Parameter Network as a mean for Driving Problem Solving Process

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Abstract: Driving problem solving process in enterprises, in most cases in R&D departments, rely on a long historical set of experiences gained through practices, methods acquisition and continuous improvement. Nevertheless, the improvement of such practices always needs to be enhanced by integrating new paradigms in accordance with the global industrial situation. It is now worldwiedly accepted that this situation is turned towards innovation concerns and among others imposes R&D departments to improve the robustness of their technological choices. In this article we propose to demonstrate how R&D choices can be driven by representing problems through a parameter network and how to extract from this parameter network a set of key contradictions to be solved as a mean for inventively drive R&D decisions and actions. Based on our assumptions, it will also be reported in a specific section an application of a developed method on an R&D project in automotive industry.

Keywords: parameter network, contradiction network, OTSM-TRIZ, problem solving process.

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1 INTRODUCTION

Since the beginnings of industrial era, great changes have characterized its evolution. These changes are an organisational response to the exigencies of a society which, in turn, evolves significantly on the level of its demography, the amount of mastered knowledge's, and its geopolitics.

Three major evolutions that can be distinguished:

The era of the productivity: characterized by an important increase of demand by society for the acquisition of technical objects.

The era of quality: characterized by the necessity for rigorous steps of measurement and monitoring of the productions in order to increase the profitability of the organization evolving towards a total strategy of optimization of its efficiency.

The era of the innovation: characterized by the need for structuring not only productivity, total quality but also building a strategy of innovation and consequently the processes which result from this, so as the internal structure of organizations.

In this context economists and managers brought answers as for the orchestration of a strategy of innovation for the organizations while researchers in social sciences brought elements on the evolution of individual's trainings and the optimization of his intrinsic creative potential. On the other hand, practices of design remain primarily focused on the optimization of known elements (requirement of the project, means and knowledge of the company). Principally, the target remains the increase of "value" concept (to face quality requirements). Regarding elements brought to answer the requirements of innovation's era, we can observe that to face with the challenge of inventing; only tools derived from the social sciences have been brought to support creativity of people.

However the organization turned towards a reorganization of its internal practices meets two major obstacles:

- To face the difficulties brought by the increasing of its complexity (Waldrop, 1992) (Turner, 1998), at the level of its structure, its operative systems and of the objects and services that it produces.
- To face the challenges of forecasting by structuring and making reliable its choices for of evolution towards which the organization is engaged technologically and strategically (Rolland, 1994) (Kucharavy et al., 2005).

Our orientations of research are within the organisational framework of company's evolution, in particular in the contribution to the structuring of the inventive processes in design mostly used nowadays in R&D departments. Our major aim is the creation of methods founded in theory, supported by tools built in coherence with the strategies of innovation of the organization assisting companies' practices in R&D when moving towards innovation era's concerns.

In our approach we will focus on Inventive Design (ID) and distinguish its typology from what is currently known as Traditional Design in the sense that ID aims at the emergence of a solution requiring the investigation, management, the choice and the integration of new knowledge in the process of design and consequently in the technical object which will emerge from it. We thus distinguish clearly a design process having for objective optimization of what is commonly known in the company and a design process open to a possible integration of new knowledge, brought outside what is mastered and known in the company at a certain level of importance thus implying the notion of risk remaining to be evaluated.

2 SPECIFIC ASPECTS TREATED IN THE ARTICLE

2.1 About difficulties for R&D to pilot projects

Many studies have shown that currently R&D departments are searching for means of improvement of their efficiency (Mullich, 2001). Thus, the company's strategy regarding methods supporting efficiently ID resides in the search for theoretically grounded methods pragmatically applicable and as close as possible to their design habitudes and culture. In this task, difficulties R&D departments encounter when measuring the value of a proposed approach are in our sense of two orders:

- The decisional order: who puts an essential question: "how to guarantee that the selected option is the best possible one taking into consideration particular strategic context?"
- The administrative order: who induces problems already expressed by (Proper et al., 1995) "how to reorganize in a dynamic way our knowledge so that times of emergence of the solutions are optimized?"

From these two questions, emerge problems related to the mode of representation and dynamic organization of knowledge in the objective to control the actions in R&D department an efficient way.

2.2 The problematic of complex systems

Considering complexity of technical systems in design has already been studyed (Steward & al., 1981) (Rechtin & al., 1991). What can be sumarized and used in our approach when using the term: "complexity" is to employ the term to qualify situations where a significant amount of interactions between components of the same system (or between different systems implied in the network of problem arising), then in the direction of a multiplicity of fields of knowledge implied in the same network of problem (technological, managerial, human …). Thus, we consider that if one or the other of these characteristics is present in the initial situation, the need for a particular approach of problem solving arises and requires the creation of new knowledge able to handle it.

3 AIMS OF THE PRESENT WORK

3.1 The needs for a structurized way for data acquisition and representation

Many companies are committed nowadays to implementing large-scale knowledge management initiatives (Park et al., 2005). To achieve such an issue, they must work to ensure that pilot projects grow into successful enterprise-wide deployments. Our proposed approach aims at providing a grid of understanding and gathering of this knowledge in order to ease its understanding, to lower its complexity while not loosing any important information, to ensure its manipulation for an efficient use in managing R&D project. The next section is dedicated to sumarize the four domains in which each knowledge expressed by company's actors will find a place.

The present work takes place as a specific point of view and partial use of several other theories aiming at assisiting problem solving and data manipulation in complex situations. The first theory constituing one of the grounding of our approach is the Theory of Inventive Problem Solving (mostly known by its Russian acronym TRIZ) (Altshuller, 1986) in which many root mechanisms such as the contradiction mechanism will be employed in our approach. Then, as it has been already stated, TRIZ limitations to address complex and multidisciplinary situations have been treated in OTSM-TRIZ's theory already expressed in (Khomenko et al., 2002 and 2005)(Cavallucci et al., 2006). The present work is thus wiedly inspired on these two theoretical groundings while presenting a specific vision of it differing on some aspect of what has already been expressed in various publications.

Since our contribution also resides in the pragmatic proposal of a constructed methodology of data treatment and use, other theoretical approached have been used like graph theory (Sowa, 1984) for representation and manipulation of networks.

