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A TRIZ-based CAI Framework to guide Engineering Students towards a Broad-spectrum Investigation of Inventive Technical Problems*

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Nowadays, a growing consensus is attributed to conceptual design in the perspective of developing effective and successful products; as a consequence, major efforts should be dedicated within the Computer-Aided Innovation field to correctly support this task. A particular line of evolution of these systems concern computer coaches, i.e. software applications capable to assist users along each step of design activities. In such perspective the authors have developed a dialogue-based system supporting a natural language questioning procedure to investigate technical problems through TRIZ way of thinking. An emerging deficiency of its first version concerns limited capabilities in providing a broad screening of the issues and features relevant within the encountered inventive problems. The integration of a further analysis module supporting the logic of the TRIZ System Operator has allowed the individuation of effective resources for breaking technical conflicts inherent to the investigated systems or formalizing contradictions in TRIZ terms. The paper provides further support about the need of developing broad thinking skills in engineering education. The new generation of Computer-Aided systems is extending its scope, by supporting the user already from the early design stages, where creativity and cognitive processes are of paramount importance. In such context, the authors have developed a natural language dialogue-based framework capable to coach designers in investigating non-routine technical problems through a TRIZ way of thinking. The first version of the questioning procedure has showed limitations in terms of the capability to widen the designer's perspective, resulting in the overlooking of aspects relevant for the problem. The new version of the dialogue-based system integrates a further analysis module, here presented, supporting the logic of the TRIZ System Operator. New tests demonstrate that the modification allows to improve the quality of the analyses, especially in terms of the identification of features to be advantageously redesigned in order to solve the addressed problems.

Keywords: computer aided innovation; dialogue-based system; broad-spectrum investigation; inventive problem analysis; TRIZ

1. Introduction

As the literature witnesses the relevance of conceptual design within product development in order to achieve business success, designers have to carry out crucial tasks, dealing often with troublesome issues and lack of information. Within any design task, both regarding engineering and other disciplines, the main kinds of problems that lead to complicate the concept generation stage can be summarized as follows:

- inventive problems [1, 2], that require the transfer of knowledge among different fields of application;
- non-typical problems [3, 4], whereas the support of standard methodologies is not sufficient to carry out the problem solving task;
- complex problems [5, 6], characterized by lack of knowledge, tangled interrelations among the constituents of the system, phenomena that imply the time dependence of some relevant aspects, non-compatible goals of the design;
- ill-structured problems [7, 8] with reference to the available solution space, the constraints about the involved parameters, the convergence of the solving process.

With the growing involvement of IT support and Artificial Intelligence in the design tasks, Computer-Aided Innovation (CAI) systems are supposed to supply a consistent contribution for gaining the solution of engineering problems in a creative and effective way. Such emerging systems should therefore provide substantial inputs for overcoming the hurdles represented by the whole set of demands due to the essence of the problems and the provided information. Proper instruments have to be selected and integrated in computer applications with the aim of aiding engineers in the conceptual design stage.

Several confirmations are available in literature about the benefits of systematic methods for inventive design like TRIZ; for example, Tomiyama summarizes the positive results of using TRIZ in industrial contexts for technical problem solving [9], emphasizing the economical benefits arising from

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the implementation of the creative solutions generated with the instruments of such theory. According to the authors' vision, the benefits of TRIZ applications originate from its systematic approach, the capability to provide a holistic description of the problem space and boundaries, the ultimate goal of giving rise to inventive solutions obtained by overcoming contradictions, thus fulfilling apparently non-compatible demands. On the contrary, the most consistent limitation of TRIZ stands in the need of a severe and long lasting training to master its tools and achieve benefits by its employment [10]. Since computer and web systems are more and more widespread in each field of teaching and training, as well as with regards to each degree of education, it is expected that the diffusion of TRIZ tools would be fostered by computerized supports. In this perspective, the integration of TRIZ logic in computer applications is supposed to reach the double objective of contributing to the dissemination of the theory and outperforming the current capabilities of CAI systems. However, a thread of literature expresses strong criticism about the effectiveness of available TRIZ-based CAI tools.

As a matter of fact, the first TRIZ-based software applications appeared in the '90s has represented the birth of the CAI field [11]. Despite the long lasting development of such products, a recent review points out how commercial software integrating TRIZ show substantial limitations in new product design [12]. From a different perspective Leon argues about the effectiveness of such instruments in solving contradictions and exploiting TRIZ fundamental laws [13]. Such limitations are supposed to be dictated by the integration within software applications of just a general problem solving scheme [14], neglecting the knowledge richness and the abstraction capabilities characterizing the application of TRIZ without computer supports.

At the same time, the diffusion of TRIZ learning (outside of the former USSR) is still consistently bounded in the industrial arena [9], although positive experiments about its diffusion within Universities are witnessed, e.g. the experiences described by Cascini et al. [15, 16].

Therefore, consistent research has to be addressed with the objective of creating novel software applications capable to effectively support designers in creative problem solving and to facilitate the dissemination of TRIZ concepts for educational purposes. In such perspective, the authors have developed an algorithm [17], implemented in a dialogue based system, that systematically supports the analysis of problems arising during the design phase, by acting as a "computer coach" [18]. The system assists the user in formulating technical problems, being a physical contradiction expressed as an intensified conflict the expected output of the questioning procedure. For inventive design purposes, the focus of the algorithm is represented by those firms, especially SMEs, which cannot afford proper vocational courses to proficiently master TRIZ knowledge. By the viewpoint of fostering the education about TRIZ, Engineering students and postgraduates represent the core users of the CAI framework. According to the results illustrated in [17], the authors have started to review the dialogue-based system in order to enhance the problem analysis capabilities and to customize the workflow according to the case study specifications and the user's background. The major lacks emerging from the first experimental activity consisted in the limited effectiveness of the procedure in surveying the interrelations between the investigated systems and their surroundings and in the extreme variability of the outcomes according to the case study analyzed by the testers [19].

The present paper shows the benefits arising from the introduction of a novel dialogue module for system exploration, in order to enhance the holistic vision of the problem. As demonstrated in this paper, such measure contributes in leveraging the quality of the outputs coming out from the questioning procedure with reference to different problem situations.

The following section reviews the literature contributions dealing with the impact of broad-spectrum system thinking in the field of inventive design and creative problem solving. Section 3 describes in detail the update of the algorithm according to the objective of the paper and the issues arising in the State of the Art. The test concerning the updated dialogue-based system is illustrated in Section 4, while its main outcomes are discussed in the subsequent chapter. Section 6 draws the conclusions of the paper, focusing on the future work to be carried out.

2. Broad-spectrum thinking in design tasks: a review

Cross [20], when analyzing the common traits of experienced and successful designers from different industrial domains, highlights their capability to take "a broad systems approach to the problem", meaning the aptitude to focus on an articulated network that encompasses a large set of issues influencing the devices under investigation. On the other hand, design tasks address the need to develop engineers' capabilities in acquiring and representing contextual and integrated rather than partial visions of the systems, viable to foster innovation paths [21]. Additionally, preliminary studies identify a not negligible correlation between the correctness of problem analysis tasks performed by Master Degree students in Engineering and their individual aptitude to explore various levels and domains of the technical systems [22].

The results of the mentioned researches suggest increasing the diffusion of techniques for broad-spectrum analysis within engineering design, in order to enhance creativity and innovativeness. The wide diffusion of systems thinking, a holistic approach to support the problem solving process, has just marginally influenced the field of technical artefacts in industry. The primary scope of system thinking regards the enhancement of teaching practices with a special focus on scientific disciplines learning. Since the '80s, several experiences witness successful adoption of systems thinking approach [23], as well as studies claim the need of its integration in educational institutions [24]. More recently it has been argued about the suitability of systems thinking to face ill-structured problems, like those that are predominant in engineering design [25], thus encouraging the dissemination of the approach within technology education in a long-term perspective [26]. Additionally, the approach has resulted to be effective in identifying components and mutual interrelations, potentially providing substantial support to design in engineering disciplines, especially those characterized by manifold and tangled interconnections among products constituents [27].

