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Techno-economic classification of contradictions and related strategies of solution

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Abstract

One of the most important objectives of modern product development is the fulfillment of the requirements derived from stakeholder/customer needs. For this reason, modern design processes start from an accurate definition of those final product features able to satisfy a given set of customer needs. However, it is well acknowledged that, during a common design process, it is often possible to find requirements conflicting with each other. Thus the choice of a successful design strategy is critical. The aim of this work is to investigate the possibility to find a rule suitable to indicate the best side of the contradiction to process in order to solve technical problems, also usable by engineers with limited experience with TRIZ. The analysis has been formerly operated on well-known solved problems belonging to Classical TRIZ literature; the emerging evidences have been further checked on a set of case studies from the authors' industrial experience.

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Keywords: design requirements, contradictions, ARIZ, design process;

1. Introduction

The high level of competition which characterizes the modern market makes the fulfillment of customer needs as one of the most important objectives of product development. This is the reason why modern engineering problems are normally faced by addressing the fulfillment of system requirements, derived from the diverse stakeholder needs. Then, it is possible to assert that an accurate definition of their specification heavily influences the final characteristics and configurations of a product.

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Furthermore, in design processes it is possible to ascertain that requirements often conflict with each other, i.e. the fulfillment of a requirement often implies detrimental effects on other aspects of a product.These design conflicts entail that the choice of the right design strategy is fundamental for the achievement of the product success.

In literature there is a plenty of different definitions and classifications concerning design requirements; however, they are mostly misaligned and incoherent with each other. Therefore, it is hard to build general guidelines about the most efficient design strategy according to the nature of the requirements to fulfill. Dealing with design conflicts is an essential concept of the TRIZ theory [1], but there are not many contribution related to the choice of the best side of the contradiction to process in order to solve it. Only ARIZ 85-C [2] proposes a suggestion to guide the problem solving process when dealing with this issue. However, as explained in this paper, the reliability of such a rule is not always confirmed.

Here the aim of this work arises, i.e. to investigate the possibility to find a heuristic rule suitable to indicate the best side of the contradiction to solve. The work is aimed at improving the results given by ARIZ suggestion, using a set of different classifications for the evaluation parameters involved in the contradiction. The secondary purpose of this work concerns the possibility to develop a rule usable by a common engineer, not experienced with TRIZ, for a rapid selection of the best direction to be considered toward the solution. Actually, ARIZ 85-C, and in particular step 1.4, suggests to choose the most convenient side of the contradiction to work out, based on a comparison of the evaluation parameters involved. In turn, it recommends to choose the side of the conflict that better satisfies the main functionality of the technical system. Besides, according to the authors' experience, this strategy is not necessarily the most convenient to adopt. Nevertheless, it is worth considering a comparison between the conflicting evaluation parameters and the system requirements they represent, as a reference element for guiding such choice.

For these purposes, an iterative analysis process has been structured, in order to test the applicability of different requirement definitions in the parameter identification process. More in detail, through the combination of different classification codes, it has been investigated the possibility to derive some general indications about how to address the problem solving process while facing with contradictions in design activities. The analysis has been formerly operated on well-known problems belonging to Classical TRIZ literature and the obtained insights have been further checked on a number of case studies from the authors' industrial experience.

Section 2 presents a short survey on the most acknowledged engineering requirement definitions, together with a short introduction on contradictions and the criterion proposed at ARIZ's step 1.4. Section 3 is dedicated to the description of the proposed analysis and to the definition of the categorization rules. Then, the application of the analysis method both on TRIZ literature case studies and on the industrial ones is described. The succeeding section shows and discusses the overall results of the study, obtained by the application of three different categorization rules. Finally, in the last section conclusions and future developments are presented.

2. State of the art

In this section, a short introduction on two key arguments is presented, concerning the work presented in this paper. The first part overviews the role of requirements in the design process and their categorization, since also in classical TRIZ the analysis of contradictions and the decisions in the problem solving process are made taking into account their characteristics.. The second part reports a brief introduction to the concept of contradiction as a particular opportunity for the designer to approach a problem.

