted maximum efforts. These objectives can be established by combining literature data, force measurements when the task is being performed, and psychometric evaluations with the users [9].

3.4. Prototype design and testing

The best means of ensuring that the users will adopt the tool is for them to design it. In practice, this is achieved through teamwork in which the workers and the ergonomist progress step-by-step towards a solution meeting the ergonomic characteristics, the users' needs, and the constraints of the task. With this participatory ergonomic approach [3], workers who are project team members take on the design of the tool and become its promoters to their peers. In situations where the tool is basically designed by the ergonomist and then presented to the workers, its adoption by the workers is often more difficult.

3D modeling and simulation software is often useful for allowing all team members to progress together in the new tool design process [10]. A common mistake is to assume that all team members can properly understand the two-dimensional sketches presenting the different design alternatives. Some software programs that can illustrate the virtual prototypes in their context of use have demonstrated their significant contribution to the special tool design process. Figure 4presents an example of modeling carried out in the design of a special welding bench (Figure 4a) in a steel structure manufacturing company (Figure 4b).Use of modeling in this project led to rapid convergence towards the prototypes that seemed the most promising in the eyes of the welders who were project team members.

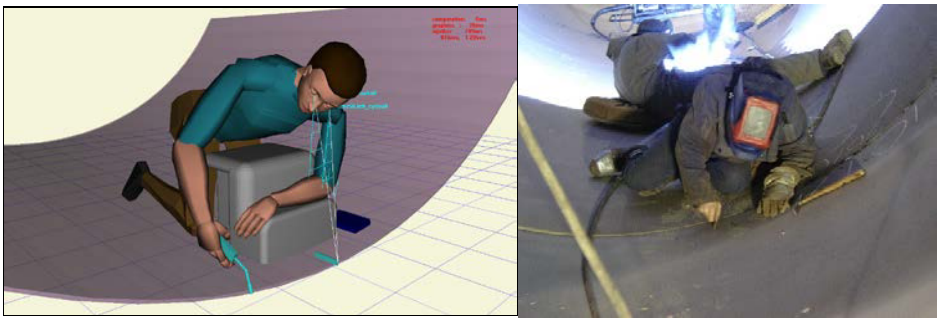

Fig. 4. (a) 3D modelingof a special bench for welders (b) Initial working posture

Weight is a very important aspect in the design of manual tools. In the specific context of special tool design, this characteristic raises a particular difficulty. In fact, considering the limitations relating to fabrication processes and the availability of materials (ref. section 2.4), prototypes are sometimes produced in-house and with the means available, and their weight can be affected. Previous experience has shown that workers have difficulty assessing the advantages of a too heavy prototype, even if they are assured that the final tool will be lighter. The same is true for all of the characteristics of the prototype, including its robustness and ease of use: there is no second chance to make a good first impression. It is therefore very important to invest the necessary effort in testing the prototypes that are the closest possible to the characteristics of the final tool, despite the technical difficulties that this may raise.

Another challenge inherent in this type of project is the adaptation of the tool to the different anthropometric characteristics of its future users. The natural reflex of ergonomists and designers is to plan for an adjustable tool. In the context of special tool fabrication, these adjustments generally lead to three major problems: they accentuate the technical difficulty of design, are less reliable, and increase the weight of the tool. In most cases, it is preferable to plan for two or three tools of different dimensions (including the diameter of the handles) that can fulfill the users' different anthropometric characteristics. In the example of the cleaning tool presented in Figure 1, two tool formats (long and short) were proposed in the final version.

A common mistake is to carry out the prototype tests in a normal production context. This decision is often dictated by the fact that designers want to validate, as realistically as possible, the correspondence between the new tool prototype and the needs and constraints of the actual situation. However, this approach has more disadvantages than advantages. In fact, when working under production conditions, the workersfeel performance pressure that can affect their capacity to correctly evaluate the prototype. Since a human being focuses on his objective when performing a task, it is difficult for workers to disregard the difficulties that arise when learning how to use a new tool. Therefore, it is clearly preferable to carry out the prototype tests in simulated situations or in non-production contexts, allowing the worker to take the time necessary to learn how to use the prototype, to assess its advantages, and to identify precisely the aspects that must be improved. During the special welding bench development project (ref.Figure 4), tests could not be conducted outside of production. It was very difficult to obtain constructive input from the workers, which contributed to the failure of that project.

3.5. Implementing the new tool and ensuring follow-up

Two important aspects must be considered when implementing a new special tool: the workers' resistance to change, and follow-up[11]. To minimize the resistance to change with the new tool, its implementation must follow certain rules. First, this implementation must initially take place in targeted production situations, normally those that present the fewest difficulties or with the lowest requirements. The implementation must then be carried out under supervision and ideally with the most open-minded and most influential workers. These positive leaders, once they are convinced of the interest of the new tool, can more easily convince their peers. The implementation should also be done gradually, if possible by reducing the productivity requirements at the start. A new tool can take a user a certain time to learn how to have it yield its full potential, somewhat like a golfer who must learn again how to play with new clubs, however high-performance and costly they may be.

Direct follow-up of the initial implementation stages by the ergonomist is crucial, first to "train" the workers in the use of the new tool, but also to rapidly detect any defect or problem with the tool. It is in fact very harmful if a "defective" tool is left in use with the workers. The word spreads rapidly between the workers when the tool has problems. It could then be difficult to counter the negative perceptions that become established with the workers. Also, the first "operational" versions of the tools often bring to light certain defects after several days of use: reliability, robustness, appropriatenessin specific cases, etc. Regular follow-up is therefore a critical aspect for rapidly identifyingthe defects and for allowingthe solutions to be considered by the users themselves.

4. Conclusion

This paper presents some of the challenges and pitfalls that could compromise the development and implementation of special purpose industrial tools. Critical success factors that should be considered during the main

steps of these ergonomic interventions are also presented. Based on past experience, these aspects are key elements, making the difference between the success and failure of such projects.

Of course, special purpose industrial tool development projects are among the most challenging assignments for industrial ergonomists. They are undertaken when all other alternatives have failed or are impossible to implement, and their success is not assured. However, when these special tools meet the needs and constraints and are successfully implemented, their potential impact on the reduction of ergonomic hazards is considerable and they are received in a very positive way by the workers.

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