Interpretation of a General Model for Inventive Problems, the Generalized System of Contradictions

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Abstract
Design of technical systems implies either optimisation or inventive problems resolution. Resolution tools and methods exist for each kind of problems. Each family of resolution tools uses specific models for problem statement. A generic model that fits both kinds of problems has been defined, the Generalized System of Contradictions model. In border of this model a problem can be stated when no solution can be found by optimisation techniques. In this paper the Generalized System of Contradictions is linked to Design of Experiments model. Moreover a step towards problem resolution is proposed by the interpretation of the generic model. This interpretation is based on the definition of exhaustive concepts, it means of concepts enabling to look for solution outside of the initially defined domain. This process of problem statement out of the result of DoE and of interpretation of the built model is detailed and then illustrated through an example.

Keywords:
Design of Experiments, problem models, contradiction.

1 INTRODUCTION

Designing new technical system means making technical systems evolve [1]. Evolution can be made by two main ways [2, 3]: (1) increase the efficiency of systems by optimisation of its parameters or (2) re-design the system when, for example, the use of a new resource or the application of a new working principle is required. A hypothesis is that these two evolution types could be fitted with two kinds of problem resolution: when optimisation techniques enable resolution or when a change in the problem model is required. In this article the first case will be defined as optimisation problems, the second as inventive problems.

At the beginning of the design process, it is rarely known if optimization will enable the satisfaction of the requirements or if inventive design will be required. Thus it often appears that it is necessary to shift from one strategy to another. Different techniques and methods for problem resolution exist, dedicated either to optimisation problems or to inventive ones. However the shifting from one kind of approach to the second one is not obvious as none operational technique covering both approaches is proposed. This emphasises the need for a unified model fitting both approaches. In this paper two methods for problem resolution will be presented: Design of Experiments (DoE) for optimisation problems and TRIZ-based approaches for inventive problems.

DoE enables to settle the problem and to rapidly check if a solution can be found or not, it also enables the use of resolution algorithms as proposed by Constraint Satisfaction Problems (CSP).

In [4-6], the complementary aspects of DoE and TRIZ were studied by the definition of concepts solutions with TRIZ methods and by making these concepts more robust by the use of DoE.

In [7, 8] the comparison of the CSP approaches in terms of problem statement and in terms of problem resolution techniques has been initiated. In [9] a general model for inventive problems representation, based on TRIZ approaches, has been defined to satisfy the existence of an inventive problem only when no optimisation solution exists.

The exploitation of such a model has to be defined to make a step from problem statement to its resolution. This article presents a first step towards resolution by the interpretation of the problem definition in order to build a meaningful representation of the problem; it means a definition that will enable to search for a solution easier way.

This article will focus mainly on the problem statement starting from a DoE model to a model enabling the use of inventive problem techniques and the way the constructed model could help resolution. A first part will describe DoE and TRIZ based models. A second part will propose the comparison and the bridging of the two models. Then an example will depict the process of shifting from a DoE representation to a model enabling application of techniques of resolution for inventive problems.

2 PROBLEM STATEMENT

2.1 Design of Experiments model

Design of Experiments [10] is a strategy to gather empirical knowledge, based on the analysis of experimental data and not on the theoretical models. In an experiment, one or more process variables (or factors) are deliberately changed in order to observe the effects these changes have on one or more response variables (or outputs).

One can recognize two kinds of tools and techniques in DoE: those dedicated to the establishment of a model and those dedicated to optimisation. The first family proposes structured methods used to determine the relationships between different factors affecting a process and the outputs of this process. The factors are controlled parameters, usually noted X, whereas the outputs are measurable, usually noted Y.

The results of experiments are generally listed in a chart and enable the building of a mathematical model. One of the objectives of DoE is to obtain the most robust model with the minimum of experiments, which can be reached by the use of Taguchi's methods [11].

The second family of DoE techniques concerns the exploitation of the obtained mathematical model. The major kind of exploitation is the determination of requested controlled parameters values: given a required value of the measured variables, the mathematical model is used to find requested controlled parameters values.

In this article the second aspect of DoE, for which many algorithms exist, won't be considered as it concerns only optimisation techniques. In the rest of article only the results of DoE will be considered, and DoE will refer to any formalisation of a set of relationships between controlled parameters and measured ones.