Despite these considerations, as previously remarked, the methodical application of systems thinking in technical design has been so far quite limited; proficient experiments that have been carried out refer mainly to problem solving tasks in chemical engineering, as illustrated in [28]. On the contrary, the effectiveness of systems thinking has been carefully assessed within complex problem solving issues related to managerial and entrepreneurial tasks, e.g. decision making [29] and industry organization [30].

Notwithstanding, the absence of a general consensus within cognitive sciences community, insightful studies, such as [31], consider the broad thinking skills as domain-independent capabilities. According to this vision, such skills refer to the individual performances in organizing a set of mental activities in a coherent whole. Within this thread of research, the key aspect of proficient broad thinking tasks actually lies in the capability of systematically structuring ideas, issues and their interrelations [32].

The specific tools to be integrated in the proposed dialogue-based system for fostering a broader analysis of the system and consequently wider investigation of the problem have thus to be selected on the basis of the suitability in performing a structured screening. In this perspective, a chance is represented by the System Operator model of classical TRIZ [33], which organizes problem features and system resources in a hierarchical (super-system, system, sub-system) and "time" domain (past, present, future), allowing to think about an extended set of influencing factors [34] within the design task.

3. CAI framework for the analysis of inventive problems

As briefly stated in the introduction, design tasks have often to deal with fuzzy situations due to the different nature of problems. Furthermore, as claimed by Lau [35], problem formulation is a crucial task that is too often neglected by designer. Therefore, the analysis of initial situation, as described by Cavallucci et al. [36], should be properly structured in order to foster the creativity of designers, shifting fuzziness towards a well-defined context.

To this purpose, the authors have developed a TRIZ-based computer-aided framework for the analysis of non-routine "inventive" problems, whose solutions cannot be obtained with a mere optimization of design parameters [17]. In other words, the algorithm is aimed at tackling those problems characterized by the need of radically change the design so that the requirements that appear as non-mutually compatible can be satisfied without trade-offs. This framework is aimed at supporting non-expert designers and experts without specific knowledge about TRIZ in clarifying the core aspects of a problematic situation, structuring it in a shape viable to point towards the most ideal solution. The description of the former version of the algorithm, available with full details in [17], is out of the scope of present paper. Yet, the main features of the algorithm, as well as its structure, will be briefly presented in the immediate hereafter, in order to better appreciate the contribution produced by the new module aimed at broadening the problem space definition.

Among the main features of the algorithm it is worth to mention that:

- the framework is based on a human-computer interaction that relies on a written sequence of questions and answers that employs a common terminology, avoiding TRIZ jargon;
- the nodes of the algorithm are either open questions, choices or messages, intended to provide proper hints in performing the problem solving process;
- the text of questions and suggestions uptakes previously introduced terms and items;
- some examples of answers are provided, as well as their grammatical form, in order to clarify the

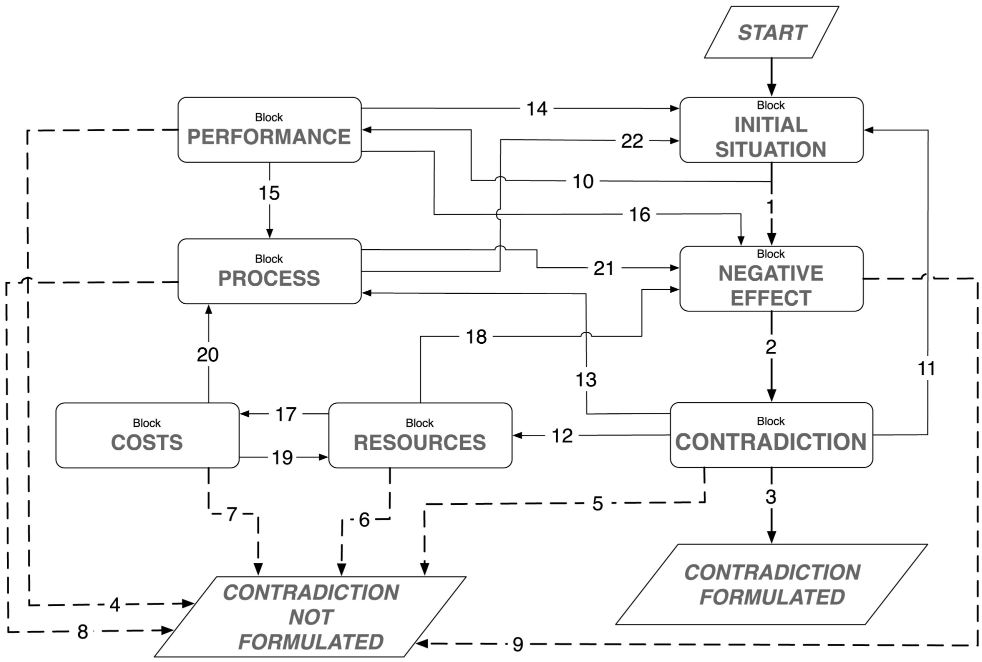

Fig. 1. The structure of the first version of the dialogue-based system for the analysis of inventive technical problems originated by the authors.

purpose of the open questions and to provide a more sound text in the downstream nodes of the algorithm;

- the questioning procedure proposes questions aimed at checking user's inputs and communication nodes for providing feedbacks about the state of the analysis.

For what concerns the framework of the algorithm (Fig. 1), it is constituted by an overall number of about 150 nodes, clustered into logical blocks aimed at examining different aspects of the technical system involved in the problematic situation. The network of links among the blocks and the single nodes of the algorithm determine an extensive bundle of paths and cycles to refine the problem formulation. In order to drive the designer in correctly describing the problematic situation, the algorithm performs a preliminary distinction among tasks concerning the presence of negative effects or drawbacks, the required implementation of new useful functions and the enhancement of performances already obtained by the system but whose achieved level is not satisfying. More in detail, whenever an undesired effect is individuated, the procedure leads the user in examining its causes and, subsequently, to the formalization of an OTSM-TRIZ contradiction [3], including two Evaluation Parameters, namely requirements that the system must satisfy, and a Control Parameter, i.e. a design variable whose opposite values satisfy just one of the requirements at a time.

The most straightforward path for formulating the contradiction, remarked in Fig. 1 with thicker lines numbered 1, 2 and 3, involves three logical blocks, intended to respectively examine the Initial Situation, to assess the presence of a Negative Effect and to identify the pair of conflicting requirements characterizing the Contradiction.

However, even when the user doesn't model the problem as the need to remove a harmful output, several different attempts can be carried out with the aim of formulating a contradiction, which is considered the most abstract model of the problem. In detail, in presence of unsatisfactory or missing functions (block Performance), the user is asked to individuate the environmental or technological barriers that prevent their satisfaction; such barriers are, in TRIZ terms, contradictions. Since the procedure is intended to both support expert and non-expert designers, the framework also has different paths to describe the problem, because lacks of knowledge might occur even within the field of expertise. Further logical blocks are aimed at investigating a wide set of features that could not be considered as drawbacks, unsatisfactory or missing functions. Such blocks support the user in pinpointing the core of elements of the problem; being them related to high costs (block Costs), to an excessive consumption of resources (block Resources), to the manufacturing process or to the delivery of a service (block Process). The sequence of questions and answers performed along these different paths have the objective of modifying user's perspective on the problem, triggering the idea that, whatever the barrier preventing the solution of a problem is, it can be seen as a drawback and then the problem can be modelled as a contradiction.