3.2 Structuring data's in the gathering phase

In this section we would like to pose the semantic bases of our paper. Specific terms will be used to describe how knowledge will be considered and it is of a high importance to understand its ontology. Four of them are defined in this section:

- **Knowledges**: knowledge can be of four different types. They are: problem (undesirable property or effect of the system), partial solution (technical idea solving part of the total set of problems), contradictions (based on dialectics) and parameters;
- **Domains**: each knowledge type is gathered in its own domain. Hence four domains coexist;
- **Layers**: The layers define a restricted area of collected and structurized knowledge related to a specific represented system (or group of systems). Thus several layers may co-exist in a single domain;
- **Networks**: Inside each layer, a graphical representation of elements of knowledge is created. It consists in nodes (each node being one out of the four possible knowledge type) linked to others by arcs (which nature depends on the domain).

Four domains are concerned by data gathering and storing, each of these domain are important both for problem formulation and solving and can be represented as layers.

- **Problem Domain** (PbD): The layer in PbD is specifically dedicated to store elements of knowledge pointing out a difficulty felt (or observed) by the company in terms of unsatisfying situation. It is important to restrict the expression of problem to a limited amount of terms in order not to include in problem formulation elements of partial solution and elements related to other problems.
- **Partial Solution Domain** (PsD): The layer in PsD is dedicated to host the elements of knowledge gathered from designer's know-how, and extracted from this know-how, restricted to the expression of elements of solutions (total or partial) answering to expressed problems. At this stage, a link between PD and PSD can be established.
- **Parameter Domain** (PaD): The layer in PaD must include all the necessary elements of description of the PbD in terms of parameterized characterization of their emergence. The content of this layer must be reduced to its essential: expressed parameters influencing others by means of qualified relations.
- **Contradiction Domain**: The layer in CD is a layer aiming at being automatically defined using the 3 other layers. Nevertheless, when a designer is expressing his knowledge, the typology of his expression sometimes relates to contradiction's formulation. It becomes then possible to fill this layer with data's partially and it become appropriate to dissociate this layer in two "ways" of representing it: the CD in relation to the necessity to constitute an element of interaction with human (designers, experts,…) in order to allow them to check incoherencies of knowledge representation and the CD in relation to a graph-like representation, allowing a mathematical treatment of it for constructing the decisions. The overall definition of contradictions must fit here to the basic definition of conflicting pairs of Technical Contradictions in TRIZ.

A summarizing figure is shown (figure 1) to represent the four domains of knowledge location for monitoring and formulating problems to be solved within R&D activity.

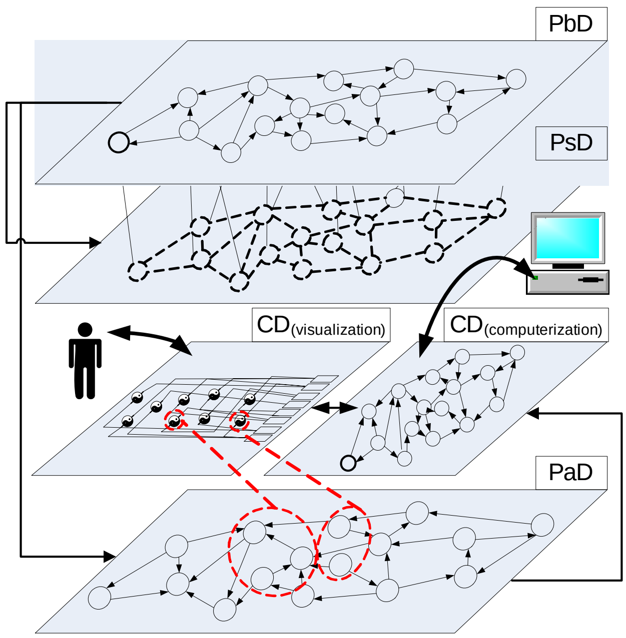

Figure 1: Four layers of Knowledge and their interactions

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4 DEVELOPMENT OF A CONSTITUING METHOD

4.1 From problem to parameter network

Separating problem domain and solution domain

It has been already stated that designers, when formulating problems, were very often expressing element of their knowledge indifferently weather they relate to problem or to solutions although it is fundamental to separate problem formulation from partial elements of solution when in problem solving situation. In our approach, we assume that designers, when expressing themselves may mix what relates to problem formulation and to elements of solution depending on the initial point of observation of the situation and the paradigm of the person. Nevertheless, for an efficient use in a solving situation they have to be stored, after gathering stage, in a separate space and identified belonging from a separate domain. Information relating to problems is linked to a set of requirements, whereas information relating to partial solutions is linked to the representation of a way to meet a requirement, (Suh, 1991).

Existing links between problem network and parameter network

A problem is often defined by « something unsatisfying ». This unsatisfaction is an undesired property of either the designed system itself or its relation with the environment. If we assume that a parameter can be a qualifying element for a clearer definition of an unsatisfying state (according to problem formulation, more than one parameter can be concerned) then a set of parameters can be linked to a specific problem for a cleared detailed definition.

Then, appear an important aspect of the representation: the fact that any designer has a point of view on a problem and its set of parameter expressing it.

Connections in the parameters network and connections in the problem network are closely related. An oriented connection from problem 1 to problem 2 signifies that solving problem 1 requires solving problem 2 (or solving problem 1 creates problem 2). An oriented connection from an influencing parameter to an influenced parameter has the following nature: the value of the influencing parameter determines the value of the influenced parameter. If two parameters are influenced by the same parameter, the unsatisfying states of these two parameters are problems connected in the problem network.

4.2 Construction of a parameter network

Methodology for construction

The constitution of a parameter network can be summarized in three phases:

1. List the problems
2. Build a separated parameter network for each problem
3. Integrate the separated parameters network

The first phase consists in listing problems as a mean to easily describe the unsatisfaction perceived by designers. One of the difficulties of this phase relates to the variation of point of view depending on the designer's paradigm. The other difficulty comes from the fact that problems listed by designers usually do not make reference to a single system and are unclearely expressed among a complex and fuzzy reality.

