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CONTRIBUTION OF VALUE ANALYSIS TO THE EVALUATION OF INNOVATIVE PRODUCT DESIGN SOLUTIONS

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Abstract

International economic competition drives companies into cost reductions but also greater innovation development. In this context, our work deals specifically with innovative product design. In order to innovate, companies have to develop their own engineering culture. They also have to be able to detect new customer's needs, and to generate and select new technological options. We propose a methodology to enhance the generation of innovative solutions. This methodology is enriched, particularly regarding the requirements (functions and constraints) which a product has to fulfil, by integrating a Value Analysis approach. This phase is essential to evaluate and compare innovative solutions as objectively as possible: a graphical software interface has been designed to improve this critical phase. This methodology is developed on an industrial example, part of a project with the French national railway company (SNCF): it involves the design of a picking up system for metallic debris due to regular train wheel wear and spread on railway tracks. Our methodology has also been developed by using the student team project activity at Ecole Centrale in Lille (France) as a test.

Keywords: Design, Creativity, Problem Solving, Value Analysis, TRIZ.

1. Introduction

Trade globalization and dazzling development of Asian countries is changing durably the Western world economy. Products productions move progressively towards countries where labour costs are smaller. This leads to considerable unemployment in countries where factories have to close down. The workforce of the countries emerging as new players in the economic world is becoming more and more skilled, and the highly technological products which they manufacture offer nowadays a very competitive quality level. For instance, China manufactures already one third of the portables sell on the planet.

To reduce manufacture costs is not enough. When selecting a product, a consumer makes his/her choice using various criteria among which appear the cost, but also the performance, the associated services, and so on. Competition amplifies consumer demand [1] and the useful life of new products shortens since they are soon superseded by more innovative ones.

To confront these challenges, we think that an crucial point is to develop a really innovative process of product design and engineering. We need thus to define and implement conceptual and methodological frameworks which may be systematically applied [2]. The objective is thus to allow enterprises to be proactive, i.e. to master innovation and to better anticipate needs and not only to react to the events.

2. Aim of the work

This paper deals more particularly with research and evaluation of innovative solutions in the product preconception stage following a rigorous specification of the needs.

In this era of constantly increasing customer demands, the capacity of a design office to generate new products or variation of products in a continuous innovation process is indeed essential in order to get a competitive advantage on rivals.

We consider that, upstream to the traditional design process, it is useful to consider two separate phases: requirement definition and research of innovative solutions.

In the second part of our paper, we present the proposed global. We give an overview of the design life cycle. Knowledge acquisition is a permanent process which must be organized in order to aliment the following phases.

The third part presents the requirement definition phase. Often, the definition of the needs is much too superficial or already oriented toward a particular solution. It has thus to be more clearly identified. We use therefore functional analysis to enrich our method, in order to identify the constraints and criteria to satisfy.

Part four deals with the research of innovative solutions and their selection. The question is also “how to find such original solutions?”. We have proposed the use of creativity tools to generate innovative solutions [3]. We claim, after our tests on concrete industrial or pedagogical projects, that the use of creativity tools is interesting in a general process design. To select a solution to be developed, currently known approaches propose to make an average of the degree of satisfaction of the various criteria. We think that this it is not a good approach since it leads to abandon some constraints or criteria satisfaction. We propose to track each criterion and constraint during the whole lifecycle, and to give to the designer an image of this tracking.

The last phase is a more classic process of conception of products and services. To ensure the requirement’s traceability, all the tools used must be merged in an integrated consistent approach.

The fifth part presents an example of experimentation for the design of a “picking up” system for metallic debris spread on railway tracks. Some screens of the application software developed to support our method are given.

3. Proposed approach

3.1. Overview of the product design lifecycle

The method we propose uses three phases to transform a first idea of the need to product delivery (Figure 1). These phases are: requirement definition, innovation / selection and product design. They are realized by a multidisciplinary team, in order to take into account all the constraints of the project as soon as possible, and to increase the capacity of innovation.

