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Design and Ergonomics. Methods for Integrating Ergonomics at Hand Tool Design Stage

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As a marked increase in the number of musculoskeletal disorders was noted in many industrialized countries and more specifically in companies that require the use of hand tools, the French National Research and Safety Institute (INRS) launched in 1999 a research project on the topic of integrating ergonomics into hand tool design, and more particularly to a design of a boning knife.

After a brief recall of the difficulties of integrating ergonomics at the design stage, the present paper shows how 3 design methodological tools—Functional Analysis, Quality Function Deployment and TRIZ—have been applied to the design of a boning knife. Implementation of these tools enabled us to demonstrate the extent to which they are capable of responding to the difficulties of integrating ergonomics into product design.

ergonomics design method TRIZ QFD

1. FOREWORD

For a number of years, hand tool design has been a focus of attention of users, manufacturers and researchers. Concern for imposing the least possible demand on the user and thus a more ergonomic design (do the job harmlessly, effortlessly, comfortably) has now complemented the initial aim involving a concern for performance-related efficiency (do the job better and quicker than by hand).

Since the early 1980s, we have in fact noted a marked increase in the number of musculoskeletal disorders in many industrialized countries and more specifically in companies that require the use of hand tools: in the food industry [1], in the car industry [2], in electronics [3] and in the assembly of household appliances [4], etc.

Early in 1999, the French National Research and Safety Institute (INRS) launched a research program on the topic of integrating ergonomics into hand tool design, within the scope of a multidisciplinary project entitled CEROM[1]. This project hinges around an industrial case study; the meat boning and carving trades [5].

2. DIFFICULTIES

A first difficulty in integrating ergonomics at the design stage relates to what is called the paradox of design ergonomics, i.e. "…to express something effectively based on a work situation, we must wait until it is fully designed, yet then it will be too late to intervene in its design" [6]. This difficulty can only be overcome by all design players validating each product development phase. This iteration phenomenon is often considered an unknown quantity, a disruption of design: "we've made a mistake, so

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[1] Acronym for "Conception ERgonomique d'Outils à Main" (ergonomic design of hand tools).

we'll have to start all over again". It is, in fact, one of the fundamental design activity characteristics and should therefore be integrated into the design method itself [7, 8]. Without the final product, absent by definition because it is in the process of being designed, only prototypes can effectively materialize the future product in the designers' minds. Prototyping techniques have now reached maturity and widely favor this type of iterative approach (Figure 1).

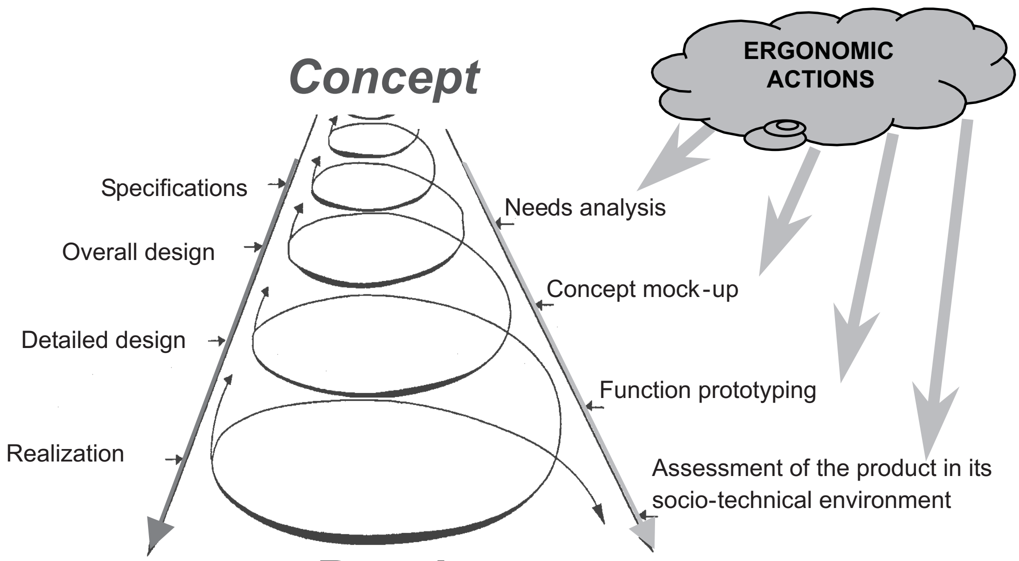

Figure 1. "Ergonomic" life cycle [9].

