Automatic Extraction and Ranking of Systems of Contradictions Out of a Design of Experiments

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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

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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 Sect. 4 by the results of the identification of contradictions with the three studied methods. Finally Sect. 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)

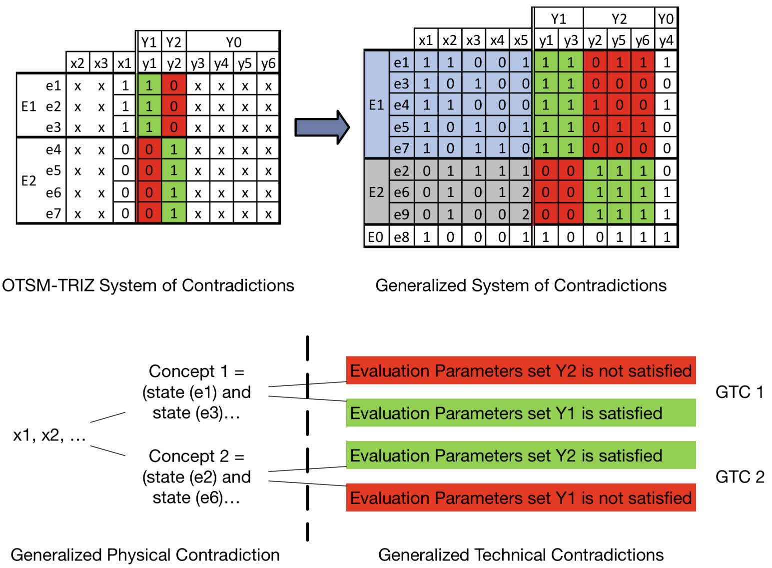
To overcome the previously cited limitation, and to propose a model of contradictions that enable the equivalence between the absence of solution and the existence of contradictions, a generalization of the OTSM-TRIZ System of Contradictions was proposed in [9, 10]. This model is presented on Fig. 1, 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.

2.4 GSC Formulation and First Statements

The automatic extraction of the GSC have been performed throughout various examples and some ascertainments have been pointed out:

- In [11], the authors illustrated the big complexity in the search of technical and Generalized Technical Contradictions: there is a lot of GTC and the human expert is not able to deal with so many possibilities (more than 100 in the given example). Then the “best” set of GTC to solve the inventive problem have to be identified.



		x2	x3	x1	y1	y2	y3	y4	y5	y6
					Y1	Y2	Y0			
E1	e1	x	x	1	1	0	x	x	x	x
	e2	x	x	1	1	0	x	x	x	x
	e3	x	x	1	1	0	x	x	x	x
E2	e4	x	x	0	0	1	x	x	x	x
	e5	x	x	0	0	1	x	x	x	x
	e6	x	x	0	0	1	x	x	x	x
	e7	x	x	0	0	1	x	x	x	x

OTSM-TRIZ System of Contradictions

							Y1		Y2			Y0
		x1	x2	x3	x4	x5	y1	y3	y2	y5	y6	y4
E1	e1	1	1	0	0	1	1	1	0	1	1	1
	e3	1	0	1	0	0	1	1	0	0	0	0
	e4	1	1	0	0	0	1	1	1	0	0	1
	e5	1	0	1	0	1	1	1	0	1	1	0
	e7	1	0	1	1	0	1	1	0	0	0	0
E2	e2	0	1	1	1	1	0	0	1	1	1	0
	e6	0	1	0	1	2	0	0	1	1	1	1
	e9	0	1	0	0	2	0	0	1	1	1	1
E0	e8	1	0	0	0	1	1	0	0	1	1	1

Generalized System of Contradictions

Generalized Physical Contradiction

Generalized Technical Contradictions

Fig. 1. OTSM-TRIZ and Generalized Systems of Contradictions

- In [12], the same kind of problem has been demonstrated, as for one selected GTC a huge number of GPC can be formulated (more than 3,000 in the given example).

Given these points, some questions have been formulated regarding the time to extract GSC, regarding the choice of the parameters to consider for building the problem model, and, finally, regarding the choice of the GSC to consider in priority to the others.