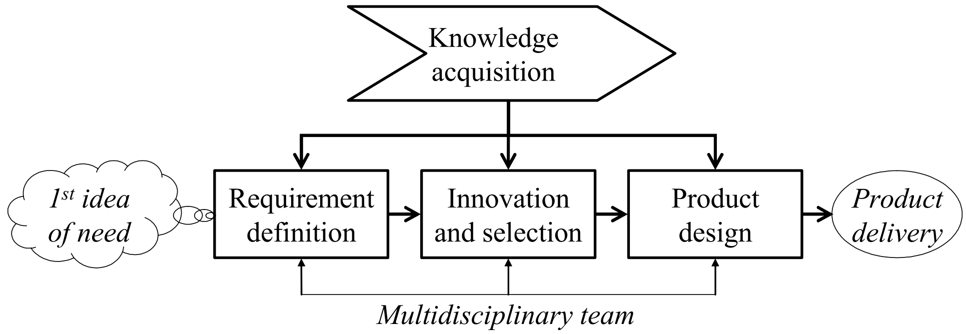

Figure 1: The three phases of the proposed approach.

The first idea of the need may emerge from different manners: market analysis to identify potential needs, new strategy in the firm leading to new product development, quality approach to highlight current dissatisfaction. This aspect is not dealt with in this paper in which the first idea of need is considered as the starting point of our methodology.

From our experience, we think that this first specification is generally incomplete, imprecise, and often expresses a lack of stand back since the client tends to describe a solution and not a need. The first phase of requirement definition aims thus to provide a systematic approach to identify the real need. Traditional project management steps do not always identify clearly this phase of requirement definition, but make it simultaneous with anteriority research, environment apprehension, solution research, and feasibility study. We prefer to isolate it phase to make sure that it is it properly taken into account.

The second phase, innovation and selection, has also to be systematized. The natural tendency is indeed to go too fast in a particular direction without taking enough time to explore a large set of solutions and to choose the one which respects all criteria and constraints optimally.

The third phase, traditional product design process, is inspired from different classical proposals [2], [4], and will not be detailed in this paper.

Knowledge acquisition is a particular process which the enterprise has to organize in order to feed the different phases, as discussed hereafter.

3.2. Knowledge acquisition

We have integrated several sources of knowledge with the aim of improving creativity in the design process by helping designers to extract information from the environment and, for instance, to organize it in a way appropriate to be used in the search for innovative solutions.

Four types of knowledge are integrated:

- Product knowledge: obtained by analyzing the company’s products or those of its competitors. Products offer a large amount of information about the ways and means of translating functions into physical architectures [5];
- Practical knowledge: provides information about the company’s know-how and the way problems are dealt with. It also gives indications about the technical production possibilities and their related costs [6];
- Principles of physics: giving all formal knowledge about materials and energy (their characteristics, their possible associations...);

- Electronic data and patent data: there are a lot of different information systems but we have focused on electronic data because they are easy to find and store. They form indeed one of the largest sources of technical information.

This knowledge has to be structured with the help of knowledge management tools, like project memories [7].

4. Requirement definition

The importance of the requirement definition phase has been previously highlighted. Human nature is relatively conservative and it is thus necessary to go beyond the first reflex which is to attempt to find a solution before to express correctly the problem.

We propose to develop three steps: need identification, information gathering and functional analysis (Figure 2).

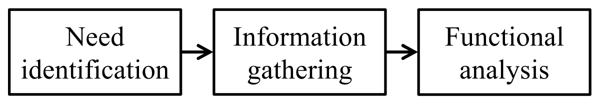

Figure 2: The three steps of the requirement definition phase.

4.1. Identification of customer’s need

In this step, we use several tools proposed in the quality management approach. The objective is to know for example who is effectively concerned by the product to develop, what are the economic and commercial issues, and so on.

For example (dealt with in one of our student’s project), a new concept of bathroom scales seems apparently to be designed to give the user’s weight. However his/her real need is perhaps not to stupidly watch a variation of some grams (the human body is subjected daily to such meaningless variations), but to know if he/she is in good health, eventually to suggest some menus for next meals tacking into account the caloric content and the user’s tastes, or to propose physical activities involving energy spending.

Important point is the specification of the user whom the desired product has to help as well as the element on which it takes effect and for which purpose. This approach allows us to stand backs with respect to existing products by abstracting the product to design. The risks of disappearance or evolution risks are searched and evaluated in order to validate the need.

Tools like brainstorming techniques or “Who, What, Where, When, How, Why?” are used.