Traditionally the operational steps for robust design are [12]: (1) statement of the problem and objective; (2) list of the responses and control parameters; (3) plan of the experiment; (4) running of the experiment and prediction of the improved parameter settings; (5) run of the confirmation experiment; (6) adoption of the improved design if objective is met or back to step (2) otherwise.

2.2 TRIZ based models

Classical TRIZ models

TRIZ [13] is a Russian acronym for Theory for Inventive Problem Solving, it is a theory built on the elicitation of the modes of the technical systems' evolution. Its aim is to give the axioms to develop methods and techniques for problems resolution in the field of technical system design and in particular for problems that cannot be solved by optimisation techniques. TRIZ has been initiated and developed under the control of Genrich Altshuller. Classical TRIZ refers to the development of the theory approved by Altshuller. In border of this theory contradiction is the main problem stating model. "A problem exists" is equivalent to "a contradiction can be elicited".

TRIZ defines three kinds of contradiction:

- The administrative contradiction identifies some dissatisfaction in a situation, without any mean to act on the situation. "I know what I want, but I don't know how to reach it".
- The technical contradiction is the expression of two opposite requirements. "The satisfaction of the first requirement disables the satisfaction of the second requirement and vice versa."
- The physical contradiction is the expression of two contradictory yet required states of the same parameter. "A parameter is required to be both in state one and in its opposite state".

OTSM-TRIZ system of contradictions

The idea of contradiction has been reinforced in border of OTSM-TRIZ [14], but for a generalized application, including non technical problems.

The administrative contradiction has not been kept in the border of OTSM-TRIZ, as this contradiction definition only refers to the objective and no corresponding solving tool exists. The two kinds of contradictions that are proposed in OTSM-TRIZ are the Contradiction of a System and the Contradiction of the Parameter, which respectively generalize the TRIZ technical contradiction and physical one.

Moreover a System of Contradictions is proposed in the frame of OTSM-TRIZ to build coherence between the levels of Contradiction of the System and Contradiction of the Parameter, as illustrated in bold on figure 1.

This system of contradictions is based on the existence of a parameter contradiction and of two contradictions of the system that justify the need of the two different states of the parameter. The two system contradictions are complementary as they correspond to the increasing of the first parameter that implies the decreasing of the second; and of the increasing of the second parameter that implies the decreasing of the first. The two parameters of the contradictions of the system are defined in [8] as taking part in the description of the objective, they are called Evaluation Parameters, whereas the parameter of the parameter contradiction is a mean to make the situation change, defined as Action Parameter.

Generalized System of Contradictions model

In [8, 9] a postulate has been proposed to build a generic model for inventive problem statement: this model has to satisfy the following equivalence: "a contradiction exists" is equivalent to "no solution can be found by optimisation of a known model". The models proposed in classical TRIZ and in OTSM-TRIZ do not fit this requirement. Thus in order to get this equivalence we propose a generalization of OTSM-TRIZ system of contradictions. As a result we get the Generalized System of Contradiction (GSC), as illustrated in italic in figure 1. The generalisation is based on the use of concepts, which are defined as logical assertions about values of the parameters.

Thus as generalization of the physical contradiction, a set of action parameters and concepts involving exclusively those action parameters respectively replace the action parameter and their values. The generalisation of the technical contradiction is then built on two concepts involving two sets of evaluation parameters. Thus the Generalized System of Contradictions is the generalisation of the OTSM-TRIZ system of contradictions where two concepts based on a set of action parameters satisfy two sets of evaluation parameters. The desired result is then the simultaneous satisfaction of the two sets of evaluation parameters. A Generalized System of Contradictions will be formulated in the example (part 4).

