



Study of Value Engineering Creativity Phase for Highway Project by Using TRIZ Techniques

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ABSTRACT : The creativity phase of Value Engineering is critical to the success of a value engineering exercise, wherein the brainstorming technique is deployed to generate ideas. But the brainstorming technique lacks direction in problem solving, and consequently the efficiency is low in generating innovative and useful ideas. This paper has explored the possibility of incorporating the theory of inventive problem solving (TRIZ) into the workshop session of the value engineering creativity phase.

The paper has developed a Value Engineering (VE) process, which applies the TRIZ and integrates its creativity tools into the creativity phase of the VE workshop session and thus makes the creativity phase more systematic, more organized and more problem-focused. This attempt will significantly enhance the creativity power of the VE team beyond their collective capability and consequently enhance the efficiency and effectiveness of the VE creativity phase.

A case study of highway project has indicated the workability of the modified VE creativity phase procedures and the usefulness of TRIZ tools and techniques in efficiently and effectively creating innovative ideas.

Keywords: Value Engineering, Creativity Phase, TRIZ, Workshop Session, Innovative idea.

NOMENCLATURE

1. TRIZ - Theory of Inventive Problem Solving
2. VE - Value Engineering
3. Su-field - Substance Field

I. INTRODUCTION

At present, the construction industry has become a trillion-dollar business worldwide. VE has been widely practiced in the construction industry and has become an integral part in the development of many projects. The outcome from VE exercise often improves the value of a project without compromising its designed functions.

The creativity phase of VE relies to a great degree on a brainstorming process. One assumption is that quantity will bring quality, i.e., the brainstorming process will generate a large number of ideas and some of these are innovative. Consequently, a substantial amount of the time and effort of the VE team is spent on free thinking in order to create as many ideas as possible. However, most of these ideas will eventually be proven useless as they are irrelevant to the problems of the project. This, in a sense, indicates a kind of waste and inefficiency in the VE exercise.

In an attempt to increase the efficiency of the VE exercise, this paper has explored the applicability of the TRIZ in VE's creativity phase through a case study of highway project. This attempt is made in view of an important feature of various TRIZ tools and techniques, generating creative ideas. This feature may complement the free-thinking brainstorming process in a VE exercise to

enhance the efficiency and effectiveness in generating innovative ideas.

II. THEORY OF INVENTIVE PROBLEM SOLVING

(A) TRIZ concepts

TRIZ is a Russian language acronym for Teoriya Resheniya Izobreatatelskikh Zadatch. Translated into English it means "The Theory of Inventive Problem Solving" [9]. It was initially developed in 1946 by Genrich Altshulle, who had studied more than 200,000 patents and found that some fundamental principles had appeared repeatedly in inventions from different industries and in different years and that the most creative patents had been embedded with solutions that satisfy contradictory requirements [10]. He extracted and compiled these fundamental principles behind those inventions into an organized body of knowledge called TRIZ. As a knowledge-based system, TRIZ includes a set of tools and techniques.

(B) General problem solving model and tools of TRIZ

All TRIZ tools follow the general problem-solving model illustrated in Fig. 1 [15, 17]. Rather than directly seeking solutions to resolve current problem, TRIZ first identifies the current problem. Then, the problem must be formulated in order to link it with certain analogous standard problems which have already been solved. As a result, a set of analogous standard solutions will be acquired from the TRIZ knowledge database. Finally, these known solutions will inspire users to find practical solutions in resolving their own problems. Then, this particular problem

is abstracted into one of the three types of standard problems: (1) a technical contradiction, (2) a physical contradiction, and (3) a substance-field model. Further, a couple of standard solutions may be found for this particular problem by examining all the standard solutions provided by TRIZ for that type of standard problems. For example, there are seven standard solutions to solve a substance-field problem [7, 17], 40 inventive principles to solve the technical contradiction problem, and four separation principles to solve the physical contradiction problem. The standard solutions are evaluated against the nine technological evolution trends to further enhance the ideality of the standard solutions. Finally, the problem solver will come out with a solution that is practical to the particular problem based on his/her experience and expertise.