4.2. Information gathering

This step uses the results of the knowledge acquisition phase: analysis of rival products, new patents related to the activity domain, new components, technical press articles, etc., with a more specified and precise objective.

Another issue of this step is to allow each team participant to express the solution he/she has in mind. Remark that a person coming with a preconceived idea will automatically try to impose this idea. After expressing a first level of such ideas, it becomes possible to search together other solutions, without frustrating anybody.

4.3. Functional Analysis

The objective of this third step is to define parameters which are positive, concrete and observable. The chosen approach relies on the norm given in [8] and on the method suggested by Mile [9].

Functional analysis brings straightforward, systematic tools to the identification of the functions and constraints having to be fulfilled by the product. In order to later evaluate new solutions, each constraint is associated with one or several criteria. Each criterion is associated to an admissible range or level and to a flexibility level.

For example, for a function: "*heat a room*", a criterion may be "*temperature T*", admissible threshold may be "*T=19°C*" and flexibility level is the acceptable tolerance on the admissible range, such as "possibility to negotiate up to 19°C but not under 18°C".

The work group may add a modality number to each criterion: solutions bringing an "over-value" compared to the initial need shall be more easily identified. In the example of Function A: "*heat a room*", the criterion "*temperature T*" has a level "*T=19°C*" and a flexibility of "*+1°C*" above this level. Then three modalities may be defined: "*difference of up to 0,5°C above 18°C*" "*difference of +0.5°C to +1°C above 18°C*" and "*difference of more than +1°C above 18°C*". The last modality corresponds to "over-value" solutions (Figure 3).

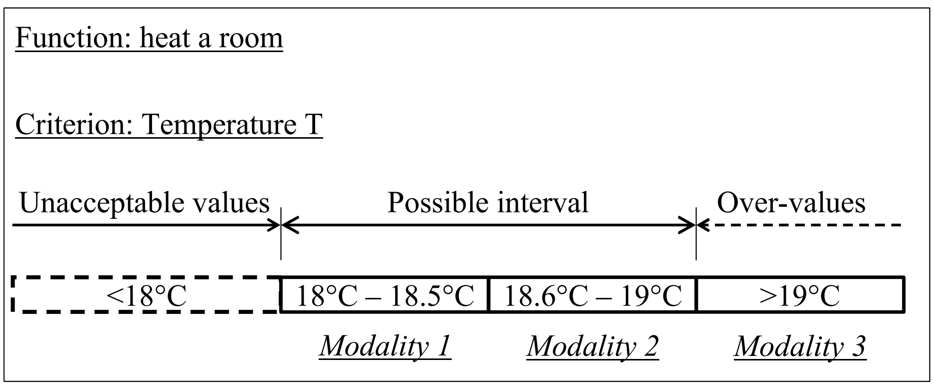

Figure 3: Three modalities for a criterion evaluation.

5. Innovation and solution selection

Here again, human nature strikes badly: everybody wants to find solutions in his/her competency domain, because everybody is prisoner of his/her culture. For a mechanical engineer, for instance, all technical solutions will need a wrench. This is why it is interesting to form multidisciplinary teams in order to confront several cultures and to develop among the actors a spirit of openness.

Furthermore, innovation often arises out of rupture; our choice consists in using several creativity methods, but other methods might be possible.

This phase groups together three steps: search of innovative ideas, evaluation of potential solutions and choice of a solution (Figure 4).

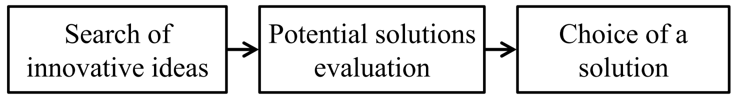

Figure 4: The three steps of the innovation / selection phase.

5.1. Search of innovative ideas

The design process can include problem solving and creativity [2], [4], [10]. According to [11], creativity is the process of generating something new that has value. It results from the action of combining previously separated elements and changing existing combinations [12].

There are many descriptions of the different stages of the creative process; they have in common the four steps shown by [13]: preparation, incubation, illumination and verification. Our proposal is based on these stages.

We have explored the creative process and the creativity techniques usually used in companies. Human factors are essential in such a process [14], [15]. Knowledge-based creativity includes various analytical steps to organize, restructure and exploit available knowledge and experience. It can also use the specially-developed and structured external knowledge bases previously mentioned.

