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Abstract. Initial Analysis is one of the most important phases of Inventive Design, where designers apply the existing methods to formulate a problem. One of these methods is problem graph, which is a powerful tool to translate the knowledge, collected from available documents and data, into a graphical model. However, this graph, by considering today's competitive world, does not have the agility to present the essential information for applying in the next phase of Inventive Design. The aim of this article is to introduce a new method, which makes a designer able to formulate an appropriate problem, according to the objectives, without wasting time. This method, along with TRIZ, could create an agile design process. An example is done to illustrate better the process.

Keywords: Initial analysis · Complex problem · Inventive design · Problem graph · Root contradiction analysis · Root causes analysis.

1 Introduction

Problem formulation, in the Initial Analysis phase of inventive design, has the greatest impact on the success of a company [2]. For this reason, the companies look for continuously good methods to formulate the problems. Among these methods, Problem Graph, Root Conflict Analysis play an important role, because they can illustrate the contradictions,which are inventive problems resulting from the conflict of the desired characteristics within a product life-cycle management (PLM) [14]. Theory of inventive problem solving or TRIZ provides the essential tools in the next phases of inventive design to solve these contradictions.The contradictions could be engendered by considering different phases of product life-cycle. Furthermore, our work provides the fist data in the first phase of the PLM.In TRIZ-based inventive design processes, the designers analyze the problem situation, and to solve it, they need to formulate the problems in the form of contradiction. However, the current methods, applied in the Initial Analysis phase, do not have suitable agility to respond to today's market requirements. Therefore, we needed a methodology, which could help to decrease the time consuming of the existing methods. This methodology is called Lean, and in our first article, we propose to apply it to Inventive Design Methodology. The proposed method in this article is the result of this application [12].

Lean theory was introduced in the early 1950s by Toyota Company to maximize value, decrease time, and reduce cost [7]. This theory provides tools and principles to eliminate non-value-adding activities within a process to achieve excellence.

In our research, we integrated the best features of Problem Graph, RCA + into a new method. In addition, we apply Lean principles to this method, in order to introduce an agile and effective tool for initial analysis. This proposed method is able also to combine the proposed solutions to solve the contradiction with Initial Analysis phase of inventive design. This paper introduces this lean-based method to the readers. Furthermore, it discusses the differences, which distinguish it from other existing methods.2 This paper is organized into five sections. In section 2, we present the state of art of the existing methods for formulating problems and analyzing the initial situation of inventive. Section 3 presents the steps of our proposition (Inverse Problem Graph). We present the discussion in the section 4, and the paper finishes by the conclusion in section 5.

2 Literature Review

2.1 Existing Methods for Formulating a Problem in Initial Situation Analysis:

Initial Analysis in inventive design is a phase to collect known knowledge, which comes from a) patent and company's internal documents, b) tacit know-how of expert, c) existing data related to a subject [6] [8] [27] [5].In the following, designers apply a wide range of methods to formulate problems. According to the state of the art, these existing methods for analyzing problems in innovation projects could be divided into two groups, first methods based on searching for causes, and second methods based on looking for the effects.

The first group related to those methods and techniques, which are applied to identify the causes creating the problems in an innovation project. It is possible to assign the available methods in this group into the two following categories. The first category includes the methods without the ability to demonstrate the contradiction and the second one related to the methods with the ability to show the conflicts. In the following, we describe the limitations related to the existing methods in each category.

A designer, by applying the existing methods in the first category, could search for the causes of a negative effect. However, these methods could not illustrate contradictions. In this category, we could find methods such as "Ishikawa", "5 Whys", and "CauseEffect Chain Analysis".

K.Ishikawa introduced "Cause and Effect" which merges mind Map and brainstorming, in order to explore the causes of the initial problem [19].The designers, by applying this method, could classify the explored causes into the category, which makes them able to identify the areas where information should be collected for further study [26] [15].However, this method does not show the way of translating the discovered causes into contradictions [9]. In addition, it would be stopped in high-level of causes, and it could not demonstrate the causes at lower levels.