2.1. Engineering Design requirements

It is well acknowledged in literature that an Engineering Design activity is performed with the aim of meeting a certain set of design specifications often called “requirements”, embodying both customer/stakeholder needs and various types of inevitable constraints. On the other hand, a univocal definition of design requirements and constraints is missing [3]. Such a lack, for example, may imply complications in the information exchange between the two parts involved in the early stage of a product development, i.e. the Product Planning and the Conceptual Design teams. The authors have faced this kind of difficulties in several industrial experiences. It often happens that, since product planner has to fulfill customer needs also from a non-technical perspective, the type of information to be processed is too abstract to be directly translated into technical specifications. Besides, also limiting the analysis within the limits of Engineering Design, many misunderstandings often arise between engineers, e.g. with different background. Not surprisingly, literature presents a rich variety of definitions, as brief reviewed here below.

Actually, it is possible to find consensus about the meaning of the term "Functional Requirement" [4], even if this term usually refers to both functional and behavioral aspects of a systems. However, many scholars refer also to another type of requirement, i.e. the "Non-Functional Requirements". For the latter case, the variety of definitions found in literature attributed by scholars to the terms which constitute the definitions, implies the impossibility to reach a shared interpretation. For instance, Glinz [4] reports that those terms are property or characteristic, attribute, quality, constraint and performance.

From the Software Engineering field, a more concise definition of functional and non-functional requirements is given by Paech and Kerlow [5], who assert that the first type is used to represent "what" the software does, while the second type delineates requirements concerning "how good" the software does something. More generally, Hull et al. [6] define a Requirement as "a statement that identifies a product or process operational, functional, or design characteristic or constraint, which is unambiguous, testable or measurable, and necessary for product or process acceptability".

From the world of Engineering Design, Kamrani and Salhieh [7] distinguish "Functional Objectives" from two other types of requirements, i.e. the "Operational Functional Requirements" and the "General Functional Requirements". Functional Objectives provide information about the expected functionality of the product. Operational Functional Requirements have been defined as the representation of the set of constraints that the design must possess in order to reach the desired functionality. Instead General Functional Requirements are intended to represent customers' secondary needs.

Cross [8] includes design specifications concerning performance, size, weight, law and safety under the term "Requirements". Moreover, the same author specifies that statements of objectives and functions should not be considered as performance specifications, due to the lack of an indication of concrete limits.

Roozenburg and Eekels [9] give a more detailed definition where they define as "Objectives" any statement about the "Goal" of a product development process. Moreover they identify as "Scaling Objectives" those where it is possible to evaluate alternative solutions in a ranked manner, while "Non- Scaling Objectives" those where solutions can be evaluated substantially only with a binary score. Finally they define as "requirement" an objective that "any design proposal must necessarily meet", while define as "wishes" all the non-essential objectives.

Maybe one of the most simple and intuitive definition is the one used in the optimization field, i.e. concerning "Objectives" and "Constraints". In fact, an Objective is a goal on which the design activity points to, e.g. the maximization or a minimization of a parameter. Conversely, a Constraint is something that needs to be respected in order to make the solution acceptable, e.g. the boundaries between which the final mass of the system has to be included. More generally it is possible to give the following definitions:

- Objective: any goal which has to be reached by means of the design activity, not expressed by means of reference values.
- Constraint: any limitation, boundary or reference value that restrict the space of possible solutions.