A second difficulty is associated with the insufficiency, even absence, of communication between design players[2]. Indeed design is a multidisciplinary activity by its very nature. Behavioral science-based disciplines, such as ergonomics, are made to intersect with engineering-based disciplines traditionally governing most design activity "Design is necessarily a horizontal discipline, in which it is essential to control meeting points between intersecting disciplines" [10]. As an organizational system allowing communication to be improved by stressing cooperation as an inter-player coordination principle, concurrent engineering is currently recognized as favoring ergonomics integration [11, 12].

Then a third difficulty is linked to the fact that a multitude of design tools exists and there is a lack of guides to assist designers in selecting which are suited to integrating ergonomics. As noted earlier, iteration, multidisciplinarity and communication are necessary conditions for integrating ergonomics into design, we therefore focused our attention on design tools which satisfy these requirements and, more particularly, on Functional Analysis (FA), Quality Function Deployment (QFD) and TRIZ. The following sections introduce these tools through their CEROM project implementation.

This work was undertaken by a multidisciplinary team combining essentially engineering and ergonomics specialists in association with Functional Analysis, QFD and TRIZ specialists, along with boning knife users and designers.

[2] The notion of player is not necessarily associated with one and the same person. A player can be a department, a company, a body represented at meetings.

3. APPLICATION OF FUNCTIONAL ANALYSIS IN THE CEROM PROJECT

Created at the end of the 1940s by the General Electric Company, Functional Analysis (FA) was rapidly employed by manufacturers needing to confront major financial and strategic challenges.

It is a multidisciplinary approach that has to be implemented within a working group combining different design players. Functional analysis results are formalized in a Needs Functional Specification [13].

Application of this method enabled a functional specification to be drafted for the cutting tool to be manufactured within the scope of the CEROM project. The main elements of information used in its drafting were:

- technical and financial data provided by the project partnering manufacturers,
- results of a field survey of 196 operators from different meat plants (Table 1),
- information obtained at working meetings led by a functional analysis consultant and involving an ergonomist, a knife manufacturer and users (deboners and sharpeners).

Research resulted in 32 functions being listed and allocated to 9 groups (Table 2). Two of these functional groups (FG 3 and FG 4) are specific to ergonomic requirements. In accordance with FA, all these functions were then characterized and prioritized.

TABLE 1. Experience of Knife Users' [13]

Part of the Tool	Complaint	Unsatisfied Operators (%)
Handle	Inadequate shape	22
	Inadequate length	12
	Inadequate diameter	16
	Inadequate grip	**45**
	Inadequate comfort	31
	Inadequate hardness	23
Handle guarding	Inadequate height	31
	Insufficient protection	25
Blade	Inadequate length	33
	Inadequate height	30
	Inadequate thickness	17
	Inadequate stiffness	20
	Inadequate curvature	14
	Bad sharpness	**42**
	Too short duration of life	**51**
	Bad quality of steel	41

Notes. Bold indicates characteristics that must be improved first.

TABLE 2. Functional Groups Identified With Functional Analysis Method

No.	Identified Expectations (Needs)	Weight (%)
FG1	Allows working with meat (carving, separation and scraping)	18
FG2	Complies with food hygiene regulations	18
FG3	Does not injure operator	18
FG4	Does not cause pain	16
FG5	Can be held in different positions	10
FG6	Quickly regains cutting edge retention characteristics	10
FG7	Is cleanable	6
FG8	Is recyclable	2
FG9	Is identifiable	2

Notes. FG—functional group.