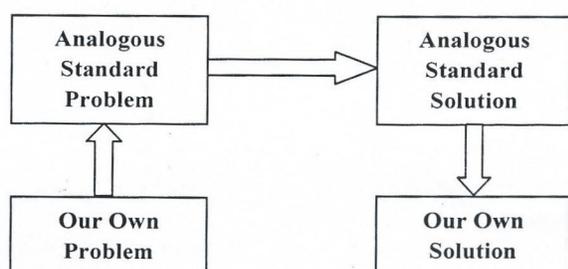


Fig. 1. General problem solving model(Zhang 2009 & Tong 2006).

III. DEVELOPING THE VE PROCESS

(A) VE process

VE is a structured problem solving process based on function analysis to improve the value of a system. Value is defined by a ratio of function to cost and consequently it can be increased by either improving the function or reducing the cost. The VE study is normally conducted by a team of members of multi-disciplinary experience and expertise. First, the VE team establishes the functional relationships in a system through a "how-why" questioning technique. Then, the VE team develops a matrix of the various functions of the system against their associated costs. The value of the system is maximized by an optimal tradeoff between the functions and their associated costs. In the context of construction, the objective of the VE study is to achieve the necessary functions with the lowest project life cycle cost. This may be done through the use of new material, creative design, simplified construction process, innovative construction method, reduced construction cost and time, improved construction quality and safety, and minimal environmental impacts [16].

A VE study includes three sessions, pre-workshop, workshop and post-workshop. Each session in turn has some phases. For example, the workshop session includes three phases: information and function analysis phase, creativity phase and evaluation phase. It is generally

recognized that the creative phase of the workshop is the most critical phase that determines the success or failure of a VE study because it is in this phase that creativity techniques are applied to generate innovative ideas for enhanced project functions and reduced project costs [8, 17].

(B) Weaknesses of traditional VE process

A traditional VE study mainly relies on free-thinking techniques (e.g., the brainstorming technique) to generate creative ideas and solutions, and it usually starts from scratch without adequately utilizing the knowledge and results generated from previous VE studies partly because the lack of a Knowledge Management System. Obviously, the chance of generating an innovative solution is limited by the current VE team members' experience, knowledge and creativity. Furthermore, in a traditional VE study, little effort is made to understand the essential problems of a project. Therefore, there is no guidance on the direction in which the search for effective and robust solutions is efficient. To overcome these shortcomings, it is proposed in this paper to incorporate the TRIZ tools in the creativity phase of the VE study to make this phase more systematic and more organized and enables the VE team to control the creative process. This attempt will significantly enhance the creative power of the VE team beyond their collective knowledge and imagination power, which is confirmed by [11] 2010 who believe that TRIZ has the potential to generate more innovative ideas and enhance the efficiency and effectiveness of the VE study.

(C) Modified VE workshop session

To improve efficiency and effectiveness, the workshop session of VE is significantly modified by incorporating TRIZ tools and techniques, whereas the pre workshop and post workshop remain the same as in a conventional VE process. As illustrated in Fig. 2 the modified workshop session consists of five phases: initial design, function trimming, interaction analysis, creativity and idealization, and evaluation. A case study of highway project has been undertaken to prove the workability of modified workshop session procedures of creativity phase and the usefulness of TRIZ tools and techniques in efficiently and effectively creating innovative ideas.

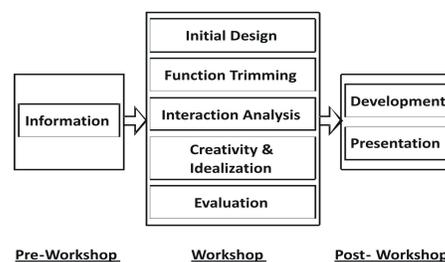


Fig. 2. VE modified workshop session (Mao 2009).

IV. PROCEDURES OF THE DEVELOPED VE CREATIVITY PHASE

As discussed in previous sections, TRIZ concepts and tools are incorporated into the VE to enhance the creativity

phase of the VE process. The procedures to conduct this improved creativity phase are shown in Fig. 3 which are subsequently discussed with help of the case study of highway project.