2.2. TRIZ Technical Contradiction

Practical engineering activities very often bring to deal with some kinds of design conflicts. Actually, when the designer spends efforts in order to reach one of the project's objectives he runs into one or more constraints; or, in simpler terms TRIZ practitioners are more familiar with, when he tries to improve a parameter at the same time another one worsens. Every designer, at least once, has experienced this kind of situation. Indeed, the second postulate of TRIZ refers to this concept: system evolution implies the resolution of contradictions. The problem solver is invited to solve contradictions, instead of compromising them, in order to generate valuable solutions. Solving a contradiction means finding a solution which satisfies both the conflicting parameters at the same time, the so called win-win solution. Classical TRIZ body of knowledge [1] identifies three different definitions of contradictions, and technical contradiction (TC) is defined as a conflict between two requirements of a given system. Supposing to have two technical conflicting parameters A and B: TC1 is represented by the satisfaction of A and the discontent of B (briefly A and anti-B), and conversely TC2 is defined by the fulfillment of B and the dissatisfaction of A (anti-A and B). A good solution has to fulfill both sides of the contradiction. Therefore, starting from the initial situation (TC1 or TC2), only one parameter has to be improved, of course preserving the satisfaction of the other. The conflicting parameters related to the requirements are connected by another parameter, which refers to a design variable. According to TRIZ nomenclature this design variable is called control parameter (CP), or action parameter (AP), and may assume two opposite values. If CP assumes the first value then TC1 is verified, while if CP assumes the opposite value, then the system satisfies the TC2 condition. How to select the most convenient side of the contradiction TC1 or TC2 for further investigation and solution generation? TRIZ offers different tools to deal with contradictions as, for example, the 40 Inventive Principles, the Contradiction Matrix, and ARIZ-85C (the Russian acronym for Algorithm of Solving Inventive Problems) [2] the most powerful Classical TRIZ tool. ARIZ offers a sequence of steps to solve a technical problem and in part 1, particularly at the step 1.4, after defining TC1 and TC2, it suggests selecting the side of the contradiction that provides the best performance related to the main function of the technical system. Then, the investigation continues with the identification of the operational space and time and the related substance-field resources, and with the analysis of the physical contradiction. If the analysis does not bring to any successful solution, the other side of the contradiction is taken into consideration.

In [10], the authors propose a method to deal with a network of contradictions and a manner to identify the best side of the contradiction to work on. When the problem solver has to tackle with a complex problem, he/she could extract more than a single contradiction and very often they are connected by a cause-effect relationship bringing to an interconnected network. As TRIZ practitioners know, only one conflict at a time can be approached. Therefore, the authors propose a strategy to elicit the most important contradiction based on mathematical processing of a set of weights given to each parameter. At the end of the process also a way to choose the best side of the contradiction is proposed, with the aim of minimizing the degree of change on the overall system. Besides, there are no proofs that the side of the contradiction implying the minimum change on the system also guarantees the most fruitful results for overcoming the contradiction.

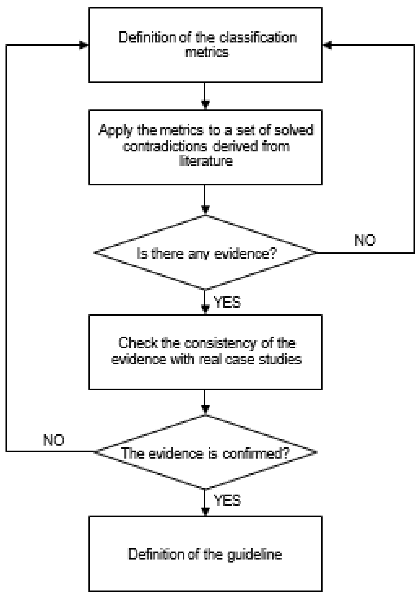

Figure 1: Diagram of the used method of investigation.

3. Method of analysis

This section describes the method of investigation used in explore the possibility to develop more efficient guidelines suitable to support the most convenient side of a contradiction to work out. The reference guideline is the step 1.4 of ARIZ. As described in Section 2, the algorithm suggests to choose the side that better fits the main useful function of the system. In turn, the logic behind this suggestion is to keep the focus on the main functional requirement of the technical system. In fact, as revealed with further details in the following sections, such a suggestion does not necessarily point to the most convenient side to analyze. For this reason, this paper investigates alternative criteria to perform the choice usually made at step 1.4 of ARIZ. Still, these criteria are defined using the design requirements as a reference.

