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Foreword

Rapid development of high technology has changed the way people think about solving the daily problem. One business man used to tell me that it takes less than one thousand NTD to fly a toy helicopter with remote control, why then we cannot develop a household semi-automatic strapping machine with less than 5,000 NTD. The psychological inertia hinders us to think it is possible to achieve the bold statement is that when people think about semi-automatic strapping machine, they think about motor, an expensive part, to drive the strapping operations. Only tap into the current development of electrical engineering, could one solve the problem with cheap driving source. There is no need to make a durable semi-automatic strapping machine, because it is designed to be a consumer appliance in the household garage. The average life cycle of such a product is about two years. As long as the strapping machine does the job in the two years, it is worthy. Here is a paradigm shift. Semi-automatic strapping machine used to be a tool in the factory for strapping parcel of newspaper and magazine and the like. It takes over 10,000 NTD to have one strapping machine. The demand quantity is low too, since it is durable and people use it for over ten years. However, when it shifts from factory use tool to household appliance, the demand quantity soars up, which induces low price to purchase it.

We want to share the story above to stimulate our audience to think with TRIZ mind to solve our daily challenge. Theory has to union with the reality, thereby rubber meets the road. It is our hope that more industrial cases will be presented in the IJoSI. Through the real world case study, it helps us re-focus what we learn in systematic innovation realm. New theory will be created in the new problem, whereby the new theory can be used to solve other problem. We are happy to announce the issue of the number 4 issue of Volume 1. Four papers are carefully reviewed under the Journal's regular publication guidelines. As usual, all the papers are then subject to rigorous peer-review process. And, team efforts contribute the complete publication of this issue. Thanks to the reviewers, the authors, and the committee for their relentless help. And you will find these papers interesting and useful to your personal application.

Finally, you are cordially invited to submit your original papers to IJoSI electronically through the website at http://www.IJoSI.org. Any feedback or question, please send email to editor@systematic-innovation.org.

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Resolution of Inventive Problems: Different Kind of Mechanisms

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ABSTRACT

The difference between inventive problems and optimization ones is defined in this article. There exist among the engineering practices different kind of tools and methods aiming at designing, but which are not specified for the same nature of problem. It is thus relevant to be able to recognize the two kinds of problems: optimization ones, for which a solution can be found by adjustment of the value of problem parameters; and inventive problems, for which no solution is known. If no solution is known, either a solution exists and has to be found, it means that it has not been formulated the right way; either no solution exists and it is required to use a method to invent a solution. For these two cases, the matter is the problem, as it is modeled has to be reformulated, the model has to be changed, in order to build a representation enabling the resolution of the problem. The article will be focused on the question of problem model change and will compare the mechanisms to change this model for inventive problems from two problem solving theories: dialectical methods and models, on the one hand; and constraint satisfaction problem (CSP), on the other hand.

Keywords: Dialectical methods, Optimization, Over-constrained problems, Problem model.

1. Introduction

The objective of our research work is to find a solution to design problems by browsing a design problem space. This problem space is defined in (Goel and Pirolli, 1992) in terms of states of problem solving, operators that move the problem solving from one state to another, and evaluation functions. We try to analyze how different solving methods explore the problem space, which operators are used for and where an adequate solution to the design problem appears in the problem space. Two kinds of design problems are suggested. The first one can be solved by optimization solving methods when adjustment of values of problem parameters gives an optimal solution (non-creative design). The second one requires some creativity for its solution. The optimization algorithms browse a space of potential solutions which is nevertheless limited by the stated problem space. If no solution is found the classical optimization algorithms are not able to explore the solution space behind. In this case inventive solving theory TRIZ proposes methods to change the stated problem model and therefore to define a new problem space.

The creative design problems were identified as ill-defined or ill-structured by (Reitman, 1964). It means that the start state of presented for both methods. In the previous work (Dubois et al., 2008), a comparatory analysis of Constraint Satisfaction Problem (CSP) issued from optimization methods and dialectical methods and tools issued from inventive solving theory TRIZ were presented. Our goal is to find a new unified solving approach based on matching of both solving methods. This unified approach will permit to overcome limits of each individual method and to benefit from their advantages. Using the optimization methods or even evolutionary computation in design domain is not a new practice. An extensive state of the art of evolutionary computation and optimization methods used in structural design is presented in (Kicinger et al., 2005).

TRIZ (Altshuller, 1988) is a theory for inventive problem resolution based on dialectical representation of problems. One among the main approaches of TRIZ for problem resolution is to use contradictions as a way to formulate problems and analyze this contradiction in order to solve the problem. A Generalized model of Contradiction has been proposed (Dubois et al., 2009a) to state inventive problems, whatever the domain of problem could be. A problem, in accordance with the generalized contradiction model, will be characterized by:

problem solving is not completely specified, the goal state could be changed or reformulated in time and the transformation function is completely unspecified. In general, there is often very little information about design problem which means problem solving requires a lot of structuring (Restrepo and Christiaans, 2003). Problem structuring is a process of drawing external information to compensate for missing information and using it to construct the problem space (Simon, 1973). It begins with an interpretation of the problem situation – definition of problem parameters and functions. Then it follows with generation of design requirements and constraints. These are used to specify the design assignment (defining the problem space) and to describe and explore aspects of the desired solution (exploring the solution space).

The goal of the present study is to compare two solving principles – optimization and inventive one – from the design problem resolution's point of view. Definition of problem space and browsing of the solution space is

- a set of evaluation parameters, which represent the objective of the problem resolution;
- a set of action parameters, which are the resources to resolve the problem, i.e. to satisfy the evaluation parameters;
- a set of relations between the evaluation parameters and the action parameters.

One of the main interests of TRIZ is to propose principles to separate the contradictory properties of a situation, and thus to solve problems.
Constraint satisfaction problem is defined as (Freuder and Wallace, 1992):

- a set of variables;
- for each variable, a finite set of possible values (its domain);
- and a set of constraints restricting the values that the variables can simultaneously take.

The solution of a constraint satisfaction problem is an assignment of a value from its domain to every variable, in such a way that all constraints are satisfied. Such systems, where it is not possible to find valuation satisfying all the constraints, are called over-constrained. There exist different algorithms to look for a solution for CSP and over-constrained CSP.

The objective of this article is to define the kind of model change that is operated by CSP resolution mechanism and also that the TRIZ principles lead to the building of a model that cannot be obtained with CSP algorithms. When a contradiction occurs in a problem, it means that two properties that cannot be satisfied simultaneously in the initial model of problem are identified. To be able to solve such a problem a new model of the problem has to be built in which the two properties can be both satisfied. What kinds of model changes are operated by the TRIZ principles to build such a model? In the article (Rasovska *et al.*, 2009a) the different spaces browsed by the mechanisms of model change have been defined. In the present article the mechanisms to define and to browse these spaces will be illustrated. Different spaces defined in (Rasovska *et al.*, 2009b) to illustrate the way problem solving principles enable to look for new solutions. These spaces (specific problem space, problem space and solution space) will also be reminded in the article.

2. What is a problem

In this part, the nature of problem will be defined in order to be able to distinguish different kind of situations and to recognize the ones tackled in this article.

Problem solving is a common activity for a lot of domains, and its crucial role in design is particularly recognized (Simon, 1987). Problem solving cannot be distinguished from problem formulation. Indeed a good formulation of a problem nearly means solving it. But what does it mean "a well formulated problem"? This supposes that some problems are not well formulated or are not real problems, so what is a real problem? The different kind of answers to this questions arise heterogeneous ways to tackle the concept of problem, of its formulation and thus of the way to manage its resolution process (Dorst, 1997). The concept of problem is directly linked to the nature of the considered knowledge. Thus, in the domain of problem solving for technical systems design, it is important to clarify the kind of knowledge relevant for the resolution.

Several dimensions characterize the resolution of problem in technical systems design. (Bonnardel, 2000) presents the design problems as being open-ended and ill-defined. Design problems are considered open-ended as they do not have one single solution but a set of possible ones. The solution synthesis is thus the result of the choice of one solution among several ones. Moreover the problem is considered ill-defined as the initial formulation of the problem is not exhaustive and do not enable the direct synthesis of a solution. The information bordering the problem to be solved is collected throughout the trials to solve it. These notions of open-ended and ill-defined problems can be matched with the one of structured problem as defined in (Simon, 1973). Indeed, the whole set of solutions being unknown a priori, and the desired solution being defined step by step justifies to consider design problems as ill-structured ones.

As the problem resolution aims at well formulating the problem, it means that it is necessary to make evolve the first understanding of the problem, the first model of the problem. In the next part a problematic situation will be described, this problem will be used to illustrate the way an initial model of problem could be changed in order to go to its resolution.

2.1 Synthesis of problem models

The problem representation model of CSP is based on a set of variables that can represent physical parameters of the system and on the variables domains defining the possible values of the variables. Further more the CSP representation model introduces a set of constraints restricting the values that variables can take simultaneously. The constraints describe relations between the variables of the system; i.e. these relations can illustrate conditions in which the system can operate, given objectives of system functions or

relations between physical parameters. A solution in CSP is an assignment of a value from its domain to every variable such that all the constraints are satisfied all together. In the case of inventive problems where no solution is found and which are called over-constrained problems in CSP, solving methods try to minimize the number of not satisfied constraints. The research space of solving methods in CSP is characterized by a set of assignments of all problem variables without verification of constraints satisfaction. The solution space of CSP is then a set of assignments of all variables which satisfy all constraints or in the case of over-constrained problems which satisfy a maximum of constraints (one speaks about constraints relaxing).

In TRIZ representation model two kinds of parameters are defined (action parameters and evaluation ones) with their respective values to satisfy. The action parameters with their required values describe different possible configurations of the system (physical parameters...) on which one can operate. While the evaluation parameters with their required parameters describe solution objectives (desired results...) and their satisfaction is fully required. TRIZ methods are looking for a contradiction inside the system model inherent to a problematic situation. A system of contradictions based on linking between a physical contradiction and two technical contradictions is proposed in (Khomenko, 2007). The physical contradiction reflects the impossible nature of the problem by identifying one action parameter of the system that has to be in two different states. The technical contradiction expresses the opposition between two evaluation parameters of the system. To solve the inventive problem means to eliminate these contradictions and for this the TRIZ methodology proposes different principles.

The final comparison of CSP and TRIZ model is illustrated on the Table 1. The parameters in contradictions and the variables in CSP can be matched. The main difference between CSP and TRIZ is that TRIZ differentiates evaluation and action parameters and does not permit to operate on the evaluation ones. This can be translated as a required unary constraint in CSP which has to be satisfied. The notion of binary constraint as a relation between two variables in CSP is close to the notion of technical contradiction in TRIZ. On the contrary the two strategies are different from the problem solving point of view; this will be shown in the next section.

If comparing the representation models of the different problem solving methods, one can notice that:

To model the system, TRIZ uses a set of action parameters and the possible values of these parameters, whereas CSP uses variables and the domain of these variables (unary constraints)

The links between the physical contradiction and the technical ones in TRIZ could also be match with the binary constraints in CSP model of the system.

At last, the way the objective of resolution is represented in TRIZ is based on a set of evaluation parameters and their required values, whereas in CSP it is one more time variables and the domain of these variables (unary constraints) that is used, without any differentiation between the model of the system and the model of the problem.

2.2 Synthesis of solving methods

In order to compare different solving modes and different principles of model changes in CSP and TRIZ methods, we have proposed in (Rasovska et al., 2009) the definition of problem space browsed by both methods. See Figure 1. The previous analysis of the browsed space involved definition of three distinct spaces:

- Specific Problem Space (SPS) is defined by variables (parameters) of the problem which are limited by the Domains of these variables (Di). The dimension of this space is equal to the number of variables defined by the inventive problem.
- Problem Space (PSp) is also defined by variables (parameters) of the problem but these are not limited by their domains. The dimension of this space is equal to the number of variables too.
- Solution Space (SSp) is defined by all possible variables concerning the system the inventive problem concerns. The dimension of this solution space is so infinite.

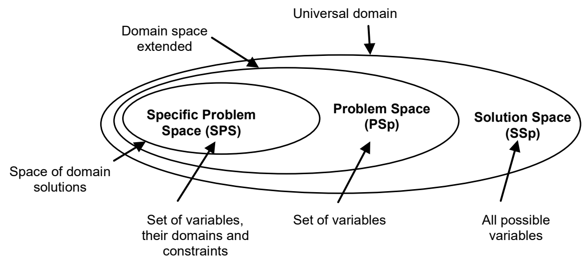

Figure 1. Definition of Knowledge Spaces.