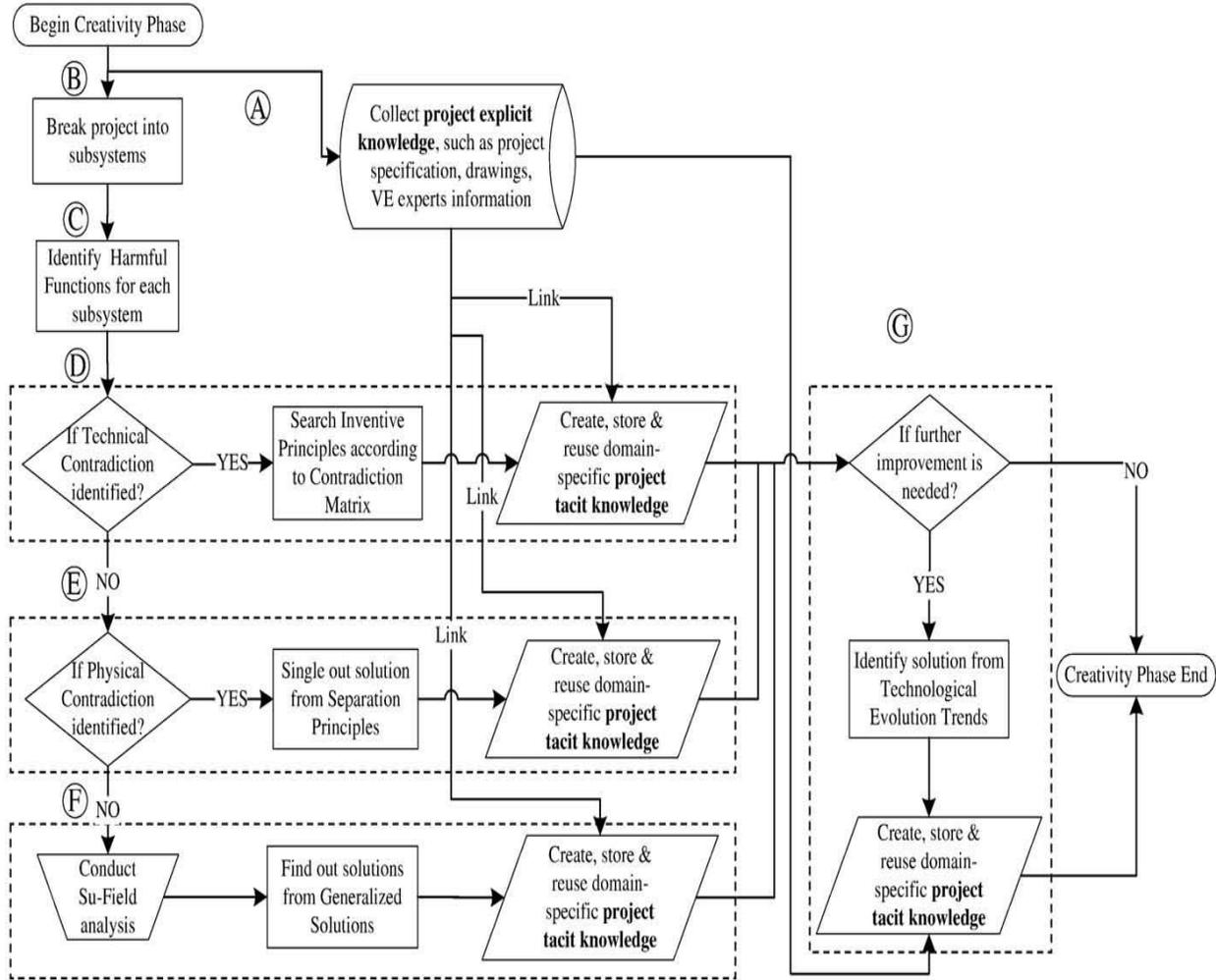


Fig. 3: Procedures of the modified VE creativity phase (Zhang 2009).

Case Study: Highway Project

The four lane highway construction project has undertaken between Ahmednagar to Shirur. The said project is located in the Ahmednagar district (Maharashtra State). The basic purpose of the project is to increase the capacity of existing two lane highways. The difference in the modified VE process from that of the traditional VE process lies in the workshop session. The study demonstrates how to conduct the creativity phase of modified workshop session in a VE exercise.

A. Collect project specific knowledge and VE team information

This step collects and stores the project specific knowledge and VE team information currently available. This knowledge is linked to the project discipline specific solutions obtained from the VE study in the database at

the end of the creativity phase. Meanwhile, VE members' contact information and their expertise are attached to their project-specific solutions so that these experts can be easily identified and reached when their knowledge and expertise are needed in the future.