Then, we can advance that FA allows ergonomists to take part in drafting specifications for the product to be designed and to formalize ergonomics-related expectations. This task is facilitated by the fact that, in addition to seeking functions themselves, the Functional Analysis approach explicitly asks the following questions in this connection [13]:

- Do we have special safety-related requirements?
- Is compliance with standards and codes required?
- What type of ergonomics is expected?

But, even if ergonomics-related needs have been identified and prioritized, this does not mean that the designed object will in fact satisfy all of them. Indeed the inevitable problems that arise during the subsequent stages of the design process, combined with the difficulty or even absence of communication between the engineering specialists and those representing ergonomics, can produce an adverse and/or unpredictable impact on satisfying such needs. Consequently, we retained the QFD method to link these needs to product design parameter definition.

4. APPLICATION OF QFD IN THE CEROM PROJECT

Created in the 1970s, one of its founders, Dr Yoji Akao (1993) [15], defined the QFD as follows: "QFD is a method for introducing quality right from design stage to satisfy the customer and to transform customer requirements into design objectives and key points that will be required to ensure quality at production stage".

As its name suggests, the QFD[3] approach is based on deploying user needs (the "Whats") in terms of design and production-related parameters (the "Hows") for the new product. This process is represented by double entry "Whats/Hows" tables allowing correlations between entries to be identified and prioritized.

The QFD method integrates perfectly into a concurrent engineering approach [17, 18] and its validity for linking customer needs and product definition is increasingly recognized today. Then, it can be asserted that this methodological tool is indeed capable of providing a solution to the difficulties of integrating ergonomics into product design [19].

The more used and the best known matrix is named "House of Quality" (HoQ). In addition to "What/How" correlations, this matrix involves a paired comparison of the different "Hows" [20]. We thereby obtain a "roof"-shaped half-matrix allowing design parameters to be identified in terms of synergies (+ sign) and opposites (– sign).

The first step in establishing HoQ involves listing customer needs (a "Whats" list). For this, we used the results of the Functional Analysis. In respect of our case study, needs requiring greater satisfaction are obviously those directly involving ergonomics requirements (FG 3 and FG 4). Moreover, the field survey and the needs Functional Analysis revealed a great user dissatisfaction with respect to cutting edge retention (around 54%) and hand grip (45%). Corresponding expectations must therefore also be better satisfied.

The second step involves listing design parameters (a "Hows" list) that will enable the previously identified needs to be satisfied. This stage is one of the key elements of the QFD method because it is the one which permits the transition to be made between what the user wants and what the designer offers.

It is at this stage that ergonomic criteria are effectively integrated into the product design process (Figure 2). These criteria are the