These spaces could be compared with the ones define to make the difference between routine, innovative and creative design in (Rosenman and Gero, 1993):

- Routine design proceeds within a well-defined state space, all the design variables and their possible range being known and the problem being one of instantiation.
- Innovative design refers to situations where the space of known solutions is extended by making variations or adaptations to existing designs. The range of values of existing design variables being thus extended.
- Creative design implies the formulation of the state space.

Thus the Specific Problem Space (SPS) is equivalent to the space of domain solutions, the Problem Space (PSp) is equivalent to the extended domain space and the Solution Space (SSp) is equivalent to the universal domain.

3. Problem statement

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

Figure 2. Components of Electrical Circuit Breaker.

The problem has been studied and the main system parameters and their domains have been defined as: x1: firing pin material (plastic – 1, metal – 0) ; x2: core internal diameter (high – 1, low – 0) ; x3: core external diameter (high – 1, low – 0) ; x4: firing pin diameter (high – 1, low –0) ; x5: spring straightness (high – 2, medium – 1, low – 0) ; y1: circuit breaker disrepair (satisfied – 1, unsatisfied –

0) ; y2: circuit breaker reusability (satisfied – 1, unsatisfied – 0) ; y3: spring core mounting (satisfied – 1, unsatisfied – 0) ; y4: firing pin bobbin mounting (satisfied – 1, unsatisfied –; y5: normal mode release (satisfied – 1, unsatisfied – 0) ; y6: firing pin initial position return (satisfied – 1, unsatisfied – 0). In this definition of the problem the xi are the action parameters whereas the yi are the evaluation ones. The system behavior was modeled by Design of Experiments and it is shown in Table 1. The objectives that have been established to build the DoE are:

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

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

Table 1. DoE for the Circuit Breaker.

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

First evidence is that no solution can be found in the defined DoE, as no experiment enables the satisfaction of all the evaluation parameters. This problem can be recognised as an inventive one, or an over-constrained one.

4. Resolution by means of over-constrained CSP

4.1 Application of the resolution mechanisms

One can consider each experiment of the previously defined DoE as a constraint, for example:

$$C_1: [1, 1, 0, 0, 1] \qquad [1, 0, 1, 1, 1, 1] \quad (1)$$

This leads the definition of nine constraints. Then the search for a solution is defined by an optimization function (Barták, 1999), defined in Equation (2).

$$\text{Max} \quad y_i \text{ Optimal Solution} = [1, 1, 1, 1, 1, 1] \quad (2)$$

The solution to Equation (2) cannot be found in the initial Specific Problem Space, it is thus necessary to refer to methods for over-constrained problems. One of the well-known methods is the hierarchy of constraints (Borning *et al.*, 1992). It means that the satisfaction of the evaluation parameters will be relaxed according to a defined hierarchy of importance. For example, one can define that the satisfaction of the parameters y_1, y_5 and y_6 are required, the satisfaction of the parameters y_3 and y_4 are strong constraints and that the satisfaction of y_2 is a weak constraint. Then the solution will be searched by satisfying first the required constraints, then the strong ones and at least, if possible the weak ones.

The experiments e_1, e_5 and e_8 satisfy the required constraints, the experiment e_1 satisfies also the strong constraints, but no solution can be found to satisfy all the constraints. Then, according to this algorithm, and to this hierarchy, the solution is the experiment e_1 (see algorithm on Figure 3).

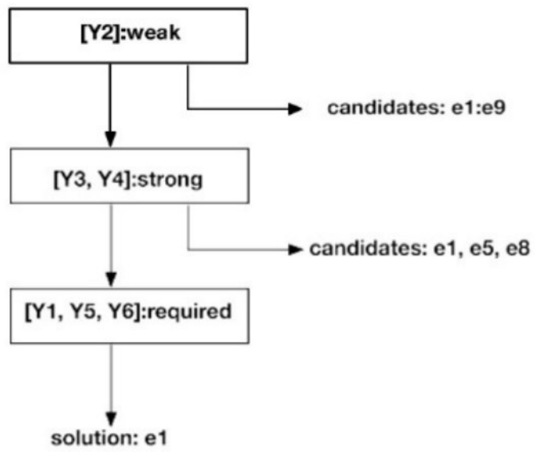

Figure 3. Over-Constrained Algorithm Resolution.

4.2 Analysis of the resolution impact on the solution space

The comparison of initial domain and domain of solution leads to the following conclusions:

- The set of parameters remains the same.
- The considered constraints are different, as the constraint y2=1 is not considered anymore.

The intensification of this mechanism leads to a space defined by the initial set of parameters without any constraints. This means that solving principles of constraint hierarchies – or Partial Constraint Satisfaction Problems (PCSP) as presented in (Freuder and Wallace, 1992) – start from initial problem defined by the specific problem space 1 (SPS1) and extend this space by relaxing certain constraints and variables in order to define a new specific problem space SPS2. This space is larger than SPS1 but always covered by respective Problem Space characterized by the set of variables describing the initial problem (see Figure 4).

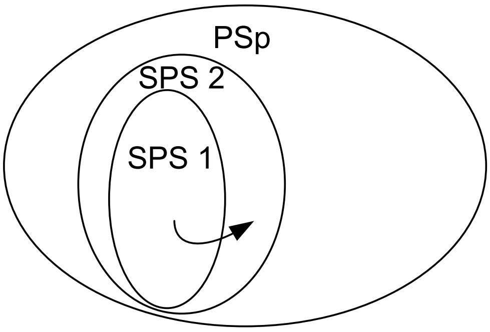

Figure 4. Model Change Mechanism of Optimization Methods.

But this solution can easily be recognized as a compromise and from an ideal point of view, i.e. if all the constraints are considered as required ones, the experiment C1 could not be recognized as a solution. And then other approaches have to be considered to find a solution.

5. Resolution by means of dialectical approach

To solve an inventive problem with TRIZ-based methods, it is first necessary to formulate the problem in an adequate form, i.e. to identify the contradictions. Then, the application of resolution mechanisms could be applied.

5.1 1 Identification of contradictions

In classical TRIZ approach (Altshuller, 1988), there exist different kinds of contradictions (administrative, technical and physical ones). Only the technical and physical contradictions are helpful as they propose the formulation of the problem enabling the application of resolution mechanisms. In (Khomenko et al., 2007) a system of contradiction has been proposed to clarify the role of each element of the contradiction and also to clarify the link between technical and physical contradictions. In (Dubois et al., 2009b) a generalization of this concept of system of contradiction is defined as Generalized System of Contradiction and is presented on Figure 5.

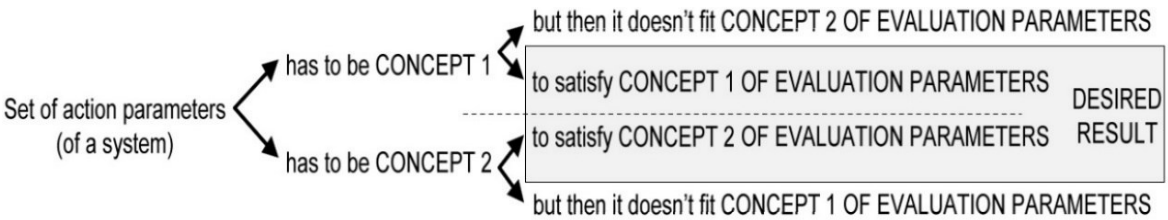

Figure 5. Generalized System of Contradictions.

The analysis of Table 1 enables the identification of several Generalized Systems of Contradictions; one of these GSC is presented on Figure 6.

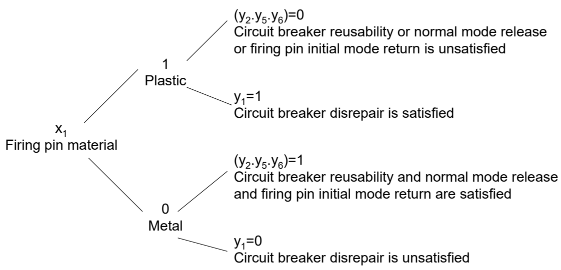

Figure 6. Generalized System of Contradictions for the Example.

The elicited contradiction can be reformulated this way: the firing pin material has to be plastic in order disable the disrepair of the circuit breaker; but the firing pin diameter has to be metallic in order to satisfy simultaneously the reusability of the circuit breaker, the normal mode release and the return in initial position of the firing pin.

5.2 Application of the resolution mechanisms

The GSC identified on Figure 6 tackles the problem linked with the firing pin diameter which has to be high and small in the same time. One of the well- known TRIZ mechanisms to solve problems is the separation of contradictory properties in space. Could the contradictory properties be separated in space? Actually the firing pin has to be metallic only from the front of the fixed core, where it begins to deform. And this fixed core is a metallic part. Then a new system of contradictions could be formulated: the fixed core has to become the firing pin as it is a metallic part, but the fixed core cannot be the firing pin as it is fixed. This contradiction can be solved easily through the application of another TRIZ resolution mechanism, the segmentation. One part of the fixed core has to become mobile. The inherent concept of solution is presented on Figure 7. On this figure one can consider that a part of the fixed core became mobile in order to reinforce the firing pin where it is thinner and thus enabling the firing pin to be plastic and metallic in the same time. Another way to present this concept is the resolution of the contradiction about the thickness of the firing pin, which has to be thin to enable its positioning and thick to resist deformation.

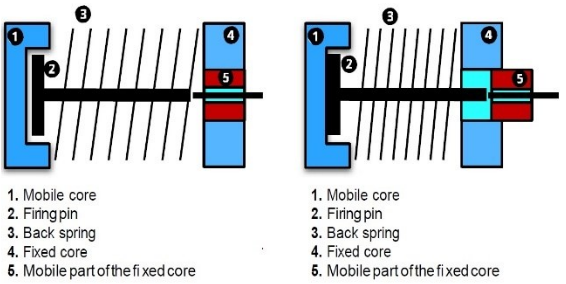

Figure 7. Concept of Solution for the Formulated Problem.

5.3 Analysis of the resolution impact on the solution space

If comparing the final concept of solution with initial model of problem, one can recognized that one parameter has been changed and a new one has been introduced. The parameter x4, firing pin diameter has been splitted into two: the diameter of the upper part of the firing pin and the diameter of the low part of the firing pin. The parameter x6, fixed core segmentation has been introduced. Thus the new solution corresponds to a new set of constraints which enables a new line in the initial DoE, as presented in Table 2.

Table 2. Representation of the Concept of Solution.

x1	x2	x3	x4a	x4b	x5	x6	y1	y2	y3	y4	y5	y6
1	1	0	1	0	2	1	1	1	1	1	1	1

If analyzing the kind of transformation achieved by these resolution mechanisms and the impact on the browsed solution space, one can consider that a new specific problem space is built, with new parameters and new constraints. And for this new SPS, a new Problems Space is defined, as illustrated on Figure 8.

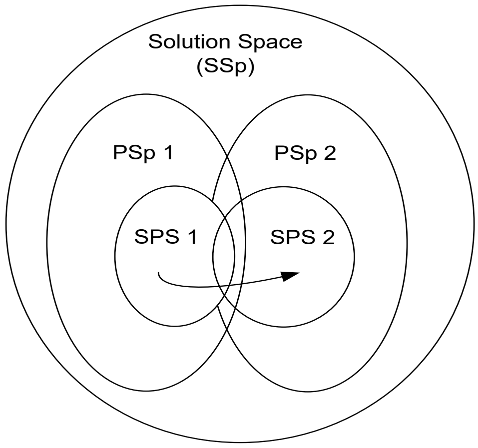

Figure 8. Model change mechanism of inventive methods.

6. Conclusion

In this article the way different kind of spaces are defined by the resolution mechanisms from optimization methods (CSP ones) and inventive methods (TRIZ based ones) is illustrated. Two aspects, the nature of the browsed spaces and the way the model changes are realized, were shown.

The consideration of the complementary aspects of both families of solving principles is of great interest and it puts the emphasis on the necessity to define a unified model that permits to shift easily from an optimization approach to an inventive one.

Each inventive method involves one or more operators of model changes. At the first time, every operator of model change and its using should be described in more details. The mutual enrichment of optimization and inventive methods will support a precise description of the inventive principles involving proposition of algorithms. At the second time, the efficiency of operators should be measured in order to prove a progress in the problem resolution. Later the whole process of inventive problem solving could be described as a succession of single model changes.