Eventually, some analysis could end without a problem model having the shape of an OTSM-TRIZ contradiction. These cases are highlighted in Fig. 1 with dotted lines. The possible reasons underlying this result are the following:

- the designer is not aware about how to modify the studied system or hasn't identified the phenomena that causes certain underperformances (line 4);
- conflicting requirements didn't emerge during the analysis or the modification of the design characteristics, in order to remove the negative effect; in other terms, it is possible to eliminate the undesired behaviour of the system, without implying the appearance of new undesired effect or the diminishment of desired performances (line 5);
- the designer hasn't succeeded to individuate a proper characterization of the undesired effect in terms of excessive amount of consumed resources (line 6), high costs (line 7) or problems having reference to any stage of the system lifecycle, whose features are influenced by the design and manufacturing/delivering process (line 8);
- the element of the technical system causing the undesired effect can be removed without any consequence or, worse, certain individuated criticalities are not considered worth to be further analyzed (line 9).

Except for the cases in which the problem gets simply solved by means of trimming or with a simple modification of a design feature, the abovementioned outcomes cannot be considered successful problem setting activities. However, the answers produced during the analysis can be exploited for searching information in available knowledge bases (e.g. patent databases).

The new block, that constitutes the original methodological contribution of this paper, is aimed at widening the problem space representation in all the situations where successful analysis hasn't been performed. From a theoretical point of view, this kind of investigation can be enhanced by the System Operator, a nine-windows model developed by G. S. Altshuller [33] and often referred as Multiscreen Schema in classical TRIZ literature. The purpose of this thinking model is to replicate the way of reasoning of a creative personality. At the same time, if used as an instrument, it helps overcoming psychological inertia, since personal aptitude, background and environmental conditions make people focus just on a limited range of directions, rather than on an overall representation of the situation.

The System Operator is conventionally represented in 9 screens (a 3 × 3 matrix) ordered according to two axes: vertical and horizontal dimensions represent, respectively, the detail level according to a spatial perspective and the dynamics according to time evolution. According to verbal reports of some TRIZ masters, the original schema in [33] was supposed to be constituted by two overlapping 3 × 3 matrices, one related to the system, the other to the anti-system (characterized by opposite features, properties etc). Besides, this potential third dimension of the model doesn't imply any positive, nor negative limitation of the authors' contribution in this paper.

In details, a talented problem solver approaches a problem by considering the system and the object receiving its Main useful function, but also the relations among system parts (subsystem), as well as its interactions with the external environment (super-system). Furthermore, each of these detail levels is considered according to a time perspective, meaning that they are examined in the time lapse in which the issue appears, but also in their past and future as well. It is worth noting that super-system/sub-system relationships and the past/future relationships are just relative concepts; in other terms, the representation of the System Operator as a nine-screen schema is just conventional, but its dimension should be arbitrarily considered extendible in any direction, as depicted in Fig. 2.

The new framework of the algorithm allows the user to deepen the analysis whenever the problem definition seems to be far from completeness, or even not correct. Therefore, its structure is slightly changed according to what is depicted in Fig. 3. The novel block embeds the logic of the System Operator: the essence of its logic is to bring the designer's

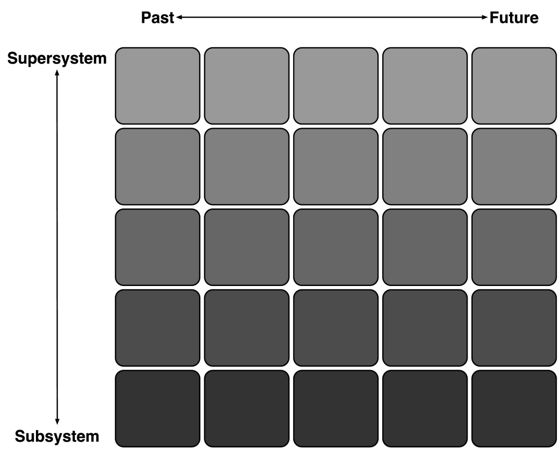

Fig. 2. The System Operator or Multi-screen Schema.

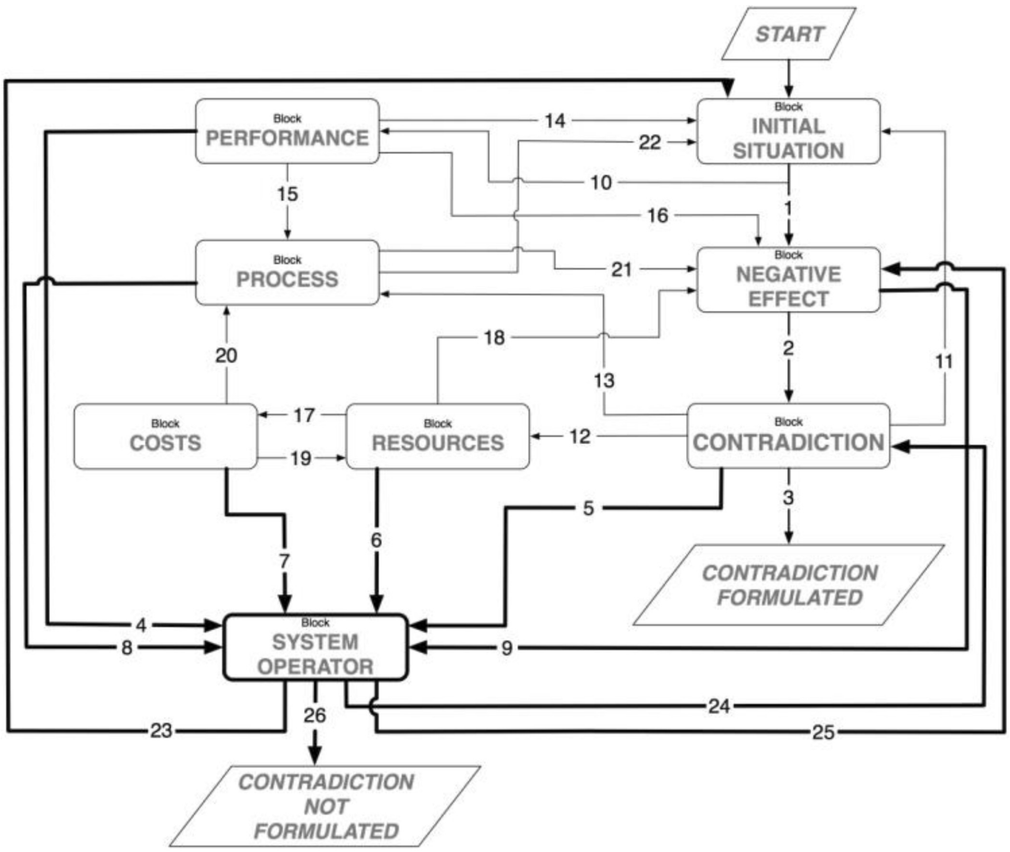

Fig. 3. The new structure of the algorithm for inventive technical problem analysis, including the logical block based on the structure of the System Operator. Thicker lines represent new elements of the algorithm (paths and logical block).

thought in front of all the windows of the multi-screen schema:

- first to define available resources, characteristics or features available in the system, as well as in its parts or in its surroundings;
- then to identify, if possible, one of the above mentioned characteristics as a means to solve the problem or to by-pass it.

The System Operator embedded into the procedure has a 3 × 3 matrix structure, since potential extensions in space and time dimensions can be considered as subsets of the main columns "Past"/"Future", as well as the main rows "Super-system"/"Sub-System".

