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On contradiction clouds

Denis Cavallucci, François Rousselot, Cecilia Zanni

INSA Graduate School of Science and Technology, Design Engineering Laboratory, Strasbourg-France

Abstract

Our proposal, through this article, addresses the issue of obtaining, representing and selecting the appropriate subset of contradictions among a complete set of contradictions resulting from an initial situation framing within a specific domain. This contribution has to be understood within the Inventive Design context since most of its grounding relies on the fact that any problem can be formulated as a contradiction (in the sense of TRIZ). By proposing the concept of "contradiction cloud" as three value graphical representation of a set of elementary contradictions, we claim that designers considerably reduce the fuzziness of a contradiction choice prior entering in a solving phase in Inventive Design processes. The modes of interpretation of this cloud will be also presented. The impact of this new element in the teaching of TRIZ was tested both in educational situations within the framework of our engineering curriculum and in several industrial partnerships. A discussion section will then highlight the assets, the limits and the perspectives of our contribution.

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Keywords: Contradiction; Clouds; TRIZ; Problem framing;

1. Introduction

In the frame of the formalization of inventive practices, few emerging theories propose a really new approach that differs from the quality concerns. Among these theoretical proposals, during the last decades, TRIZ [1] [2] [3] [4] appears as a breakthrough, since its groundings propose a totally new paradigm in design. This places TRIZ ahead several expectations from its potential users, but compared to other quality based approaches, this theory possess its internal own contradiction: to be both [fully axiomatically described] in order to be learnt, transferred and practiced worldwide (also by non experts) AND [fuzzily described] in order to leave spaces for numerous broad and multidisciplinary understandings and interpretations.

In current TRIZ expert practices, the formulation of a contradiction remains a fundamental stage whose relevance can engage the quality of the whole resolution process that follows [5]. Among the available articles and books written by Altshuller, many examples illustrate the way in which a given contradiction can reflect a particular situation. These explanations are extremely useful in a theoretical logic of training on the concept of contradiction, but prove to be of a poor impact in a logic of practical application of this knowledge by a non-expert.

On this subject, two elements seem to be missed in the knowledge corpus on the subject of TRIZ that is written and available. Which role does the perception of an individual play in his way of observing the world when

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formulating this contradiction? When do formulations of contradictions have to end in the description of an initial situation and with which depth of description?

This lack of completeness in the definition of TRIZ especially limits the modes of transmission of the theory (its learning) moreover in engineering and scientific worlds. But even if a choice of representation is taken, so as a choice of description's depth, it nevertheless leaves to the designer a whole set of contradictions representing key-problems associated with the evolution of a technical system. This statement currently does not allow engaging a relevant resolution process. Indeed, how to represent this whole set of contradictions? How to structure their interrelationships? How to associate this mode of representation with a particular corporate strategy?

2. On the notion of contradiction

As it has already stated in [6], a Contradiction includes 3 types of components: the elements, the parameters, the values. For each of these terms, in the next paragraphs we will clarify their meanings according to our proposed framework.

Elements

The Elements are constituents of a system. From a syntax viewpoint, they may be names or groups of names or nouns (for example: the hammer drives the nail, E = hammer). The nature of the elements can change any time based on the description which is given upon a certain viewpoint. Thus "the hammer drives the nail" may become "the anvil pushes the nail" when expressed by another expert. In the second case, E = anvil. For a third expert "The man pushes the nail". In this case E = The man. It is important, when identical situations are described with divergent points to organize a consensus in forcing the reformulation within the meaning of fundamental physics and the systemic decomposition according to contradiction's syntax.