Another interesting result is the recognition that not all the GPC are equivalent in terms of resolution. If the formulated GPC can be very complex, the algorithm also enables the elicitation of "contextual" classical TRIZ physical contradictions, i.e., GPC were found with only one conflicting parameter. This means that they are equivalent to classical TRIZ contradiction but, under some conditions, which are defined by fixed values for the others action parameters [13].

In [14] a method was proposed to help in choosing the GTC to consider in priority and then the GSC that have the more weight on the chosen problem, based on the use of Feature Selection algorithm and based on the analysis of the Pareto frontier. In this article, 3 different ways to extract and choose the GSC to consider will be proposed and compared.

3 Case Study

3.1 Presentation of the Case

The experimental study was realized at the Center for Studies and Research on Cutting Tools (CEROC), Laboratory of Mechanics and Rheology (LMR), it was completed in the framework of two theses [15, 16]. Optimal conditions for milling T800 M21 carbon/epoxy composite material were established by response surface methodology [17, 18]. The study of the lead angle effect was established [19].

Down milling tests were performed on a horizontal high speed milling machine, PCI METEOR 10 HSK63A (spindle speed Nmax = 24000 RPM, Power P = 40 kW). The multi-axial composite carbon/epoxy T800S/M21 was machined with a single Diamond Like Carbon (DLC) insert provided by the cutting tool manufacturer [20] as shown in Fig. 2.

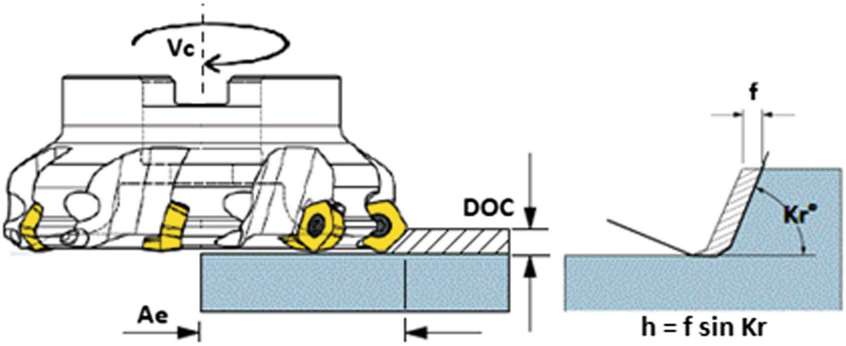


Fig. 2. Cutting tool and parameters

The axial depth of cut DOC was set at 1.04 mm, a thickness corresponding to four layers of carbon fabric, to avoid the effect of fiber orientation. The radial engagement ae was set at 50% of the tool diameter (ae = 36.4 mm). The cut length Lc is 55 mm.

The cutting conditions was tested with a depth of cut equals to four plies in order to minimize the influence of plies orientation. The orientation of the composite plies is described by [(45/90/135/0)16]s with ply thickness equal to 0.26 mm as illustrated in Fig. 3. Dry machining conditions were used during the experimental tests. The thickness h of the shaving depends on the feed rate f per tooth and the angle of attack Kr = 19° or 60°, and is given by equation: $h = f \times \sin(Kr)$.

3.2 Design of Experiments and Action Parameters

To minimize the number of experiments, a central composite design (CCD) with 9 combinations was studied using two quantitative parameters, cutting speed (Vc) and chip thickness (h) as shown in Fig. 3. The same DOE has been doubled to take into account a qualitative parameter which is the lead angle Kr.

A diamond like carbon (DLC) with a thin film of 1 µm diamond coating has been tested through the experimental part. A 6% cobalt content cemented carbide has been chosen as a substrate. In Fig. 3, which shows the testing environment, an insert type PDKT0905DEFR11 with a Kr = 19° lead angle has been equipped on a penta high feed milling cutter from Safety manufacture. Another milling cutter called ‘penta 60’ has been used for Kr = 60° lead angle inserts.

Finally, the latter was repeated 3 times to take into account another qualitative parameter which is the coating of the cutting insert. Three diamond coatings were studied, a diamond like carbon (DB3), a micro-crystalline chemical vapor deposition (DSP3 N) and a nano-crystalline chemical vapor deposition (DB6).

The total number of experiments was 54.