For this project the VE related information is taken from client through questionnaire survey and is shown in Table 1.

Table 1: Salient features of the highway project.

S. No.	Salient Features	Details
1.	Type of Pavement	Flexible - Bitumen
2.	Length & Width of Highway	56 Km. & 7.5 m
3.	(a) Cost of Project (Estimated)	Rs. 155 Cr.
	(b) Cost of Project (Actual)	Rs. 180 Cr. till date
4.	Name of Client	P.W.D., Ahmednagar
5.	Name of Contractor	Chetak Enterprises
6.	Opinion Authority	Client, Asst. Engg.

B. Break project into subsystems

According to TRIZ, a project consists of a group of subsystems that provide various functions. The second step breaks down a project into subsystems down to a level at which project functions can be sufficiently identified and properly analyzed. This can be done based on a hierarchical analysis. For example, a building project could be either broken down based on the disciplines of its components or based on their physical nature (*e.g.*, foundation, floor, wall and roof). This step facilitates the categorization of various solutions into specific domains to make the knowledge retrieving process more efficient and effective.

The said project is divided into eight subsystems like town pass, intersection of roads, village pass, ghat pass (Gentle slope), farm pass, ghat pass (Steep slope), banking and river cross. Here, only one subsystem intersection of roads (Kinetic Chowk) is considered. The basic function of this subsystem is to provide quick access to all routes.

C. Identify harmful functions in each subsystem

Function analysis in TRIZ is a modification of original function analysis in VE, utilizing the same basic approach to modeling a system in terms of components and functions they deliver [12]. However, "function" in TRIZ has a different definition from that in VE. In TRIZ, function is defined as an effect of a physical interaction between two system components whereas in VE it is regarded as an action performed by a system component. This action is expressed in a two-word abridgment, in which an active verb describes what action is being done and a measurable noun indicates what the action is being done to. Due to this difference, in TRIZ there are the terms of "useful functions" and "harmful functions" while in VE there are the terms of "necessary functions" and "unnecessary functions". Function analysis of TRIZ has algorithms for ranking functions and formulating problems in the patterns required by other TRIZ problem solving tools. Harmful functions in each subsystem are first and then ranked in accordance with the VE team's level of intolerance [8, 17]. The intolerance level may be from 1 to 10, with 10 representing the most intolerable level. This ranking directs the attention and focus of the VE team on the most intolerable harmful functions. TRIZ tools will be deployed to generate technical solutions to remove the harmful functions or minimize them to a level below a threshold intolerance level, as be discussed in steps D to F. Different technical solutions will incur different costs. The solutions that have the highest benefit/cost ratios will be selected. Here the benefit means the intolerance level reduced by a particular solution.

The interaction analysis of VE workshop session has identified both useful and harmful functions associated with a project alternative. The summarized harmful functions or parameters for subsystem intersection of road are listed in Table 2.

Table 2: Summary of harmful functions

S. No.	Existing Resources	Harmful Functions
1.	Sewer	Increase flow
2.	Residents	Noise Complaint
3.	Land	Limit use of space
4.	Commercial Area	Decrease area
5.	Vehicles	Knowledge of use
6.	Environment	Reduce green area

D. Identify and solve technical contradictions

A technical contradiction represents the conflict between two parameters of a system/subsystem. This contradiction occurs when improving one parameter of a system/subsystem worsens another parameter. This means the measure taken to remove/minimize one harmful function will worsen another useful function. Two examples are:

1. A vehicle has higher horsepower but uses more fuel.
2. An electric vehicle can go long distances between recharging but the battery weight gets too high to move at all.

A conventional approach to solve this dilemma is to seek a compromise between the two parameters. However, this is not an ideal solution. To find better solutions, TRIZ has identified 39 engineering parameters and 40 inventive principles (Refer to in Appendix), based on which a 39×39 contradiction matrix is developed and shown partially as in Fig. 4 [2, 5].

In this matrix, the 39 parameters are listed on the horizontal axis in a worsening feature and on the vertical axis in an improving feature, and some of the 40 inventive principles are located at the cross point of the column and row. These inventive principles solve the contradiction represented by the parameters on the corresponding vertical and horizontal axis. Specifically, the corresponding principles improve the parameter on the vertical axis without worsening its counterpart on the horizontal axis. For a particular system/ subsystem, once a pair of contradicted parameters is identified, the corresponding inventive principles can be obtained from the contradiction matrix. These principles will guide the direction to search for the most innovative solutions to this contradiction.