Parameters

Parameters describe elements by assigning them a specificity, which reflects an explicit knowledge of the area observed. They are mainly names, objects or adverbs. The form of expression is diverse, sometimes contradictory when expressed by different experts. We distinguish two categories of parameters:

- Active Parameters (AP) (sometimes also called "control parameters"): On which the designer has the power to modify its state (the designer can make the choice to design an anvil having a light volume or small one, in this case volume = AP). This type of formulation has generally two directions that can potentially result in positive impacts on the object or its super system.
- Evaluating Parameters (EP): The nature of these parameters can be observed in their ability to evaluate both positive and negative results of a designer's choice. The consequence of designing an anvil having an important mass is that its ease of driving is improved (in this case ease of driving = EP). This type of parameter has often a logical sense of progress (its positive direction seems obvious) while the other seems absurd.

Values

Values are mostly adjectives used to describe a parameter (the volume of the anvil should be heavy; in this case V = heavy). Note that the fundamental aspect of the concept of contradiction, when expressed at a physical level, is the qualitative difference of values of a parameter: if the meaning induced by the adjective associated with the V leads to positive aspects, then it is essential (in order to complete a contradiction) to investigate adjectives qualifying V's antonyms to highlight the contradictory aspects of the analysis and then to validate it or not. We choose, as a first step for practical reasons, to limit the values of V pairs consisting of an adjective and its antonym. Thus, a heavy anvil volume leads to an ease of driving while a light anvil volume results in an ease of manipulation; in this case the pair chosen for V is heavy / light.

$TC_{n.m}$	Active Parameter AP_n	
	Va	$V\bar{a}$
Evaluating Parameter EPx	☺	☹
Evaluating Parameter EPy	☹	☺

Figure 1: Generic table of a contradiction (from the TRIZ point of view) according to [6] [7].

3. Gathering elements for contradictions synthesis

Since Parameters are crucial components of contradictions. There is a need for a structured way to collect them, to ensure exhaustively their domain coverage and to trace their link with laws of engineering systems evolution in order to later be able to associate contradictions and laws. Within TRIZ body of knowledge, there exist three sources that facilitate the emergence of parameters prior to the synthesis of contradictions.

Multi-screens represent a permanent ongoing picture of the studied system in the context of its evolution correlated with its supersystems and its internal subsystems. To fully understand the mechanism of a system's evolution, it can be observed that parameters are involved in this evolution in the sense that they have evolved either in a positive way or in a negative way. Such an evolution through parameter's synthesis can be disclosed with domain experts using multiscreen scheme (see figure 2) as a graphical support for group discussion.

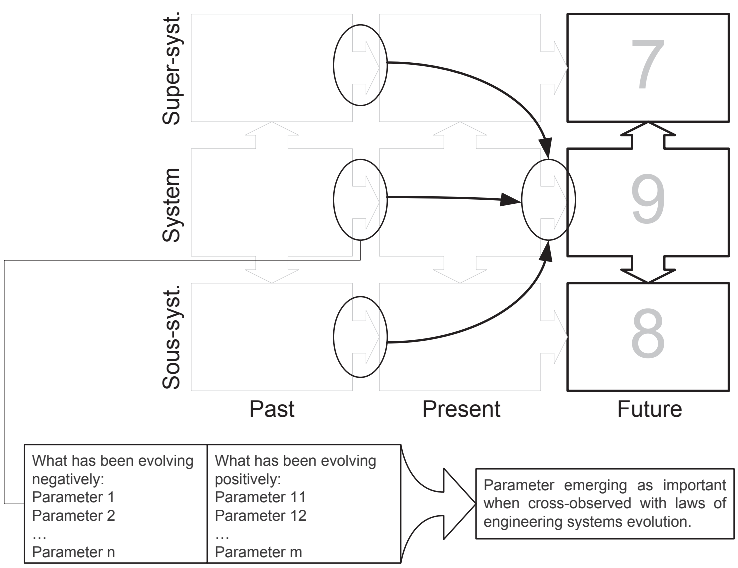

Figure 2: Location of parameters extracted from the multiscreen scheme analysis

Another important point of a TRIZ study is to observe an engineering system in the context of its evolution through Altshuller's laws. Here, each law become an opportunity to observe the studied system statement (its actual maturity regarding "S" curve, its potential evolution (through a minor improvement or a breakthrough – see figure 3). As a result it will be pointed out the importance of a law or another in the evolution (see a more detailed explanation in [8]) and the list of parameters previously started using multiscreen can here be completed by initiating a group discussion on each law and adding any new emerging parameter to the list. At this point, it is important to preserve a trace of a link between a parameter and a law since we will later need to use these links for contradiction ranking.