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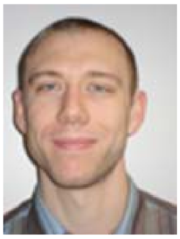

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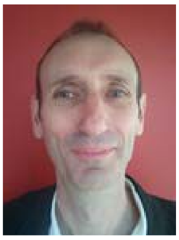

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Designing a Lowering Temperature Safety Device for Vehicles, Based on TRIZ Su-Field Analysis

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Abstract

There have been many reports from around the world of people dying inside overheated airtight vehicles. If the inside temperature could have been lowered in time, some of these tragedies would almost certainly have been avoided. In this study, a new, feasible problem-solving process based on a TRIZ Su-Field analysis model is constructed. The Su-field analysis enables the author to generate ideas to solve the overheated vehicle problem. A set of innovative safety device designs for vehicles that are going through a systematic application process is proposed. Based on this work, several patents were generated which include: Shaking-induced air-flow security device for kindergarten buses (R.O.C., I.P.O., Patent No, I295249); Sound-induced air-flow security device for kindergarten buses (R.O.C., I.P.O.; Patent No, I298300), Tread-induced Security Device for Vehicles (R.O.C., I.P.O., Patent No. I306067); and Induction air-flow safety device for vehicles (R.O.C., I.P.O., Patent No. M346545).

Keywords: Fatally hot airtight vehicle, Induced lowering temperature safety device, Patents and awards, Su-Field analysis.

1. Introduction

1.1 Aims and Motivation of the Research

Following the rapid pace of economic development, the automobile has become a major form of everyday transportation as well as an universal necessity. However, the steep increase in the numbers of cars has also brought a marked rise in traffic accidents and in the casualty toll. Traffic accidents figure in the top ten leading causes of death and are a cause of much personal and social woe and national economic damage.

Automobile tragedies are generally the result of careless behavior. There have been, for instance, many cases around the world of young children being locked in hot airtight vehicles, resulting in fatal accidents. Newspapers in Taiwan report that, between 1995 and 2005, designated vehicles taking children to and from kindergartens were involved in an average of 4.4 case of annual traffic accident statistics. The average Number of people for serious injury and death among children was 4.5 people annually. Between 1992 and 1999, there was a series of 10 serious kindergarten vehicle accidents that took 27 lives and the average of deaths and injuries per accident was 2.7 and 13.3, respectively. A number of young children suffered asphyxia and dehydration in kindergarten vehicle accidents in April of 1996 in Pintung, and in May of 2004 and September of 2005 in Taichung. In a similar case, a seven-year old boy and a five-year old girl were trapped and death in their father's car in 1999 in Miaoli County. In November of 2006 in Hsinchu, a two-year old child walking near a kindergarten bus, out of the driver's line of sight, was killed when the bus crashed. In 2003, in the United States, there were many reported asphyxia deaths of young children left alone in overheated cars. In 2007, in Guangdong Province, China, there were four school vehicle asphyxia fatalities, and in 2007, a two-year old child died from the same cause in Fukuoka, Japan.

In the past, when kindergarten vehicle tragedies of this kind happened in Taiwan, the people found at fault were punished, some were imprisoned, a number of kindergarten and day-care establishments were closed down and sums of compensation between NT$8,350,000 and NT$9,200,000 were agreed on.

The fact that, in 1996, 2004, and 2005, three children died each year from asphyxia and dehydration in kindergarten vehicle accidents highlights the pressing need for providing vehicles with appropriate security devices. The aim of this research, therefore, is to use a TRIZ Su-Field analysis model to design such devices and to provide the basic concepts for developing patents.

It is apparent from the above discussion that there are many big, unanswered questions concerning safety and kindergarten vehicles that must be faced and answered. It is very important to prevent such things happening again. There have been only few studies in this area of research. Therefore, the target here is the development of appropriate patents and improved rescue alarm devices.

2. Literature Review

2.1 Vehicle Safety

The automobile industry has witnessed frequent upgrades and development of vehicles, with overall enhancement of vehicle functions. However, there has also been a tragic increase in automobile accidents, making the search for effective prevention an issue of vital concern. Chai (2004) states that the goal of active vehicle management is to minimize the danger and damage of automobile accidents, the consequent loss of life and limb and the waste of social resources. The aim also is to make driving safer on different roads in different environments, while providing users with vehicles equipped with desired functions. Vehicle safety must be checked more frequently and strictly.

The Taiwan Government Institution of Transportation recognizes the importance of safe driving and the need for strengthening transportation laws. For this reason, "The Safety Inspection and Certification System for Vehicles by Type" for large-size automobiles was introduced on October 26th, 1996 and was extended to other vehicle types in succeeding years (Tseng, 2003).

1.2 TRIZ Su-Field analysis model

Su-Field analysis is a basic concept used to symbolize a technical system and to identify its completeness and effectiveness. Recognized as one of the most valuable contributions of TRIZ, Su-Field analysis is used to not only model a system in a simple graphical approach and to identify problems, but also to offer standard solutions to improve the system.

According to TRIZ, the rationale of creating a Su-Field model is to set up a system with the ultimate objective of achieving a function. This normally consists of two substances and a field, as shown in Figure 1. The term S2 represents an object that needs to be manipulated, and the term S1 represents a tool that acts upon S2. Both substances can be as simple as a single element or as complicated as a big system with many components, each of which can also be explained by individual Su-Field models. The field is the energy required that will enable the interaction between the substances. The states of substances can be typical physical forms (e.g., gas, liquid and solid), interim forms or composite forms (e.g., aerosol, power, porous). Likewise, the field can refer to a broad range of types of energy such as mechanism, chemistry, physics, acoustics, optics and radiations.

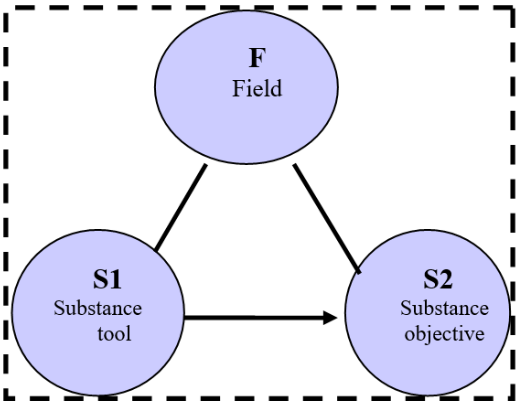

Figure 1 Basic Substances-Field Triangle Model

Genrich Altshuller and his colleagues, the creators of TRIZ, graphically represent a Su-Field model as a triangle. This is a simple and ingenious way to explain a technical system. Given the assumption that the field is generated by a hidden substance, the triangle can be simplified into a dumbbell shape with the field indicated above the arrow and the relationship indicated beneath the arrow, as shown in Figure 2. There are five main types of relationship between the substances: useful impact, harmful impact, excessive impact, insufficient impact and transformation. Among these relationships, useful and harmful interactions are the most common.

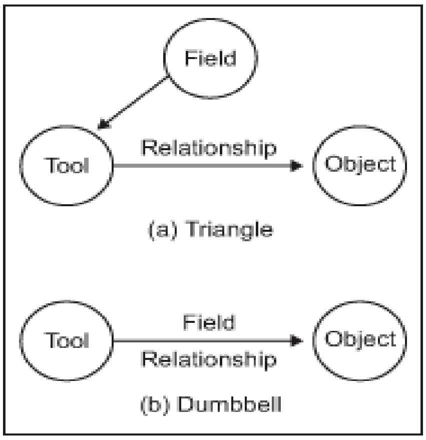

Figure 2. Basic Triangle and Dumbbell Su-Field Model (Mao *et al.*, 2007).

The Su-Field model is a fast and simple analytic tool for identifying problems in a system and for providing insights that help with the evolution of the system. Once a model is created, Su-Field analysis is used to determine if any of the three elements of the model is missing, or if there are any undesired effects in the system. Then, the analysis indicates the direction for improving the system. A complex system can be modeled using multiple, connected Su-Field models. Generally, there are four types of basic Su-Field models: (1) an effective complete system, (2) an incomplete system that requires completion or a new system, (3) a complete system that requires improvement to create or to enhance certain useful impacts and (4) a complete system that requires the elimination of some harmful or excessive impacts. (Terninko, 2000; Mao, et al., 2007)

3. Innovative Concept for a Safety Device in a Vehicle

3.1 Su-Field analysis

3.1.1 Case analysis of problems

Below, four cases are provided, and their problems are analyzed and summarized afterward:

1. Children suffered asphyxia and dehydration in kindergarten buses in April of 1996 in Pintung, and in May of 2004 and September of 2005 in Taichung (all Taiwan).
2. Four children suffered asphyxia on school buses in 2007 in Guangdong Province, China.
3. In 2003, in the United States, a number of children left alone in cars died from asphyxia because of the high temperature inside.
4. In 2007, a two-year old child on a bus suffered asphyxia in Fukuoka, Japan.

Problems of the four cases: People outside the vehicle were not informed in time that at least one child was left alone in the closed vehicle. The condition of the closed vehicle was not a ventilative environment and/or the temperature was not controllable.

3.1.2 Demand function

There are three demand functions as shown below:

1. **The presence of the children was not noticed in time. Demand function**: Need to realize someone is still in the vehicle in time
2. **The vehicle is not ventilated. Demand function:** Need to ventilate
3. **The temperature inside is too high. Demand function:** Need to lower the temperature

3.1.3 Model of the problem

As Figure 3 shows, the airtight vehicle, identified as the tool substance, is represented by S1 and the people trapped in the vehicle, the objective substance, are represented by S2. If the temperature in S1 increases, S2 might suffer asphyxia and dehydration. The thermal field, identified as the fatally hot temperature, is represented by T1. S1 is harmful to S2. The model of the problems is given in Figure 3.

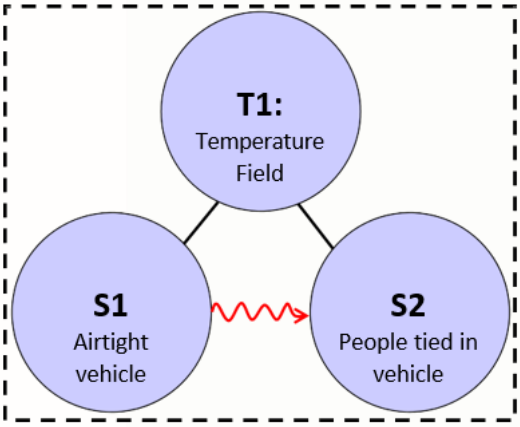

Figure 3. The Model of Problems of Young Children Who Died from Asphyxia and Dehydration n Kindergarten Buses.

3.1.4 Solution in the model

As for the Standard Inventive Solution 1.2 of Su-Field analysis, when a Su-Fields model has some harmful, unwanted, or unneeded functions, it is advised that the most efficient way to destroy the

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harmful, unwanted, or unneeded functions is to introduce a third substantial component that is a modification of one or both substantial components composing the given Su-Field. Figure 3 shows that S1 "airtight vehicle" is harmful to S2 "people tied in vehicle."

and thus avoid the possibility of people dying from excessively high temperature. T2 is induced by sensor S3. S2 induces (Mechanical field) sensor S3,

Figure 4 shows that the solution provided by the model is to apply the Standard Inventive Solution 1.2 of the Su-Field analysis; that is, to add the refined element, S3, to effectively eliminate harmful, redundant and unnecessary substances or fields. Therefore, this research adds the opposite thermal field T2 to lower the temperature between S1 and S2 which passes through a circuit (Electric field) to trigger safety device S4 (one or more of a variety of methods for lowering temperature) to lower the temperature inside the vehicle in time.