The space dimension is examined starting from the System, then the sub-system and, at last, the super-system. The time perspective is taken into account by starting from the "Present" column in order to proficiently exploit all the answers the designer already provided during the former analysis. The boundaries of such time lapse are the beginning and the end of the main useful function delivered by the technical system under investigation. Then, the Past column is examined before the Future column in order to favour preventive directions of solution rather than ones that just mitigate the undesired effects. It is worth to notice that the time axis of the System Operator has, in principle, several complementary meanings: it can be conceived as the time flow of a process (in this case the past column refers to previous phases, while future column points to the following phases). Time can be associated also to cause-effect chains, such that past represents the root cause of a problem, the present illustrates the failure mode and the future the consequent negative effect. Eventually, the horizontal axis can be interpreted as evolutionary time, thus with different generations of the same system in adjacent columns. In this study, the first definition is chosen as the reference interpretation of the System Operator.

In order to improve the efficiency of the problem analysis process, after the analysis of each screen, the user has the faculty to skip the remaining part of System Operator investigation. Indeed, when the designer perceives that one resource can be exploited to reformulate a problem or even solve it, it is possible to directly model the problematic situation according to OTSM-TRIZ by entering the

Contradiction block (line 24) or to formulate a new problem from scratch (line 23) starting over with the analysis of the initial situation. However, at the end of System Operator exploration, some users may exit the block without a successful outcome (line 26), or continue the analysis by exploring the undesired effect; this option is suggested by the algorithm when its investigation has not been previously carried out (line 25).

The new sequence of questions proposed by the algorithm is summarized in Table 4, available in the Appendix.

This new procedure has been tested with a group of students coming from two different academic institutions; the results of such activity are presented in the following Section.

4. Testing activity: description and preliminary analysis of the results

The testing activity has been carried out with a group of Italian students attending Master Degree courses pertaining to the class of Industrial Engineering and coming from Politecnico di Milano (9) and the University of Florence (6). This group of students attended about 20 hours of TRIZ lectures, then they cannot be considered TRIZ or, at least, skilled problem solvers, since the most relevant industries using TRIZ in R&D department train their fellows with 40-hours long (basic) to 200-hours long courses (experts) [37, 38].

Furthermore, this experiment is aimed at comparing the capabilities of the new module in enhancing the problem modelling activity with reference to the previous version of the algorithm. To this purpose, the activity has been willingly carried out without a control group. Indeed, the contribution of the new module can be assessed considering what results could be reached with the two different versions of the algorithm, taking into account that the new one allows the users that end without a successful outcome to go on with the analysis by means of the System Operator block.

The problems to be analyzed by means of the algorithm have been described and proposed in English language, as follows:

Problem A: A system for applying a piece of a thin film on the surface of a glass includes a driving roller, a support roller and a vacuum system which is integrated in the device supporting the film. A non-sticking separator protects the adhesive side of the film; an appropriate device (separator mechanism) removes the protection before the film is applied on the glass. At the end of the process of application, the adhesive film cannot be supported by the vacuum system; as a result the film is free to move from its supporter and traps air bubbles when it joins the glass. These air bubbles are considered a defect. The implementation of a vacuum system within the support roller has to be rejected since its surface must have no holes for a good quality of application of the film. Furthermore, an attempt to reduce the distance between the free end of the film and the support roller has not solved the air bubble problem.

Problem B: It is required to fasten the panhandle to the main body of a frying pan. Rivets are conventionally used in order to fix the mutual position between the panhandle and the main body. However, this structure worsens the cleanliness of the main body, since food residuals usually get stuck in the joining place. Consequently, in order to enhance the cleanliness of the frying pan, the main body is fastened to the panhandle through a welding joint and a threaded joint. The main body, the panhandle, a dowel, a ring nut and a bolt

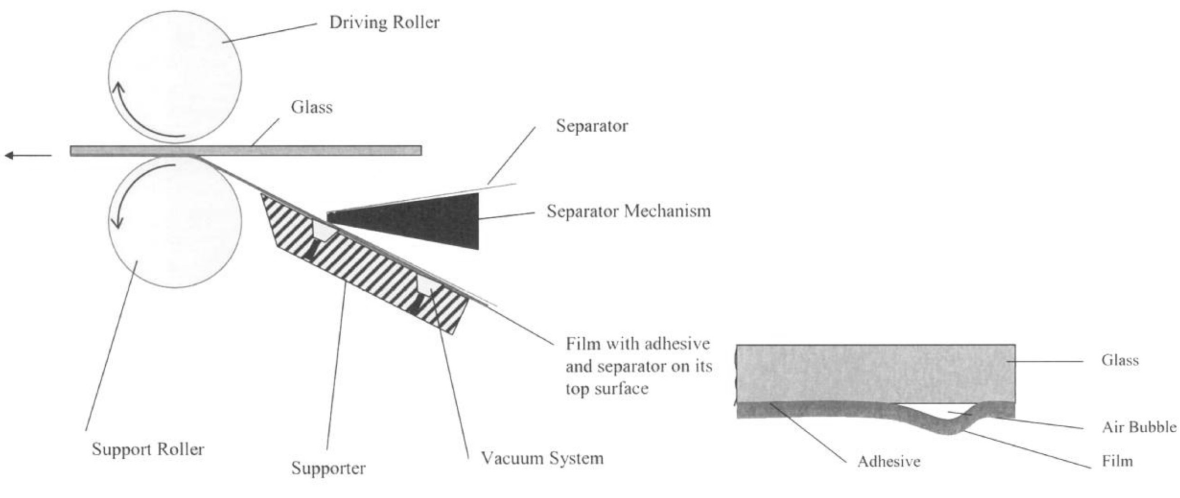

Fig. 4. Images describing how the system for glass coating works and how the problem appears.

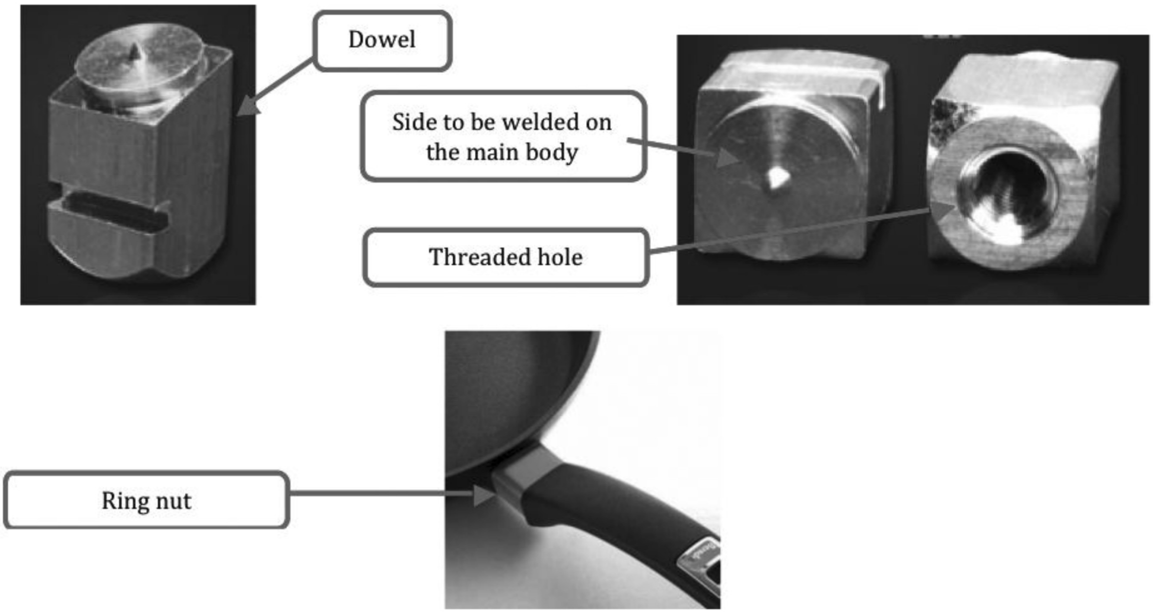

Fig. 5. Some elements of the joint composing the junction between the panhandle and the panbody.

compose the assembly. The main body and the dowel are made in aluminium while the panhandle is in Bakelite. The dowel gets externally welded to the main body, while internally has an internal screw thread. The ring nut covers the dowel and gets locked in a fixed position by means of reference ribs. The ring nut delivers two functions on the panhandle: protects it from heat and stabilize its position when the assembly is complete. The panhandle is locked from its lower part to the remaining parts by means of a bolt that is joined to the internal thread of the dowel. The threaded joint produces a small deformation in the main body when the bolt is fastened to the dowel. As time goes by, this deformation increases and the whole assembly starts to lose stability. When the frying pan is in use, it also bears the load of the food contained in the main body. This further induced deformation increases the instability and, after a while, the frying pan gets unusable because of the loosening of the panhandle.