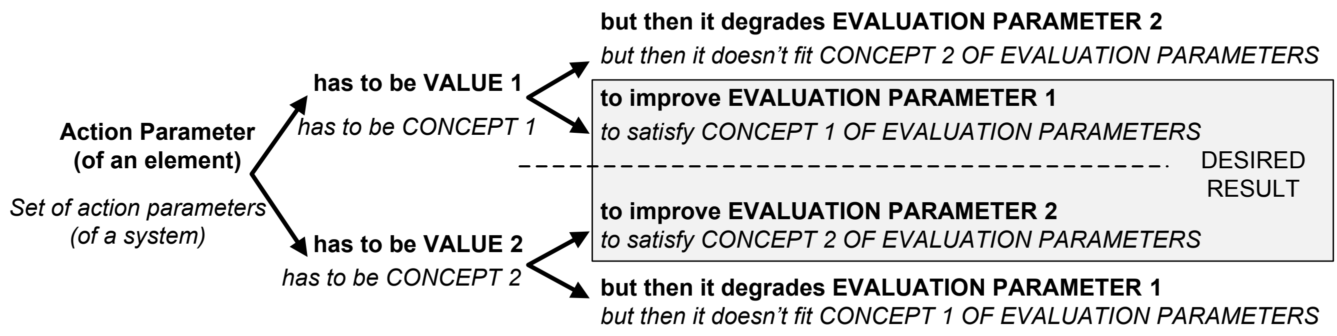
3 COMPARISON AND BRIDGING OF THE APPROACHES

3.1 Comparison of the models

Even if the model of DoE is not explicitly defined in order to state problems, it is quite compatible with the Generalized System of Contradictions model. The analogy between the two models is quite evident, as defined in table 1. Both models define two categories of parameters, those to evaluate the result and those to act on the system in order to reach the desired result.

	Generalized System of Contradictions	Design of Experiments
System model	Action Parameters	Controlled Parameters
Result evaluation	Evaluation Parameters	Measured Parameters

Table 1: Comparison between the GSC and the DoE models.



Bold: OTSM-TRIZ system of contradictions

Italic: Generalized System of Contradictions

Figure 1: OTSM-TRIZ system of contradictions and Generalized System of Contradictions.

The defined analogy shows the potentiality in terms of model coherence to define a fitting between optimisation models and resolution tools and TRIZ-based inventive ones.

3.2 Bridging DoE and Generalized System of Contradictions

Based on the previously explained analogy, the Generalized System of Contradictions can be represented in a DoE model quite easily. Independently from the values of the action parameters, a Generalized System of Contradictions can be recognized on the arrangement of a set of evaluation parameters.

Let us define a DoE characterized by a set of controlled parameters $X=(x_1,\ldots, x_l)$, a set of evaluation parameters $Y=(y_1,\ldots, y_r)$ and a set of experiments $E=(e_1,\ldots,e_9)$ as presented on table 2. An experiment e_i is characterized by a set of values $(v_{i1},\ldots, v_{il})$ attributed to the set of controlled parameters and by a set of values $(z_{i1},\ldots, z_{ri})$ taken by the evaluation parameters. In the rest of the article the values z_{ij} will be considered logical values, equal to 1 if the evaluation parameter y_i is satisfied by the experiment e_j, equal to 0 otherwise.

	x_1	…	x_l	y_1	…	y_i	…	y_r
e_1	v_{11}		v_{1l}	z_{11}		z_{1i}		z_{1r}
e_2	v_{21}		v_{21}	z_{21}		z_{2i}		z_{2r}
…								
e_8	v_{81}		V_{8l}	z_{81}		z_{8i}		z_{8r}
e_9	v_{91}		v_{9l}	z_{91}		z_{9i}		z_{9r}

Table 2: A Design of Experiments table

If no solution exists in such a table, i.e. if no experiment satisfies all the evaluation parameters, a Generalized System of Contradictions could be formulated [9]. Identifying a Generalized System of Contradictions in such a table is looking for:

- Three sets of evaluation parameters Y_0, Y_1 and Y_2, such as $Y_0 \cap Y_1=\varnothing$, $Y_1 \cap Y_2=\varnothing$, $Y_0 \cap Y_2=\varnothing$, $Y_0 \cup Y_1 \cup Y_2=Y$, $Y_1 \neq \varnothing$ and $Y_2 \neq \varnothing$
- Three sets of experiments E_0, E_1 and E_2: $E_0 \cap E_1=\varnothing$, $E_1 \cap E_2=\varnothing$, $E_0 \cap E_2=\varnothing$, $E_0 \cup E_1 \cup E_2=E$, $E_1 \neq \varnothing$ and $E_2 \neq \varnothing$. Moreover
  - E_1 is a set of experiments for which all the evaluation parameters of Y_1 are satisfied.
  - E_2 is a set of experiments for which all the evaluation parameters of Y_2 are satisfied.

The table 3, which is obtained by permuting rows and columns of table 2 in order to group the identified E_i and Y_i, represents the properties of the Generalized System of Contradictions from the values of the evaluation parameters.