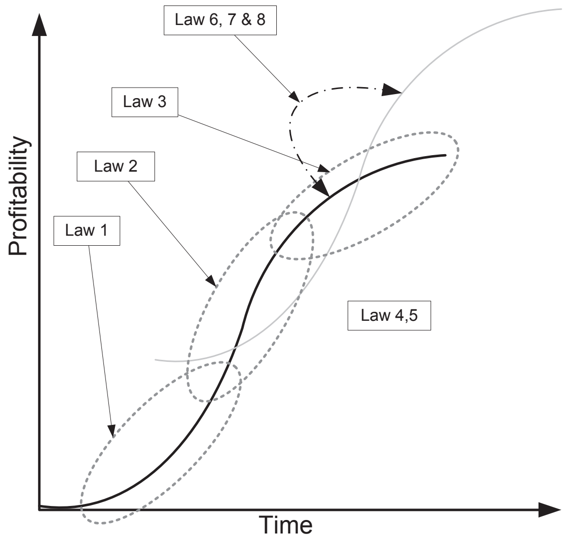

Figure 3: Summary of Altshuller's laws location along the "S –curve" scheme

A third opportunity to complete parameter's list is to use ENV template (from OTSM-TRIZ) [9] [10]. Here we are assuming two major steps in the contradiction synthesis. The creation of influencing links between parameters (revealing also whether a parameter is active or evaluating) and the contradiction synthesis whose formalism forces us to find parameters influencing the opposite state of an assumption for a correct contradiction formulation. Until ENV template is not complete (Figure 4), we can't consider that all influencing parameter of the study are disclosed.

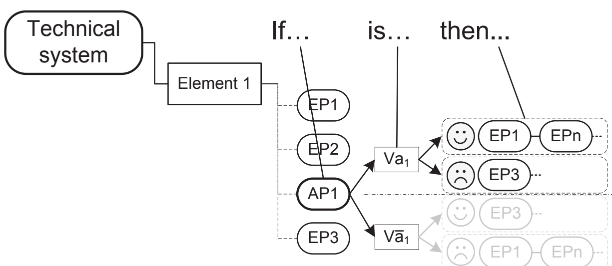

Figure 4: Template for ENV diagram completion (after OTSM)

Let us note that there is a high probability that the nature of the expressed knowledge will not appear using the contradiction syntax. Indeed, few experts are used to formulate both sides of a contradiction since traditionally a single side of a contradiction is expressed. Nevertheless through this single side formulation, we propose to enter in the contradiction syntax, with the aim to systematically questioning experts to highlight the opposite side of the contradiction. In case of impossibility of finding an inverse positive situation, there might not be any contradiction attached to this AP. In other cases we can either reveal a new EP or a link with an existing one.

Links between contradictions to form a network

We have observed, within solving processes, that when contradictions having the same active parameter were considered, solutions concepts generated by design members were likely guiding the thinking process to similar categories of ideas. This creates a limitation in the scope covered by solutions. In a reverse way, when a similar couple of EP is considered, a solution concept impacts unexpected contradictions since we did not engage the solving process through these ones. As a consequence and in order to be able to compute and observe the consequence of a specific solution concept (for instance useful in R&D decision making) links between contradictions have the same pair of EP can be created and sorted upon the fact that their root problems are sorted the same way.

On the amount of contradictions: from one to many

When analyzing TRIZ literature standards, one can easily find a huge amount of examples of contradiction formulation starting from an initial situation description. Among 150 example found in TRIZ literature (this is not an exhaustive amount but simply a statistically relevant population), 95% only express a single contradiction behind a more or less wide initial situation. We can therefore ask ourselves several questions:

1. Is the contradiction formulated in this way the only existing one behind the initial situation?
2. Would another designer/engineer (even trained to TRIZ) formulate the same one?
3. If the initial situation is described in other terms (although expressing the same thing) will the contradiction be formulated in the same terms?