Each student has a free personal access to a website where the algorithm has been implemented (www.smeinnovation.org) and no specific time limit for carrying out the analysis, even if they were advised that an analysis should not require more than an hour and a half, as a whole.

Among the 30 analysis tests that were carried out:

- just 3 of them (10%) didn't conclude the analysis and stopped before the conclusion;
- 10 of them (33,3%) identified a contradiction according to the OTSM-TRIZ contradiction model (an example is represented in Fig. 6);
- 12 (40%) of them solved the problem by identifying a characteristic of the system or of its surroundings without formalizing a contradiction;
- 5 (16,7%) of them stopped the analysis without deepening the investigation by means of the new System Operator block.

Then, it is possible to claim that about three quarters of the proofs resulted in a successful

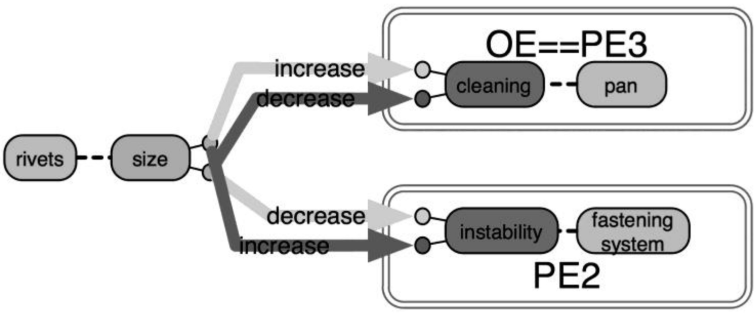

Fig. 6. problem of the frying pan: example of OTSM-TRIZ model of contradiction.

analysis of the problems by means of the procedure and just one quarter didn't come to a proper model of the problematic situation. Furthermore, it is worth noting that in 12 exercises out of 30 (40%) the students analyzed the problematic situation by means of the System Operator block and none of their analyses produced unsatisfactory results. This result, if compared to what would happen with the previous version of the algorithm, highlights that the System Operator block improves the capability of the system in producing valuable problem analyses. Indeed, without the help of this new logical block, 20 out of 30 (66,7%) students wouldn't carry out a correct problem analysis.

More in detail, in the 12 experiments that have involved the System Operator block, the students modelled the problem with a contradiction in just two cases, while in the remaining 10 cases they just identified a useful resource that can help in solving the problem without implying any further drawback for the technical system. At last, it is important to point out that none of these students chose to reformulate the problem from scratch.

With the aim of better pointing out the advantages arisen with the second version of the dialogue-based system, it is worth to mention that the previous testing activity had different purposes than these experiments, as reported in Table 1. Nevertheless, the wide body of results emerging from the first testing campaign, if examined according to a different metrics, can be compared to this second experimental activity. This allows to highlight the benefits arising by the introduction of the module for broadening the analysis of problems, which are illustrated in the following section.

5. Discussions

The results of the test point out the relevance of broad-spectrum problem investigation and, in the specific case, the contribution provided by thinking through System Operator when designing with the support of a TRIZ-based CAI system. With reference to the test performed with the previous version of the procedure [17], the rate of completed analyses, formulated contradictions and quality outcomes is significantly enhanced, although the new block is not addressed to play an equivalent role according to each single issue, as summarized in Table 2. Additionally, if compared with the outcomes recalled in [19], the topic of the analysis seems to play a significantly lower impact in determining the ratio of good results. Indeed the two exemplary case studies show the same percentages of formalized contradictions and non-inventive problem formulations; unsuccessful cases differ for the percentages of interrupted questioning procedures (13, 3% for the air-bubble formation, 6, 7% for the frying pan) and stopped analyses neglecting the System Operator blocks (13, 3% vs. 20%).

It has to be highlighted that the further employment of the new logical block occurs in those cases that no section of the dialogue-based system is capable to guide the user in performing a proper formulation, typically after few elements of the problem have been investigated. Consequently the exploitation of the System Operator branch should not imply a consistent time burden when performing the analysis with the dialogue-based system, being it preferentially accounted at the beginning of the problem analysis process. The hypothesis is confirmed by the average number of answered procedure nodes: the survey of the results indicates how, on the average, 48 nodes have been tackled when the new block is involved, 64 when the user is not directed in such investigation area. The 30 analysis tests required a different time amount without significant differences between the two problems; the overall range spans from about 45 to about 90 minutes.

Table 1. Comparison of the tests performed with the previous and the current version of the algorithm

	Previous version of the algorithm	Current version of the algorithm
Objective	Demonstrate that the algorithm improves the results of non-supported analysis of inventive problems	Demonstrate that the introduction of a module for broadening the analysis of inventive problems improves the results of computerized analyses
Metrics	• Correctness of the answers; • Amount of identified problem features; • Reusability of variables for patent searches.	• Number of formalized contradictions; • Type of problem formulation; • Quantity of concluded analyses.

Table 2. Comparison of the tests performed with the previous and the current version of the algorithm

	Test with the previous version	Test with the current version
Formalized contradictions	13%	33%
Non-inventive formulation of the problem	13%	40%
Concluded analyses	63%	73%

Further insights regard the quality of the results, not just in terms of the formal correctness of the problem schematization, but also from the viewpoint of the usability of the outcomes within real problem solving tasks. The formalized contradictions were qualitatively evaluated in terms of the explicitness of the typed parameters and elements in effectively representing conflicting issues to be overcome in order to reach an inventive solution. Students that individuated non-inventive formulations of the problems (regardless the involvement of the System Operator block) were asked to motivate why the measures they would undertake would lead to improve the system without particular negative consequences. Whereas relatively few relationships among the parameters constituting the contradictions resulted vague, a greater ratio of ideas provided according to non-inventive formulations were evaluated by the authors as partial, poorly creative, hardly feasible or however unclear solutions. An example follows of doubtful non-inventive formulations regarding both the case studies (Table 3).

The motivations provided by the students remark how, in several cases, such inaccurate problem descriptions result as a consequence of separately elaborated solutions, thus trying to force the procedure towards the embodiment of a previously conceived idea. The tendency of concentrating on solution embodiments and justifying their effectiveness results as a common behaviour of novice designers, such as those involved in the testing campaign of the dialogue-based system. The crucial stage of problem analysis typically results incomplete due to their consideration of an insufficient number of relevant issues within the design problem [39]. Kokotovich argues that inexperienced designers lack appropriate thinking tools for accurately mapping the complex interrelations among the concepts and the issues involved in the design [40].

On the basis of these considerations, it can be assessed that the developed logical block for broad-spectrum thinking has resulted very useful in identifying resources or features capable to impact on the core problem of the investigated topics, but it has just marginally influenced the solution-oriented aptitude of novice designers. From this point of view, further developments of the dialogue-based CAI system should be performed aiming at customizing the procedure according to the user experience in design tasks. Such measure should allow the questioning algorithm to consistently comply with the individual behaviour of designers with regards to their preferred orientation towards the careful analysis of the problem or rather the focus on thought solutions and their further flaws. Of course, in the second case (to be discouraged), the procedure should be capable to address in each case a comprehensive system analysis and to show alternatives and advantages with respect to previously determined ideas. In order to ease the mapping of relevant issues of technical problems, additional human-computer interactions should be experienced than the unique text communication form currently supported by the dialogue-based system (e.g. by exploiting visual representation tools). Moreover, the capability to map the complexity of the relationships of the systems should be supported through performing multi-contradiction analyses rather than highlighting single conflicts.