The harmful function 'Increase flow of sewer' is treated as technical contradiction. To solve the problem of increase in flow of sewer, one contradiction is found from the contradiction matrix. Contradiction is between Parameter 7 (*i.e.* Improving parameter-Volume of moving object) and Parameter 31 (*i.e.* Worsening parameter-Object generated harmful factors). This contradiction is further expressed as "Increased flow of sewer harmful to overflow of waste water." The contradiction matrix shown in Fig. 4 provides four inventive principles (1. Segmentation, 2. Taking out, and 17. Another dimension and 40. Composite material) to

Improving Engineering Parameter	Worsening Engineering Parameter	...	Speed	Force	Tension/Pressure	Shape	...
			9	10	11	12	
	∴	-					
9	Speed		-	13, 28, 15, 19	06, 18, 38, 40	35, 15, 18, 34	
10	Force		13, 28, 15, 12	-	18, 21, 11	10, 35, 40, 34	
11	Tension/Pressure		06, 35, 36	36, 35, 21	-	35, 04, 15, 10	
12	Shape		35, 10, 37, 40	35, 10, 37, 40	34, 15, 10, 14	-	
	∴						-

Fig. 4. Partial contradiction matrix (Domb 1997 and Chang 2004).

solve contradiction. After examining these inventive principles, it is realized that two of them, 1 and 17, may have the potential to resolve the contradiction. Table 3 provides the possible solutions to the contradiction as

provided by the writers based on the two inventive principles, which are compared to the general solutions as provided by TRIZ for the two inventive principles. The recommended solution for contradiction is summarized in the Table 3.

Table 3: Summary of technical contradiction - Increase flow of sewer.

S. No	Harmful functions	Improving (I) and worsening (W) features	Inventive Principles	TRIZ solutions	Recommended solutions
1.	Sewer - Increase in flow of sewer	I: Volume of moving object	#1 segmentation	#1. Increase the degree of fragmentation or segmentation.	Increase capacity of existing sewer line.
	Contradiction- Increased flow of sewer harmful to overflow of waste water.	W: Object generated harmful factors.	#17. Another dimension	#17. Use a multi-story arrangement of objects instead of a single story arrangement.	Make an additional drainage line.

(# Serial number of respective TRIZ tools principle from appendix)

E. Identify and solve physical contradictions

A physical contradiction results from incompatible requirements on the same parameter of a system/subsystem, i.e., this parameter is required to be modified in two opposite directions to remove or minimize a harmful function e.g. a highway should be wide enough for easy traffic flow but narrow for low impact on communities.

Physical contradictions do not occur as frequently as technical contradictions. Although a physical contradiction sometimes can be converted to a technical contradiction, it is differentiated as a separate stream for better knowledge management.

TRIZ provides four general separation principles to solve physical contradictions [6]:

1. Separation in time.
2. Separation in space.
3. Separation between the whole system and its parts.
4. Separation based on different conditions.

These principles help in finding a solution to a physical contradiction.

Harmful function "Land: limits in use of space" treated as "Physical contradiction" by analyzing interaction analysis phase. To find better option, use four separation principle to minimize said physical contradiction. After examining the four separation principles, it is realized that the principle of "separation in time" is applicable in solving this contradiction. Results of TRIZ solution and recommended solution are summarized in Table 4.

F. Conduct substance-field analysis

The components of a technical system perform various functions (as mentioned earlier, a function in TRIZ refers to the interaction between two components). There are mainly five types of interactions (useful, harmful, excessive, insufficient, and transformation) among which useful and harmful interactions are the common ones [10]. In substance-field analysis (Su-field), an interaction is graphically represented by a triangular model after abstractizing the two components and their interaction. As shown in Fig. 5 (a), the substance-field model includes two substances (*i.e.*, an object S_1 and a tool S_2) and a field. The field is a kind of energy that acts on the tool to modify its interaction with the object. The field can be mechanical, acoustic, thermal, chemical, electric, magnetic, or electromagnetic. If the field is generated by a hidden substance, the triangle could be simplified into a dumbbell shape with the field indicated on top of the arrow and the interaction indicated underneath the arrow, as shown in Fig. 5 (b). A complex system can be modeled using multiple connected substance-field models. In general, there are four basic types of substance-field models [14]:

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 enhance certain useful interaction, and
4. A complete system that requires the elimination of some harmful or excessive interaction.