The outline of the analysis method is depicted in figure 1. The first step concerns the proposal of a classification scheme for the conflicting parameters. Such a metrics has to be as general as possible, so as to be usable with contradictions encountered in any technical field. Since each elementary contradiction is composed by two parameters related to system requirements, all the defined metrics are characterized by two alternative classifications. Each classification scheme is applied to a set of contradictions derived from classical TRIZ literature, in order to highlight any emerging correlation between the classification of the requirements and the side of the contradiction that brings to the proposed solution. To this purpose, literature case studies have been investigated in order to individuate the side of the contradiction that is closer to the proposed solution. The underlying assumption is that, through this reverse engineering approach, it is possible to identify the most convenient choice to make while analyzing the contradiction in order to generate the solution available in literature. The authors are aware that the considered solutions are not necessarily the best ever, nor the only existing ones; it is also inappropriate to state that the rejected TC is not worthy of consideration. However, since the analyzed solutions belong to the classical TRIZ literature, they can be considered as a robust reference for this study. Such a procedure has been repeated for all the contradictions extracted from the selected literature source, and a statistical analysis is applied to check if some regularity exists. The emerging regularities are checked with respect to a second set of contradictions collected by the authors in their professional activity.

The investigation has been carried out by defining different types of classification scheme. The first one is directly derived from the engineering language. Since the purpose of the proposed approach is to offer an aid to designers not necessarily TRIZ expert, well known engineering definitions are a good candidate to classify the conflicting parameters of the contradiction. As already mentioned, a typical engineering design activity is performed towards the satisfaction of requirements, distinguished between objectives and constraints. Thus, a first classification of the contradiction parameters discriminates between objectives and constraints. It is worth to notice that not necessarily the conflicting parameters must be one of a kind, as shown in the next section. Indeed, in some contradictions, both the parameters, according to the definitions of objective and constraints given in the second chapter of the paper, result of the same nature. Thus a second scheme of classification is proposed. Taking into account a nomenclature already adopted in [11], the conflicting parameters can be classified as Driver and Barrier. Such nomenclature is not formally defined in the cited paper, but the standard meaning of these terms perfectly. Suit the object of the study: a driver is a factor which causes a particular phenomenon to happen or develop, while a barrier is a circumstance or obstacle that prevents a desired change of the system. More specifically, in the classification of the parameters involved in a technical contradiction, a heuristic rule has been defined in order to ensure that each time an opposite classification is assigned to the conflicting parameters. The adopted rule is based on the definition of the technical contradiction, and on the starting situation of the system. The designer has to consider which one, between TC1 and TC2, is closer to the current state of the system. On the basis of such assessment, the parameter that is already satisfied gets the title of Barrier and the discontented one that is desirable to change is defined as the Driver. Such a definition lets to easily identify which side of the contradiction, analyzing its solution, has been followed to overcome it.

Finally, a further classification concerns the technical or economic characterization of the conflicting parameters. A technical parameter is related to the application of scientific knowledge for practical purposes, especially in industry or to the evaluation of some performance of the system, while an economic is related to the production and consumption of goods and services and the supply of money, but also relating to the careful management of available resources.

3.1. Analyzing solved contradictions

The study has been carried out starting from the solved contradictions reported in a milestone book of classical TRIZ [1]. The book reports 70 examples or exercises concerning the various topics of the TRIZ theory, but since not all of them include a contradiction, a first selection has been made in order to deal with problems with the requested features. The second set of contradictions derives from a number of professional experiences faced by the authors. The evidences extracted by testing the proposed approach to the problems deriving from the literature have been checked with several contradictions encountered in real industrial problems arising from different technological fields, from microelectronics to household appliances. Among the 70 problems reported in [1], only 14 of them have been considered for the study. The reason of this severe selection is due to two main causes: the first concerns the need of an explicit contradiction behind the task to solve. Effectively, the proposed problems refer to different topics of the TRIZ theory, and of course not all of them clearly describe a conflict to be addressed. Furthermore, also among the exercises containing a contradiction, some of them have been rejected because the book misses to propose their solutions. The solution to the task is essential in order to identify which side of the contradiction is more suitable for its resolution.

Hereinafter, the process used to extract the evidence is exposed. After the selection of the solved conflict, each of them has been represented according to the OTSM-TRIZ model of a contradiction [12]. Thus, two evaluation parameters and one control parameter have been extracted from the description of the problem. As formerly described, a heuristic rule has been defined; such a rule takes into account the technical contradiction, and allows defining one parameter as a Driver and the other as a Barrier. To assign the proper classification to the parameters, the rule suggests choosing which one, between TC1 and TC2, is closer to the description of the initial situation, as it appears in the explanation of the problem. The Driver is the parameter that, according to the expression of the contradiction, is unsatisfied, while the Barrier is the fulfilled parameter. The problem 6 reported in [1] has been reported as an exemplary case of the adopted approach (see figure 2).