6. Conclusions and future activities

The encouraging results coming out of the current testing activity constitute a further evidence of the usefulness of broad thinking approach in engineering design and inventive problem solving. The outcomes provide support also for the need of improving engineering students' systems thinking capabilities, which constitute even a relevant issue of TRIZ body of knowledge. The carried out test shows the advantages of implementing broad-spectrum investigation capabilities into CAI applications in order to support problem analysis tasks. The last consideration is particularly relevant from the viewpoint of the algorithm development, given the performed integration of System Operator logic.

As a consequence of these promising results, the authors have planned to enrich the CAI framework with a module capable to exploit the answers provided during the broad-spectrum analysis, so that the user can be supported in the search for useful information in patent databases.

The considerations reported in the previous section highlight how the evolution of the tool should take into consideration measures to better support inexpert designers in the modelling of the system, avoiding solution-oriented shortcuts. This goal should be obtained through improvements of the dialogue-based system concerning both the questioning procedures and techniques to help the users

Table 3. Examples of unclear non-inventive problem formulations according to the authors' evaluation

	Modification of certain features assessed by the tester as feasible and without negative consequences
Frying pan problem	Decrease the dowel's deformation (in order to weaken the instability of the system)
Air bubble problem	Increase the power of the vacuum pump (in order to weaken the inadequate expulsion of air)

in mapping the system issues. In order to best fulfil the declared objectives, the authors are planning further testing activities involving designers from industry and academics, characterized by limited experience and/or limited knowledge about TRIZ way of thinking. The test is aimed at determining with greater precision common problem analysis patterns and recurrent mistakes according to the users' profiles. In this perspective very useful insights could be attained by performing tests with designers coming from different countries and cultural contexts. Readers interested in contributing to the performing of testing activities are welcome and are kindly invited to contact the corresponding author.

References

1. D. Cavallucci, F. Rousselot and C. Zanni, Assisting R&D activities through definition of problem mapping, *CIRP Journal of Manufacturing Science and Technology*, **1**(3), 2009, pp. 131–136.
2. M. Barak and P. Mesika, Teaching methods for inventive problem-solving in junior high school, *Thinking Skills and Creativity*, **2**(1), 2007, pp. 19–29.
3. N. Khomenko, R. De Guio and D. Cavallucci, Enhancing ECN's abilities to address inventive strategies using OTSM-TRIZ, *International Journal of Collaborative Engineering*, **1**(1–2), 2009, pp. 98–113.
4. R. Ginevičius and V. B. Ginevičienė, The compliance of master's degree studies with the economic needs of the country, *Technological and Economic Development of Economy*, **15**(1), 2009, pp. 136–153.
5. J. Funke and P. A. Frensch, Complex problem solving: The European Perspective, in *Learning to solve complex scientific problems*, Jonassen D.H. (Ed.), Lawrence Erilbaum, New York, 2007, pp. 25–47.
6. J. Quesada, W. Kintsch and E. Gomez, Complex problem-solving: a field in search of a definition?, *Theoretical Issues in Ergonomics Science*, **6**(1), 2005, pp. 5–33.
7. H. A. Simon, The structure of ill structured problems, *Artificial Intelligence*, **4**(3–4), 1973, pp. 181–201.
8. D. H. Jonassen, Instructional Design Models for Well-Structured and Ill-Structured Problem-Solving Learning Outcomes, *Educational Technology Research and Development*, **45**(1), 1997, pp. 65–94.
9. T. Tomiyama, P. Gu, Y. Jin, D. Lutters, C. Kind and F. Kimura, Design methodologies: Industrial and educational applications, *CIRP Annals—Manufacturing Technology*, **58**(2), 2009, pp. 543–565.
10. [10] I. Belski, Teaching Thinking and Problem Solving at University: A Course on TRIZ, *Creativity and Innovation Management*, **18**(2), 2009, pp. 101–108.
11. S. Hüsig and S. Kohn, Computer aided innovation—State of the art from a new product development perspective, *Computers in Industry*, **60**(8), 2009, pp. 551–562.
12. X. Y. Liu, Y. Li, P. Y. Pan and W. Q. Li, Research on computer-aided creative design platform based on creativity model, *Expert Systems with Applications*, **38**(8), 2011, pp. 9973–9990.
13. N. Leon, The future of computer-aided innovation, *Computers in Industry*, **60**(8), 2009, pp. 539–550.
14. D. Mitra, Computational Creativity: Three Generations of Research and Beyond, *Papers from the 2008 AAAI Spring Symposium*, Chicago, United States of America, 13–14 July, 2008, pp. 47–52.
15. G. Cascini, D. Regazzoni, C. Rizzi and D. Russo, . . . and suddenly students invent!, *Proceedings of the 15th International CIRP Design Seminar*, Shanghai, People's Republic of China, 22–25 May, 2005.
16. G. Cascini, D. Regazzoni, C. Rizzi and D. Russo, Enhancing the innovation capabilities of engineering students, *Proceedings of the TMCE (Tools and Methods of Competitive Engineering) 2008 Conference*, Izmir, Turkey, 21–25 April, 2008, pp. 733–742.
17. N. Becattini, Y. Borgianni, G. Cascini, F. Rotini, Model and algorithm for computer-aided inventive problem analysis, *Computer-Aided Design*, in press, 2011.
18. T. Lubart, How can computers be partners in the creative process: Classification and commentary on the Special Issue, *International Journal of Human-Computer Studies*, **63**(4–5), 2005, pp. 365–369.
19. N. Becattini, Y. Borgianni, G. Cascini, F. Rotini, Computer-Aided Problem Solving—Part 2: a Dialogue-Based System to Support the Analysis of Inventive Problems, *Proceedings of the 4th IFIP Working Conference on Computer Aided Innovation*, Strasbourg, France, 30 June–1 July, 2011, pp. 132–148.
20. N. Cross, The Expertise of exceptional designers, *Proceedings of the Expertise in Design—Design Thinking Research Symposium 6*, Sydney, Australia, 17–19 November, 2003.
21. R. Adams, D. Evangelou, L. English, A. Dias de Figueiredo, N. Mousoulides, A. L. Pawley, C. Schiefellite, R. Stevens, M. Svinicki, J. M. Trenor and D. M. Wilson, Multiple Perspectives on Engaging Future Engineers, *Journal of Engineering Education*, **100**(1), 2011, pp. 48–88.
22. Y. Borgianni, G. Cascini, F. Rotini, Preliminary studies on human approaches to inventive design tasks with a TRIZ perspective, submitted for the *11th TRIZ Future Conference*, Dublin, Ireland, 2–4 November, 2011.
23. J. P. Zuman, S. L. Weaver, Tools for Teaching Problem Solving: An Evaluation of a Modeling and Systems Thinking Approach, *Annual Meeting of the National Association for Research in Science Thinking*, Lake of the Ozarks, United States of America, 10–13 April, 1988.
24. C. Lannon-Kim, Revitalizing the Schools: A Systems Thinking Approach, *The Systems Thinker*, **2**(5), 1991, pp. 1–4.
25. T. Kelley and N. Kellam, A Theoretical Framework to Guide the Re-Engineering of Technology Education, *Journal of Technology Education*, **20**(2), 2009, pp. 37–49.
26. I. Kang, J. I. Choi and K. Chang, Constructivist Research in Educational Technology: A Retrospective View and Future Prospects, *Asia Pacific Education Review*, **8**(3), 2007, pp. 397–412.
27. R. G. Hadgraft, A. Carew, S. A. Therese and D. L. Blundell, Teaching and Assessing Systems Thinking in Engineering, *Research in Engineering Education Symposium*, Davos, Switzerland, 7–10 July, 2008.
28. C. A. Koh, Promoting Systems Thinking and Problem Solving Skills through Active Learning, *Proceedings of the 6th International CDIO Conference*, Montréal, Canada, 15–18 June, 2010.
29. K. E. Maani and V. Maharaj, Links between systems thinking and complex decision making, *System Dynamics Review*, **20**(1), 2004, pp. 21–48.
30. A. Skaržauskienė, Managing complexity: systems thinking as a catalyst of the organization performance, *Measuring Business Excellence*, **14**(4), 2010, pp. 49–64.
31. G. F. Smith, Thinking skills: the question of generality, *Journal of Curriculum Studies*, **34**(6), 2002, pp. 659–678.
32. G. Smith, Are There Domain-Specific Thinking Skills?, *Journal of Philosophy of Education*, **36**(2), 2002, pp. 207–227.
33. G. S. Altshuller, *Creativity as an Exact Science: The Theory of the Solution of Inventive Problems*, Gordon and Breach Science Publishers, New York, 1984.
34. T. L. Liu and S. T. Kuo, A Study of Applying TRIZ to Technological Patenting Deployment, *International Journal of Systematic Innovation*, **2**(1), 2011, pp. 1–8.
35. W. Lau, A Study on Professional Designers' Initial Perceptions of Design Briefs: Some Reflexions on Design Problem Formulations, *Proceedings of the International Association of Societies of Design Research Conference*, Hong Kong, People's Republic of China, 12–15 November, 2007.
36. D. Cavallucci, F. Rousselot and C. Zanni, Initial situation analysis through problem graph, *CIRP Journal of Manufacturing Science and Technology*, **2**(4), 2010, pp. 310–317.
37. R. Adunka, Lessons Learned in the Introduction of TRIZ at