The second phase consists of the description of the problem as a set of interconnected parameters. This phase is to be developed for each listed problem. The problem should first be described as (at least one) unsatisfying parameter state. The cause of this unsatisfying state is then presented as a chain of parameters: designers have to explain the cause and effect chain initiated by a design choice and resulting in the problem (the root parameter should describe a design choice, and the final parameter describes the problem). For this task, interviews with technical expert are usually the easiest way. Questioning the expert helps him (or her) to reveal his (or her) tacit knowledge. Then the next step is change of the root parameter value: as the analysed problem is the result of the value of the root parameter it can be solved by changing the root parameter value (changing the value of the root parameter is a partial solution that should be mentioned in the « solution layer »). The potential resulting problem should then be identified as at least one parameter having an unsatisfying value. The creation of the resulting problem should further be explained as a chain of parameters (the physical phenomenon that creates the resulting problem should be described as a chain of parameters linked by causal relations). Finally building the separated parameter network might lead to the necessity to reformulate initial problem (updating it).

The third phase is the integration of each separated parameter network in a single one. This might need reformulation and addition of parameters. Coherence with parameter network rules and coherence with designer's knowledge are the two criteria to check the validity of the complete parameter network.

4.3 From parameter network to contradiction network

Interpretation of a parameter network

Build a parameter network consists in compiling existing element of knowledge. These elements can be found both in expert's know-how and in specialized literature. When literally expressed and computerized, existing semantic approaches may be helpful for assisting contradictions building. In this article we will focus on a non-automatic procedure and detail the way they can be extracted out of a parameter network.

In order to build a contradiction, it is necessary to state at first on each parameter typology. A parameter can be controllable through a possible modification (a designer's choice) in order to observe the effect of this modification; we will then identify this one as an action parameter. A parameter can also be formulated as a target to be reached by the design activity; we will then identify an evaluation parameter. An important point is to remind that depending on the point of view of the actors of the description, a parameter can be reformulated and through this reformulation switch from a typology to the other. Thus a description has a sense according to a specific paradigm, and paradigm constantly evolve in time.

Based on this first statement, each action parameter must be defined more accurately. For this purpose, a value needs to be expressed both in terms of acceptable level (a numerical unit) and a semantic definition featuring an opposition of state when possible (a word and its antonym). Both opposite defined values needs then to be connected to the evaluation parameters influenced positively. In some cases a cause and effect link can be established between a chain or more of two evaluation parameters. This link will be called a subsequence and will signify that a "cause-and-effect" situation is identified.

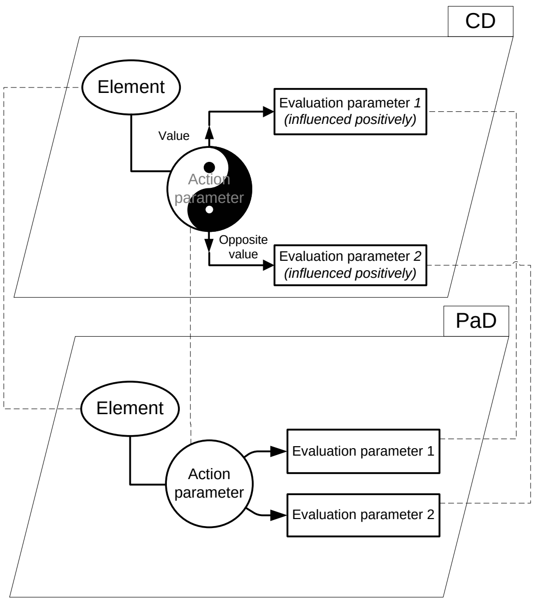

Fig2. Connections between contradiction and parameter

The three parameters mentioned in the contradiction are components of the parameter domain.

Contradiction network

We have shown in the last paragraph how contradictions can be identified and extracted out of a parameter network. When in solving situation, it is necessary to target a restricted area of contradictions to be solved in order to lower the complexity of problem treatment.

As it has been stated in §3.2, two kinds of representation can be used for representing contradiction network:

- A representation focused on conputational issues with a structurized way of collecting and storing data's as attributes to each node (contradiction) and arc (expressed link between contradictions).
- A representation focused on its graphical aims (Minsky, 1975) mostly dedicated for sharing the representation among each participant of the company and easing the refining of the modeled knowledge through harmonization of viewpoints.

As TRIZ tools are not well adapted to treat simultaneously more than one contradiction, it is necessary to filter the obtained set of contradictions and identify a limited amount of key contradictions out of it. As semantic networks are used for problems (Brachman et al., 1990), solutions and parameters domains, it is evident that the first trial to filter contradictions should also use network approach. Network is defined by nodes and arcs. Nodes in a contradiction network are obviously contradictions. However, the nature of arcs connecting contradiction still has to be clarified. Up to now, we can propose the following types:

- Type 1: arc between two contradictions means that solving a contradiction will automatically solve the other contradiction. For such connection, the key contradiction is the root node. Such a connection comes from subsequences among evaluation parameters of two contradictions. Contradictions of type 1 are represented with a continuous arrow (figure 3)

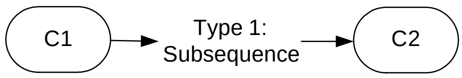

Figure 3. Connections of type 1 among contradictions

- Type 2: arc between two contradiction means that one contradiction is more important than another. The importance of each evaluation parameter can be evaluated by relative weighting. Hence, the importance of a contradiction can be evaluated by combining weights of its evaluation parameters. Here again, the key contradiction would be the root node ;

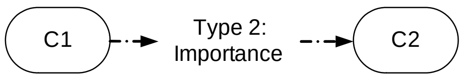

Figure 4. Connections of type 2 among contradictions

- Type 3: arc between nodes means that the two contradictions have common parameters. The key contradiction would be a Meta contradiction able to represent many connected nodes. A contradiction can have not more than three connections of this type. We represent this type of connections with non oriented dashed lines (figure 5)

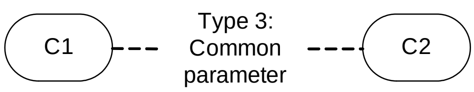

Figure 5. Connections of type 3 among contradictions

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4.4 Using contradiction network for R&D decisions

We have underlined in the introduction paragraph about the, necessity to assist R&D decision stage at the level of problem formulation and the consequences of their resolution (Larson, 2004). For this purpose, we underline that based on the model of contradiction representation; several decisions can be assisted by the interpretation of the layers.