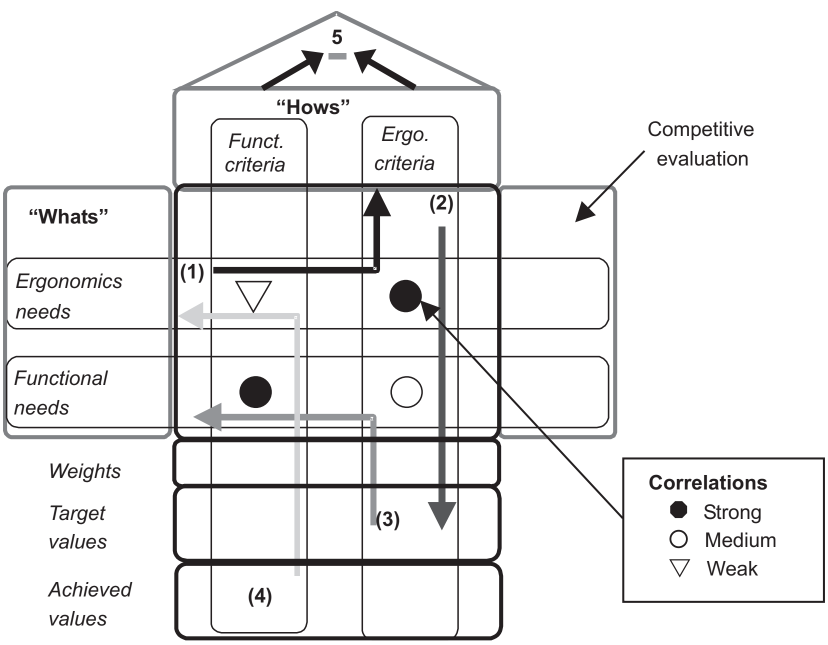

Figure 2. Integration of ergonomic criteria into the House of Quality. *Notes*. Funct.—functional criteria, Ergo.—ergonomics.

[3] For further details of this QFD method and its application, we recommend the reader to refer to the bibliographical references [14, 15].

parameters that allow ergonomics-related expectations to be satisfied (1). They can then be prioritized and target or limiting values can subsequently be fixed for them (2). Matrix presentation very easily allows on the one hand, assessment of the impact of ergonomic criteria on other expectations (3) and, on the other hand, prediction of the consequences of modifying one or more design parameters on ergonomic expectations (4).

Thus, in terms of our boning knife redesign problem, all the target values for the ergonomic criteria were defined with an activity analysis of operators linked with specific experimental results and also a bibliographic study (Figure 3).