The "5 Whys", classical Root Cause Analysis, is a question-asking method, which is applied to find the cause and effect relationships related to a particular problem[11]. The process of "5 Whys" starts with writing down a specific problem. Then, the designer should search for the reasons of the problems by asking the "Why" question and finding its answers. This asking-answering should be repeated until the identification of the root cause of the specific problem[11]. The application of the "5 Whys" method is easy to determine some causes of a specific problem[11]. Nevertheless, this method could not show the contradictions. Furthermore, it has a shortage to demonstrate the root causes related to a problem, and designers could not sometimes give answers to all "Why" question [11] [20].

The "Cause-Effect Chain Analysis (CECA)" method has been successfully applied in many consulting projects of GEN3's Partners for developing new products [20] [1]. This method is started with a selected problem, written in a box on top of the diagram. Then, the designers identify its underlying causes by asking, "What causes that problem?", and link them to the top problem [28]. "CECA" could reveal hidden causes of a target problem, which leads designers to more ideal solutions [26] [15] [28]. However, the shortage of revealing the contradictions still remains with this method. Accordingly, the designers, especially those who look for an innovative solution for their problems, need the existing methods in the second category, such as the method "RCA+".

The second category related to those methods with the ability to illustrate the contradictions. Among them, there are "Root Conflict Analysis", "Cause-Effect Chain Analysis Plus", which are described in the following. Because in inventive design, we need to overcome the contradiction in a complex problem. Our concentrate is on this category.

Root Conflict Analysis (RCA+), Fig. 1, eliminates difficulties in the extraction of contradictions [9] [22] [24].Its process starts with a general expression by a statement of a negative effect [21].Designers apply "What is a cause?" question to discover the related causes of the general problem [1] [28]. The subsequent cause in the answer to "what" question could have a negative effect, and so forth. If the identified cause leads also to a positive cause, it is verified as a conflict in the RCA(+) diagram. Once the found cause, it has just a negative effect, the chain of the cause will be explored downward until an over-control or a conflict appears. [22]. Once the first chain has been completed, the process should be done for other negative effects in the diagram until all causes have been explored [11].However, a designer, by applying "RCA+", should create all the chains of causes in the Initial Analysis phase of inventive design, which takes a long time, without paying attention to their utility in the solution step. Additionally, this method did not merge the solution part into its main structure.

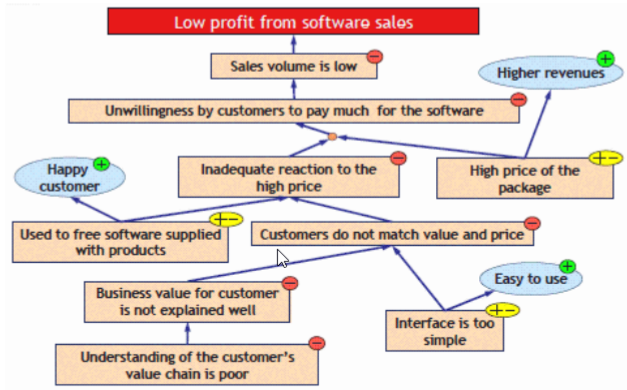

Fig. 1. A project, which applied Root Conflict Analysis to formulate problem [23]

The Cause-Effect Chain Analysis Plus has been introduced by Lee et al. [20]. This method has a development trend quite similar to "RCA+". In fact, designers choose a general problem and put it on the top of the diagram. Then, they start to create the chains of causes related to the first problem until they receive the cause with positive and negative effects in each chain, Fig. 2.This method could demonstrate the contradictions and add to solve them. However, loss of time for creating unusable chains of causes, like other discussed methods in this category, has been ignored. Furthermore, this proposed method cannot show the solutions, which could partially solve the negative effect. This drawback has been solved in the proposed methods in the second group.

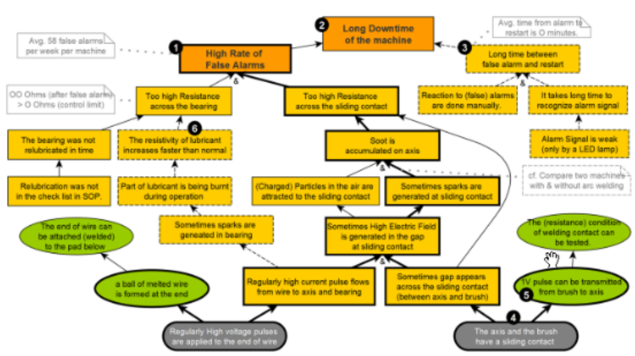

Fig. 2. Part of a Cause-Effect Chain Analysis Plus done for a project[20]

The second group is related to those techniques, which they are looking for the effects of the initial problems. In this group, we could find Network of Problems (NoP), and Problem Graph, which is an improved version of NoP.