We have surveyed 172 creativity methods and their classification in 10 families has been proposed in [3]; it helps us to select among the different methods which ones are more useful and appropriate in every case or with every culture.

Among these tools, we have chosen some of them which are integrated in our proposal. These tools are Brainstorming, Checking list, Mind Mapping [16], Triz Matrix (or other tools derived from TRIZ theory [15]) and Animal crackers for analogical thinking. So, we have combined an intuitive approach with the systematical one. Other tools can be used, and our choice has been made in consideration of our cultural user's customs. They are well known by engineers, and easy to practice.

5.2. Solution evaluation

This step consists in evaluating each solution with respect to each criterion identified in the step of functional analysis.

Here, the method is systematic: each function or criterion has a value that locates it in one of the possible modality.

A graphical representation allows the user to understand immediately the level of criterion satisfaction. For instance, we can see in Figure 5 three examples: unsatisfied criterion, satisfied criterion, over satisfied criterion.

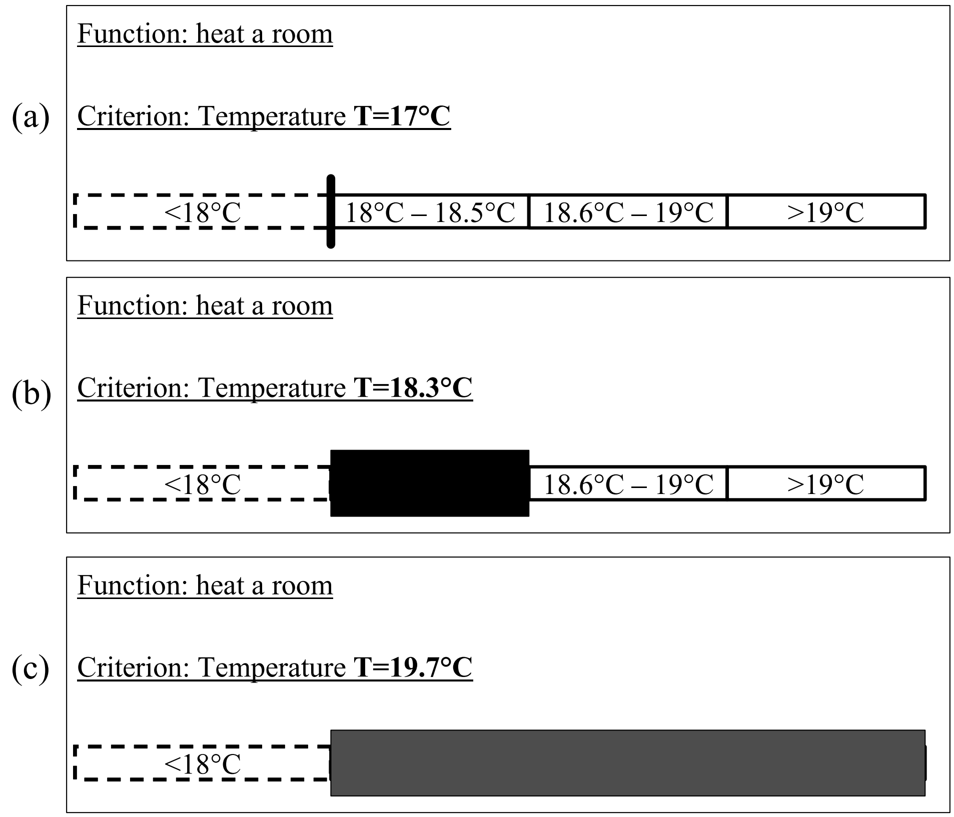

Figure 5: Unsatisfied criterion (a), satisfied criterion (b), over satisfied criterion (c).

5.3. Choice of the solution to develop

In order to choose the solution to develop, a first method consists, as in [17], in making an average of the various criteria. However this approach risks to suppress some constraints or to neglect some functions which might be progressively forgotten.

We prefer thus to save the set of functions and constraints that have emerged from functional analysis, and to offer to the designer a graphical tool allowing the comparison of the solutions.

The developed software tool allows the selection of complete or partial solutions, their comparison (Figure 6) and the visualization, function per function, of each solution (Figure 7).