The first question rise the problematic of "space coverage" where within a given domain, an existing problematic situation (possibly called an administrative contradiction in TRIZ terms). Behind this notion sub-questions appeared and invited us to consider further investigations for clarifying possible answers since we couldn't find any references in TRIZ literature. Among these questions: "how deep should an initial situation description stop in order to obtain satisfactory domain coverage for an efficient solving process to be engaged?"

The second question raises the problem of the "point of view" and its possible links with the nature of the contradiction terms. Will the evaluating parameters be the same if the concerns of the "formulator" changes? Are there elements within the TRIZ literature that are helpful for appropriately observing an initial situation? Again we couldn't find any elements to axiomatically setup a process and ensure a relevant guide for a contradiction formulation process.

The third question raises the problem of the "description accuracy" and its possible links to lead the "formulator" to an inappropriate contradiction formulation. Regarding this issue, we can also link our observations with some existing field of research like semantic analysis and text mining procedures. Here, we already have partial answers proposing to observe patents as a voice of authority to describe accurately inventive problems. But beyond patents or reference texts (such as encyclopaedia or informational web-contents) there is a human interpretation or expertise in which we should pay attention to since it represent 98% of a resources for contradiction formulation in TRIZ literature. Several sub-questions should once more be formulated: "how much inaccurate understanding of an expert "a formulator" leads to an inappropriate contradiction formulation?"

To conclude on this subject, our proposal to consider the expressed questions in this section is to cover the domain and the problem space in crossing several experts viewpoints and text of authority known and accepted in their domain (patent, research reports, peer reviewed scientific literature). This is not a way to avoid any precise answers on the posed questions, but simply to lower the inaccuracy of contradiction formulation by spending more time and resources for a wider domain coverage and co-validation prior to decide which sub-set of contradiction shall be engaged in an inventive problem solving process using any existing TRIZ technique.

4. Representing and positioning contradictions

We have identified 3 ways for differentiating contradictions. Our aim is to be able to use a graphical display of these differences in order to be able to analyse, rank and choose which contradiction subset can be engaged in a solving process. The next paragraphs summarize our 3 ways of contradiction weighting:

- Importance
- Universality
- Amplitude

Importance

The contradictions components (an Active Parameter a pair of Evaluating Parameters) do not have the same importance; Evaluating Parameters better characterize the essentials of the problem than others. Thus, it is possible to associate a qualitative value to each Evaluating Parameters which compose a group of contradictions. This evaluation has only the aim to place them on a relative scale of importance. The essence to be preserved among parameters relationship is the scale amplitude to be simply established around a certain amount of divisions out of a scale allowing this differentiation.

Then, the role of the Active Parameter within a contradiction is not of the same order as the one provided by Evaluating Parameters. Very often, the active parameter represents the element on which it is necessary to act in a contradiction. We propose that the element which will allow differentiating a set of active parameters between them articulates around the potential impact that this APx (setted at Va AND Vā) will have on the problems to which it is related. This fundamental aspect in the importance of a contradiction is likely to atrophy or dope the importance of a pair of EPs, we gave the APs capacity to influence EPs by a multiplying coefficient. This way, we allow the addition of both EPs (EPn+ EPm) to be reduced when facing a weak impact or to be multiplied when facing a strong impact. For this multiplying coefficient, we agreed on a range from 0,5 to 2.

Therefore, X (importance), the first criterion of differentiation among different technical contradictions may be expressed:

Let us consider ITC, the set of all the identified technical contradictions and a technical contradiction $TC \in ITC$, represented by a triplet:

$$TC = (AP_i, EP_j, EP_k)$$

meaning the association among an active parameter AP_i and two evaluating parameters EP_j and EP_k.