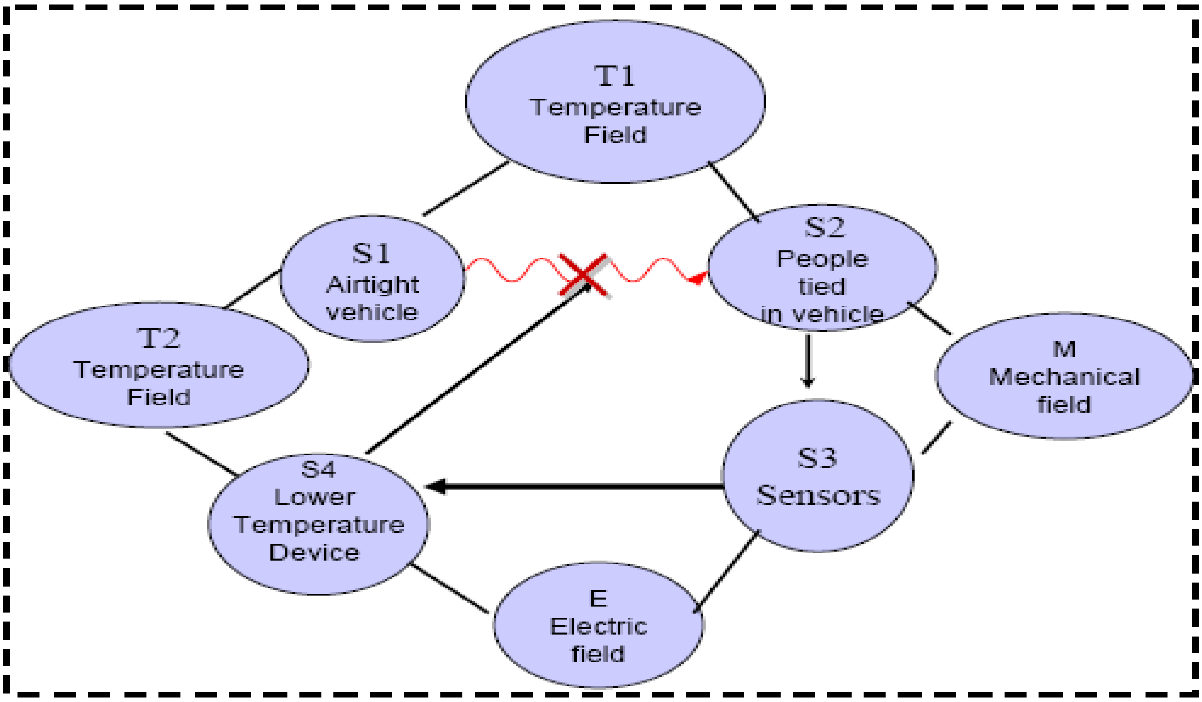

Figure 4. The Model of Solutions of Young Children Who Died from Asphyxia and Dehydration in Kindergarten Buses.

3.2 Safety device design for kindergarten buses

The design covers two groups of devices. The first is comprised of sensors such as those that detect movement (shaking or vibration), sound, tread, or detect by microwave, supersonic, infrared rays sensor or the variation of atmosphere, CO2 concentration. The second is comprised of security devices such as those that could open a window or switch on the air conditioning or the fan to lower the inside temperature. The device could also be a sensor linked to an alarm. Other examples include viewing or detecting devices, such as a camera linked to a monitor that allows the driver to determine who or what is present in the vehicle, or a device that alerts the driver when the vehicle is overloaded. For example, when the vehicle is parked with its doors locked, the safety system turns on. Any noise made by a child left inadvertently on the bus will trigger the safety device, which will in turn open at least one window. A patent search is underway at present to avoid violating any intellectual property rights during the process of innovation analysis. The information collected and analyzed in Table 1 is undergoing a Taiwan patent search in the Intellectual Property Office, Republic of China. The information shows the relationship between the safety device and sensors for kindergarten vehicles. In Table 1, "V" stands for "able to be researched and developed," and "X" stands for "someone's patents." Through a systematic process, a set of innovative designs is proposed. Table 1 shows the relationship between safety devices and sensors for kindergarten school buses.

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Table 1. The Relationship between Safety Devices and Sensors for Kindergarten School Buses.

		Safety Device			
		Open Side Window (vent hole)	Open Electric Fan	Air Conditioning	Sunshade
Sensors	Shake	V	V	V	V
	Sound	V	V	V	V
	Pulling rings	X M293866	V	V	V
	Tread	V	V	V	V
	Microwave	V	V	V	V
	Air pressure	V	V	V	V
	supersonic	V	V	V	V
	Infrared rays	V	V	V	V
	CO_2 Concentration	X M298200	V	V	V
	Complex	V	V	V	V
	Monitor	X I294848	V	V	V

3.2.1 Lowering the temperature

Figure 5 shows a safety device in a kindergarten bus. When the engine is switched off, and the vehicle is parked and locked, a sensor inside is activated. So, for example, any noise made by a frightened child left inadvertently in the vehicle will trigger the sound-induced security device. Or, if the child beats the windows or crystalloid windows, the shaking-induced security device is triggered. When either or both of these safety devices are triggered, a control window or vent hole opens, or the air conditioning or an electric fan switches on to circulate air/lower the temperature, thus prolonging life and increasing chances of rescue for those trapped in the vehicle.

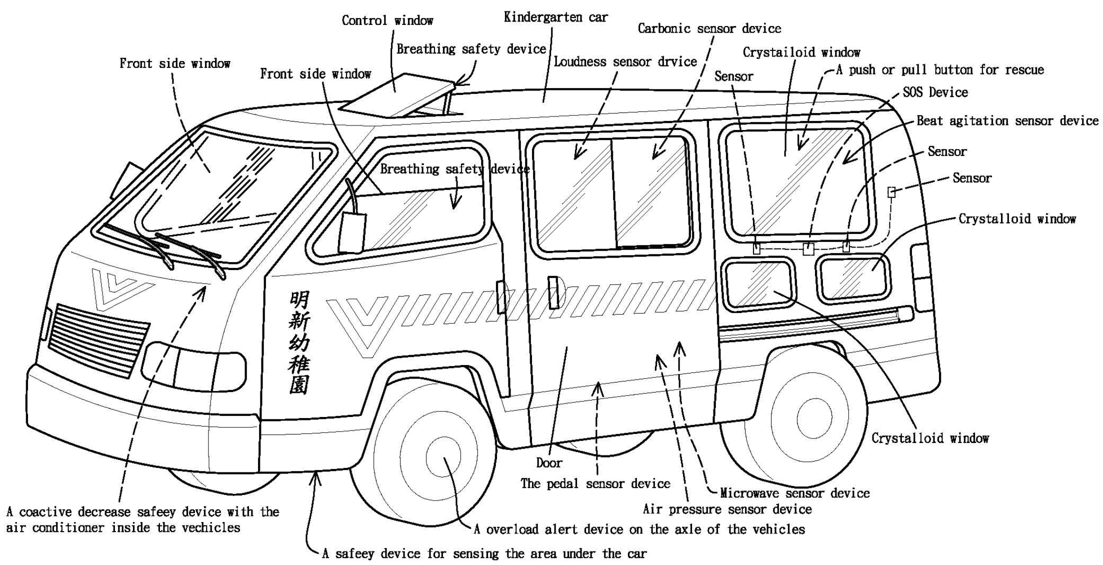

Figure 5. Young Children's Safety Device in Kindergarten School Buses.

3.2.2 Objectives for Safety Devices in Vehicles

These devices enhance and ensure the safety of children using kindergarten vehicles. In addition, they are suitable for usage in vehicles that carry seniors, pregnant women and disabled or mentally challenged people.

3.3 Present Achievements

The following detailed information relates to six safety device designs that have been approved or are awaiting the outcome of patent applications.

1. Shaking-induced air-flow security device for kindergarten buses (R.O.C., I.P.O., Patent No, I295249)

When the bus is parked and locked, the security device, powered by the car battery, is set on alert. Any movement made by a child inadvertently left on the bus will trigger the security device, which in turn will transmit a message to the person in charge and also open at least one window to allow ventilation.

2. Sound-induced air-flow security device for kindergarten buses (R.O.C., I.P.O., Patent No, I298300)

When the bus is parked with doors locked, the security device is set on alert. Any noise made by a child still on the bus will trigger the security device, which in turn will transmit a message to the person in charge and also open at least one window to allow ventilation.

3. Tread-induced security device for vehicles (R.O.C., I.P.O., Patent No. I306067)

This constitutes tread-induced security device for vehicles. It features a tread-conduction device and a rescue-signal device. The first part is comprised of a treadle with a spring on top of a conducting board. The items are electrically wired together and placed in the desired position in the vehicle. The whole device is in a box that is linked to the rescue-signal device by a circuit, and the device is powered by the vehicle. When the vehicle is parked with doors locked, the security device, powered by the car battery, is activated. With the vehicle doors closed and locked, anyone inside who steps on the treadle will trigger the conducting-board, which will trigger the rescue alarm and security device. The security device will then transmit a signal and also open at least one window. This will allow ventilation and alert people outside that someone inside the car needs help. Figures 6 and 7 shows geometry of treadle.

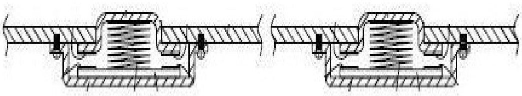

Figure 6. Treadle with a Spring without Someone Steps on-Car Floor Is Convex and with Electric Conductivity.

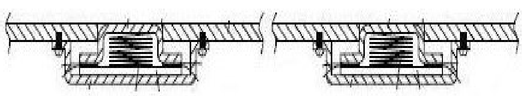

Figure 7. Treadle with a Spring with Someone Steps on-Car Floor Is Flat and without Electric Conductivity.

4. Induction air-flow safety device for vehicles (R.O.C., I.P.O., Patent No. M346545)

The induction air-flow safety device is comprised of a supersonic and/or infrared sensor in the vehicle. The sensor is linked to the SOS device, which is powered by the vehicle. After the power of the vehicle is turned off, the SOS device will be activated if the sensors are triggered by the rescue alarm and security device. The SOS device will open at least one control window or vent hole to allow ventilation and also to alert someone outside that someone inside the car needs help.

5. CO2 concentration-induced security device for vehicles (R.O.C., I.P.O., Application No. 095143243)

Situated inside the vehicle, the device is connected to a rescue signal device by a circuit, which is powered by the vehicle. If the CO2 concentration inside an airtight and locked vehicle exceeds a set limit, the CO2 induction device will be triggered, transmit a rescue signal, and open at least one window. This will allow ventilation and alert people outside that someone inside the car needs help.

6. A safety device to coactively decrease the temperature in vehicles (R.O.C., I.P.O., Application No. 097109945)

Linked to sensors inside the vehicle, the device serves as an SOS device. When the bus is parked with doors locked, the SOS device is activated as soon as any sensor detects that help is needed, and the SOS device activates another device to decrease the inside temperature.

7. Induction rescue device for vehicles (US, I.P.O., Application No. 12/385,646)

An induction rescue device for vehicles is comprised of at least one sensing element mounted in a vehicle. The sensing element is electrically connected to a mayday activation apparatus, which is powered by the power supply of the vehicle. Once the vehicle is turned off, if the sensing element senses that someone is trapped in the vehicle, it will activate a mayday activation apparatus and issue a mayday signal to the outside for help. The mayday will trigger at least one controlled vent to open and/or at least one coercive cooling-down apparatus to circulate the air in the vehicle and to cool the temperature. This would allow the trapped passenger to survive and alert people outside of the problem within the vehicle.

Table 2 shows the patent applications in this research.

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Table 2. The Patent Applications of this Research.

		Safety Device			
		Open Side Window (vent hole)	Open Electric Fan	Air Conditioning	Sunshade
Sensors	Shaking	I295249	097109945	097109945	US,12/385,646
	Sound	I298300	097109945	097109945	US,12/385,646
	Pulling rings	X	097109945	097109945	US,12/385,646
	Tread	I306067	097109945	097109945	US,12/385,646
	Microwave	M346545	097109945	097109945	US,12/385,646
	Air pressure	M346545	097109945	097109945	US,12/385,646
	Supersonic	M346545	097109945	097109945	US,12/385,646
	Infrared rays	M346545	097109945	097109945	US,12/385,646
	CO2 Concentration	X	097109945	097109945	US,12/385,646
	Complex	I295249	097109945	097109945	US,12/385,646
	Monitor	X	097109945	097109945	US,12/385,646

4. Conclusions and Suggestions

People in many parts of the world die in hot, airtight vehicles. The crucial cause is the extremely high temperatures that can be reached inside the vehicle. If the temperature can be lowered in time, such tragedies can be avoided.

In this study, a new, feasible problem- solving process based on a TRIZ Su-Field analysis model was constructed. The airtight vehicle, identified as the tool substance, was represented by S1; and the people trapped in the vehicle, identified as the objective substance, were represented by S2. If the temperature in S1 increased, S2 might suffer asphyxia and/or dehydration. The thermal field, identified as the fatally hot temperature, was represented by T1. S1 is harmful to S2. Therefore, the solution provided by the model was to apply transfer rule 4 of Su-Field analysis, add a refined element S3 (sensor) and thus effectively eliminate harmful, redundant and unnecessary substances or fields. The added opposite thermal field, T2, lowered the temperature between S1 and S2 and avoided fatalities caused by the high temperatures. T2 was induced by sensor S3. S2 induced (Mechanical field) sensor S3 to pass through a circuit (Electric field) and turn on the safety device, S4 (a variety of methods for lowering temperature), which then lowered the inside temperature in time.