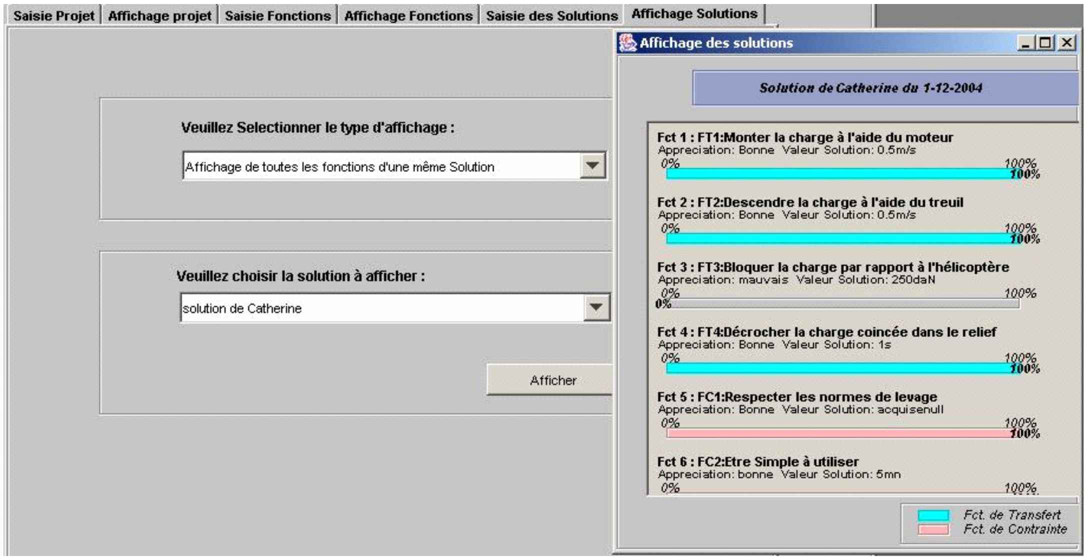

Figure 6: Display of the functions of a solution.

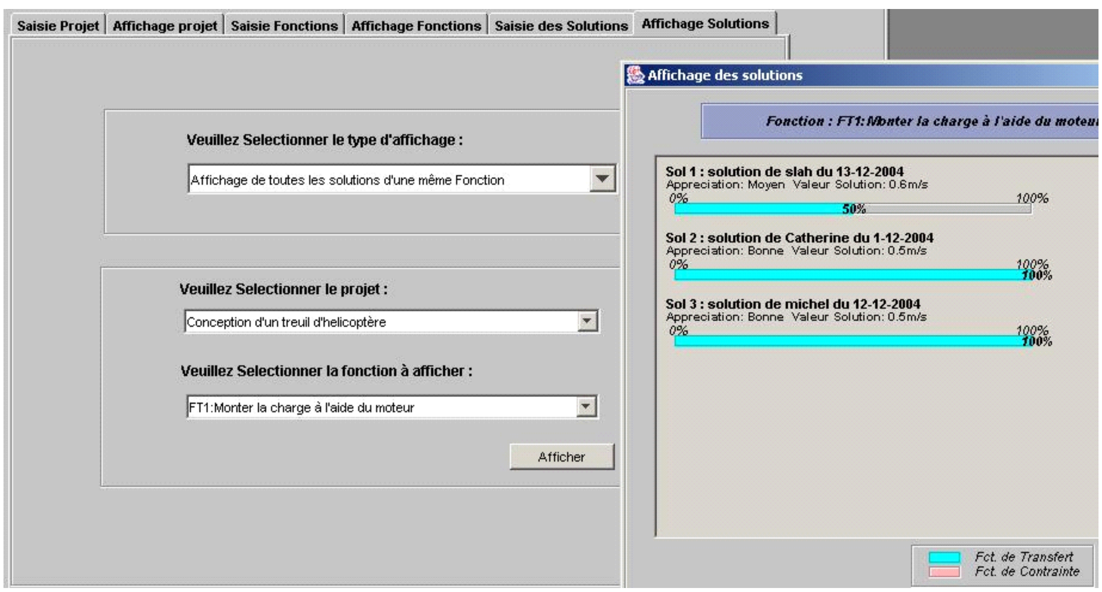

Figure 7: Comparison of the solutions for a given function.