AP_i is associated with a multiplicative coefficient α_{AP_i} and EP_j and EP_k are associated with C_{EP_j} and C_{EP_j} coefficients that represent the relative importance among evaluating parameters.

Within this framework, the importance X of TC is:

$$X_{TC} = \alpha_{AP_i} * (C_{EP_j} + C_{EP_k})$$

Universality

In our observations of the typology of sets of contradictions, we noted that EPs qualify the objectives sometimes hidden in inventive challenges. Some of these EPs seem to appear in a recurring way in a large amount of contradictions. This observation led us to build the assumption that a simple measurement of the universality of a contradiction could be established. This measurement would aim at specifying that a contradiction having recurrently present EPs in a large amount of other contradictions represents the universality of this same contradiction. The universality criterion Y thus takes the following form:

Let us consider again the expression of a technical contradiction $TC = (AP_i, EP_j, EP_k) \in ITC$.

We calculate QTY_{EP_j} and QTY_{EP_k}, the quantities of occurrences of EP_j and EP_k in ITC.

Within this framework, the universality Y of TC is:

$$Y_{TC} = QTY_{EP_j} + QTY_{EP_k}$$

Amplitude

In the structure of a contradiction, an AP is associated with a pair of EPs. But in a more general way, the same AP is often associated with a variable quantity of EPs. As a result, some APs involve the opposition of only one pair of EPs whereas others have an impact on a large amount of EPs and involve the opposition of a consequent series of pairs of EPs. Our proposal is thus to establish a third criterion of differentiation, Z (amplitude), that is related to the quantity of pairs of evaluating parameters associated with the same active parameter, to form different contradictions. This criterion would take the following form:

Let us consider again the expression of a technical contradiction $TC = (AP_i, EP_j, EP_k) \in ITC$.

We calculate QTY_{AP_i}, the quantity of all the pairs (EP_x, EP_y) related to the same AP_i that appear in ITC.

Within this framework, the amplitude Z of TC is:

$$Z_{TC} = QTY_{AP_i}$$

We thus have 3 criteria X, Y and Z to differentiate contradictions. While placing criteria X and Y according to a system of axis, we obtain a cloud of dots. By associating each point of this cloud criterion Z, we obtain (as represented on figure 6) a group of dots with variable diameters.

Linking contradictions

The notion of contradiction network has been sometimes brought forward by several publications. What remains unclear so far is the way a contradiction will be linked to the other. Even if some proposals have been made, a clearly elaborated contradiction network representing a set of contradictions within a given domain has not been published so far. Another rising question is about the term used, are we concerned by a network or by a graph? Despite the fact that both terms have been declared as very close [11], in our approach, we will start by formulating the aim of such eventual links. Then, since we are aiming at using algorithms for considering the set of connected contradictions, the term "graph" seems closer than the term "network". A first type of link is to represent either a cause-and-effect chain or a mono-directional engineering consequence between sets of evaluating parameters. This will undoubtedly be helpful for identification of the root contradiction to be considered in priority. Revealing such links can additionally be eased using a table representation.

A second type of link is to draw a bidirectional line between two contradictions having the same set of evaluating parameters. Such a link has been proven to be helpful when using Inventive Principles associated to Altshuller's matrix since both entry parameters (to be improved and not to be degraded) are the set of evaluating parameters from the considered contradiction. Added to the layout proposed in our cloud representation such links can highlight subsets of contradictions possible resolved in chain by considering the most weighted one as a priority target.

The advantage of "clouds" representation

The obtained set of dots with variable diameter is sometimes insufficient for highlighting a subset of contradictions since we have already tested the proposed method in [12]. We encounter a limitation in choosing often a subset within a group of contradiction possessing the same active parameter. In several other situations, we have observed that when the active parameter was different, the core element at the heart of the observation provoked solution concepts of a different type, enlarging the scope of the proposed solution to different areas.

