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To cite this version:

Hicham Chibane, Sébastien Dubois, Roland De Guio. Automatic Extraction and Ranking of Systems of Contradictions Out of a Design of Experiments. 18th TRIZ Future Conference (TFC), Oct 2018, Strasbourg, France. pp.276-289, 10.1007/978-3-030-02456-7_23 . hal-02279775

HAL Id: hal-02279775

https://inria.hal.science/hal-02279775v1

Submitted on 5 Sep 2019

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Automatic extraction and ranking of systems of contradictions out of a Design of Experiments

Hicham Chibane[1], Sébastien Dubois[1] and Roland De Guio[1]

[1] CSIP, ICube Laboratory, INSA de Strasbourg, 24 bld de la Victoire, Strasbourg, France
sebastien.dubois@insa-strasbourg.fr

Abstract. This paper shows to what extent data used in design optimization process and TRIZ based models of contradictions can benefit from each other. New design often starts by optimizing existing systems by experimental and numerical means. This approach requires building a model linking on the one hand, a set of Action Parameters; and on the other hand, Evaluation Parameters measuring the quality of a solution. When none of the solutions satisfy the objectives, a redesign of the system is required. Our hypothesis in this paper is that the analysis of experimental or simulation data, can be used as input to automatically extract systems of contradictions, and moreover that it can help to make a ranking of these systems of contradictions.
In the article 3 ways to extract, out of Design of Experiments, and to prioritize Generalized Systems of Contradictions will be presented. These methods will be illustrated throughout a case study related to a cutting process.

Keywords: Generalized Systems of Contradictions, Design of Experiments, Cross-fertilization optimization-invention.

1 Introduction

The evolution of the design of products and manufacturing systems is leading to an increasing digitalization of design tools (big data analysis, simulation tools, computer-aided innovation, and s.o.). Many data related to this digitalization are gradually becoming available. We hypothesize that these tools contain a lot of information that artificial intelligence tools can use in the context of systems understanding and inventive design. Thus, for several years, we have addressed the development of contradiction identification tools based on experimental design data. This research forced us to clarify the concept of contradiction and propose the concept of generalized contradiction. Several methods for identifying contradictions are now available and we are moving into a phase of exploitation, improvement and validation of these tools in an inventive problem-solving context. The identification of contradiction systems has a dual purpose: (1) to thoroughly understand an invention or research problem; and (2) to be an input for problem-solving methods of invention such as TRIZ. This article proposes a feedback on the use of three methods of identifying contradictions from the results of experimental design. In particular, we

were curious to know if the strategies of reduction of the space of search of the contradictions of two of them are effective.

The paper is organized as follows. Section 2 below provides a brief review of the Design of Experiments (DoE) and of the work that led to the methods of identifying the contradictions that are employed in this study. Section 3 presents the case study and the results of the DoE; it is followed in section 4 by the results of the identification of contradictions with the three studied methods. Finally section 5 analyzes and discusses the results and concludes with the perspectives from this study.

2 Background

In this part will be presented, first a brief overview of Design of Experiments, then the classical TRIZ System of Contradictions, as well as some of its limits. Then the model of Generalized System of Contradictions, which enable to overcome these limits will be introduced, and also the first statements of the use of this generalized model.

2.1 Design of Experiments

Design of Experiments (DoE) is a powerful tool for analyzing, modeling and optimizing process. The term experiment is defined as the systematic procedure carried out under controlled conditions in order to discover an unknown effect, to test or to illustrate a known effect. When analyzing a process, experiments are often used to evaluate which process inputs have a significant impact on the process output, and what the target level of those inputs should be to achieve a desired result (evaluation parameters). Experiments can be designed in many different ways to collect this information.

Designed Experiments are also powerful tools to achieve manufacturing cost savings by minimizing process variation and reducing rework, scrap, and the need for inspection.

Appropriate data can be analyzed by statistical methods such as Response Surface Methodology (RSM) [1] and Linear Regression Methodology (LRM) [2]. Statistical validation of experimental design is necessary to draw meaningful conclusions from the data [3]. An effective alternative to the composite factorial design is the Central Composite Design (CCD), originally developed by Box and Wilson [4], and improved by Box and Hunter [5]. CCD gives as much information as a three levels factorial design, requiring a lower number of tests than the latter, and describes a majority of steady-state process responses.

In this study, the DoE was used to optimize the machining process of a composite material. The influences between several action and evaluation parameters were evaluated. The identification of contradictions from the DoE was developed. The resolution of these contradictions will allow to overcome the Pareto front (defined by

the dominant points of the optimization space) of the solutions and to reach the targeted solution.

2.2 Classical TRIZ Systems of Contradictions limits

The contradictions, in TRIZ, are recognized as being one powerful model to formulate the problems, as they well represent the limits of the considered system, and also because they are a strong cognitive tool to change the representation of the situation for human experts. Technical contradictions represent conflict at the system level, when two Evaluation Parameters (EP) of the specs cannot be satisfied together [6]. Physical Contradiction state the core of the problem, pointing out a design parameter which has to be in two different states to satisfy the previously identified conflicting Evaluation Parameters [7]. During the development of OTSM-TRIZ, Khomenko defined the System of Contradictions, linking the models of physical and technical contradictions and stating that "many Physical Contradictions may be linked to a given pair of Technical Contradictions" [8].

In [9] the authors have formulated the limit of this System of Contradictions, illustrating on a case example that a problem could occur for which it is impossible to formulate, formally, contradictions. Counter-examples were given that the presence of an OTSM-TRIZ System of Contradictions is not equivalent to the absence of solution. In such cases, human experts formulate problems but based on partial consideration of the model of the system, but considering the whole model, no such contradictions exist.

2.3 Generalized System of Contradictions (GSC)

To overcome the previously cited limitation, and to propose a model of contradictions that enable the equivalence between the absence of solution and the existence of contradictions, a generalization of the OTSM-TRIZ System of Contradictions was proposed in [9, 10]. This model is presented on figure 1, illustrating the difference between OTSM-TRIZ System of Contradictions and the generalized one, and how they can be recognized in table of experiments, where e_i are experiments, x_i are Action Parameters (AP) and y_i are Evaluation ones (EP). E_i and Y_i define sets of experiments or Action Parameters.

Furthermore, this model enables the automatic extraction of contradictions out of tables of experiments (which can, for example, be the result of Design of Experiments). In [11] the authors present an algorithm to identify the complete set of Generalized Technical Contradictions (GTC) from experiments. And in [12] the Generalized Physical Contradiction (GPC) is described through binary integer programming and an algorithm is proposed in order to identify and extract the complete set of Generalized Physical Contradictions. Thus this GSC generalized classical TRIZ system of contradictions, referring not only to pairs of EPs but to two sets of EPs, for the technical contradictions; and also to two different states of several APs for the physical one.