In table 3, the values of the evaluation parameters are normalized as being 1 if the parameter is satisfied, according to the objective of the resolution, and as being 0 if the parameter does not fit the requirement.

X	Y_1	Y_2	Y_0
E_1	$E_1 \times Y_1$: $z_{ij}=1$	$\forall e_i \in E_1$ $e_i \times Y_2$: $\exists j / z_{ij}=0$	$E_1 \times Y_0$
E_2	$\forall e_i \in E_2$ $e_i \times Y_1$: $\exists j / z_{ij}=0$	$E_2 \times Y_2$: $z_{ij}=1$	$E_2 \times Y_0$
E_0	$E_0 \times Y_1$	$E_0 \times Y_2$	$E_0 \times Y_0$

Table 3: Representation of a GSC in a DoE

The matrix of table 3 has specific features:

- $E_1 \times Y_1$: $\forall (i,j) / (e_i \in E_1)$ AND $(y_j \in Y_1)$, $z_{ij}=1$.
- $E_1 \times Y_2$: $\forall i / (e_i \in E_1)$, $\exists j / (y_j \in Y_2)$ AND $(z_{ij}=1)$.
- $E_2 \times Y_2$: $\forall (i,j) / (e_i \in E_2)$ AND $(y_j \in Y_2)$, $z_{ij}=1$.
- $E_2 \times Y_1$: $\forall i / (e_i \in E_2)$, $\exists j / (y_j \in Y_1)$ AND $(z_{ij}=1)$.

The analysis and automatic extraction of the three sets out of the DoE result has to be studied and proposed, but several algorithms exists to facilitate this extraction [15]. A manual approach to obtain the Y_i and the E_i is proposed in the example of next section.

3.3 On the use of the Generalized System of Contradictions

The main interest of formulating problems through the Generalized System of Contradictions pattern is to propose a synthetic description of the root cause of problem. This synthetic description enables to build a new understanding for the designer. In [7] the difference between optimisation methods and inventive problems resolution tools has been defined as the ability to change the parameters which model the system. The Generalized System of Contradictions focuses the attention on the conditions that strictly have to be considered, rejecting other ones.

Moreover, formulating the problem through a system of contradictions shape could lead to the application of OTSM-TRIZ resolution tools, as they are defined to be generic for contradictions resolution whatever the domain is. However, this point has still to be tested.

Thus, currently the only recognized point is the interest of this synthetic definition to rebuild a meaningful representation of the problem out of a rich description of the problematic situation.

4 ILLUSTRATION

4.1 Description of the problem

Let us consider an electrical circuit breaker. When an overload occurs, the overload creates a force (due to magnets and electrical field) which operates a piece called firing pin. The firing pin opens the circuit by pressing the switch, located in the circuit breaker. In case of high overload, the firing pin, this is a plastic stem, breaks without opening the switch. Components are presented on figure 2.

Figure 2: Components of electrical circuit breaker.

4.2 Problem statement

The problem has been studied and the main system parameters and their domains have been defined as: x_1: firing pin material (plastic – 1, metal – 0) ; x_2: core internal diameter (high – 1, low – 0) ; x_3: core external diameter (high – 1, low – 0) ; x_4: firing pin diameter (high – 1, low – 0) ; x_5: spring straightness (high – 2, medium – 1, low – 0) ; y_1: circuit breaker disrepair (satisfied – 1, unsatisfied – 0) ; y_2: circuit breaker reusability (satisfied – 1, unsatisfied – 0) ; y_3: spring core mounting (satisfied – 1, unsatisfied – 0) ; y_4: firing pin bobbin mounting (satisfied – 1, unsatisfied – 0) ; y_5: normal mode release (satisfied – 1, unsatisfied – 0) ; y_6: firing pin initial position return (satisfied – 1, unsatisfied – 0). In this definition of the problem the x_i are the action parameters whereas the y_i are the evaluation ones. The system behaviour was modelled by Design of Experiments and it is shown in table 4. The objectives that have been established to build the DoE are:

- the satisfaction of at least one evaluation parameter in each experiment;
- each of the action parameters has at least one time each of its possible values;
- to minimize the number of experiments.