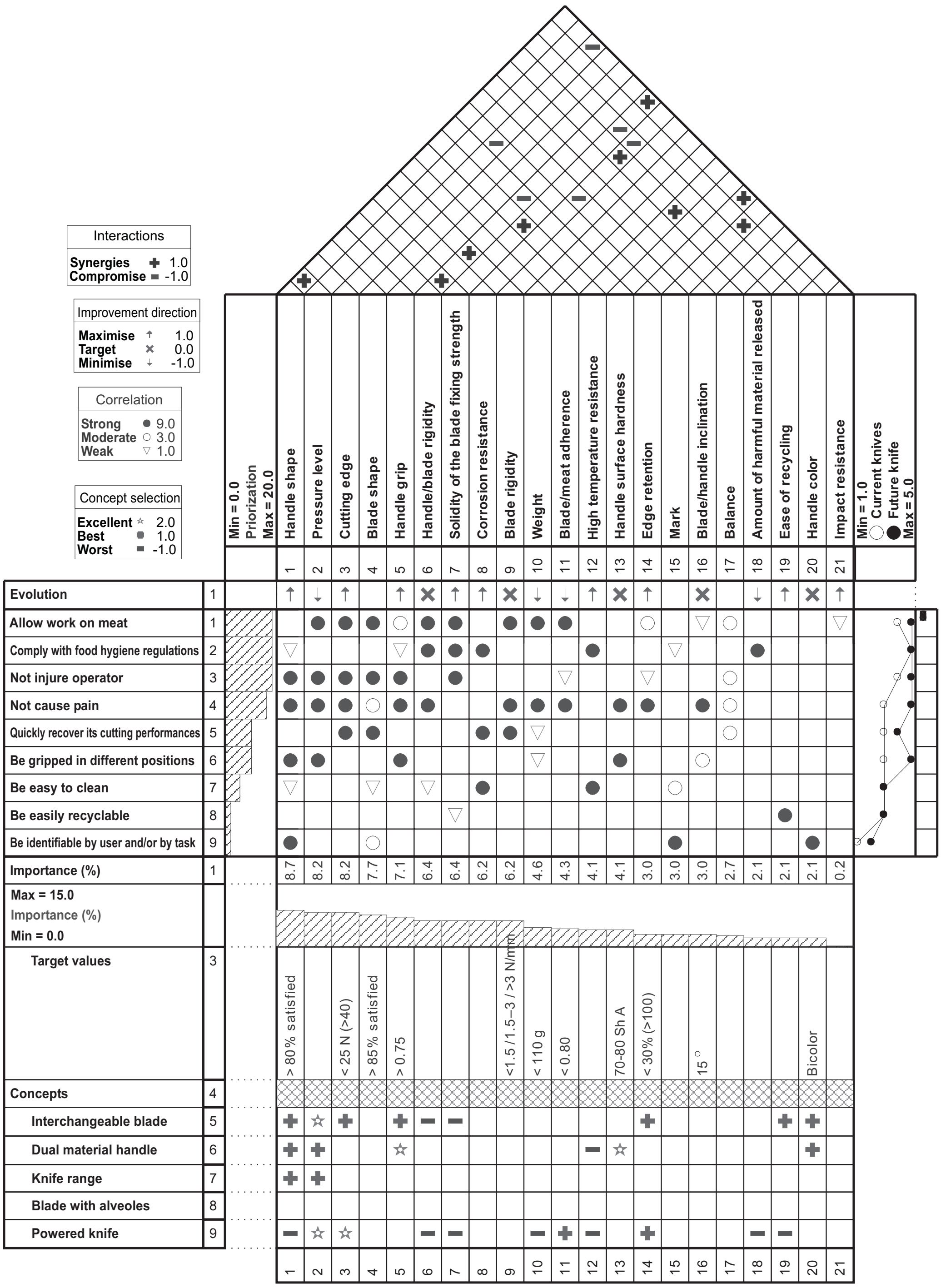

Figure 3. Boning knife House of Quality.

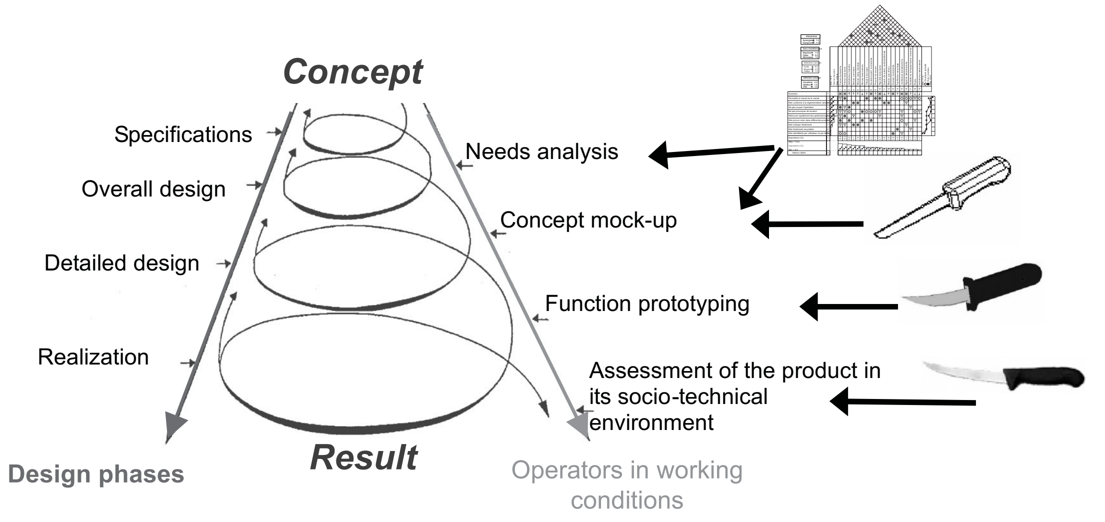

Figure 4. House of Quality as a graphical model.

One of the main criteria identified with respect to ergonomics needs is the shape of the knife handle (strong correlation). Moreover, this parameter correlates with several other functional expectations and, as a result, it turns out to be one of the most important knife criteria. If one considers that in ergonomics there is no average individual [21, 22], ideally this parameter should not be given a single target value but several and even a specific value for each individual to take into account the variation in hand anthropometrical dimensions. This fact then generates a number of product concepts such as a knife with an interchangeable handle or a range of knives with different size handles.

Another important ergonomic criteria is the handle grip (strong correlations with ergonomics needs). Experimental results combined with the activity analysis allows us to proposed a static friction coefficient greater than 0.75. With this handle grip, it is foreseen that more than 95% of the users should be satisfy of the handle grip [23].