This had a positive impact on the study since a wider solution space was covered with a limited amount of solution concept, more evenly distributed within several scientific domains. Here, we would like to underline that what is targeted is not the quantity of solution concepts but their layout among several domains, a situation convenient for inventive outcomes.

As a result we have enhanced our graphical representation from a single set of dots to several sets belonging to the same active parameter, highlighted by a set of clouds covering the space of each subset of contradiction belonging to the same active parameter. The range displayed in the X and Y axis automatically adjusts in order to display all existing dots in optimizing the graphical area.

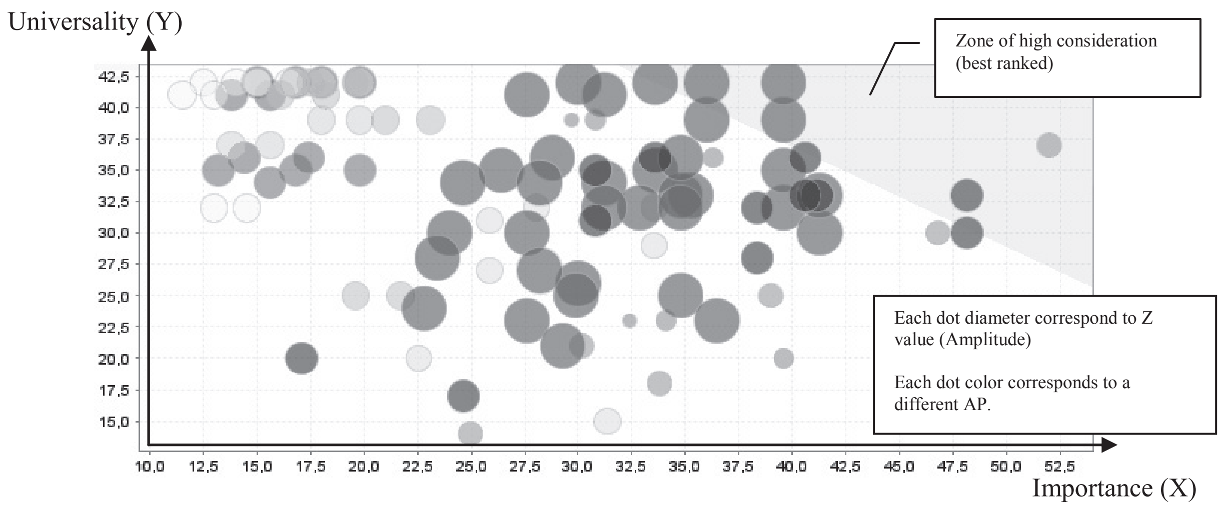

Figure 5: Graphical display of clouds featuring X, Y and Z values

Choosing a reduced set of contradictions among others

The advantage of such a representation is to clearly display all contradictions concerning a problematic domain. This display, organized based on the 3 value described before, highlight that some contradictions, among others, have a more significant impact of the covered domain if located in the upper right corner of our graph (see grey zone). Therefore, the logical use of such a representation is to decide, considering time resources, which contradictions are to be treated in priority for a wider impact on an initial complex problematic.

5. Teaching situations: Fifth engineering year of INSA Strasbourg

We have started a testing through 85 engineering student of the fifth year, coming from seven different field of engineering. The condition of this campaign started with the constitution of groups from 3 to 4 persons working on a technical object's evolution. The first part of this directed work consisted in using our approach in order to synthesize and represent a set of contradictions. Based on this representation a choice needed to be justified in the chosen subset of contradiction prior to engage a solving process using Inventive Principles and the matrix.

The available time for this test was 28 hours:

- 14 hours of theory for teaching our approach
- 14 hours of project divided in 7 sessions of two hours each.

Due to the limitation of time, both for teaching and directed work, chosen objects should be simple (not carrying a lot of components and different technologies). Only basics of TRIZ were taught and subjected to use (for instance limited to Multiscreen, laws and Inventive Principles).