Nikolai Khomenko developed the NoP in the framework of OTSM-TRIZ theory to decompose an overall problem to a set of sub-problems, which are easier to solve [10] [4] [3].The network of problems can be defined as a graph, which includes nodes of problems, partial solutions or goals ,Fig 3. This graph is an illustration of the problem situation, which is derived from the collection and analysis of existing information of the initial situation. Its analysis could highlight a series of key problems of the whole problematic situation [17] [18]. These key problems, which created the bottlenecks in the system, should be extracted. A series of contradictions are hidden in these bottlenecks, which are applied to construct the network of contradiction.However, The original version of NoP did not propose a clear definition for the nodes, problem and partial solution, forming its structure [4]. Additionally, a problem, which is considered a supper problem, is most of the time too general. This makes the network of problems in many cases too large and complex for designers. For solving drawbacks related to NoP, Problem Graph was proposed to solve some of them.

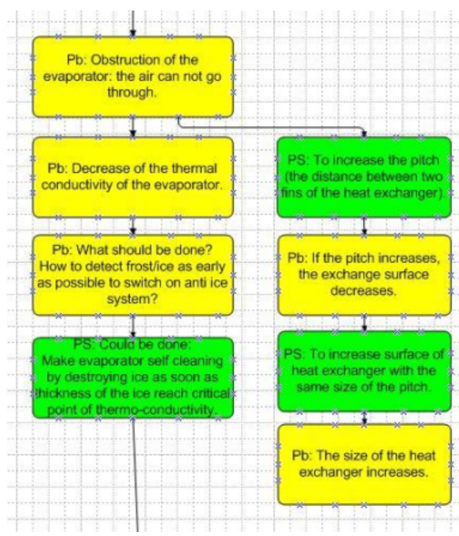

Fig. 3. Part of a NoP [16]

D.Cavallucci proposes Problem Graph by improving the original version of NoP. This graph also, like NoP, demonstrates a connection between a large set of problems and partial solutions, which are resulted from the main problem [19] [13] [25]. The process of problem graph's construction is like NoP. This process starts with a problem, which is the most critical for team members. Then, it is time to discover the immediate effect of the problem, which could be another problem or a partial solution, by asking the question "What is the effect of the problem?" and "What could initially solve this problem?". When a problem, results in an implementation of a partial solution to solve some of its aspects, a link between problem space and partial solution space has been created. A partial solution, which gives birth to a new problem, creates a relationship between partial solutions space and problem space. When a problem is resulted by another problem, a chain of interdependent problems has been created, Fig. 4. After creating a network of problems and partial solutions, the related parameters, including evaluation parameters and action parameters, should be extracted. These parameters are applied in the formulation of contradictions. Besides, they could connect the graph to the solution concept in TRIZ.

Fig. 4. Application of problem graph to formulate problem [25]

As we considered in the most important methods, which they can formulate the complex problems in the Initial Analysis step of inventive design, all of them did not pay attention to the usability of the created chains of causes and effects in the Solution step. Additionally, the amount of time that designers should assign to collect the information at the beginning of the project, without thinking if they are useful to receive the final solution or not. As a result, it was necessary to apply Lean to improve the agility and effectiveness of the process. Result of this application, it was a new agile method to formulate the problems. In the next section, we introduce this method.