As a result, by ensuring a visual grouping of all effective data for decision-making in relation to product design, HoQ can be considered as a common reference encouraging communication between different design players. Moreover, in an iterative design process, this matrix can be recognized as a graphical model of the product allowing validation by all actors involved in the needs expression and specification stages. It plays a similar role to digital models and prototypes for validating other stages (Figure 4).

Drawing up QFD matrices nevertheless raises certain difficulties. The main one involves the creation of enormous matrices, which subsequently become unusable, with a view to being exhaustive. It is therefore very important to establish priorities for the elements to be deployed. A second difficulty is associated with manipulating the matrices combined with the need to keep them alive. As communication support, they must, in effect, be regularly updated or else they will quickly become obsolete. Use of computing tools is an effective aid in this area.

Finally, to help designers solve the HoQ-highlighted compromises between certain functional parameters and ergonomic criteria, we retained the TRIZ creativity method. This method distinguishes itself from other creativity methods by its specific tools for seeking technical solutions that reject design parameter compromises.

5. APPLICATION OF TRIZ IN THE CEROM PROJECT

TRIZ is a Russian acronym meaning “innovation problem solving theory”. Genrich Altschuller developed this theory from 1946 on to assist inventors and more generally engineers in solving technological problems in a methodical manner [24].

This method integrates several families of tools, which help the designer to reformulate his or her problem in terms of physical or technical contradictions:

- a physical contradiction appears when two contradictory characteristics are required of the same parameter. This type of contradiction highlights the insoluble character of a problem at first sight;
- a technical contradiction is generated when two system parameters oppose each other, an improvement in one leading to a deterioration of the other.

These two types of contradiction can then be solved by applying independently or in combination the different tools provided by the TRIZ method (Figure 5). These tools will direct the designer towards generic solutions that have enabled past, similar problems to be solved. Transposition of these solution models into effective solutions to the problem raised continues to lie in the field of creativity.

effect essentially based on group psychology (brainstorming, synectics, trial and error, etc.) approaches, which are usually relatively ineffective for solving technological innovation problems because of their random nature [25, 26].

The main limits and difficulties associated with the use of TRIZ result essentially from the fact the different TRIZ design parameters defined are highly generic and it is therefore sometimes difficult to model a specific problem [27, 28]. The same goes for the interpretation of solution models in the form of a specific solution.

In offering many extensively commented and illustrated examples, the different software programs supporting this method form an effective aid to overcoming these difficulties.

We present below the approach adopted for solving the following two contradictions revealed by the QFD method:

- between the handle surface hardness, which must not be excessive to avoid causing pain and the handle/blade connection, which must be as strong as possible;
- between the initial cutting power and the cutting edge retention, both of which must be as high as possible.

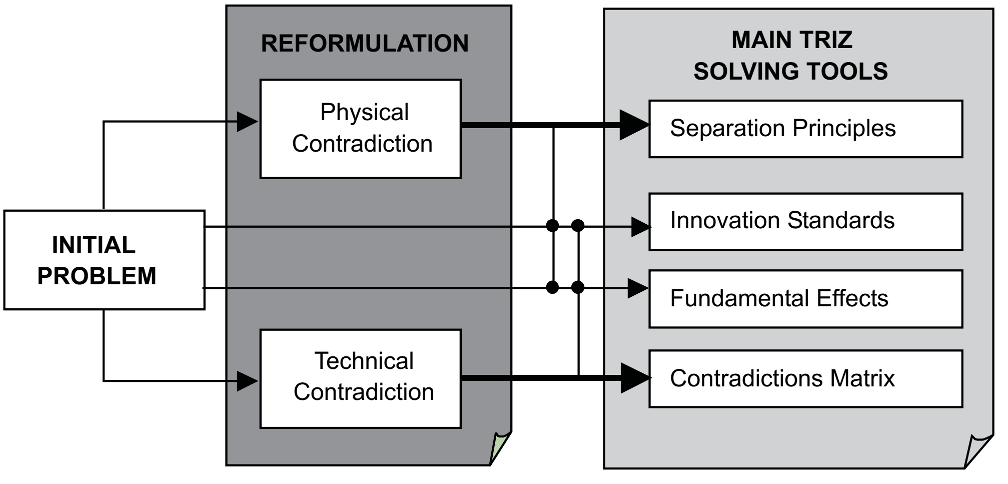

Figure 5. Main TRIZ tools for solving technical problems. *Notes*. TRIZ—innovation problem solving theory.