This research used the systematic innovation method and provided several innovative designs for which patents were applied. Three invention patents and one new style patent have been received, and three invention patent applications are still being processed. This research suggests that researchers can use TRIZ Su-Field analysis to solve problems in engineering. Although the TRIZ Su-Field analysis, in principle, can be used to achieve solutions, feasibility and costs should still be considered.

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Innovative Design of Substance-Field Notations for Reformulating the Seventy-Six Standard Solutions in TRIZ

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Abstract

The substance-field model and 76 Inventive Standard were conceptualized by Genrich Altshuller who has built classical TRIZ. The paper shows the innovative notation methods so called Su-Field Notations which can indicate characteristics of TRIZ problems and solutions instantly. Intuitive understanding the characteristics of TRIZ problems is the main purpose of Su-Field notations (aka. Amang's notation). This innovative notation method makes possible to understand the Su-Field model based concept solutions only with minor knowledge of the Inventive Standards. The tractable results are used for demonstration in the real-world applications.

Keywords: TRIZ, TIPS, Su-Field Model, Innovation, Inventive Standard

1. Introduction

The substance-field model (Haijun, 2009; Soderlin, 2003) and 76 Inventive Standard (Domb, 1999; Domb, 2003; Soderlin, 2003) were conceptualized by the founding father of TRIZ, Genrich Altshuller (1984; 1997). Even though, 76 Inventive Standards do not provide graphic models for every standard and the standards are not new to the TRIZ community, they can help the TRIZ specialist find solutions concepts for many kinds of problems as a collection of methods to identify (Domb, 2003). The Standard Solutions are grouped by constraints, so they can help the specialists find appropriate solution concepts (Slocum and Domb, 2003). They are more accessible to TRIZ newcomers than ARIZ (Grace et al., 2001; Zlotin and Zusman, 1999), since the user is liberated from the ARIZ dictum of mastering every step before using any step. The 76 Inventive Standard Solutions are among the fundamental techniques that provide the foundation for most of commercial major TRIZ softwares but they are not currently being used widely (Domb, 2003).

There are several reasons why the Inventive Standards are not applied widely and two main reasons are addressed instantly. First, people learning TRIZ still must do a lot of case studies that illustrate the principles of TRIZ using terms and technologies before using Inventive Standard correctly. Second, the standards are categorized by physical interactions. The Inventive Standards (76 Standard Solutions) are well defined and organized (Domb, 1999). But it is still difficult to learn and complicated even for TRIZ specialists. More importantly, the 76 Inventive Standards are not intuitive (Soderlin, 2003).

Currently, TRIZ tools are applied not only in physical engineering but also in software (Kim, 2010; Kim, 2011), even in business area (Domb, 2003; Miller and Domb, 2002). Most of physical interactions are not have direct matches with the actions in software or business. TRIZ specialists must abstract the solutions to fit their area for solving their problems. The standards must be reformulated more intuitive way.

The special notations so called Su-Field notations (aka. Amang's notations, Amang is the alias name of the author) are introduced in the paper. The notations give intuitive explanations both problems and solutions based on the Inventive Standards. The core for Su-Field model notation is adopted by the queuing model notations also known as Kendall-Lee notations. Basically, Kendall-Lee notations can explain all kind of queuing model and users who know the rules of the notations understand the characteristics of the queuing model almost instantly when they see the notation (Tijms, 2003). Su-Field notations cover all of the Inventive Standards except for Group 5 which is the set of guidelines for other four groups. Someone who does not even have the full knowledge of the 76 Inventive Standard solutions can understand the problems and candidate solutions intuitively by applying Su-Field notations. The paper simultaneously offers an opportunity for the TRIZ community to contribute to improving global welfare.

2. Queuing Model and Its Notations

Before starting Su-Field notations (Amang's notations), Theory of Queuing system and its notations (Kendall-Lee notations) are introduced first (Tijms, 2003). Queuing theory is the mathematical study of waiting lines, or queues. It is generally considered a branch of operations research because the results are often used when making business decisions about the resources needed to provide service.

Queuing system is one of major topics in stochastic modeling to analyze the system. This mathematical model can be applied not only in McDonald but also in traffic engineering for Internet and mobile communications even human resource management. It is applicable in a wide variety of situations that may be encountered in business, commerce, industry, healthcare, public service and engineering. Applications are frequently encountered in customer service situations as well as transport and telecommunication. It is also directly applicable for intelligent transportation systems, call centers, network management, telecommunications, server queuing, mainframe computer of telecommunications terminals, advanced telecommunications systems and traffic flow.

There are many kinds of queues with various conditions but all of queues can be categorized by the certain notation schemes. Classification of the queuing models has been suggested by D. G. Kendall in 1953 as a three-factor notation of queuing system and it has since been extended to include up to six different factors by A. M. Lee in 1966. This queuing notation has been known as Kendall-Lee notation and it exhibits the summarized main characteristics of a queuing system.

$$(a/b/c):(d/e/f) \tag{1}$$

where the symbols *a, b, c, d, e* and *f* stand for basic elements of the model as follows:

a = arrivals distribution,
b = service time distribution,
c = number of servers (*c*=1, 2, 3, …)
d = service properties (i.e., FCFS, LCFS, SIRO)
e = capacity of the system
(a waiting room and servers)
f = population of input resources.

The standard notation replaces the symbols *a* and *b* for inter-arrivals and service-time distributions:

M = Poison input distribution or Exponential service-time distribution,
D = deterministic or constant,
E_k = Erlangian or gamma distribution with the exponential phases,
GI = general independent distribution,
G = general distribution.

For instant, M/G/1{/FCFS/∞/∞} is the open queuing system (i.e., population of input resources is unlimited) system with Poison input, general service property and unlimited waiting capability. M/G/1 queuing system is one of most typical queuing systems (see Fig. 1).

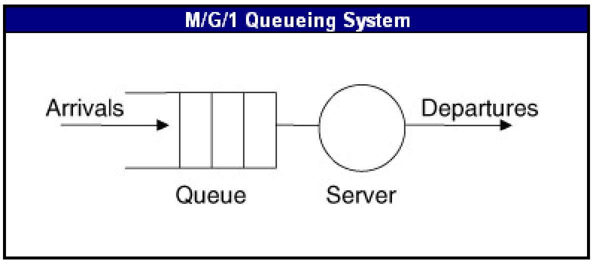

Figure 1. This is an example of a figure caption.

The queuing system and theories are attractive topic and required the in-depth study but it is not included in the paper because the research is only adopting the queuing notations.

3. Substance-Field Notations

The paper introduces the similar notation scheme to cover the 76 Inventive Standards. In addition, it is classified the Inventive Standards more simple way and users can be guided to the candidate solutions from the problems based on Su-Field model with the minimal knowledge of 76 Inventive Standard solutions. The notation for Su-Field model (Su-Field notation) is introduced (aka. Amang's notation,"Amang" is alias of author).

The Su-Field model for Inventive standard solution can exhibits the summarized main characteristics of a Su-Field model.

$$(x/s/f):(/a) \qquad (2)$$

where the symbols *x, s, f* and *a* stand for basic elements of the model as follows:

x = solution (or problem) types (x = 1, 2 or 4)
s = substance attributes,
f = field attributes,
a = strength of actions (a=0; *Normal* or a=1; *Stronger*)

The attributes of the substance S are as follow:

S^* = general terms of the substance that can solve the problems
S^+ = +1 substance from basic structure to solve the problems
S' = modify the substance (tool) to solve the problems without changing the number of components from basic structure
S^- = -1 substance from basic structure (i.e., tool is missed)
S^∞ = substance (tool) is divided infinitely (Technical System Evolution)
S'' or S^2 = adding the clone of the substance (+1)

The attributes of the field f are similar with substance attributes:

F^* = general terms of the field that can solve the problems
F^+ = +1 field from basic structure to solve the problems
F' = modify the field to solve the problems without changing the number of components from basic structure
F^- = -1 field from basic structure
F^∞ = field is divided infinitely (Technical System Evolution)
F'' = adding the clone of the field (+1)
$\overleftarrow{F}$ = reverse direction of the field

The attributes for fields and substances indicate how to modify the substances and the fields.

3.1 Basic structure of Su-Field Model

The basic structure of Su-Field model for the Inventive Standard consist one object (S1), one tool (S2) and one field (F) The basic structure can be notified as:

$$x/s/f\{/0\},\ x=1,2,4 \qquad (3)$$

where x is the types of problems or solutions (see Figure 2)

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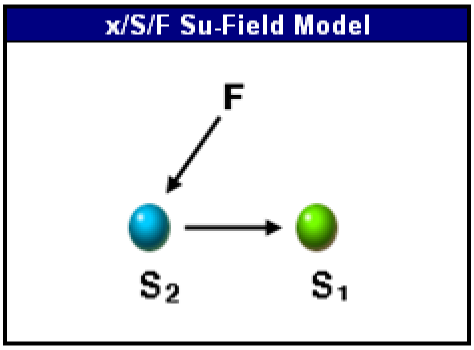


Figure 2. Basic Structure of Su-Field Model

Overall of 76 Inventive Standards except for Group 5, the problems can be categorized as three types. Type 1 is the problem that contains the weak useful action (or function) and the candidate solution of Type 1 is enhancing the strong useful action. Type 2 is the problem that contains the harmful action and the candidate solution of Type 2 is removing the harmful action. Type 4 is mainly measuring problem that is the separate group of 76 Inventive Standard solutions. Group 4 in the Inventive Standard are exact matched with Type 4.

For instant, *2/S/F* is the problem (see the Figure 3) contains the harmful action and the candidate solution is *2/S$^+$/F* that means removing the harmful action by additional substance S^3 (remarked as S^+ in Su-Field notation). As seen above, Problem Types also represent Solution Types (i.e., same type number). So, it is same type in Su-Field notation regardless of problems or solutions. The following sessions provide the explanation of the solution types that matched with the problem type more detailed

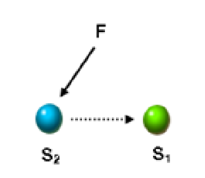
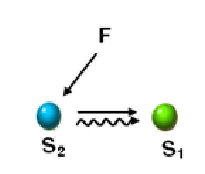
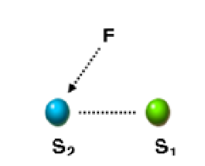
Problem Type	Su-Field Diagram	Solution Guideline
1 (1/S/F)		Enhancing the useful action
2 (2/S/F)		Removing the hamful action
4 (4/S/F)		Mesurement (Same as Group 4 in 76 inventive standards)

Figure 3. Types of the Problems

4. Solution Types Based on Su-Field Notations

This session gives the more detailed about the solutions based on Su-Field notations. There are 3 solution types based on the problem types. Comparing to the group of 76 Inventive Standard, Group 1, 2 and 3 are integrated to Type 1 and 2. Group 4 in the Inventive Standard is integrated to Type 4 that is much simplified and remained as Concept Solution.

4.1 Type-1 Solution

Problem Type 1 contains two sub types based on the problem conditions. Type 1-1 is the problem because of missing the substance (tool) or the field (action). Type 1-2 is the problem of weakness.