5 CASE EXAMPLE

5.1 The "thin tank project"

Thin and flat fuel systems are requested for automotive applications in order to combine car aero dynamism, inside modularity and high cockpit. However, decreasing the thickness of a fuel tank generates a lot of problems. The working principle of many subsystems has to be changed. The main components of a fuel system (figure 6) are as follows:

- the plastic shell, which simply stores the fuel;
- the gauge: system sending electric current which represents the position of a float;
- One fuel trap, which is a small tank constantly filled by fuel from the plastic shell. The fuel sent to the engine is pumped from the fuel trap;
- one draining point: zone where fuel in the plastic shell is suck and sent to the fuel trap;
- FLVV: tube which depth determines the quantity of fuel that can be filled in the plastic shell (a minimum air volume is required).
- Rollover Valve: valve aiming at closing the tube connecting plastic shell and vapor filter. This valve guarantees a free vapor flow while stopping liquid. It uses a float.

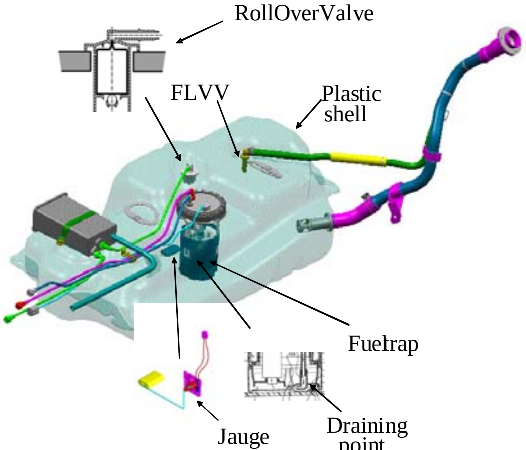

Figure 6. Traditional fuel system

5.2 From problem network to partial parameter network

List the problems

Six problems are initially listed by designers (Table 1). They are not yet connected in a problem network.

Build a separated network for each problem

Using the problem numbered Pb1; we show how the initial problem list is updated and how parameters are extracted.

In extreme conditions (for example when the car accelerates) the fuel is projected far from draining point and the fuel trap keeps emptying (to feed the car engine) but is not filled (fuel trap filling flow is zero). The parameter in unsatisfying state is “fuel trap filling flow in extreme conditions”: it is added in the parameter layer (PE1).

Having a single draining point is the design choice initiating the unsatisfying state of the fuel trap filling flow in extreme conditions: the fuel projected far from draining point cannot be sucked. Hence, the parameter “number of draining points” influences the “fuel trap filling flow in extreme conditions”. This root parameter is added in the parameter layer (PA3). In parallel, a partial solution is added in the solution layer to represent the design choice: number of draining point is low (partial solution PS3).

Increasing the number of draining point would solve the problem of fuel trap filling flow (this partial solution is added in the solution layer and named PS3’; there is an oriented arc from PS3’ to PS3 because PS3’ solves Pb1, which has been created by PS3). However, two problems resulting from the introduction of many draining points are mentioned by designers: the total pipe length (needed to connect each draining point to the fuel trap) and the total cost of the fuel system would be both too high. These two problems are added in the problem layer (Pb7 about tube length and Pb9 about cost; there is an oriented connection from Pb1 to Pb7 because solving Pb1 creates Pb7; the same arc exist from Pb1 to Pb9). Two parameters are added in the parameter layer: total pipe length (PE 7) and total cost (PE9). They are both influenced by the number of draining points (PA3).

The initial problem list has been updated: starting from Pb1 (fuel trap filling flow is zero) two others are added (total pipe length is high, Pb7, and total cost is high, Pb9). The separated parameter network built while describing this problem is made of one influencing parameter (PA3: number of draining points) and three influenced parameters (PE1: fuel trap filling flow in extreme conditions, PE7: total pipe length and PE9: total cost).

Origin	***Id***	***Name***	***Evaluation parameter***	***Value***
Initial list	Pb 1	Fuel trap filling flow in extreme conditions is unsatisfying	PE1	Low
	Pb 2	Autonomy in curves is unsatisfying	PE2	Low
	Pb 3	Distance between bottom of tank and ground is unsatisfying	PE3	Low
	Pb 4	Total autonomy is unsatisfying	PE4	Low
	Pb 5	Contact with car body is unsatisfying	PE5	High
	Pb 6	Gauging precision is unsatisfying	PE6	Low
Added problems	Pb 7	Total pipe length is unsatisfying	PE7	High
	Pb 8	Fuel mobility is unsatisfying	PE8	High
	Pb 9	Total cost is unsatisfying	PE9	High
	Pb 10	Height of fuel system is unsatisfying	PE10	High
	Pb 11	Tank deformation is unsatisfying	PE11	High

Table 1. List of initial and added problems

Id	***Name***	***Action parameter***	***Value***
PS1	Short FLVV	PA1	Low (a few millimeters)
PS1'	Long FLVV	PA1	High (close to plastic shell height)
PS2	Thin plastic shell	PA2	Low (a few centimeters)
PS2'	Thick plastic shell	PA2	High (more than fifty centimeters)
PS3	Few draining points	PA3	Low (one)
PS3'	Many draining points	PA3	High (six, for example)
PS4	Short plastic shell	PA4	Low (around half a meter)
PS4'	Long plastic shell	PA4	High (more than two meters)
PS5	Low fuel level at valve	PA5	Low (the valve is open at horizontal position)
PS5'	High fuel level at valve	PA5	High (the valve is closed at horizontal position)
PS6	Mobile draining point	PA6	High(this can be achieved by attaching a mass to the open end of a hose)
PS7	Thin venting valve	PA7	Low (a few millimetres: this can be achieved by the use of membranes).

Table 2. List of partial solutions

Integrate the separated parameter networks

Shaded boxes of Figure 8 show the separated parameter network obtained by the analysis of Pb1. The other

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parameters come from the other separated parameters networks, built from the other problems of the initial list. The analysis of this parameter network shows the existence of three subsequences between influenced parameters:

- S1: fuel mobility (PE8) influences fuel trap filling flow in extreme conditions (PE1);
- S2: fuel trap filling flow in extreme conditions (PE1) influences autonomy in curves (PE2);
- S3: total pipe length (PE7) influences total cost (PE9).

The problem and partial solutions layers are built on the basis of each initial problems analysis (Figure 7).

An oriented arc between problems describes the fact that solving the first problem creates the second one. A non oriented arc between problems describes the fact that the two problems are connected by at least two opposite oriented arcs: solving one problem creates the other one and vice-versa. Shaded boxes of the problem layer detail the components identified while analysing Pb1 (oriented arc are not grouped in non-oriented arcs): solving Pb1 by the use of PS3' creates both Pb7 and Pb9; solving Pb7 or Pb9 by the use of PS3 creates Pb1; due to the subsequence S3, solving Pb7 also solves Pb9.