TRIZ can be distinguished from other creativity methods by its functional approach to innovation problems. Traditional creativity methods are in

As recalled earlier, the TRIZ method requires formulation in the form of contradictions between the harmful and the useful function:

"The handle must be both soft to avoid causing pain and rigid to hold the blade". This is therefore a "physical"-type contradiction.

To solve this type of contradiction, TRIZ recommends applying the Separation Principle: separation in space, in time or by transition towards a sub-system. With regard to separation in space, descriptions of the recommended principles are:

- divide an object into independent parts;
- place objects in series, one inside another;
- use multilayer assembly of objects rather than single layer assembly;
- use an intermediate object or process.

As for the contradiction between initial cutting power and cutting edge retention, we used both the Contradiction Matrix tool and the Separation Principle.

This contradiction can effectively be formulated as a technical contradiction between two parameters: initial cutting power and cutting edge retention. In this case, the parameter retained for enhancement is "strength" and the deteriorating parameter is "ease of usage" according to the TRIZ taxonomy.

This contradiction can also be formulated as a physical contradiction. Initial cutting power and cutting edge retention being effectively both conditioned essentially by the blade sharpening angle [29], the contradiction can be expressed in the form "Blade sharpening angle must be both small for high initial cutting power and large for good cutting edge retention". Descriptions of the proposed parameters are:

- divide the object into independent parts;
- facilitate object disassembly;
- replace an expensive object with a set of cheap objects;
- have each part of the object fulfill a useful and different function.

This led us to envisage a design featuring a removable and/or disposable blade associated with a bimaterial handle (Figure 6).

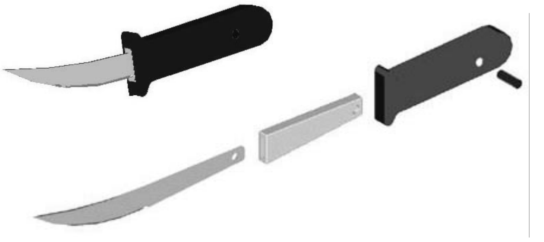

Figure 6. Illustration of removable blade and bimaterial handle design.

6. IMPACT OF THESE METHODS ON HAND TOOLS DESIGN

As it is shows by the functional analysis and the HoQ, a concept of knife which combined the "interchangeable blade" and "bimaterial handle" solutions turned out to be one of the most interesting (Figure 3).

The main foreseen advantages of this concept are:

- to allow a better fitting of the handle to the hand anthropometrical characteristics;
- to permit the choice of the blade in relation to the tasks to be performed;
- to sharpen the blade with a greater accuracy because the handle and especially the guard on current single piece knives hamper accurate blade positioning;
- to facilitate the recycling;
- to personalize and to identify the knife through the handle color and/or marking.

Currently, prototypes of knives based on the proposed concept ("interchangeable blade" and "bimaterial handle") and that incorporated the proposed ergonomics criteria [23] are currently made in order to test them in real working conditions by the users and then to validate their usability. At the time of writing this paper, for reasons of industrial ownership (registration of patent in progress) we cannot describe in detail the proposed technical solution.

In order to confirm the pertinence of these methods for integrating ergonomics at the design stage, we can also mentioned the following:

- Eurohandtool[4], a project where the QFD method was used to improve the ergonomic quality of pruning shears [19];
- Experience of the SOFRAGRAF[5] company which has used, with success, for several years the QFD method for the design of hand tools, staplers, nailing machines, etc. [30].