Missing Substance and/or Field (Type 1-1): the problem that is missing either substance or field can be solved by making the basic structure:

$$1/S^-/F \; or \; 1/S/F^- \rightarrow 1/S/F \quad (4)$$

Enhancing the Useful Action within Basic Structure (Type 1-2): the problem that is week actions can be solved by adding or modify the substance in the basic structure:

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$$1/S/F \rightarrow \begin{cases} 1/S^{+}/F, & S^{*}=S^{+} \\ 1/S'/F, & S^{*}=S' \\ 1/S^{\infty}/F, & S^{*}=S^{\infty} \end{cases} \quad (5)$$

and Su-Field diagram for Type 1-2 can provide the clear picture of the solution models:

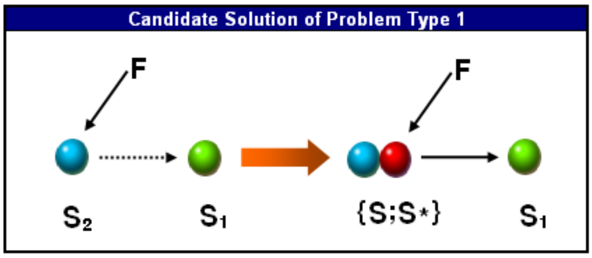

Figure 4. Su-Field Solution Diagram $1/S^{*}/F$

The $1/S^{\infty}/F$ that means the unlimited modifications of the substance and the field based on Technical System Evolution can be the candidate solution of Problem Type 1-2. There are the several candidates that be considered as the solutions for solving Problem Type 1 (see Figure 5):

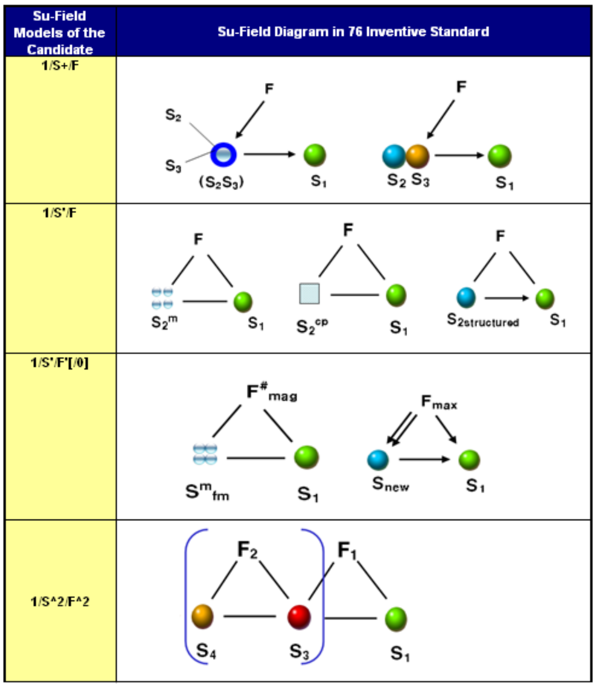

Figure 5. Su-Field Model for Type-1 Solutions

From (4) and (5), the solution for Problem Type 1 can be concluded as follow:

$$1/S^{\{-1\}}/F^{\{-1\}} \rightarrow \begin{cases} 1/S/F, & \because Type-1 \\ 1/S^{*}/F, & \{S^{*} | S', S^{+}, S^{2}, S^{\infty}, S^{n}\} \\ 1/S/F^{*}, & \{F^{*} | F', F'', F^{+}, F^{\infty}\} \\ 1/S^{*}/F^{*}, & \end{cases} \quad (6)$$

4.2 Type-2 Solution

Problem Type 2 is the problem that contains the harmful action and the candidate solution is basically removing the harmful function:

From Figure 6, the candidate solution of Problem Type 2 can be determined as follow:

$$2/S/F\{/0\} \rightarrow \begin{cases} 2/S^{*}/F, & S^{*}=S^{+}\ or\ S' \\ 2/S/F,^{+} & \\ 2/S/F/a, & 0<a<1 \end{cases} \quad (7)$$

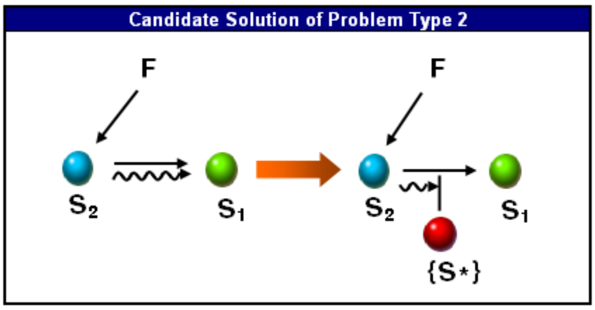

Figure 6. Su-Field Solution Diagram of $2/S^{*}/F$

More detailed description of (7) is provided on Fig. 7:

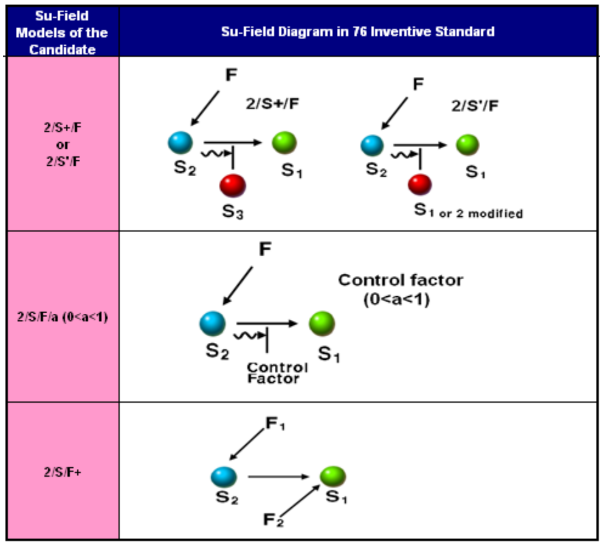

Figure 7. Su-Field Model for Type-2 Solutions

4.3 Type-4 Solution

Problem Type-4 is the measurement of the system. Even though Group 4 in 76 Inventive Standards can be applied Type-4 problems, Amang notation can be applied for the measurement problems. In case of Type-4, the notation for the action attributes is mandatory factor because the strength of the measurement signals:

$$4/S/F \rightarrow 4/S^{(*)}/F^{(*)} \qquad (8)$$

and Su-Field diagram for Type-4 can provide the clear picture of the solution models:

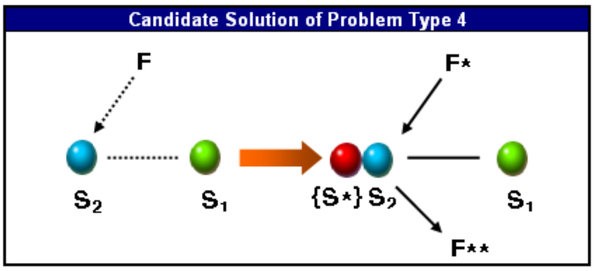

Figure 8. Su-Field Solution Diagram of $4/S^{*}/F^{*}/1$

One of the practical solutions for the Type-4 Problem is $4/S^{-}/F^{-}$ that means removing the components requiring the measurement (i.e., Inventive Standard 4-1-1). From (6), (7) and (8), the Su-Field notations care simple but practically cover all of the Inventive Solution (Group 1-4). The concept solutions can be applied not only in the classical TRIZ problems but also in the problems of software and business more flexible.

5. Real-World Applications

There are several problems in each problem types and the session provides the potential solution for basic problems. The session gives the guidelines how to adopt Su-Field notation into TRIZ problems in real-world.

Several TRIZ applications in the mobile industry and the related research papers have been published in TRIZ Symposium (Kim, 2010) and IEEE (Kim, 2010) by author. The main solutions in the researches are developed by using Inventive Standard and the solutions in the research can be explained by using Su-Field notations (aka. Amang's notations.) Two real-world applications are introduced in this session as case studies. First case is the enhancement of user experience (Kim, 2010) and second case is LBS application in mobile industry(Kim, 2011).

5.1 Enhanced UX Based on User Behavior Data

The playlist in a MP3 player and a mobile phone is a basic user interface and recently user behavior has been changed because of memory expansion. Most of recent MP3 users can contain more than thousands of songs in one device and it is big changes when we compare with the situation of couple of years ago. Listing within thousand songs is heavy task these days.

According to Su-Field Notation, this is *2/S/F* problem (i.e., Type-2 Problem) which is the problem for removing harmful effects. The core problem is for building a playlist for MP3 player without extra operations. From (7), the conception solution of the problem is *2/S+/F* (See Figure 9.)

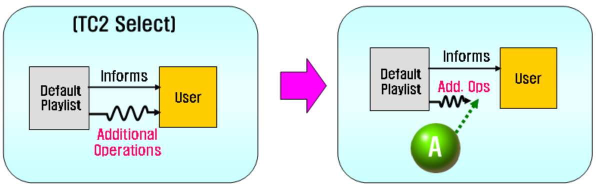

Figure 9. $2/S^{+}/F$ Solution for UX of Enhanced Playlist

The actual solution based on 1-2-2 in 76 Inventive Standard solutions from the previous research (Kim, 2010) can be also obtained by the concept solutions based on Su-Field notation. The actual solution of this case is that the priority factors are calculated based on the data from common user behaviors such as total player (application) running time, number of music player launching, total running time of actual song playing and so on. These data are very common from most of music players. After gathering these statistics, the playlist is considered as a set and proceeding couple of mathematical implementations, the songs can be ordered based on the weight factors and let be the index set of favorite songs based on the weight factors. The enhanced playlist is the playlist based on human behavior data via the truncated index set:

$$\Xi^* = \{s_{w_1^*}, s_{w_{21}^*}, \ldots, s_{w_n^*}\}. \qquad (9)$$

Ξ^* is not only the ordered sets based on optimized weight factor w_k^* as mathematical perspective but also the actual playlist that contain the ordered name of songs based on human behaviors (Kim, 2010).

5.2 Enhanced LBS UX Design based Behavior

Location Based Service (LBS) is an information and entertainment service, accessible with mobile devices through the mobile network and utilizing the ability to make use of the geographical position of the mobile device by using Global Positioning System (GPS). GPS is a mandatory technology for LBS applications but it takes more than ten minutes to find the initial location position of a device. Assisted GPS (A-GPS) is design for gathering the initial position much faster but A-GPS is required higher application chipset process power. Currently, a LBS application is very common and it is embedded even in a low tier devices. The initial GPS position must be calculated before launching the LBS applications but required the additional process power.

The main problem is improving the determination of the initial position. According to Amang's notation, this is 1/S/F problem (i.e., Type-1 Problem) which is the problem for enhancing the useful effects. The concept solution for LBS application can be 1/S+/F of Amang's notation and it indicates the same solution guideline based on Inventive Standard 1-1-3 (see Figure 10.)

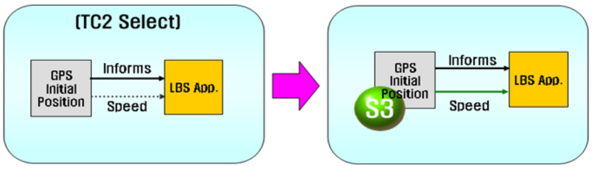

Figure 10. *1/S⁺/F* Solution for LBS Application Enhancement

The actual solution of this case is providing the pre-process before LBS applications starting and a user is not even notified the pre-process for enhancing the initial position for the LBS applications. The workflow for the implementations based on the concept solution is shown as Figure 11 (Kim, 2011).

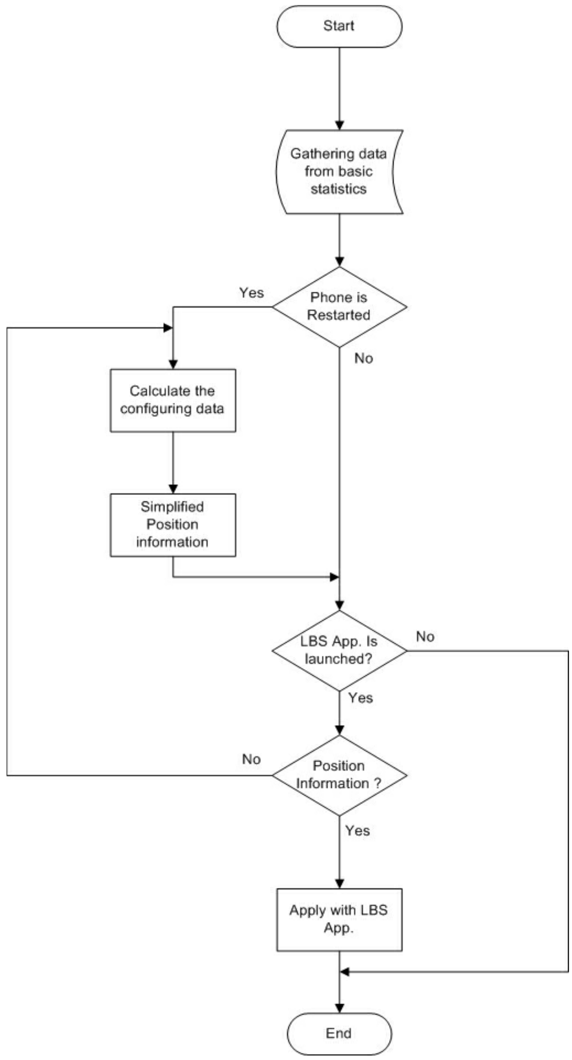

Figure 11. Workflow of the Enhancing the Initial Position for LBS Applications

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6. CONCLUSION

Su-Field notation (Amang's notation) is the generalization of the classic 76 Inventive Standard solutions and the reformulating of them on Su-Field model. Queuing notations are adopted to give intuitive explanations not only the characteristics of the problems but also suggest the candidate solutions because the notation by itself provides the concept solution that can be widely applied for various areas. The problem solvers can adopt the candidate solutions based on Su-Field notations without the full knowledge of 76 Inventive Standard solutions. In addition, the examples of the real-world applications for mobile industries will give you the guidelines how Su-Field notions to apply other areas of real-world problems especially in IT industries.