3 Proposed Method: Inverse Problem Graph

3.1 Notions of Components of Inverse Problem Graph (IPG)

The Inverse Problems Graph is constructed with the following types of entities, which are shown graphically in Fig.8:

1. Problem: In Inverse Problem Graph, a problem is a sentence, which describes a barrier, which prevents the achievement of what has to be done. There are 5 types of problems in IPG :
   (a) Initial problem: a problem that has been defined according to the objective of the project, and it is placed in the first level of the graph.
   (b) Harmful problem: A problem with harmfulness for the system.
   (c) Source of partial solution: A problem with harmfulness leading to the partial solution.
   (d) Harmful-useful problem: A problem with Harmfulness and Usefulness for the system (Problem with convertibility to partial solution).
   (e) Out-of-capacity problem
2. Partial solution: A phrase, which expresses knowledge of designers or members of the design team about a registered patent by the company or its rival and their experience.
3. Parameters: the existing parameters in IPG's structure are divided in two groups:
   (a) Evaluation parameters: they are the parameters, which gives to the designers the capacity of evaluating their design choice.
   (b) Action parameters: their nature lies in the capacity of state modification.
4. Level: the level precise the location of the problem and partial solution in the IPG, by considering initial problem.
5. Iteration: Number of entry to IPG, in order to choose a contradiction. This notion has been added to the structure of the proposed method, that we should create a flow of information.

3.2 Process of Inverse Problem Graph

In this section we present the steps of our methods using a case study of Food-Storage-Box design. For confidentiality reason we cannot explain more in detail this study.

1. Step1: Define the objective of the project: At the beginning, the objective of the project should be defined. For example, a Food-Storage-Box has been designed to store vegetables and fruits, but this product does not have the ability to help to save the stored material for a long time without using cooling electrical energy. The problem here is the short life of vegetables and fruits in the interior of Food-Storage-Box and the objective, as Fig. 5 shows, is to increase the life of them in the interior space of the box.

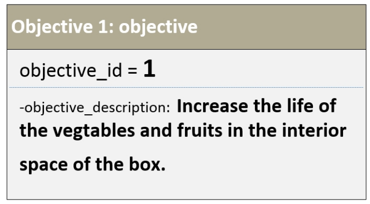

Fig. 5. Definition of objective in the example

2. Step 2: Write the initial problem of Inverse Problem Graph (IPG): Write the initial problem by considering the objective of the project in the first step of Inverse Problem Graph. In our example, the initial problem is “the vegetables have a short life in Food-Storage-Box”.
3. Step 3: Find related problems to initial problems: In order to find all the problems and partial solutions , it should be asked “what in the Selected-Level cause the initial problem?” “This problem is the effect of what in the Next-level of graph, Fig. 6.

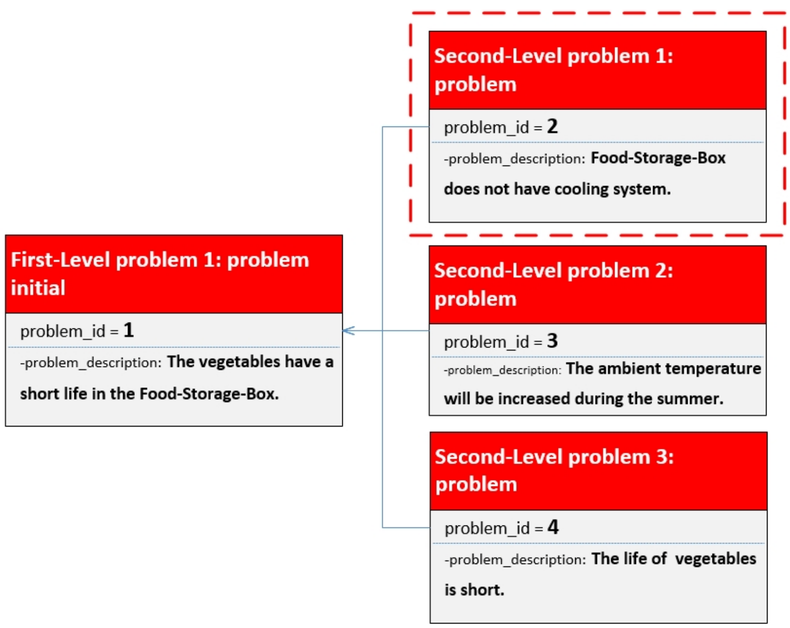

Fig. 6. Selection of the most important problem in the example

4. Step 4: Determine the type of the selected problem: For each second-level problem it should be identified, as a Harmful-Useful problem, or as a Harmful problem. This step includes the following sub-steps:
   (a) The Harmful-Useful problem should be converted to a partial solution. For ex-ample, the problem "Food-Storage-Box does not have a cooling system" has usefulness for the system, which could reduce electricity consumption for the customer. Fig. 7 shows this conversion in our example.For this type of problems, we :