Equivalent rules are used in the partial solutions graph: an oriented arc between two partial solutions describes the fact that using the first partial solution further requires the use of the second one. Then, a non oriented arc between two partial solutions describes the fact that the two partial solutions are connected by at least two opposite oriented arcs: using one partial solution further requires the use of the second one, and vice-versa. Shaded boxes of the partial solution layer detail the components identified while analysing Pb1: using PS3 creates Pb1, which can be solved by PS3'; using PS3' creates both Pb7 and Pb9 which can be solved by PS3. The subsequence S3 has no meaning in the solution layer.

Contradictions are obtained from the analysis of the problem graph if the two opposite oriented arc between two problems represent incompatible partial solutions. In the partial solution layer, contradictions exist when two partial solution, connected by two opposite oriented arc, are incompatible.

Problem and partial solution domains are connected by the fact that (1) each oriented arc among problems is a partial solution mentioned in the solution layer and (2) each oriented arc among partial solution is a problem mentioned in the problem layer. In order not to increase the complexity of the picture, this connection between these two layers is only detailed for component identified while analysing Pb1 (dashed lines).

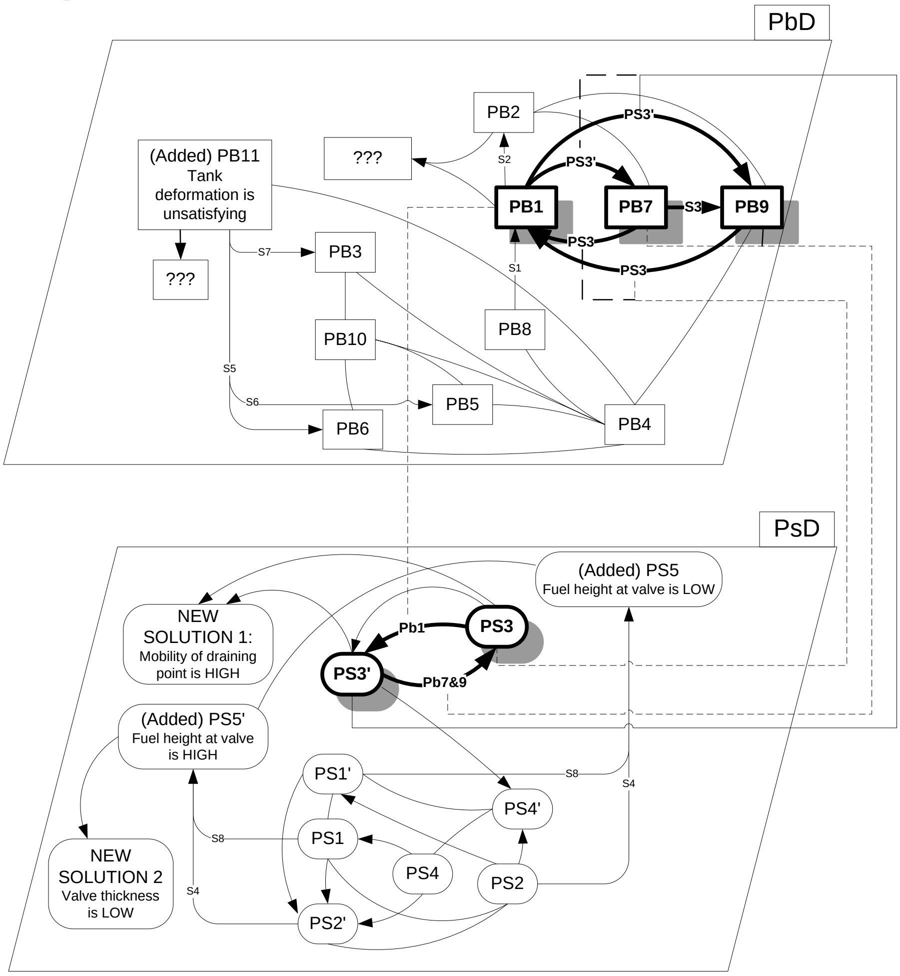

Figure 7. Problems and partial solutions layers

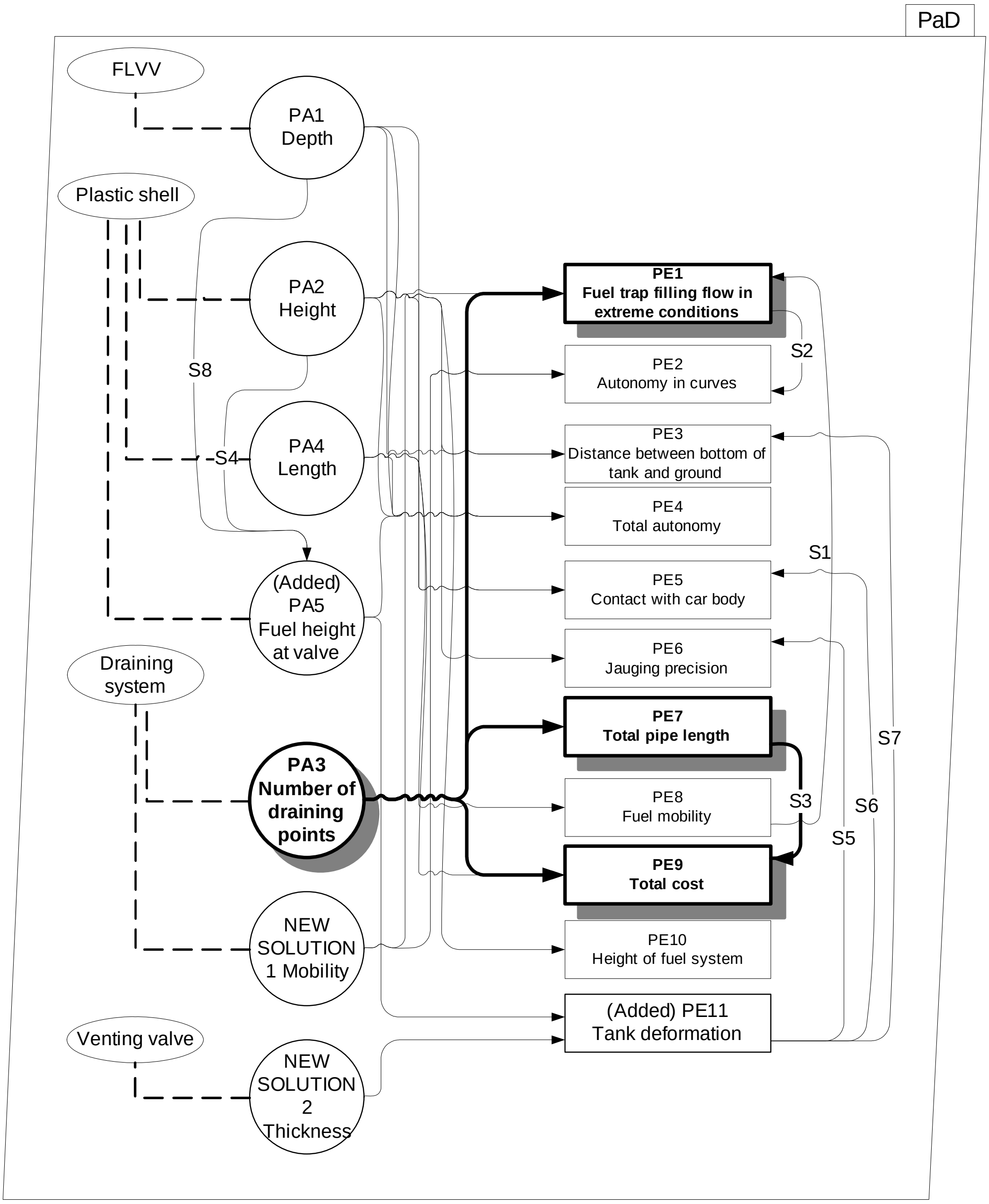

Figure 8. Parameters and subsequences in the parameter layer

5.3 Contradiction network

Parameters obtained by the analysis of the problem Pb1 give birth to two contradictions, named C1 and C2.

The satisfying states for the three influenced parameters are: low total cost and total pipe length, and high fuel trap filling flow during extreme conditions. The value of "number of draining point" should be "high" in order guarantee the satisfying state of "fuel trap filling flow during extreme conditions". Two harmful consequences are created by such a design choice: if the value of number of draining point is high, the unsatisfying states of both "total cost" and "total pipe length" are created. These two parameters are incompatible with the fuel trap filling flow: the value of the number of draining points should be low, in order to guarantee the satisfying states of both the total cost and the total pipe length. High and low are two incompatible numbers of draining points.