This comparison allows the user to propose new solutions obtained by mixing several solutions.

At the end of this innovation process, we may begin a more classical process of design and realization of a product / service, like the one presented in Figure 8.

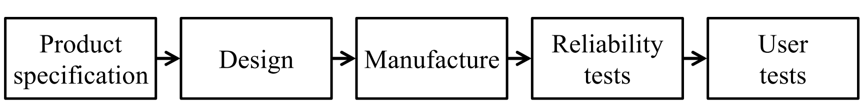

Figure 8: Classical process of design and realization of a product.

6. Application: a picking up system for metallic debris

Our method has been applied to the design of a picking up system for metallic debris due to regular train wheel wear and spread on railway tracks.

6.1. The Problem treated

Trains spread regularly metallic debris coming from their rotating parts and braking systems.

The tracks are segmented into sections linked together by rail joints; these joints are a priori isolated from each other, but, in suburban areas, where passenger traffic is very important, the quantity of metallic particles is such that it ends up creating a electric circuit continuity. The consequence is that traffic lights are closed at inopportune moments.

The picking up of these metallic debris is actually done manually or with the help of an electromagnet placed on the crane of a SNCF track inspection railcar.

In both cases operation is very slow, quite inefficient and localized. Moreover, it needs the intervention of ground employees.

In a first formulation, the objective of the innovation to develop consists in mechanizing the picking up of metallic debris due to the braking systems of trains in the railway tunnels, in order to reduce the electric circuit dysfunctions and to ensure the traffic regularity for passengers satisfaction.

It can be remarked that an effort is already done in this first formulation to distance oneself slightly from the simple picking up of debris and to be interested in the notion of passengers service. A validation of the need identifies indeed that the system to create will be useful both to passengers and to SNCF employees.

However the given document includes very precise functional specifications but they are also very oriented toward a particular solution; one can notice for example that the product has "to produce the electric energy necessary for the magnet".

6.2. Requirement definition

A first improvement work allows us to express the problem in another way: "to mechanize the picking up of metallic debris" becomes "to maintain the tracks clean[1]". A clean railways track is a track that has no particles likely to generate faulty connections at the level of tracks joints. The notion of cleanliness will be later associated to a criteria.

We proceed then to a first inventory of the ideas for solution. During this process, we naturally find back the electromagnet idea (because it already works although manually). Other ideas are also emerging: to brush the track, to suck up or to throw a fluid etc. Already some opposition appears: "one hasn't the right to throw a fluid"; perhaps, but in which regulation is it written? And is it forbidden to throw a fluid that is immediately sucked up?

We are finally able to read attentively the given functional specifications, and to extract from them the real functions and constraints (that doesn't presuppose a particular solution). It is in

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[1] Another solution might be to tolerate dirty tracks and to question the electric circuit that controls the traffic lights. This path has been immediately abandoned due to economical reasons, because it needs to transform the current infrastructure on many kilometers of railway tracks.

this step that the railway track cleanliness criterion is clarified: the track join must offer a electric resistance lower than a given well-specified value.

6.3. Innovation and selection

The search for innovative solutions has been realized according to two great families: prevention and action. Figure 9 gives some examples of the first level of the solutions considered for these two families. Globally, 18 solutions groups have been found.