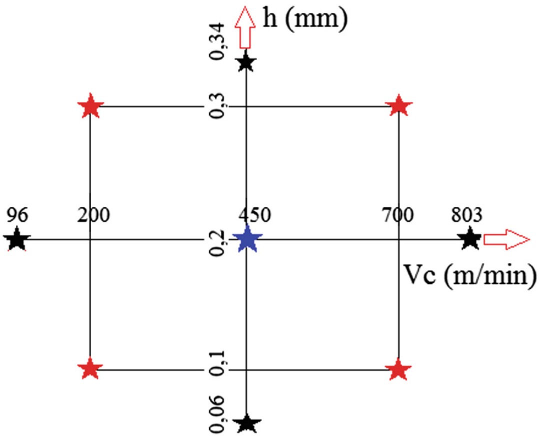


Fig. 3. Central composite design of experiment

Note that the central test was repeated 3 times.

The levels of machining parameters were chosen in accordance with the recommendations provided by the cutting tool manufacturer [21] as shown in Table 1.

Table 1. Machining parameters levels

Variables level	Quantitative parameters		Qualitative parameters	
Min (−1.21)	Cutting speed (m/min)	Chip thickness h (mm)	Lead angle Kr (°)	Coating of cutting insert
Min (−1)	96.5	0.06		
Mean (0)	200	0.1	19	DLC
Max (+1)	450	0.2		Micro-CVD
Max (+1.21)	700	0.3	60	Nano-CVD
	803.5	0.34		

3.3 Measuring Output Parameters (Evaluation Parameters)

In this study, several parameters related to the quality of machining parts were examined. Vibration levels (Arms), delamination length (DL), workpiece temperature

(T) and cutting force (Fmax), material removal rate (MRR), Surface roughness (Ra) and fiber flaking (FF), were measured for each test in one pass. The Table 2 summarizes the experimental methods used in this study and their technical specifications.

Table 2. Experimental methods used in this study and their technical specifications

Evaluation parameters	Used material	Manufacturer reference	Specificity
Workpiece temperature T (°)	Infrared camera	CEDIP, JADE MWIR	Spectral response 3 to 5 µm, fa = 176 Hz
Cutting forces F (N)	Force sensor	Kistler mod.9255B	fa = 10 kHz
Vibration levels Arms (m^2/s).	Tri-axial accelerometer	(Brüel & Kjær 4520)	Sensitivities of 10 mV/g
Delamination length Ld (mm)	Stereo microscope	LEICA	Expansion x4
Surface roughess (µm)	Optical profilometer	VEECO, WYKO NT1100	Vertical resolution 0, 1 nm to 1 mm
Material removal rate (cm3/min)	Mathematical model		$MRR = \sqrt{\frac{ap \times f \times V_c \times a_e \times z}{\pi \times d}}$

3.4 Results of the Optimization

The purpose of this study was to find optimal configuration of machining process according to a defined situation. For example, an optimization situation that favors maximum production with a good surface roughness and without machining defects (flaking of the composite fibers, delamination of the composite folds and thermal degradation of the resin).

The choice of the values of the evaluation parameters targeted to was set according to the need sought, as shown in the Table 3.

The experiments were conducted and a part of this Design of Experiments is presented in Table 4.

Table 3. Targeted Evaluation Parameters

Evaluation parameters	Min	Max	Target
Workpiece temperature T (°)	0	80	Minimize
Cutting forces F (N)	0	200	Minimize
Vibration levels Arms (m^2/s).	0	80	Minimize
Delamination length DL (mm)	0	0.1	Minimize
Fiber flaking FF (mm)	0	0.1	Minimize
Surface roughness Ra (um)	0	3	Minimize
Material removal rate MRR (cm3/min)	1200	2000	Maximize