Two contradictions are formulated to represent components obtained from the analysis of Pb1 (Figure 9): C1 mentioning the total pipe length ; C2, mentioning the total cost. The subsequence S3 (from total pipe length to total cost) is translated as a connection of type 1 between the two contradictions (arrow from C1 to C2). The two others connections among the contradictions (of type 3, represented by dashed lines) describe the same influencing parameter (number of draining point, PA3) and a common influenced parameter (fuel trap filling flow, PE1).

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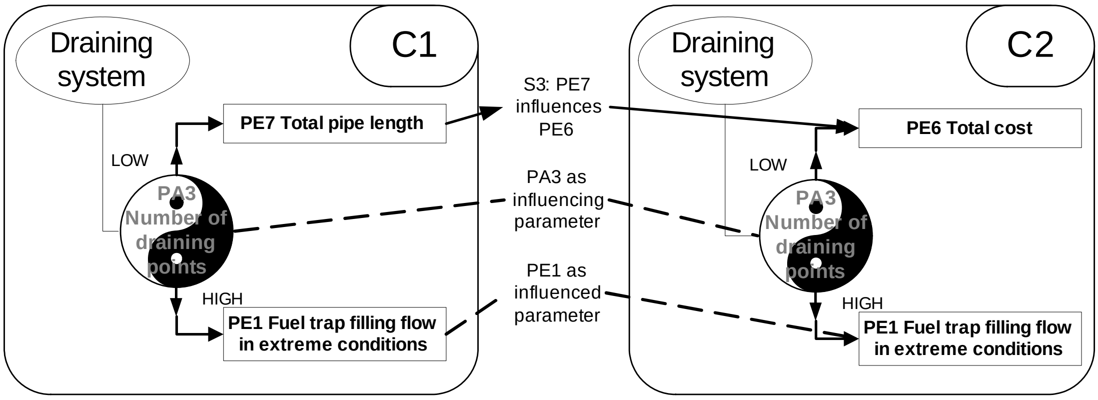

Figure 9. Connections among C1 and C2

Thirteen contradictions (C1 to C13) are formulated by the analysis of the obtained parameter network. Arcs between contradictions are type 1 (arrows) or type 3 (dashed lines) connections. The three subsequences identified in the parameter layer create the connections of type 1.

Analysing the contradiction network provides the two following results:

- Due to existing subsequences, solving contradiction C1 might solve contradictions C2, 3, 4, 5 and 13 (Table 3). This means that contradiction C1 should be solved in priority;
- Many type 3 connections exist among contradictions C6, 7, 8, 9, 10, 11 and 13. This means that it is worth trying to introduce a new contradiction to combine all of them. This added contradiction should have subsequences with the connected contradictions. “Tank deformation” is formulated by experts as a parameter influencing both “contact with car body”, “jauging precision”, and “distance between bottom of tank and ground”; fuel height at valve is proposed as a parameter influenced by both “depth of FLVV” and “plastic shell height”. This added contradiction is numbered C14.

The action parameter of C14 is PA5 “Fuel height at valve”. This parameter is influenced by both the FLVV depth (PA1) and the plastic shell height (PA2). These two influences are subsequences among action parameters (Figure 8, S4 and S8). If the fuel level at valve is too high, the tank deforms when thermodynamic conditions change. This new parameter is the tank deformation (PE11). If the tank deformation is high, gauging reliability (PE6, subsequence S5), contact with car body (PE5, subsequence S6) and distance between bottom of tank and ground (PE3, subsequence S7) are unsatisfying. The other parameter directly influenced by the fuel height at valve is the total autonomy (PE4). The fuel height at valve should be high to guarantee a good total autonomy, and should be low to guarantee a good (i.e. low) tank deformation. The contradiction layer shows the complete contradiction network: the initial contradictions and C14.