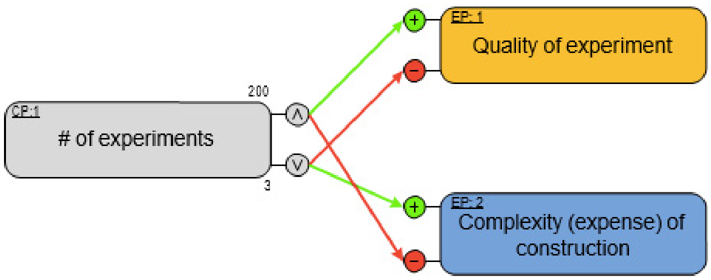

Figure 2: Model of contradiction extracted from the problem number 6 extracted from [1].

The following quoted and italic text is as the problem was presented in the book by Altshuller. “At a factory turning out agricultural machinery, there is a small piece of ground for testing machinery (such as ploughs) on their ability to move forward, turn, etc. However, the ‘maneuverability’ of machinery depends on the state of the ground. The need has arisen for conducting tests on two hundred different types of soil. It is impossible to build two hundred different testing grounds. What can be done?”. The conflicting parameters of the task are the “quality of the experiment” and the “complexity of the system”, related by means of the parameter “number of experiment”. Hence, the technical contradiction can be expressed as follows:

- TC1 - If the number of experiment is high, then the quality of experiment is satisfying but the system is too complex to realize;
- TC2 - If the number of experiment is low, the system is easily implantable but the quality of the experiment is unsatisfactory.

Relating to the explanatory text of the problem, TC2 better represents the initial problematic situation, thus, according to the rule parameter "quality of experiment", which is the one unsatisfied, becomes the Driver, and parameter "complexity of the system" is the Barrier. The same procedure has been applied to the whole set of the considered contradictions. It is worth to notice that not all the selected problems had a well-defined contradiction. In some cases, in fact, neither the short problem's description, nor the rest of the book, reports a clear explanation of the contradiction. In those cases, however, the authors extracted the conflict by themselves (see figure 3).

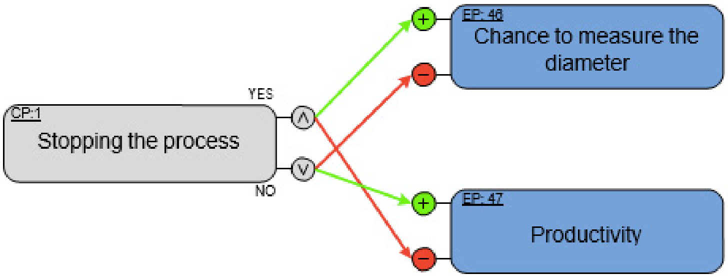

Figure 3: Model of contradiction extracted (by the authors) from problem number 8 of [1].

When Drivers and Barriers have been identified for all the contradictions, the authors analyzed the solutions, so as to highlight which side of each contradiction brought to solve the problem. By means of a sort of reverse engineering of the solution, it is possible to recognize which value of the control parameter has been adopted to solve the problem and then which parameter between Driver and Barrier the solution fulfilled firstly. Turning back to the example of the agricultural experiments: the solution suggested by Altshuller consists in adding a ferromagnetic powder into the soil and activating a magnetic field the characteristics of the mixture soil and ferromagnetic powder can be changed. Thus, the solution lets to obtain a large number of different soils and then a large number of experiments. The corresponding value of the control parameter fulfills the "quality of experiments", which has been labeled as the Driver of the contradiction. Iterating the process for all the remaining contradictions, some of them have been solved using the side of the Driver and some others the Barrier. Hence, apparently there wasn't a regularity to be used. Then the conflicting pair has been categorized also in relation to another kind of classification relating to the technical and/or economical nature of the parameters, trying to find more regularity. The contradictions composed by two technical parameters (T-T) have been solved choosing the Barrier side of the conflict, while the contradictions with one technical and one economical parameters (T-E) have been solved working on the Driver side of the conflict (see figure 4). Such methodology is named by the authors as Rule 1, because further investigations brought to the definition of another approach (called Rule 2) consisting in following every time the Driver side of the contradiction.