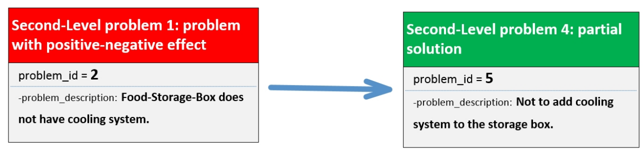

Fig. 7. Conversion of the problem to partial solution in the example

      i. Determine the source of the contradiction by asking the question "What problem in the Next-level of graph cause this partial solution?" "This partial solution is the effect of which problems in the Next-level of graph?". The result of this sub-step determines the source of contradiction.
      ii. Determine the cause of the source of the contradiction by asking this question "What problem in the Next-level of graph cause the source of the question?". This step might be done, if a designer needs to explore the root conflicts of the source of contradiction after evaluating the concept.
   (b) For a Harmful problem, it needs to ask this question "What problem in the Next-level of graph causes this problem?" "This problem is the effect of which problems in the Next-level of the graph?", Fig. 8.
5. Step 5: Extract the illustrated contradiction from the graph: extract the contradiction of the most important problem to solve. We should consider that in each iteration designer can select just one contradiction to receive to a flow of information. Fig. 9 shows our extracted contradiction in our example.
6. Step 6: Allocate appropriate parameters: For the problems and partial solution in the selected contradiction, allocate the appropriate evaluation parameter, and the appropriate action parameter. In our example and for the first iteration, we created the allocation in Fig. 10.

4 Discussion

In order to make readers of this article more aware of the difference between Inverse Problem Graph and Network of Problem, it was necessary to visualize this difference, as Fig. 11 shows.