Hence, the contradiction network can be filtered by the use of the subsequence among the constitutive parameters: solving C1 and C14 can solve all the other contradictions. The oriented connections among contradiction (type 1) is synthesised in Table 3. As solving C1 might solve C2 due to the subsequence S3, “S3” is written in the cell of first line and second column. This table shows that contradiction C1 and contradiction C14 should be solved in priority, as they might solve respectively seven and five other contradictions.

		Influenced contradiction													
		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	Total
Influencing	C1		S3	S2	S2	S3								S3	5
	C2			S2	S2										2
	C3		S3		S3	S3								S3	4
	C5	S1	S1		S2										3
	C14 (Added)						*S7 S8*	*S5 S8*	*S6 S8*	*S4 S6*	*S4 S7*	*S4 S5*	*S4*		*7*

Table 3. Connections among contradictions

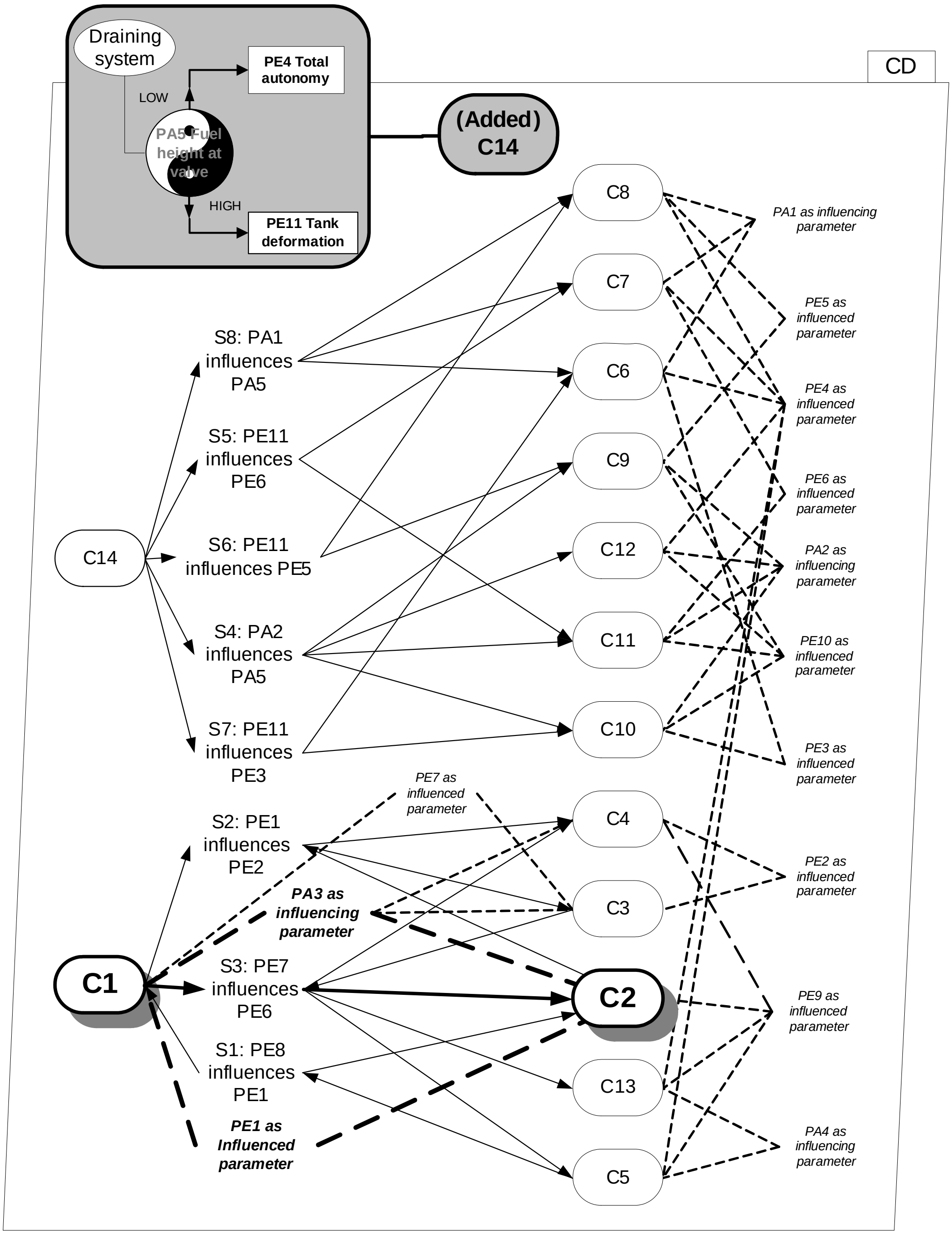

Figure 10. Contradiction domain

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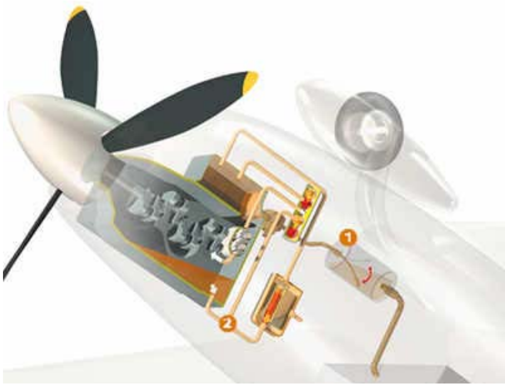

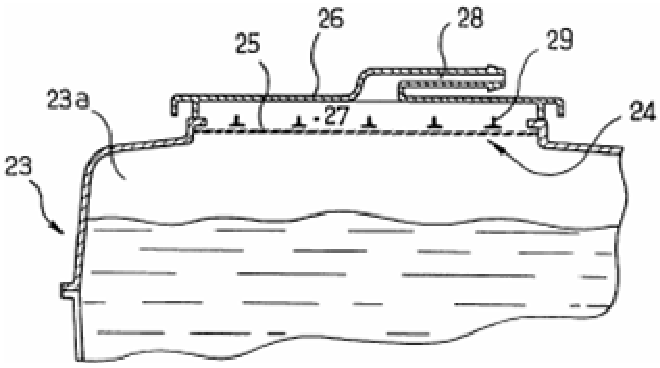

Fig. 11a & 11b: (a) flop tube in aerobatic air planes; (b) Use of membrane for venting

5.4 Decisions in terms of R&D directions

For confidentiality reasons, we disclose in this article two solutions proposed within the project having evaluated as already known solutions. Inventive solutions evaluated as potentially patentable by the company are under development and are enclosed into a Non Disclosure Agreement.