Siemens A&D, *Proceedings of the 7th TRIZ Future Conference*, Frankfurt, Germany, 6–8 November, 2007, pp. 127–130.
38. J. Y. Lee, Implementing TRIZ at Samsung Electronics, *Proceedings of the Global TRIZ Conference in Korea*, Seoul, Korea, 11–13 March, 2010.
39. S. Ahmed, Encouraging Reuse of Design Knowledge: A Method to Index Knowledge, *Design Studies*, **26**(6), 2005, pp. 565–592.
40. V. Kokotovich, Problem analysis and thinking tools: an empirical study of non-hierarchical mind mapping, *Design Studies*, **29**(1), 2005, pp. 49–69.

Appendix

As mentioned at the end of Section 3, Table 4 describes the questions related to the new module that integrates the logic of the System Operator. Text in square brackets represents variables that the user assigns by answering the questions. Some variables cited in Table 2 are defined in the part of algorithm already presented in [17]. In order to allow a complete comprehension of the sequence of the questions, a brief description of these variables follows.

[SYS] is the technical system under investigation, [GPF] is the Main Useful Function it delivers and [OBJ] is the element or substance on which the technical system exerts its action. [FOTB] and [FOTE] are two instants, respectively when the system starts and when it ends working. [COMP] represents a list of parts composing the system (Sub-Systems), while [SSYS] is a list of characteristics or elements surrounding the technical system (Super-Systems). At last, [OE] represents the undesired effect to be removed and [LPVOE] is a list of parameters pertaining to the element causing the undesired effect. The cells of column "Type" may assume two values: A is for Assignment nodes, while D is for Decision nodes. Cells pertaining to the columns labelled "Next", "Yes" and "No" collect Id of destination nodes. When they are included in blocks presented in [17], the authors indicated a reference to the logical block where the node leads: CNF and NIP mean respectively "Contradiction Not Formulated" and "Non-Inventive Problem"; IS, NE and CTD respectively relate to the Initial Situation block, the Negative Effect block and the Contradiction block.Node 206 represents just an example of the nodes from which the user can skip the System Operator branch in order to reformulate the main problem (line 23 of Fig. 3) or refine the problem model according to OTSM-TRIZ contradiction model (line 24 of Fig. 3). There is a total of 9 nodes (number 206–198) that allows the user to skip the procedure, each of them shares the same formulation of node 206; the only difference stands in the variable in square brackets proposed to user's attention, according to the screen from where the analysis of the system operator gets skipped.

Table 4. Detail of the new branch of the algorithm for problem analysis. Nodes pertaining to the System Operator branch

Node Id	Text	Type	Next	Yes	No	Variab.
228	You are close to the final question, but it seems that the problem formulation is not going to result in a successful outcome. It could be worth to further detail the technical system "[SYS]" by answering a new set of questions which are viable to formulate alternative or bypass problems. Do you want to proceed with this kind of analysis?	D		227	CNF	
227	Before the investigation please confirm that the main issue concerning the [SYS] is related to the [OE]. If yes, click on the "save and continue" button; otherwise correct it and then "save and continue".	A	226			[OE]
226	You are going to start an analysis of potentially available resources within your technical system and its surroundings. During the following steps you will be asked to reformulate your original problem in order to identify a new alternative problem whose solution could be easier and fulfils the same requirements.	A	225			
225	You identified the technical system under investigation as "[SYS]" and the whole analysis has been focused on the delivery of its function "to [GPF]" during the time interval from [FOTB] to [FOTE]. Answer the following set of questions by taking into account the whole time interval in which the [SYS] is working. Type, in the blank space pertaining to SYSPR, a set of properties of the [SYS] that characterizes it when it is delivering the function "to [GPF]", regardless the influence of such properties on the delivery of the function. *Example: "Encumbrance of the [SYS], length of the [SYS], friction factor of the wheel,..."*	A	224			[SYSPR, OBJPR]

	Type, in the blank space pertaining to OBJPR, a set of properties of the [OBJ] that characterizes it when the [SYS] delivers the function "to [GPF]", regardless the influence of such properties on the delivery of the function by the [SYS]. *Example: "mean size of grains, paper color, ..."*					
224	*"What should the [SYS] or the [OBJ], or one of the below mentioned properties, [SYSPR] [OBJPR] do in order to reduce the [OE]?"* Can you mentally answer such question? If you can't, please press "No"; otherwise keep reading, since you may have an alternative problem formulation. Is the new problem formulation easier to be faced than the original one?	D		206	223	
223	You identified the technical system under investigation as "[SYS]" and the whole analysis has been focused on the delivery of its function "to [GPF]" during the time interval from [FOTB] to [FOTE]. Answer the following question by taking into account the whole time interval in which the [SYS] is working. Type, in the blank space, a set of properties of the components of the system that characterize it during the time interval after [FOTB] and before [FOTE], also specifying the component the property belong to, regardless the influence of such properties on the delivery of the function "to [GPF]". In order to help you in answering this question, this is the list of components belonging to the [SYS] you previously typed. [COMP] *Example: "maximum pressure of the coffee brewer; diameter of the feeding pipe, ..."*	A	222			[COMPPR]
222	[COMP] [COMPPR] *"What should one of the above reported items, or a combination of them,do in order that the [OE] doesn't appear or affect significantly the [SYS], one of its components or something in the immediate surroundings?"* Can you mentally answer such question? If you can't, please press "No"; otherwise keep reading, since you may have an alternative problem formulation. Is the new problem formulation easier to be faced than the original one?	D		205	221	
221	You identified the technical system under investigation as "[SYS]" and the whole analysis has been focused on the delivery of its function "to [GPF]" during the time interval from [FOTB] to [FOTE]. Answer the following set of questions by taking into account the whole time interval in which the [SYS] delivers its function. At last, you identified the following items [SSYS] as elements that surround the system. What properties characterize such elements during the time interval during the [SYS] works in order to [GPF]? Type them in the blank space, regardless the influence of such properties on the delivery of the function by the [SYS], also specifying the element the property belong to. *Example: "Speed of conveyors, voltage and frequency of electric current, ..."*	A	220			[SSYSPR]
220	[SSYS] [SSYSPR] *"What should one of the above reported items, or a combination of them, do in order that the [OE] doesn't appear or affect significantly the [SYS], one of its components or something in the immediate surroundings?"* Can you mentally answer such question? If you can't, please press "No"; otherwise keep reading, since you may have an alternative problem formulation. Is the new problem formulation easier to be faced than the original one?	D		204	219	
219	You identified the technical system under investigation as "[SYS]" and the whole analysis has been focused on the delivery of its function "[GPF]" during the time interval from [FOTB] to [FOTE].	A	218			[OBJP, SYSP]