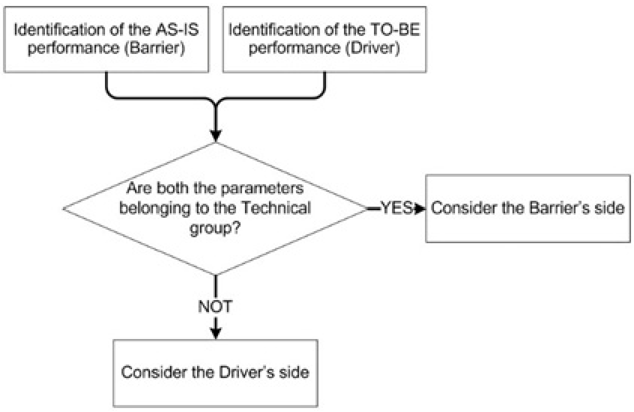

Figure 4: flow diagram of the rule 1 procedure.

To check the consistency of the regularity found by studying problems coming from the literature, the same procedure has been tested with a set of contradictions faced in real industrial problems. Some of these conflicts have been solved directly by the authors and some others have been approached together with domain experts during training activities delivered in several Italian Companies. In analogy with the working hypothesis made in Section 3 about the analysis of literature problems and solutions, also for the industrial case studies a pragmatic assumption is necessary: the adoption of a solution by the industry stakeholders is considered as sufficient to judge the solution "successful", and thus worthy to be taken as a reference for this statistical investigation. Also in this case, alternative, possibly better, solutions could be conceived, but nonetheless this study cannot rely on them.

Usually, the technicians who participate to these activities had already attended a 40 hours basic course on TRIZ, and eventually they essayed the method with a practical real case study from their own professional activity. Typically, they are engineers of R&D departments, with a long experience in the same technical field the problem belongs to. All the contradictions used for the check have been extracted from a whole problem solving process. As for the case studies derived from the literature, only the conflicts with a concrete solution have been taken into account. The greater part of the set of solutions has also been prototyped by the Companies and really tested demonstrating their reliability. The results of this study will be exposed in the next section.

4. Emerging evidences and discussion

As introduced in Section 3, defining contradictions in terms of Objectives and Constraints brought to inconsistent results. In fact, limiting the analysis on problems extracted from [1], in the 64% of the considered cases both the evaluation parameters were of the same nature, hindering the possibility of further considerations. Conversely, defining contradictions in terms of Drivers and Barriers with the rule introduced in Section 3 allows to perform concrete observations when analyzing solutions of selected case studies. More specifically it has been found that when both the evaluation parameters which form the contradiction (i.e. the Driver and the Barrier) belong to the technical domain (T-T case), Rule 1 introduced in Section 3 is valid for 83% of the cases. Instead, when one of the two evaluation parameters belongs to the economic domain (T-E case), the percentage of success is 63%.

As a reference, the same sample has been analyzed again considering the rule expressed in ARIZ step 1.4. Results show that in T-E cases, Rule 1 is equivalent to the ARIZ rule, which instead show a 100% of success on T-T cases, against a 83% of Rule 1.

In order to further investigate on the validity of the above mentioned observation, the same analysis has been repeated on a sample of 20 industrial case studies previously faced by authors. Results of this further analysis, even if with a slightly minor percentage of success, substantially confirm the previous data for the T-T cases, i.e. a 36% of success for Rule 1 against the 55% of ARIZ 1.4. Conversely, for T-E cases the percentage of success of Rule 1 is 78%, resulting this time sensibly better than ARIZ 1.4 (which register a 44% of success).

Therefore, Rule 2 has been introduced, with the aim of improving Rule 1 in T-T cases. Since the rule has been developed by observing the industrial case studies, a significant improvement has been registered in these topics. In fact, the percentage of success on T-E cases has been maintained, while in industrial T-T cases it has grown to 64%. However, coming back on problems extracted from [1] and repeating the analysis, the results have been overturned again. In fact, even maintaining the same rate of success for T-E cases, Rule 2 is extremely worse than both ARIZ 1.4 and Rule 1. The above described results are resumed in figures 5 and 6.