5.4.1 Contradiction C14

In order to solve the second key contradiction (figure 10), a solution is to develop in a new sort of valve. This valve should be thinner than the current existing ones. Doing so, the fuel height at valve location can be high without generating a big tank deformation (the valve would not block). With high fuel height, the total autonomy is satisfying: the contradiction C14 is solved. Gore-Tex membrane can be used to develop such thin valve, as mentioned in (US patent 6557719) (figure 11b). This solution is mentioned as “new solution 1” in figure 7.

5.4.2 Contradiction C1

In order to solve the first key contradiction (figure 10), a solution developed for aerobatic airplanes can be adapted (Tenner, 2002). The solution is known as « flop tube »: a flexible hose with a weight in the free end. The free end and the weight are plunged in the fuel tank; the other extremity of the hose is connected to the engine. In normal flight, the weighted end of the hose stays in the bottom of the tank and sucks fuel to the engine. When the airplane flights upside down (see figure 11a), the fuel and the weight are projected to the top of the tank (reference 1 in the figure). We can say that the principle is to connect the suction point to a component which moves like the fuel because they are subjected to the same force.

The adaptation of this principle can be done by designing a mobile draining point, to which a weight is attached. This weight would be projected in the same location than fuel in extreme conditions. Doing so, the total tube length is satisfying (because the number of draining point is still one) and the fuel trap filling flow in extreme condition is also satisfying (the draining point is moved where fuel is projected). This solution is mentioned as “new solution 2” in figure 7.

5.5 Decisions in terms of R&D directions

We have shown in the last paragraph that a contradiction network can be built on the basis of a parameter network interpretation. In this section we would like to emphasis that such graphical representation has been of a crucial help for R&D manager of the company for several reasons:

- In terms of targeting the right problem to be solved: Traditional approach used in the company relied on intuition and trial-and-errors. Here, a substantial time saving (thus costs) can be observed since there is a systematic way of selecting the most influencing problem to solve for a specific strategically objective is used;
- In terms of categorization of the proposed solutions: Since a graphical representation of all defined problems is proposed, when in solving stage several solution concepts have been drawn by designers. Among these solutions, 3 categories appeared with various level of maturity of the concepts (ready to implement – applicable with minor testing – breakthrough with necessity to perform some research). This categorization has helped in the construction of strategies regarding the use of the solution concepts (patenting, prototyping, cost estimation).
- In terms of constructing a strategy for gathering know-how: In the sessions with the engineers, we have seen that what was unusual for them was to spend an important amount of time for representing their know-

how. This has sometimes led the group to doubt regarding the usefulness of our work. Nevertheless, they later understood the meaning of such activity since we also used some of their time to explain that the exploitation of this time was an investment for the future studies. Building a computerized representation of their know-how after a refining of its definition and a harmonization of its representation through collective corrections has been recognized has an important issue for their future strategies in R&D.

6 DISCUSSIONS

6.1 Discussions regarding our contribution

Our proposed article states that existing knowledge in a company, shared among several actors (designers, managers, technicians…) can be gathered and dynamically stored using a logical questioning and four domains for representation. We have observed during the application of this way of dynamically storing knowledge that using theoretical groundings of TRIZ and OTSM-TRIZ results in complexity reduction. This reduction is observed since a large amount of collective knowledge has been expressed, manipulated and clearly represented through the use of graphical representations. Using these representations, contradictions can be reorganized by the use of stated subsequences among parameters. In the boarder of the case study, a significant time saving has been observed due to the computer assisted contradiction's organization and the fact that compared to traditional TRIZ approach, here, a set of contradiction has been trated by designers and not a single one. In this article two situations have been shown and constitute an important part of the results of our contribution:

- A contradiction can be priorized due to the subsequences among its constitutive parameters and other parameters of the network (C1)
- A new contradiction can be constructed for a new paradigm representation. This new contradiction consists in a logically constructed fusion of several others and its resolution becomes of a much higher challenging level (C14).

The logical exploitation of graphs can ease the computerization and manipulation of represented elements of knowledge. We can forecast that many application of the use of the models of representation will be constructed in a near future. But what has also been observed during the sessions is the fact that only expertise of designers together with clearly stated representation rules can lead to a pertinent evolution of the graph.

The construction in parallel of the three describing layers (PbD, PsD, PaD) ease the codification of Expert's knowledge and help the creation of connections between these layers. We have also noted that a contradiction is invited to be described when a loop is observed between connected elements in the graphs of PbD and PsD. Thus the constitution of the fourth layer (CD) is also eased by the observation of the graphical representation.

6.4 Limitations of our approach

In the section 4.3, we have stated that subsequences among evaluation parameters create oriented relations among contradictions. However, a limitation of our approach resides in the difficulty to integrate (within both graphical representation and contradictions extraction) relations between more than two elements of any network (parameter, contradiction or problems). For example the effect of an influencing parameter on an influenced one can depend on the value of other influencing parameters; the solution of a problem can be one partial solution out of a set or the combination of all of them.

Another limitation comes from the fact that problem solving needs constant reformulation of the problems, contradictions and parameters (Sujan et al., 2002). Inventive problem are solved by overcoming mental locks and by imagining other ways to use existing components (Frizelle et al., 2000). The use of rigid graphs to represent problems, contradictions and parameters appears in contradiction to this statement and creates for us a challenge for the evolution of our approach.

6.3 Research perspectives

Problems, contradictions and parameters layers are linked since problems are described by parameters involved in contradictions. Therefore, any change in one of the network requires also an evolution of other networks (Lopez-Suares et al., 1998). We think that conducted manually, consistency among different description layers becomes too difficult to guarantee. Thus, it becomes obvious that a software application able to manage connections between layers needs to be developed in order to facilitate the treatment of situations of a higher complexity level.

In this article, we propose to represent the problematic situation with four layers: problem, solution, contradiction and parameters. We think that investigating and describing their evolution through problem formulating and solving is the next step in the building of a computable problem solving process model.

Another research direction is to widen the flexibility of our representation to the psychological effect embedded in inventive design. This would require a higher level of dynamicity of the four description layers. To do so, cognitive aspects of problem solving will have to be investigated (intergating people's paradigms) and software applications built to assist problematic situation's representation through domains of knowledge associated with human (or social) paradigm will need to be developed.

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