Table 4. Design of Experiments

	Action Parameters (AP)				Evaluation Parameters (EP)						
Test Number	Coating of cutting insert	Lead angle Kr (°)	Cutting speed Vc (m/min)	Chip thickness h (mm)	Surface roughness Ra (µm)	Fiber flaking (mm)	Delamination length Ld (mm)	Work-piece temperature T (°)	Cutting forces F (N)	Material Removal Rate MRR (cm3/min)	Vibration levels Arms (m^2/s)
test 1	DB3	19	96,5	0,2	11,26	3,30	0,00	56,00	164,41	754,56	61,94
test 2	DB3	19	200	0,1	4,20	2,10	0,00	95,00	302,78	1532,43	73,88
test 3	DB3	19	200	0,3	11,12	3,70	0,00	67,00	129,14	464,42	160,15
test 4	DB3	19	450	0,06	2,35	0,00	0,00	122,00	461,22	933,05	85,30
test 5	DB3	19	450	0,2	19,00	2,40	0,00	101,33	207,28	493,50	141,60
test 6	DB3	19	450	0,34	9,44	0,00	0,00	62,00	112,99	147,54	203,46
test 7	DB3	19	700	0,1	3,92	0,86	0,00	282,50	874,15	448,15	190,26
⋮			⋮						⋮		
test 50	DSP3N	60	450	0,2	1,51	1,10	2,80	118,00	411,36	19,84	93,18
test 51	DSP3N	60	450	0,34	2,59	2,00	6,10	98,00	285,28	12,86	113,78
test 52	DSP3N	60	700	0,1	0,90	0,00	0,52	159,00	580,24	32,71	79,24
test 53	DSP3N	60	700	0,3	1,68	0,00	3,67	121,00	314,66	12,35	124,50
test 54	DSP3N	60	803,5	0,2	2,11	0,00	3,20	134,00	381,05	13,17	128,74

4 Contradictions Analysis

The previously presented case study and the results on Table 4 show the limits of the solutions that can be reached by optimization methods. In the table, no test was performed enabling to satisfy all the EP. This problem can then be recognized as an inventive problem, and the search of contradictions can be performed. In the next parts, three ways to extract and choose the contradictions will be presented.

4.1 Exhaustive Extraction of Contradictions

In [11, 12] algorithms to extract automatically Generalized Systems of Contradictions were presented. A first algorithm is applied on a table of experiments, a GTC is chosen, and for the chosen GTC, the GPC are extracted with the second algorithm. In [22] it was proposed to choose as priority contradiction, the dominant one.

If applying the exhaustive extraction of GTC on the previous table, with 54 tests, 201 GTC are proposed. But only one covering all the 7 EP, this one can thus be easily recognized as the dominant one. For this dominant GTC, 156 GPC are extracted by the application of the second algorithm. The only way to prioritize these GPC are the easiness of the use for resolution, the easiness for interpretation, but no objective ranking. And about this easiness some GPC are recognized more interesting as they are so-called "contextual classical-TRIZ Physical Contradictions", as, under some defined context (fixed values for some AP) Physical Contradiction on one AP can be formulated. In the previous case, two such contextual PC can be formulated, as the one represented on Fig. 4.

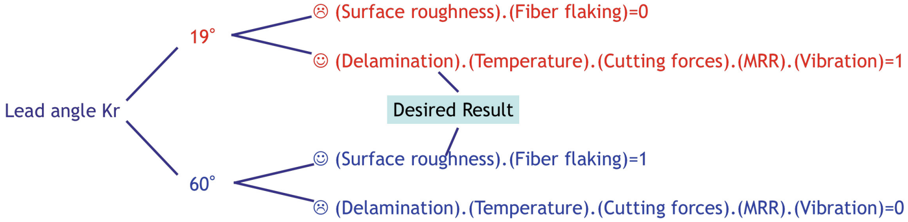


Fig. 4. Contextual classical-TRIZ General System of Contradiction

4.2 SVM Analysis of Data

The exhaustive extraction of GSC pointed out the huge amount of GSC than can exist for a given problem. Thus the choice of the one to consider priority is a real stake. In [14], the authors aimed at answering the questions: "How can the relevant contradictions be chosen or defined?" and "How can we extract the relevant contradictions without exhaustive research?". In the article a "SVM-based methodology was proposed to conduct data preprocessing to filter a large amount of irrelevant contradictions and reduce contradiction size". The Support Vector Machine (SVM) was proposed in [23]; SVM essentially performs linear classification by a non-linear mapping of the original space to a high-dimension space, which is called kernel trick.