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Innovative Installation Method for LPG Storage Tank Using TRIZ

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Abstract

LPG (Liquefied Petroleum Gas) vehicles in metropolitan area are being applied to improve air quality and have been proven effective for the reduction of air pollutants. In addition, LPG demand is growing rapidly as an environmentally friendly energy source and its number of gas stations is also increasing every year. These gas stations are required to install the securest storage tank because of possibility of causing huge loss of life and properties. Therefore, in this paper, underground containment type is proposed as installation of the LPG storage tank using TRIZ, which is considered to be safer, economical, efficient, easy checking and simple construction method than any other.

Keywords: TRIZ, Installation Method, LPG, Storage Tank.

1. Introduction

Recently, the Korean government promotes green growth promises as a paradigm of national development which are to reduce greenhouse gases and environmental pollution by exhaust gases from automobiles. The automobile sector accounts for 19.3% of national energy consumption and has an ability to cut larger than other sectors, OECD (1996).

These fuel sources for vehicle's operating have been recently turned from gasoline to the gas to some extent. According to Korean Statistical Information Service, as shown in Table 1, the LPG quantity for transportation has increased 9.0% over the previous year. The demand for LPG bus station is increasing [AEGPL (1999)] causing air pollution problems. To solve the air pollution in urban areas, especially, LPG is projected as a relatively cost-effective alternative. According to Park (2009).

Changing in the gas fuel is a problem of the 'survival' beyond the 'quality of life' improvements, It rep- resents a new paradigm of 'sustainable development' which pursues economic development in harmony with environmental conservation.

When we use gas as fuel, it is effective in im- proving the environment by significantly reducing air pollutant emissions. It has a good efficiency in eco- nomic aspects because of a high-octane number. This is evidenced as domestic LPG gas station has increased three times during the last 10 years and the number of people completing training courses for safety manager about these facilities has grown rapidly.

Table 1. The state of LPG Consumption. (units: 1,000 ton).

Section	2004	2005	2006	2007	2008	Rate of increase(%)
Business	2,065	2,184	2,081	1,911	1,679	△5.4
City gas	75	96	69	62	178	2.8
Traffic	3,860	3,968	4,069	4,366	4,379	3.9
Industrial	481	509	504	637	650	4.2
Fuel	1,226	1,236	1,445	1,516	2,045	13.6

But, the studies of Lee and Lee (2003), CCPS (1994), Reid (1980), Kim et al. (2000), have shown that fire and explosion caused by leak incidents have occurred in large-scale facilities despite residing of safety manager. This is because LPG gas is difficult to detect due to its properties of colorless, odorless and formless. Especially, the representative examples of the accident in gas station occurred in Iksan gas station (UVCE: Unconfined Vapor Cloud Explosion) and Bucheon gas station (BLEVE: Boiling Liquid Expanding Vapor Explosion) resulting in many casualties and losses of enormous properties.

As the result of abovementioned two events in LPG station, Many researchers have inverted the related issues: Roh et al. (1999), investigated damage effect from Boiling Liquid Expanding Vapor Explosion (BLEVE) of LPG charging facilities; Bae (1999), studied on the Quantitative Analysis in LPG Tank's Fire and Explosion; Leem and Huh (2010) quantitatively Analyzed and Estimated damages to Surround Building caused by Vapor Cloud Explosion in LPG Filling Station; Lee and Lee (1999), researched consequence analysis of the fire & explosion on the flammable liquid handing facilities and LPG stations.

Jo (1999) studied on the minimum safe separation distance from LPG filling station and Park et al. (1999), learned about risk assessment of LPG storage facilities.

Based on these studies, the installation of storage tanks type regulations are buried underground or ground type to prevent accidents pursuant to Article 1[facility and technical standards of liquefied petroleum gas business] of Liquefied Petroleum Gas Safety Management and Business Law Enforcement Regulations Article 8 (2007).

LPG storage tank status installed is shown in Figure 1. According to research results of Jin et al. (2001), the most important factors causing the accident were structural defect and external accident in LPG leakage at charging facilities.

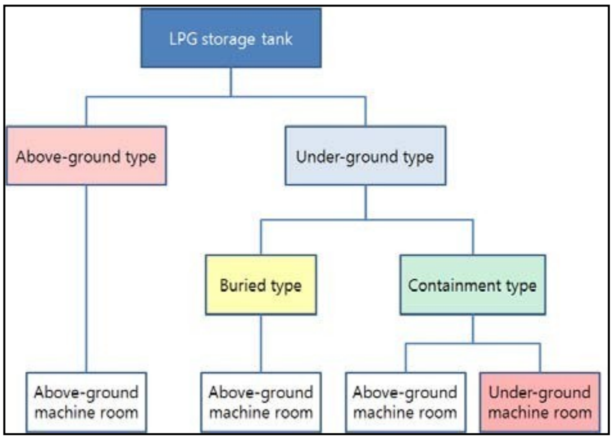

Figure 1. The State of the Installation for LPG Storage Tank.

To prevent this, he emphasized that the normal operation state through regular maintenance and repair works is important.

Therefore, Leem and Huh (2006) developed an intelligent decision system by safety distance of gas storage tank for safety managers in the field to prevent accidents complying with the related laws.

According to Korea Gas Safety Corporation, LPG storage tank status installed in charging facilities ap- plied by the current regulatory laws is shown in Table 2. It is noted that structural defects of storage tanks are actually difficult to check frequently because they are mostly installed as buried underground type.

Lee (2001) stated that the storage tank Installed on the ground has occurred BLEVE at temperature around 873K of its outer surface exposed to the fire.

Therefore, the storage tank installed above the ground pursuant could cause UVCE and BLEVE by a gas leak while buried underground type tank is extremely vulnerable to corrosion which degrades safety and economical efficiency.

Table 2. The State of LPG Filling Station. (Locating Type).

(units: ea)

Section	The storage tank(Locating type)			
	Above ground	Underground		Total
		Burial	Containment	
Total	173	1,703	110	1,986
Vessel	29	38	3	70
Vehicle	33	1,219	36	1,288
Vessel and Vehicle	70	420	70	560
Other	41	26	1	68

In this paper, construction method taken ad- vantage of practical TRIZ Step 6 of Kim (2006) and TRIZ techniques was proposed to reduce the danger and improve the economical efficiency of above-ground and buried underground types.

The existing containment type is similar to proposed style in this paper in the aspect of installing storage tank underground but transportation facilities as well as equipment parts of safety device are set up underground together. This is why the existing containment type has a high probability of gas leakage.

Containment shape proposed in this paper has a structure of only the storage tank is underground while moving all of the joints of equipment parts to above ground.

2. Theory

TRIZ is a Russian acronym for the Theory of Inventive Problem Solving, a problem-solving method based on technology rather than psychology. Genrich Altshuller, the TRIZ inventor, determined that the process of inventing could be significantly enhanced with a system that provides:

* A systematic step-by-step procedure
* Guidance to the area of the best solutions
* Reliable and repeatable results
* Access to the accumulated experience of innovation

According to Teplitskiy and Kourmev (2005), Royzen (2008), Domb (2000), Altshuller (1988), TRIZ grew to incorporate the knowledge abstracted from more than two million patents. As the TRIZ knowledge base grew, rigorous analysis revealed an objective, verifiable set of patterns and regularities related to the evolution of technological systems.

TRIZ helps us improve systems toward ideal design and it is useful for anyone to solve the problem easily and creatively.

Practical TRIZ 6 steps were applied to creativity one by one through the steps such as those in Figure 2. (6SC steps) 1) graphic representation, 2) the system's functional analysis, 3) ideal final result, 4) contradiction and the principle of separation, 5) element - inter- action, 6) evaluation and solutions and you can explore more creative solutions by looking at other methods for each principle.

3. Application of 6SC and evaluation

It is analyzed step by issue by applying 6SC to look for the solution of problems of above ground and buried underground type of LPG storage tanks.

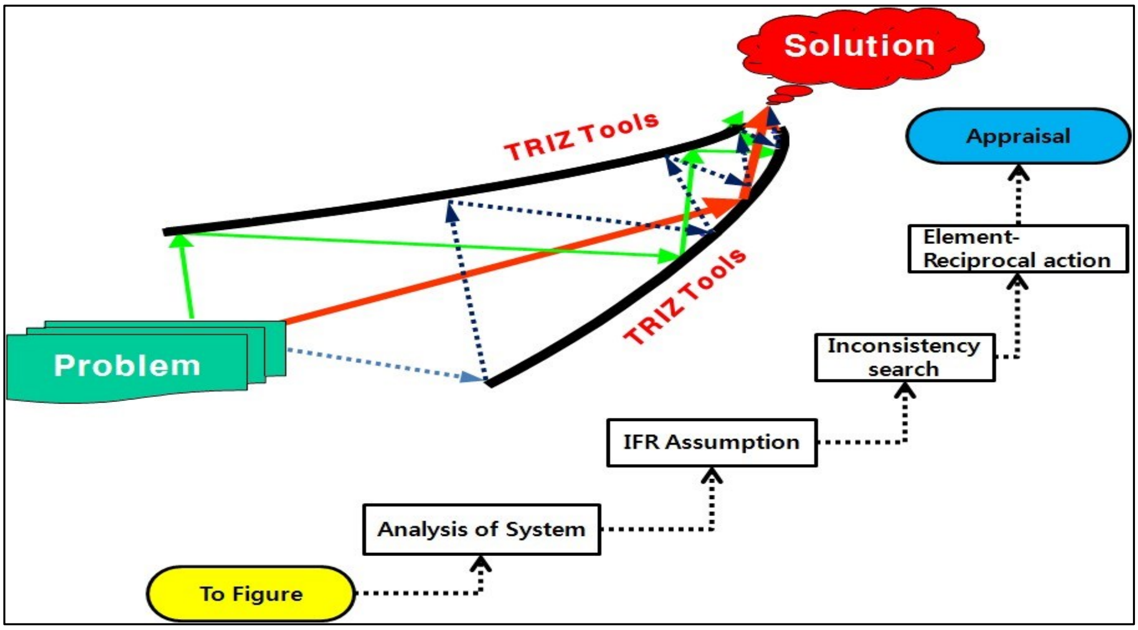

Figure 2. Application of 6SC Method.

3.1 Graphic representation

The best way to refine people's thought is to use pictures or diagrams. Graphic representation of the problem makes it easier to analyze situations and to determine the exact cause of the problem. They can be quickly and easily identified by representing the system as shown in Figure 3.