7. CONCLUSION AND PROSPECTS

As a result of this CEROM project, we can advance that the three multidisciplinary tools used (Functional Analysis, QFD and TRIZ) are suited to integrating ergonomics at the design stage. As a matter of fact, this paper shows that starting from an activity analysis, the ergonomist will be in a position to:

- integrate ergonomics-related expectations;
- take part in drawing up the design parameters ("Hows" list) by integrating therein the necessary ergonomic criteria;
- contribute to determining the various degrees of correlation for expectations and/or ergonomic criteria;
- identify possible contradictions between these ergonomic criteria and other design parameters ("the House of Quality roof");
- identify the solution concept from those proposed that best respond to ergonomics-related expectations;
- anticipate the consequences of modifying a specific design parameter on ergonomics-related expectations.

Furthermore, these three methodological tools can be logically sequenced (Figure 7). In this way, they enable the overall design process to be formalized [31, 32, 33, 34]. An additional step would be taken if all the software supporting these tools would be linked (or merged) together. An ultimate step consists in linking these tools with computer-aided design (CAD) software. This is the aim of the system model introduced by Hasan et al. (2003) [35].

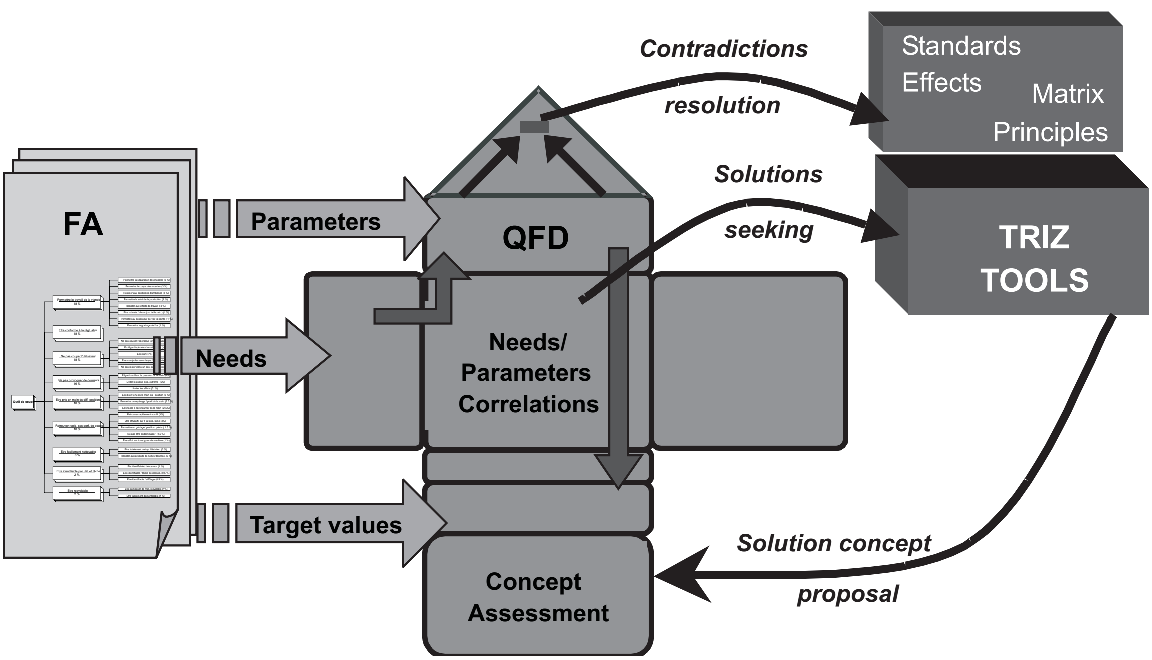

Figure 7. FA/QFD/TRIZ logical sequencing. *Notes*. FA—Functional Analysis, QFD—Quality Function Deployment, TRIZ—innovation problem solving theory.

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[5] French subsidiary company of SENCO Group.

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