Even if the assumption is not totally consistent, the action parameters have been considered independent in the limits of their defined domains.

	x1	x2	x3	x4	x5	y1	y2	y3	y4	y5	y6
e1	1	1	0	0	1	1	0	1	1	1	1
e2	0	1	1	1	1	0	1	0	0	1	1
e3	1	0	1	0	0	1	0	1	0	0	0
e4	1	1	0	0	0	1	1	1	1	0	0
e5	1	0	1	0	1	1	0	1	0	1	1
e6	0	1	0	1	2	0	1	0	1	1	1
e7	1	0	1	1	0	1	0	1	0	0	0
e8	1	0	0	0	1	1	0	0	1	1	1
e9	0	1	0	0	2	0	1	0	1	1	1

Table 4: DoE for the circuit breaker

First evidence is that no solution can be found in the defined DoE, as no experiment enables the satisfaction of all the evaluation parameters. Looking for Generalized System of Contradictions in such a table could lead to several ones, at least one per evaluation parameter, as soon as each evaluation parameter is at least satisfied once.

Assuming that the choice of action parameters is done such a way that each evaluation parameter will be satisfied at least in one experiment, and assuming that no solution is found in the table, one can say that each evaluation parameter will have at least one experiment in which it will be satisfied and one experiment in which it will not. Thus a contradiction could be formulated for each of the evaluation parameters. But of course the Generalized System of Contradictions also enables the formulation of more complex Generalized System of Contradictions, implying two combinations of evaluation parameters. Thus a set of Generalized System of Contradictions can be formulated for one solutionless DoE.

A first question arises then: should all the Generalized System of Contradictions be elicited? If no, how to choose the Generalized System of Contradictions, or set of contradictions to be considered? In this article, the postulate is to choose the Generalized System of Contradictions that minimizes cardinality of E_0, as it is composed by the experiments that won't be considered in the contradiction model. The hypothesis is that the more experiments the Generalized System of Contradictions will include, the more representative of the problem it will be.

To build the Generalized System of Contradictions in the example, the frequency of simultaneous satisfaction of two evaluation parameters has been studied; it is presented in table 5. It shows that the parameters y_5, the normal mode release, and y_6, the firing pin initial position return, are simultaneously satisfied in six experiments.

	y1	y2	y3	y4	y5	y6
y1		1	5	2	3	3
y2			1	3	3	3
y3				2	2	2
y4					4	4
y5						6
y6						

Table 5: Simultaneous satisfaction of pairs of evaluation parameters

Thus, the minimization of E_0 leads to a Generalized System of Contradictions where

- E_0 is made of two experiments, $E_0=(e_3;e_7)$.

- E_1 groups the experiments where y_5 and y_6 are simultaneously satisfied, $E_1=(e_1;e_2;e_5;e_6;e_8;e_9)$
- E_2 corresponds to the experiment 4 where the evaluation parameters y_1, y_2, y_3 and y_4 are satisfied.

Therefore the DoE is organised, as shown on table 6, to graphically represent the Generalized System of Contradictions.

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

Table 6: Graphical representation of the Generalized System of Contradictions

4.3 A meaningful representation of the problem

A first way to interpret the Generalized System of Contradictions model out of the reorganized DoE is to simply enumerate all the states of the action parameters that are characterized by E_1 and E_2. We have then two concepts C1 and C2 defining E1 and E2 respectively:

E_1:
$C1=(x_1=1.x_2=1.x_3=0.x_4=0.x_5=1)OR(x_1=0.x_2=1.x_3=1.x_4=1.x_5=1)OR(x_1=1.x_2=0.x_3=1.x_4=0.x_5=1)OR(x_1=0.x_2=1.x_3=0.x_4=1.x_2)OR(x_1=1.x_2=0.x_3=0.x_4=0.x_5=1)OR(x_1=0.x_2=1.x_3=0.x_4=0.x_5=2)$

E_2: $C2=(x_1=1.x_2=1.x_3=0.x_4=0.x_5=0)$.

These concepts may be too long or difficult to be understood by a human. Thus we are looking for more simple concepts C'_1 (C'_2) that recognize any element of E_1 (E_2) and do not recognize any element of $E_1 \cup E_0$ ($E_2 \cup E_0$)

Exhaustiveness of discrimination

The interest of C1 is to provide a concept out of the action parameters that is discriminative. But another representation could exist to propose a more synthetic representation of the concepts

A discriminative concept of each of the three sets of experiments Ei is a definition that will strictly include experiments of the considered set, excluding any other experiment (within the set of know experiments). The advantage is to be sure that the definition will not be able to include "false" element, it means that if an experiment fits the definition it is sure that this element belongs to the considered set. The pitfall of such a representation is that the definition is based on a particular point of view of the problem made of the considered action parameters, and does not allow to change this point of view. A solution for the problem will have to satisfy the two sets of evaluation parameters included in the contradiction, i.e. the solution will have to combine advantages of both E_1 and E_2.