Summary of the teaching session's results

What appears the most significant outcome from the teaching sessions is the improvement of the student's autonomy in conducting the gathering of parameter and the choice of the contradiction to be engaged in the solving process. Compared to the previous year (when our approach was absent from the syllabus) the students requested much more assistance when conducting contradiction synthesis and choice. As a result, we decided to develop this procedure in a software prototype for further investigations and confirmation of our first observations.

6. Industrial case study: ArcelorMittal's continuous annealing furnace

Steel material hardens after cold rolling due to the dislocation tangling generated by plastic deformation. Annealing is therefore carried out to soften the material. The continuous annealing process comprises heating, holding of the material at an elevated temperature (soaking), and cooling of the material. Heating facilitates the movement of iron atoms, resulting in the disappearance of tangled dislocations and the formation and growth of new grains of various sizes, which depend on the heating and soaking conditions. These phenomena make hardened steel crystals recover and re-crystallize to be softened.

This type of annealing involves uncoiling, and welding strips together, passing the welded strips continuously through a heating furnace, and then dividing and re-joining the strips.

The total length of the strip in the line is approximately 2,000m while its travel speed is about 200 to 700 m/min for a strip of 0.15mm in thickness (a maximum speed of 1,000 m/min. is still possible). To operate such lines, speed control, tension control, and tracking control of the strip are necessary, in addition to a high level of automatic temperature and atmosphere control.

Our company partner has observed for already several years that among these parameters an optimum situation is reachable but strip defect are observed and provoke line interruption regularly.

Line interruptions are provoked mainly due to thermal situation within the furnace.

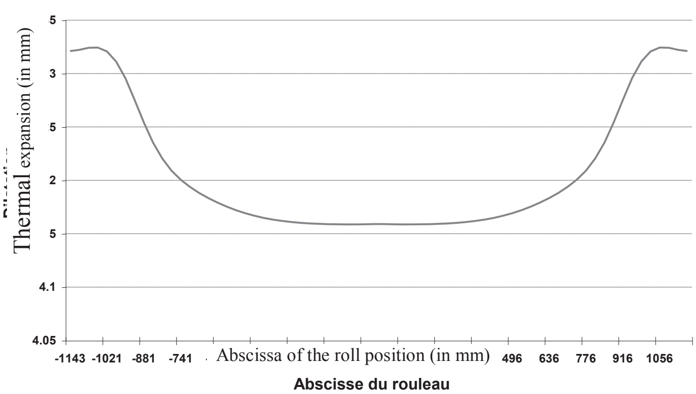

Figure 6: Roll profile distortion under thermal influence in a furnace at Max. Temperature

The observed thermal expansion of rolls (transporting the strip) is unevenly distributed along its volume (see figure 5) resulting in two different situations:

- Lateral strip movement due to non-perpendicular velocity of the strip to roll axis. As a result, the strip is hitting the furnace and gets degraded.
- The formation of thermal folds, depending directly on strip traction, provoke the necessity to stop the process, remove either partially or completely the damaged strip and start over the production line.

Summary of the industrial use's results

The partnership consisted in proposing a technologically validated solution to these recurrent problems, taking into consideration all existing attempts (both partial successes and failures) already tested and their competitor's known solutions (mostly observable through patents).

The figure 4, used for explaining our graphical way of representing contradictions, displays the result of our first investigation in gathering all contradictions of the problematic domain expressed by ArcelorMittal's experts. A sum of 105 contradictions was expressed and the clouds graph has highlighted in the upper right corner several of them (figure 7). When discussing on this first set, a reduced choice was made to treat four of them (one belonging to each AP top ranked in the graph). This choice can be explained by the decision of the group to address a wider way of resolving the case, but also to efficiently use our available time with continuous annealing experts.