Considering global industrial case studies results showed in figure 6 (TOTAL), it is possible to assert that Rule 2 is reasonably more successful than ARIZ 1.4. However, the results of the analysis performed on CES problems do not confirm such a claim.

It is worth to notice that the authors are conscious that the size of the sample of case studies is relatively too small for a reliable statistical analysis, then other case studies are to be collected to extend the robustness of the study.

Nevertheless, with the considered sample of data, it can be observed a high level of variability of the obtained results, which substantially makes impossible to confirm the validity of any of the proposed rules. In turn, despite the diverse attempts of classification of the conflicting requirements, it is not possible to identify a universal rule suitable to identify the most convenient side of a contradiction to process. It can be inferred that a decision based on the nature of the conflicting requirements is not a winning strategy and, therefore, other investigations should be performed, focusing on different classification criteria based on other characteristics, e.g. maturity of the system , available resources etc.

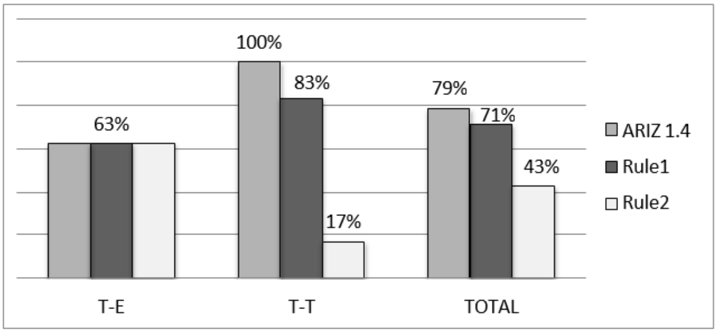

Figure 5: Percentages of success of the considered rules registered in the analysis of problems extracted from [1].

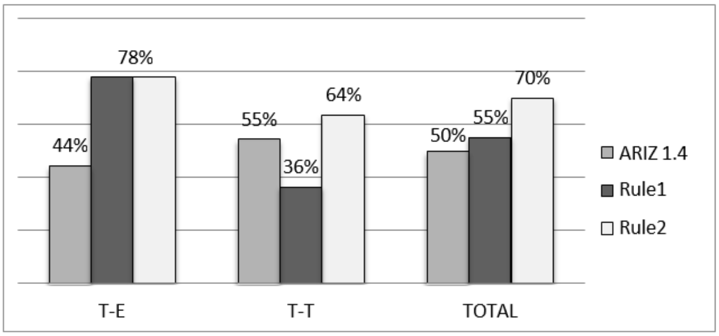

Figure 6: Percentages of success of the considered rules registered in the analysis of problems related to industrial case studies.

5. Conclusions and future developments

The present work aims at identifying any regularity occurring in the identification of the most profitable side of technical contradictions while trying to solve them. Since the only suggestion in TRIZ literature refers to functional requirement of the technical system (step 1.4 of ARIZ 85-C), and since common engineering design process is guided by the definition of a requirements, then authors tried to extract a rule to approach contradictions based on some requirements classifications. Different metrics to characterize technical conflicting parameter have been proposed, and they have tested both with respect to literature problems and with real case studies. Results of such metrics have been compared with the classical ARIZ recommendation, thus demonstrating that no one, neither authors' approaches, nor Classical TRIZ proposition, could be considered as universal or satisfactory. As a matter of fact, ARIZ

1.4 recommendation results to be more effective for addressing the contradictions proposed in Classical TRIZ literature, but the rule proposed by the authors behave significantly better in case of real industrial case studies. The overall main evidence of this study is that proposing a requirements-based approach for choosing the most convenient side of the contradiction to work out, is not effective. It is worth to notice that the size of the sample of case studies is relatively too small for a reliable statistical analysis, thus other case studies have to be collected to extend the robustness of the study.

Further on-going research activities carried out by the authors deal with different strategies of investigation, as for example evaluating the maturity of the system, the availability and the consumption of internal or external resources, and other classification of the system elements.

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