	Answer the following set of questions by taking into account the whole time interval that comes before the instant [FOTB]. Type, in the blank space pertaining to SYSP, a set of properties of the [SYS] that characterizes it before it start to [GPF] (since it is assumed that some properties of the system may change during the delivery of its function). *Example: "Position during the transport, encumbrance of the box, . . ."* Type, in the blank space pertaining to OBJP, a set of properties of the [OBJ] that characterizes it before the [SYS] starts to [GPF]. *Example: "Roasting degree (of coffee beans), quantity of caffeine, . . ."*					
218	*"What should be done in advance, exploiting the following properties [SYSP] [OBJP] in order to prevent the [OE]?"* Can you mentally answer such question? If you can't, please press "No"; otherwise keep reading, since you may have an alternative problem formulation. Is the new problem formulation easier to be faced than the original one?	D		203	217	
217	You identified the technical system under investigation as "[SYS]" and the whole analysis has been focused on the delivery of its function "[GPF]" during the time interval from [FOTB] to [FOTE]. Answer the following set of questions by taking into account the whole time interval that comes before the instant [FOTB]. Type, in the blank space, a set of properties of the components of the system that characterize them during the time interval before [FOTB], also specifying the component the property belong to. In order to help you in answering this question this is the list of components belonging to the [SYS] you previously typed. [COMP] *Example: "Volume of the drum of the washing machine, radius of the steering wheel, height of the door of the refrigerator, ..."*	A	216			[COMPP]
216	[COMPP] *"What should be done by one of the above reported items, or a combination of them, in order that the [OE] gets prevented?"* Can you mentally answer such question? If you can't, please press "No"; otherwise keep reading, since you may have an alternative problem formulation. Is the new problem formulation easier to be faced than the original one?	D		202	215	
215	You identified the technical system under investigation as "[SYS]" and the whole analysis has been focused on the delivery of its function "[GPF]" during the time interval from [FOTB] to [FOTE]. Answer the following set of questions by taking into account the whole time interval that comes before the instant [FOTB]. At last, you identified the following items [SSYS] as elements that surround the system. What properties characterize such elements during the time interval before the [SYS] starts to [GPF]? Type them in the blank space, also specifying the element the property belong to. *Example: "air composition; direction of wind; water salinity,..."*	A	214			[SSYSP]
214	[SSYSP] *"What should be done by one of the above reported items, or a combination of them, in order that the [OE] gets prevented?"* Can you mentally answer such question? If you can't, please press "No"; otherwise keep reading, since you may have an alternative problem formulation. Is the new problem formulation easier to be faced than the original one?	D		201	213	
213	You identified the technical system under investigation as "[SYS]" and the whole analysis has been focused on the delivery of its function "[GPF]" during the time interval from [FOTB] to [FOTE]. Answer the following set of questions by taking into account the whole time interval that comes after the instant [FOTE].	A	212			[OBJF, SYSF]

	Type, in the blank space pertaining to SYSF, a set of properties of the [SYS] that characterizes it after it ends to [GPF] *Example: "Temperature of the coffee machine; shape of the ice-maker, ..."* Type, in the blank space pertaining to OBJF, a set of properties of the [OBJ] that characterizes it after the [SYS] has ended to [GPF]. *Example: "Temperature of the coffee, volume of the ice cube, ..."*					
212	[SYSF] [OBJF] *"What should the above properties should do in order to mitigate the undesired effects caused by the [OE]?"* Can you mentally answer such question? If you can't, please press "No"; otherwise keep reading, since you may have an alternative problem formulation. Is the new problem formulation easier to be faced than the original one?	D		200	211	
211	You identified the technical system under investigation as "[SYS]" and the whole analysis has been focused on the delivery of its function "[GPF]" during the time interval from [FOTB] to [FOTE]. Answer the following set of questions by taking into account the whole time interval that comes after the instant [FOTE]. Type, in the blank space, a set of properties of the components of the system that characterize them during the time interval after [FOTE], also specifying the component the property belong to. In order to help you in answering this question this is the list of components belonging to the [SYS] you previously typed. [COMP] *Examples: "thickness of the table top, stiffness of table top, flow ratio of the pump, number of holes in pump inlet,..."*	A	210			[COMPF]
210	[COMPF] *"What should one of the above reported items, or a combination of them, do after the [OE] in order that its/their effects become negligible"?* Can you mentally answer such question? If you can't, please press "No"; otherwise keep reading, since you may have an alternative problem formulation. Is the new problem formulation easier to be faced than the original one?	D		199	209	
209	You identified the technical system under investigation as "[SYS]" and the whole analysis has been focused on the delivery of its function "[GPF]" during the time interval from [FOTB] to [FOTE]. Answer the following set of questions by taking into account the whole time interval that comes after the instant [FOTE]. At last, you identified the following items [SSYS] as elements that surround the system. What properties characterize such elements during the time interval after the [SYS] ends to [GPF]? Type them in the blank space, also specifying the element the property belong to. *Example: "density of the air; temperature of the environment, viscosity of water, noise level ..."*	A	208			[SSYSF]
208	[SSYSF] *"What should one of the above reported items, or a combination of them, do after the [OE] in order that its/their effects become negligible"?* Can you mentally answer such question? If you can't, please press "No"; otherwise keep reading, since you may have an alternative problem formulation. Is the new problem formulation easier to be faced than the original one?	D		198	CNF	
207	Unfortunately it seems that you didn't identify any formulation of alternative problems that may result easier to be solved. Is the following list empty? [LPVOE]	D		NE	CNF	

206 (198)	It seems that you find some useful inspiration among the below mentioned resources in order to solve or to formulate an alternative problem. You are now kindly asked to specify what is the resource you just identified among. [SYSPR] [OBJPR]. Please write, in the blank space pertaining to PVOE, the property you want to exploit in order to reduce the [OE] and in the blank space pertaining to VOE the element it belongs to. (Example: PVOE = diameter; VOE = ball; PVOE = speed; VOE = pump; ...)	A	197			[PVOE, VOE]
197	Do you think that the [PVOE] of the [VOE] may positively impact on the [OE]? If you think so, please click on the "yes" button and you will be directed to a path that may help you in deepening the problem analysis and finding some useful solutions. Otherwise, if you think it's worth to formulate a new alternative problem, click on the "no" button and you will be supported in its new analysis	D		196	IS	
196	If you properly modify the [PVOE] of the [VOE] in order to, at least, reduce the effects of the [OE], this results in the worsening of some useful effects already delivered by the [SYS] or by one of the following elements? [COMP]	D		CTD	195	
195	It seems that the [PVOE] of the [VOE] is an appropriate resource capable to solve the original problem, since its modification doesn't imply any worsening in the functioning or in the structure of the [SYS]. Does the required modification of [PVOE] somehow negatively impact on the following elements? [SSYS]	D		CTD	194	
194	Since the [PVOE] of the [VOE] can be properly modified in order to remove or limit the [OE] without worsening any useful effect, being it functional or structural, you may have a powerful direction of solution for your problem. Do you want to investigate further negative effects pertaining to the [SYS]?	D		NE	NIP	

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