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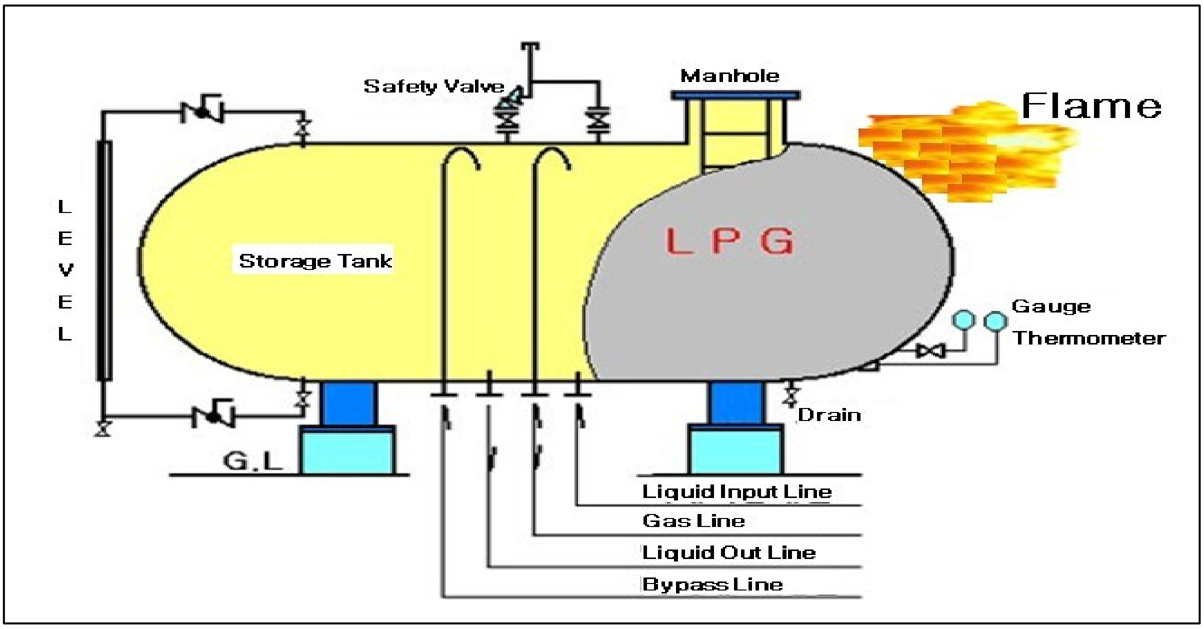
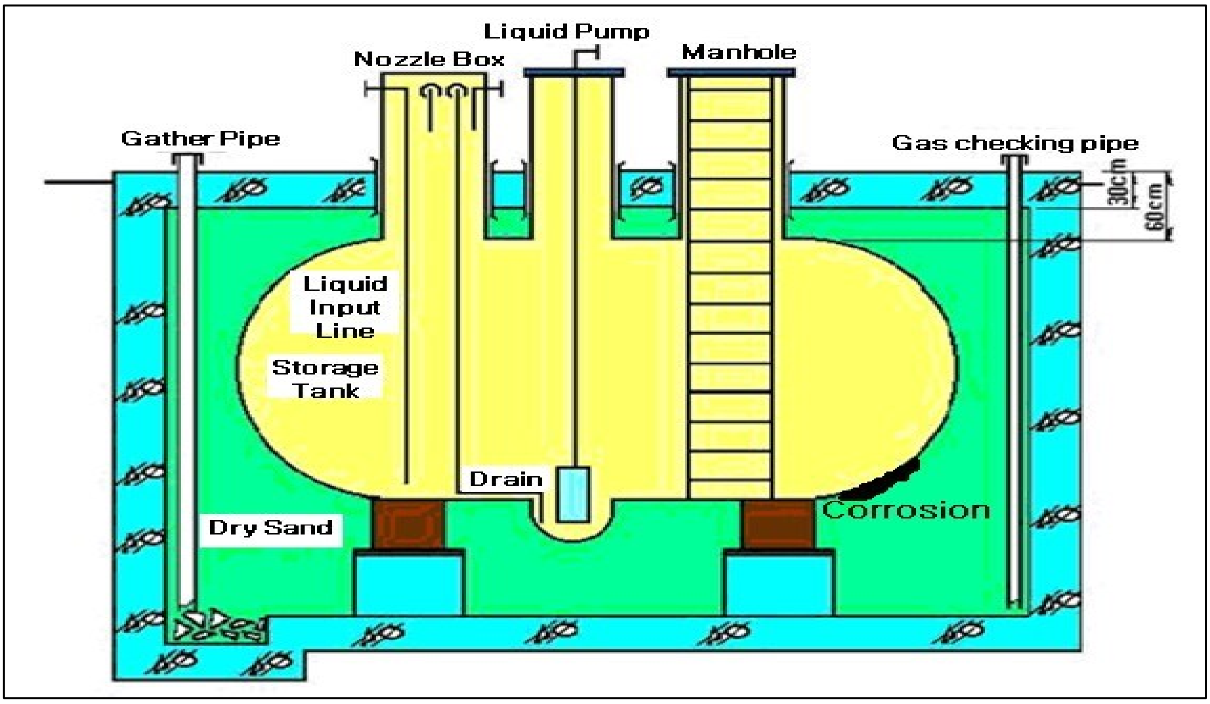


(a) Above ground type



(b) Underground buried type

Figure. 3. The Form of Existing Storage Tank.

3.2 Function analysis of the system

The functional analysis of the system is very importantly in the case when the technical challenges are not clear especially intertwined with its complexly. Especially, it is useful to represent schematically the contradictory relationship among parts or modules of complex systems.

Figure 4 is shown schematically problems and contradictions in the relationship of the above and buried underground type storage tank.

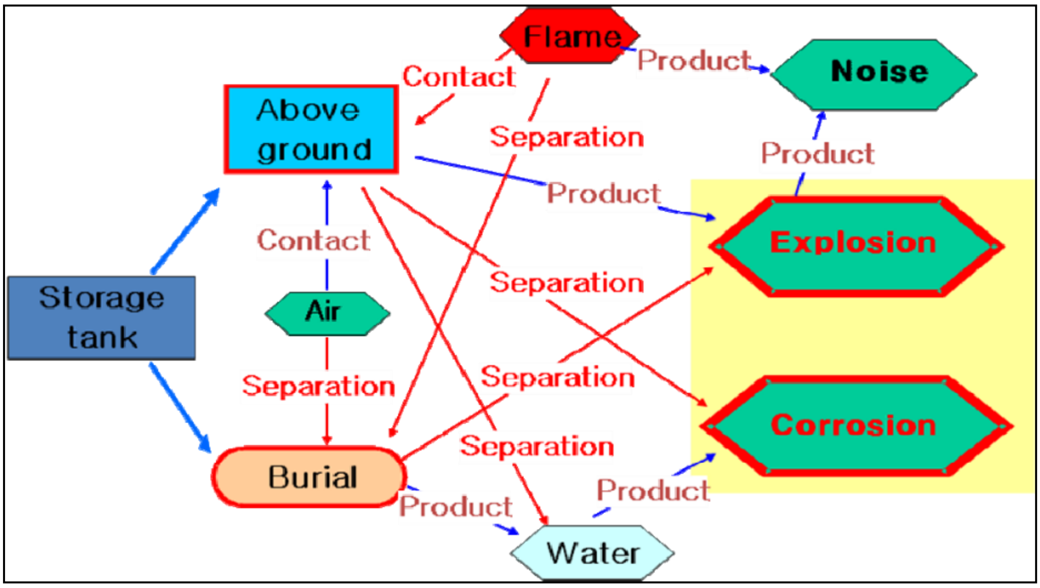


Figure 4. Composite Function Analysis of the System.

3.3 Ideal Final Result

The concept of the ideal final result is based on the law that Altshuller first formulated as follows: "The development of all systems proceeds in the direction of increasing the degree of idealness." This definition is start with the ideality equation (1).

$$Ideality = \frac{\sum Benefits}{\sum Costs + \sum Harm} \quad (1)$$

The formula generalizes numerous expressions presented to describe the level of technologies, inventions, and solutions. It was adapted from the value equation of Techniques of Value Analysis and Engineering in the early 1950s.

All systems have the ability to perform useful results and harmful effects at the same time. The Greek symbol Σ means "the sum of", so this equation reads, "ideality is the sum of all benefits divided by the sum of all costs and all harm." Useful features are that all the features you want in the system and harmful functions are the undesired results triggered from system cost, space, other pollution, and energy consumption.

IFR (Ideal Final Result) is a good methodology to escape from the stereotypes about problems and it is a system that does not exist while performing the required function.

3.4 Contradiction and the principle of separation

If you try to improve one attribute of the system, the other characteristics of the system deteriorate the situation. These contradict situation is one of the important concepts of TRIZ. it consists of two kinds; the technical contradiction and the physical contradiction. In this paper, the problem was resolved by solving 'physical conflict' having high utility.

LPG storage tanks must need to save the gas but it should not be for safety. The above ground type storage tank has dangerousness of an explosion caused by fire, so it should not be on the ground and the buried underground style should not be buried underground due to the economic loss by its corrosion. Therefore, storage tank should not be on the ground and buried underground.

3.5 Element-Interaction

Figure 5 is shown the element for interaction between above ground type and buried underground style. Element-interaction is a new methodology which can analyze in depth the problematic nature of each element. If you take advantage of this method, it is likely to find new technology separating from existing techniques.

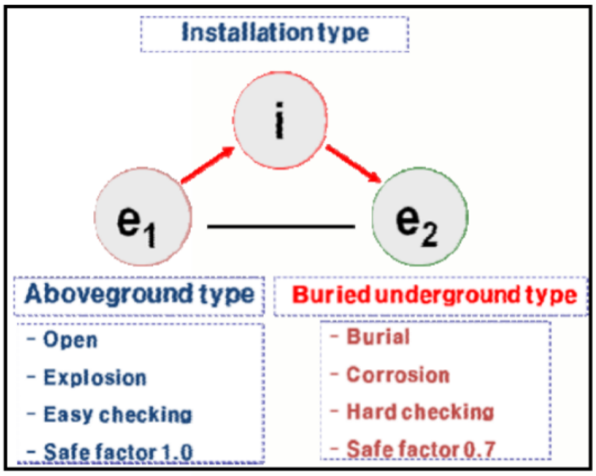


Figure 5. Elements-Interaction.

3.6 Evaluation and solution

Step 6 of 6SC is the final step to select and evaluate different solutions for the main problems.

Figure 6 shows the form optimized the issues of conflict and supplement of Figure 2. We can see in this graph that the problem of “the risk of exposing to fire” associated with above-ground type is ruled out and the problems of “economical issues from inspecting outer tank surface and the danger of corrosion and examination” associated with buried underground style is solved.

4. Conclusions

In this paper, the practical TRIZ 6 steps were implemented to solve the problems of LPG storage tanks. The problems of safety and economy are settled by using 6SC and the following effects are expected.

1. Underground containment type compared to the existing style is considered to shorten the construction period by improving the ability of working. Also the economic benefits will occur because it doesn't necessary to attach the sand.
2. Safety accidents could be prevented compared to conventional buried underground type thanks to the convenient operations.
3. It is expected to be more cost effective by reducing land area for charging facilities applied to the current legal regulations for the above-ground type.
4. It does not cause economic losses due to shell-type test cost of buried underground tank applied to legal regulations and it can rule out the risk of corrosion.
5. Containment type storage tanks contribute to vehicle filling business activation by social incongruity decrease of existing ground style storage tank.

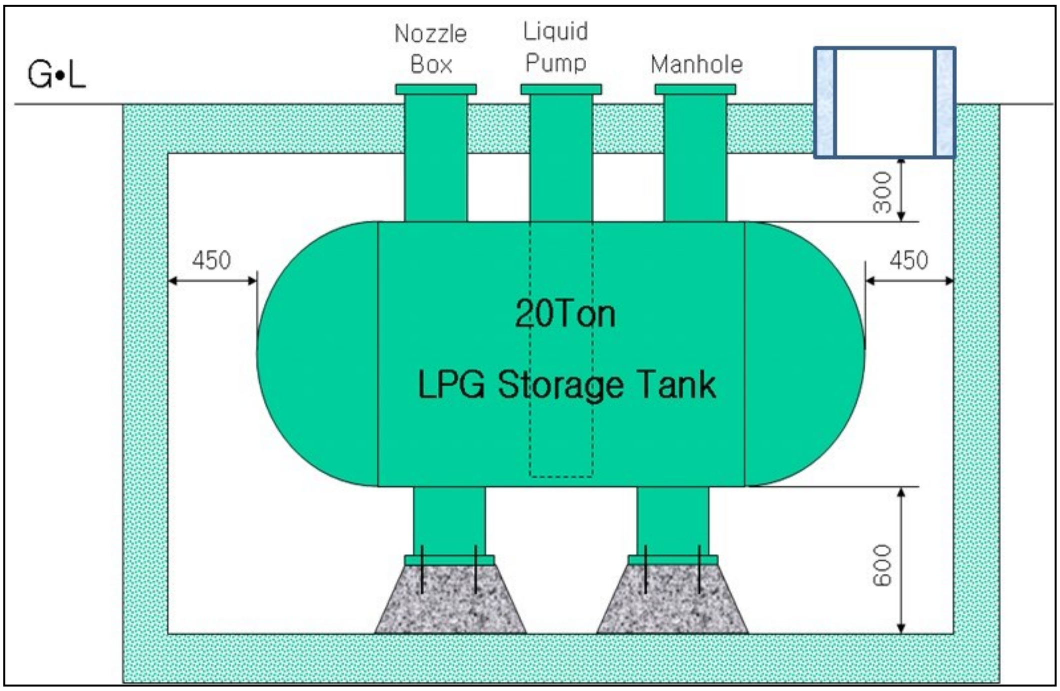


Figure 6. The Form of Improving Storage Tank.

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