Thus it is proposed to build an synthetic representation of the two concepts C_1 and C_2 enabling to enlarge the sets of experiments to unknown ones, it means to experiments to be discovered after redefining the problem model.

The rule considered to build the definition of such a representation is to be discriminative in respect to two others groups, i.e. for example the definition of C'_1 has to be discriminative in regard of the known elements of E_2 and E_0.

In accordance with this rule the new definitions of the concepts are:

E_1: $C'1=(x5\neq0)$

E_2: $C'2=(x5=0).(x2=1).(x3=0)$

The inherent Generalized System of Contradictions is represented on figure 3.

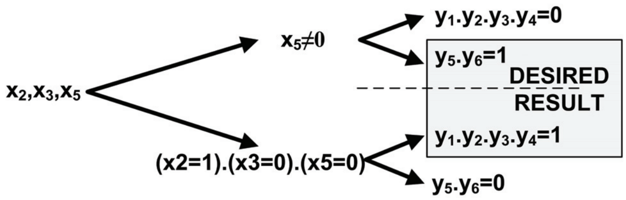


Figure 3: Generalized System of Contradictions for electrical circuit breaker problem.

For the domain experts, the initial representation of the concepts is totally not meaningful, but the new definition is more relevant:

"The straightness of the spring must not be low to satisfy the normal mode release and the firing pin initial position return; and the straightness of the spring has to be low with a high internal diameter of the core and a low external diameter of the core to satisfy the circuit breaker disrepair, the circuit breaker reusability, the spring core mounting and the firing pin bobbin mounting."

Such a synthetic representation brings the advantage to be better understandable and meaningful. But it can provide the bias not to be fully discriminative.

5 CONCLUSIONS AND PERSPECTIVES

5.1 Benefits of the model

The proposed Generalized System of Contradictions model is a model that covers both optimisation and inventive problems. As soon as no solution can be found by optimisation algorithms, a set of Generalized System of Contradictions can be formulated.

The first interest is to enable a linking between optimisation tools and inventive problems resolution tools such as those from TRIZ-based approach. As most of the time, the nature of the problem is not known at the beginning of the problem resolution process, it is interesting to be able to shift from one family of resolution tools to the second one.

The contribution of this paper is to increase usability of the Generalized System of Contradictions model by defining a representation of the used concepts which give more sense to the problem statement in accordance with an objective of resolution. It means that the proposed definition does not only state the DoE knowledge but enable to consider more knowledge as the solution has to be found in a domain larger than the one considered initially.

5.2 On-going work

Several steps are still remaining and several questions still have to be answered. The proposal of algorithms to extract automatically contradiction out of optimisation models has already been tackled in this paper. This can be done by the help of machine learning algorithms or with Constraint Solving Problems methods, as was presented in [7].

One of the remaining questions related to this automation is the reproducibility of the approach. In the treated example the comparison of the evaluation parameters by pairs was sufficient to apprehend the minimization of E_0 but in more complex systems, with higher number of evaluation parameters, this comparison could be not relevant. At least it will have to be completed by more complex comparisons, 3 by 3, 4 by 4 and so on.

Then the question of the contradiction to take into account has also to be considered. In this paper the hypothesis was to consider the Generalized System of Contradictions minimizing the size of E_0, but maybe the resolution could be easier with other contradictions, the different hypothesises will be tested. Another question is the evaluation of the meaning of the contradiction; it is represented currently by the dimension of E_0, but what if this dimension is high? What if its dimension is higher than the ones of E_1 and E_2? As the resolution phases have not been tackled for the moment, it is difficult to propose an answer, but the relevancy of the Generalized System of Contradictions will be evaluated in accordance to the benefits of its resolution. This means also that one important criterion to evaluate the relevance of a Generalized System of Contradictions is the number of considered evaluation parameters.

Last point of discussion is the way to simplify the definition of concepts, this step could also be improve by the use of family classification algorithms [16].

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