Two ways to apply these SVM-based heuristics are proposed, the first enabling to weight, and thus to keep, the AP most influencing the EP, the second enabling to weight the values of the kept AP. The first result of this process was that all the AP are relevant candidates for the GTC identification. The second result was the set of relevant values and their relative weight, as illustrated in Table 5, were the most influent values have been highlighted in red for negative influences and in green for positive ones.

The analysis of the previous table leads the selection of a subset of 12 experiments, on which the extraction of GSC has been conducted. This reduces the number of GTC to 165, but it decreases dramatically the number of GPC, for one chosen GTC. Among them the contextual one illustrated on Fig. 4 is still present.

Table 5. Weights of values of AP on EP, after SVM analysis

		Ra (µm)	FF (mm)	Ld (mm)	T (°)	F (N)	MRR (cm3/min)	Arms (m^2/s)
Coating of cutting insert	DB3	-0,32	0,30	-1,50	2,49	-1,10	0,00	-2,92
Coating of cutting insert	DB6	-0,32	-3,30	3,00	-1,59	1,88	0,00	2,40
Coating of cutting insert	DSP3N	0,65	3,00	-1,50	-0,90	-0,78	0,00	0,52
Lead angle Kr (°)	19,00	-0,47	-3,68	5,93	1,55	5,00	-5,72	-3,73
Lead angle Kr (°)	60,00	0,47	3,68	-5,93	-1,55	-5,00	5,72	3,73
Cutting speed Vc (m/min)	96,5	-0,10	-0,42	-1,59	4,73	1,42	-4,00	7,54
Cutting speed Vc (m/min)	200	-0,22	0,16	3,15	2,53	0,69	-1,34	4,80
Cutting speed Vc (m/min)	450	-0,30	1,61	0,82	-2,40	-0,31	0,85	-1,87
Cutting speed Vc (m/min)	700	0,73	-1,52	-2,36	-2,95	-1,21	2,66	-6,38
Cutting speed Vc (m/min)	803,5	-0,10	0,17	-0,02	-1,90	-0,58	1,83	-4,10
Chip thickness h (mm)	0,06	-0,10	9,95	2,16	-1,13	-2,56	-4,00	5,56
Chip thickness h (mm)	0,1	0,73	-1,95	1,08	-1,57	-3,56	-1,34	3,69
Chip thickness h (mm)	0,2	-0,30	-4,59	-2,01	0,50	-0,33	0,85	-1,25
Chip thickness h (mm)	0,3	-0,22	0,59	-0,29	1,15	3,04	2,66	-5,27
Chip thickness h (mm)	0,34	-0,10	-3,99	-0,94	1,04	3,42	1,83	-2,73

4.3 Pareto Analysis of Contradictions

A last method is illustrated in [24, 25] were the choice of contradictions to consider is based on the consideration and explanation of the concept of dominance, and thus, on the Pareto frontier of the experiments. This analysis revealed that 5 subsets of experiments are on the Pareto, but if combining this analysis with strategic weighting of EP defined by the experts, only two subsets (then one GTC) exist, which is represented on Table 6.

Table 6. Pareto and weighting analysis of the data

	Coating	KR	Vc	h	Ra (µm)	T (°)	MRR (cm3/min)	Ld (mm)	FF (mm)	F (N)	Arms (m^2/s)
2	DB3	19	200	0,1	0	0	1	1	0	0	1
7	DB6	19	200	0,1	0	0	1	1	0	0	1
12	DSP3N	19	200	0,1	0	0	1	1	0	0	1
4	DB3	60	200	0,1	1	1	0	1	0	0	1

The analysis of this table, once more, pointed out, but as unique GPC, the one illustrated on Fig. 4, for different sets of EP.

4.4 Summarizing Results

Table 7 below summarizes results and contradiction search criteria of the 3 methods. The systems of contradictions of the 3 approaches overlap. Moreover, in our case, the same GSC, which seems afterwards to be the more relevant by experts, was found by the three methods. Thus it seems at least on our case that the three methods are effective for identifying the GSC. Comparison of the methods efficiency is provided in the next section.