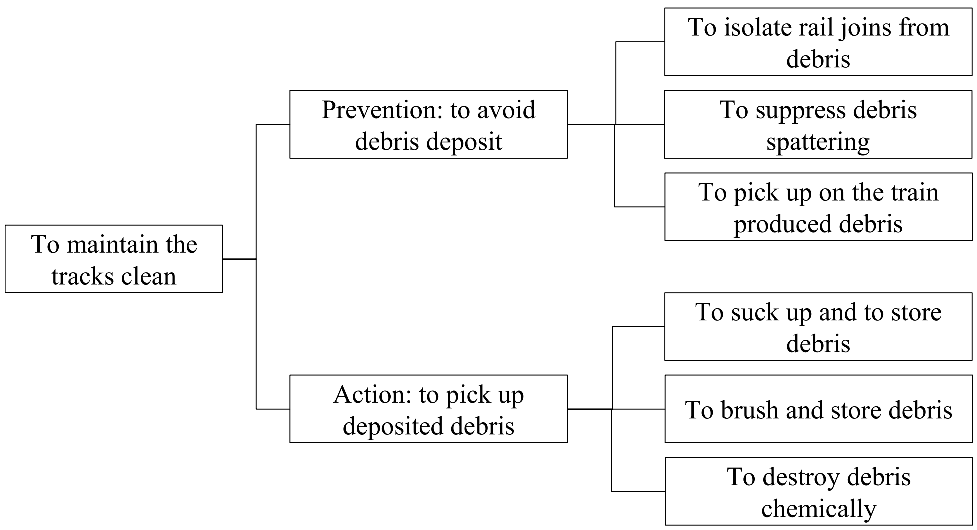

Figure 9: First level of came up solutions.

In the "action" type of solutions, three functions have to be exerted on the metallic debris: collection, transport and storage. They can be realized by three juxtaposed solutions or by solutions insuring several functions (Figure 10).

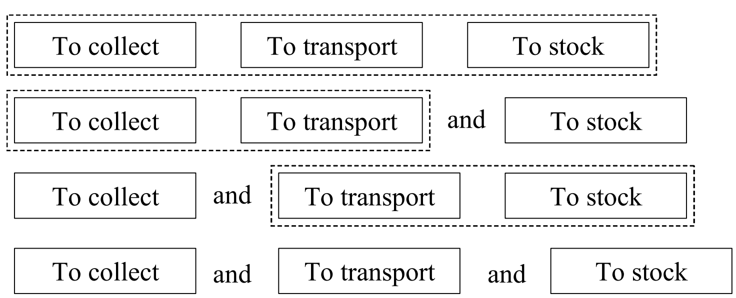

Figure 10: Solutions regrouping different functions to exert.

Many variants have been studied. For that purpose, the TechOptimizer tool [18] has been made available to both our industrial project with the French national railway company (SNCF) and to our student team project activity [19].

No solution has been rejected without justifications regarding to functions and constraints to satisfy.

A partial solution is shown in Figure 11: it is a mixed throw and suck up system moved close to the track.

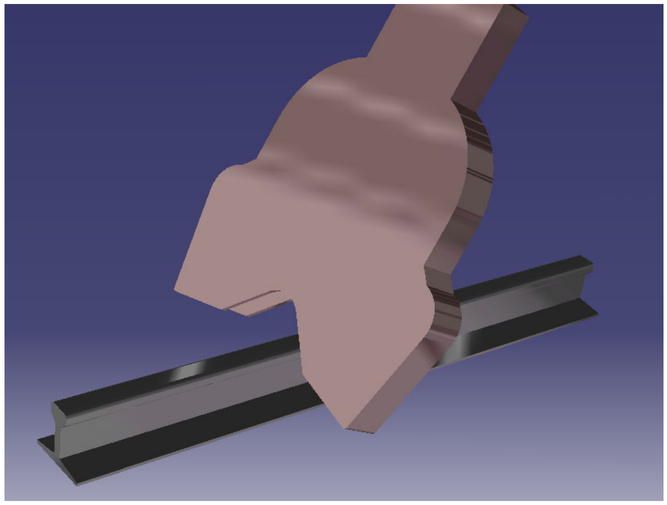

Figure 11: Partial solution.

Conclusion

In this paper we have proposed to develop two phases upstream to a traditional design process: requirement definition and innovation – selection of a solution.

We suggest the use of creativity in the global design process. We recommend an overall approach that acts at different moments and takes into account the environmental, personal and technological dimensions. Our vision of creativity has a direct impact on the way we develop innovation through the improvement of creativity in companies. This representation pinpoints the importance of knowledge during the creative process.

Several software tools were realized as a support of our proposal. They follow the presented approach, and are open to the inclusion of new tools.

A global action does not simply mean an action on separate levels. It also implies building bridges between them and to work on each level while wondering how it is linked to the others. In this sense, a global approach to creativity could lead to various actions:

- To design ergonomic tools and methods that correspond to practitioners' reasoning and problem solving processes (technology serves people and not the opposite).
- To design flexible tools or to link them in order to make their implementation easier in the various organisational contexts in which they are supposed to be used (a form of environmental ergonomics).
- To develop design training courses that improve individual skills to get increased benefit from the knowledge contained in the environment: learning to learn and also learning to be more open and receptive.

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