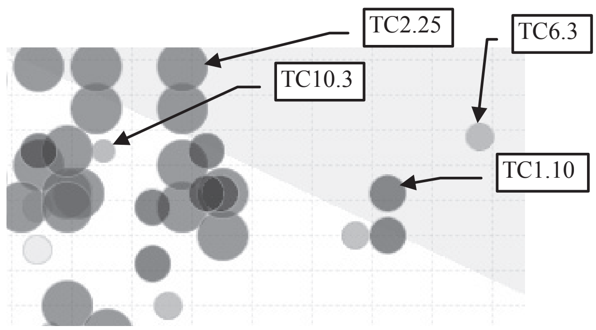

Figure 7: Upper right corner of the clouds graph with selected set of contradictions

The result of the decision discussion was to treat in priority:

- **TC6.3**: (E)[Roll]'s (AP6)[Geometry in cold states] must be both (Va)[plane] for (EP7)[minimising strip bending] AND (Vā)[curved] for (EP6)[minimizing strip deviation].
- **TC2.25**: (E)[Roll]'s (AP2)[local adaptability] must be both (Va)[yes] for (EP7)[minimising strip bending] AND (Vā)[no] for (EP12)[minimizing roll's complexity].
- **TC1.10**: (E)[Roll]'s (AP1)[thermal expansion coefficient] must be both (Va)[low] for (EP7)[minimising strip bending] AND (Vā)[high] for (EP11)[cost reduction].
- **TC10.3**: (E)[Roll]'s (AP10)[diameter] must be both (Va)[small] for (EP6)[minimising strip deviation] AND (Vā)[big] for (EP2)[maximizing line productivity].

What has been observed in the industrial situation is a significant reduction of fuzziness concerning the choice of the contradictions to be engaged in a solving process. Methodologically, the prior art was to intuitively decide which problem to tackle without a deep analysis of the impact of this choice on the efficiency of the findings. As a result, various brainstorming-like sessions have led to numerous alternatives having a low satisfactory impact in terms of expected results. In our case, after the four contradiction resolution using classical TRIZ tools, thermo-mechanical calculations of the chosen solution concept have proven that a simple concept might have an important impact on continuous annealing lines. This has raised the confidence in the choices undertaken and eased the justification of resources demands that engineers have requested to their managers for developing the concept and test in real "on line" situations.

7. Discussions

The proposed contribution has been proven to be efficient both in educational and industrial contexts. The accuracy of the methodology description does not leave place for fuzziness and allows educators to base their Inventive Design teaching on a precisely established procedure. In parallel, such accuracy has also been appreciated in industrial situations since each engineer involved in the study can easily understand why we choose this problem and how we formulate it prior to engaging a solving process despite the fact that they might not have been trained to TRIZ fundamentals.

The limitation of our proposal has also been studied and the most evident one we found was that our study mostly relies on the fact that an appropriate set of active parameters has been disclosed. Even if a consequent knowledge mapping work is achieved within a study team, we are nevertheless directly dependent on the fact that the known partial solutions are exhaustive or that the team has properly identified all potentially concerned active parameters. In light of this observation, our next investigation in line with the subject developed in this article will be devoted to the study of the completeness of a set of active parameters to describe an initial solution space.

8. Conclusions

As an introduction to this paper, we underlined the lack of procedure for contradiction gathering and representation in TRIZ literature. Although TRIZ practices still remain rather intuitive (expert dependent), there is an urgent need for formalizing procedures aiming at simplifying both TRIZ education and robust industrial practices. By proposing a 3 value weighing and comparison together with a graphical representation, we have observed a significant improvement of the confidence practitioners (both students and experiences engineers) were claiming regarding TRIZ. Compared to situations where they were more relying on the voice of authority and the expert's intuitive know-how, the observed situation shows a willingness to appropriate themselves the methodology and a capacity to later justify to their managers (for engineers) or during a viva (for students) the way they have investigated their initial situation, stated the problem and engaged efforts in a specific direction more than another.

Finally, our developed approach is aiming at being an open framework for discussion and improvement. We have observed that using a software prototype, the observed phenomena was even more visible and has open new perspectives in the systematization of Computer Assistance to Inventive Practices.

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