Table 7. Comparison of the 3 methods

	Technical contradictions		Physical contradictions	
	Number of GTC	Selection criteria	Number of GPC	Selection criteria
Exhaustive extraction of contradictions	201	1. Dominance: Number of implied EP 2. Exhaustiveness: Number of implied experiments	156	Easiness to solve and interpret
SVM analysis of data	165	1. Dominance: Number of implied EP 2. Exhaustiveness: Number of implied experiments	6	Easiness to solve and interpret
Pareto analysis of contradictions	10	Expert ponderation of EP	1	N/A if one GSC; Weight of AP otherwise

5 Discussion and Perspectives

In this section we first comment on the results according to two points: comparison of the efficiency of the methods with each other, comparison of the methods in the context of analysis of the initial situation. Then we discuss their limitations and the research perspectives they generate.

5.1 Comparing Methods Efficiency

When comparing the number GTC and GPC for the chosen GTC, one can remark that some methods provide more contradictions than others. The purpose is then to know which contradictions are relevant or how to sort among them. In the first method (the exhaustive algorithm) many contradictions are proposed, but this methodology has not a real intrinsic capacity of generalization, but it provides several specific types of contradictions. That is the reason why the SVM method tries to reduce the area of search of the GPC by removing the variables that may provide “noise” in the interpretation of the DoE, that is to say by keeping only the AP that have a good discriminant influence on the objectives reaching/failing. The third method is more focusing on finding the relevant GTC, by selecting the candidates in the Pareto set of the binarized matrix of experiments (reducing the area of search of the GTC). Technical the computer time to provide the contradiction is small enough to be neglected. The difference is in the selection of the contradictions. The second and the third methods provide intrinsically a filter, which leads to reduce the noisy contradictions, thus the filtering activity of the human. To conclude this part we observed what was expected, which confirms that use of data analysis method brings promising benefits in the way to tackle big data complex problems, as it enables to decrease dramatically the number of GSC.

5.2 Impacts on the Analysis of the Initial Situation

The identification of contradictions from the DoE also has an impact on how one can perform the analysis of the initial situation. Indeed, one can have results of experiments established beforehand to a problem-solving study with the TRIZ. Thus, once the objectives are set, the contradiction identification is almost automatic and very fast compared to conventional methods requiring the use of experts. The contradiction is no longer the final phase of the analysis of the initial situation, but its starting point. The problem solver has not to bring out the contradiction anymore; he has to get it validated and/ or interpreted. This inversion of paradigm leads us to the questions: What we can learn from an identified contradiction? Does the contradiction bring a different understanding of the problem to the expert of the problem? Does the generalized contradiction bring a new qualitative vision to the understanding of the problem compared to the traditional TRIZ contradiction or traditional DoE analysis methods?

The feedback from the expert of the case study problem is the following. The expert participated in real time in the identification of contradiction by the third method. He had no difficulty in choosing the generalized technical contradiction among the five points of the binary Pareto. His comments are as follows: “The classical method analysis of the DoE makes it possible to understand the combined influence of APs on a EP while the system of generalized contradiction allows understanding the influence of a AP on all EP simultaneously. It provides a level of global understanding that traditional DoE analysis tools do not bring.” We complete his commentary with ours. The analysis of pairwise conflicts of EPs (classical TRIZ) leads to the same limits of understanding of the problem as classical DoE analysis methods (i.e.: they do not allow having a global vision). Note that in our case there is no system of contradiction corresponding to the model of OTSM-TRIZ or classic TRIZ in the data of the DoE. Unfortunately we did not experiment in parallel in order to know what would have been the outputs when applying classical TRIZ approach for getting the contradictions.

The second lesson and feedback on the case study reported by the problem holder is that “the APs coating, Vc and h that influence the optimization process do not explain the EP values limitations”. Our comment to this remark is that we hypotheses that the APs coating, Vc and h may also explain the limitation, but not in a parameter conflicting manner.

5.3 Limitations and Perspective

In the case study presented in this paper, we did not encounter any particular difficulty to identify the contradictions. Complementary cases have to be addressed to validate the methods. In [26] we have shown on an example of machining that some APs can act in harmony with the objectives in order to push the limits of a system. This information provides a complementary path of exploration and innovation to the contradiction. The highlighting of this property was made on a problem with 2 EPs. For the future, we want to develop an approach to identify this track systematically when the problem handles with more than two EPs. We could thus validate or invalidate the hypothesis made in the last paragraph of Sect. 5.2.

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