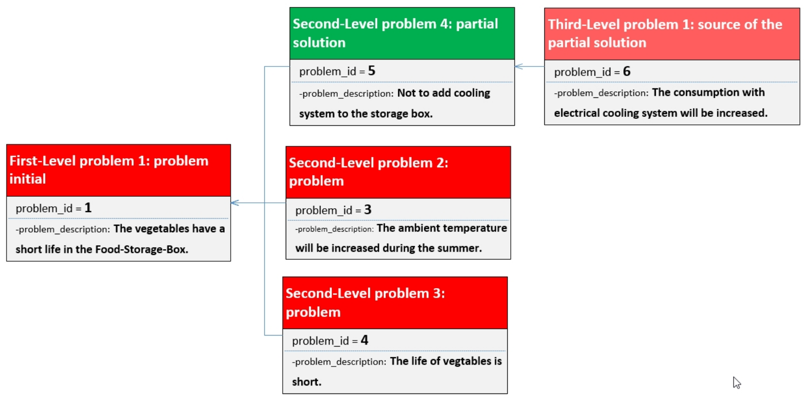

Fig. 8. Inverse Problem Graph of the example in the first iteration

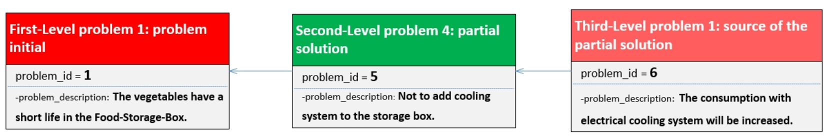

Fig. 9. Extraction of the contradiction in the example

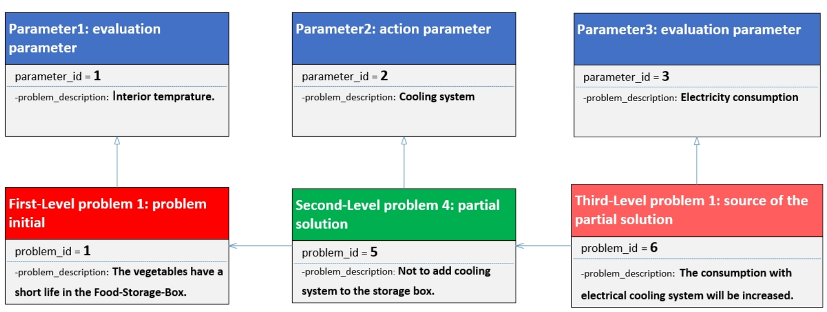

Fig. 10. Allocation of the parameters in the example

To verify the applicability and the advantage of our proposition, it is necessary to compare it with the discussed methods in the state of art section. The Table 1 shows a comparison between the reviewed methods in the literature and our proposed method. This comparison is built on the following criteria : contradiction structure, time agility of the process, and ability.

The contribution of this work to inventive design process is reflected on a number of aspects. First, our proposed method could reveal hidden root causes, as well as illustrate contradictions. Second, it could improve readability of the created chains by added iteration notion. As the third important contribution, our work could increase the agility of inventive design of process. Unlike other existing methods to formulate problems, we do not develop all chains at the beginning of the project. Instead, we start from a chain, which is more important for the designers. In the following, we develop the chains according to the needs in the solution step.

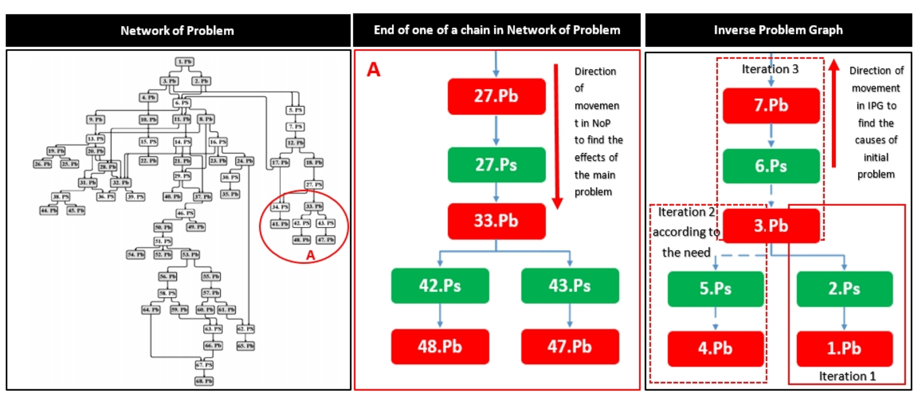

Fig. 11. Network of Problem and its difference with Inverse Problem Graph[18]

Table 1. Comparison of the existing methods of initial analysis phase with Inverse Problem Graph

Criteria	RCA+	CECA+	Problem Graph and Network of Problem	Inverse Problem Graph
Contradiction	The effects of a positive-negative problem help to illustrate the contradictions.	The effects of a positive-negative problem help to illustrate the contradictions.	The contradiction is between the effect and the cause of a partial solution.	The contradiction is between the effect and the cause of a partial solution.
Development of the chains of causes and contradictions	Regardless of the need in concept solution step.	Regardless of the need in concept solution step.	Regardless of the need in concept solution step.	Considering the needs in concept step.
Time spending of the methodology	Significant to collect all information.	Significant to collect all information.	Significant to collect all information.	Short because we collect only required information for an iteration.
Agility of the process to introduce a contradiction to other stages of ID	Need to complete the initial analysis process.	Need to complete the initial analysis process.	Need to complete the initial analysis process.	A designer can start other steps of ID after finding the contradiction related to the most important problem.

5 Conclusion

In this research, we analyzed the existing methods to formulate problems. We concluded that all the analyzed methods ignored time spent to collect useless information. Accordingly, we integrated the best characteristics of analyzed methods into a new method called Inverse Problem Graph. Besides, we applied Lean principles to this proposed method to increase its agility. Finally, we compared this proposed method with the methods with the ability of illustrating the contradictions.

Further investigations are necessary in order to appreciate the proposed method and its application. One of the future investigations focuses on combining this proposed method in a process that, along with TRIZ tools, could connect faster the extracted contradiction in the initial analysis phase to the solution phase. This new process is called "Agile Inventive Design Process".

The other investigation focuses on developing a software that, with the help of machine learning, could facilitate finding the innovative solutions.

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