Once su-field models are developed, it is possible to identify the system's problems generically through further analysis. Su-field analysis is often used when a harmful function cannot be explained by a technical or physical contradiction. The objective of such an analysis is to maintain/strengthen useful functions and eliminate/minimize harmful functions. It first checks whether any of the three elements (tool, object and field) of a su-field model is missing or whether there are undesired interactions in the system. Then, it points out the direction for improving the system.

TRIZ recommends 76 inventive standards (typical patterns) for solving problems associated with su- field models. To facilitate su-field analysis and increase efficiency, Mao (2007) have condensed the 76 inventive standards into seven general ones [7]:

1. Completing an incomplete substance field model,
2. Modifying the tool to eliminate or reduce the harmful function,
3. Modifying the object to be insensitive or less sensitive to the harmful function,
4. Changing the existing field to reduce or eliminate the harmful function,
5. Eliminating, neutralizing, or isolating the harmful function using another counteractive field,
6. Introducing a positive field, and
7. Expanding the existing substance-field model to a chain.

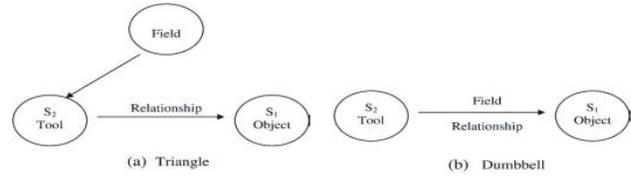


Fig. 5. Basic substance-field model (Zhang 2009).

The harmful function "Residents: Noise complaint" is neither technical nor physical contradiction for this project. Therefore, it is minimized by using Su-field analysis (*i.e.* to use seven generalized solutions). To solve this problem, the interaction between the noise and the residents are represented in a Su-field model as shown in Fig. 6 (a). The noise (the tool) acts upon the residents (the object) using an acoustic field. To remove this harm, a counteractive field may be introduced and shown in Fig. 6 (b), by installing

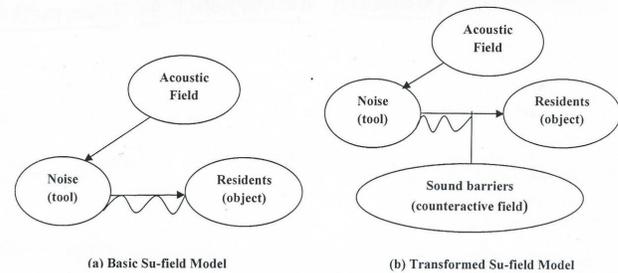


Fig. 6 Su-field model for harmful function 'Residents: Noise complaint'.

sound barriers around the surrounding area. The detail of TRIZ solution and recommended solution is summarized in Table 4.

Table 4: Summary of solution of harmful functions for intersection of roads.

S. No.	Harmful functions	TRIZ tool	TRIZ general Solution	Recommended Solution
1.	Residents-Noise Complaint	Su-Field Model	#5.Eliminate, neutralize, or isolate harmful impact using another counteractive field	Sound Barriers around Traffic circle
2.	Land-Limit use of space	Physical contradiction	#2. Separation in time, Inventive Principle: #10-Preliminary action	Negotiate by from current owners.
3.	Commercial Area-Decrease area	Physical contradiction	#2. Separation in time, Inventive Principle: #19-Preliminary action	Resone land
4.	Vehicles-Knowledge of use	Su-Field Model	#5. Eliminate, neutralize, or isolate harmful impact using another counteractive field	Fix appropriate signs
5.	Environment-Reduce green area	Su-Field Model	#6.Introduce a positive field	Build a park in the center of circle

(# Serial number of respective TRIZ tools principle from appendix)

G/ Improve the project according to technological evolution trends

TRIZ holds that a technical system develops according to objective laws that have been used in different fields in various formats for a long time. Consequently, TRIZ condenses these laws into nine evolution patterns:

1. Life cycle of birth, growth, maturity and death,
2. Systems evolving toward ideality,
3. Uneven evolution of system components,
4. Increasing dynamism,
5. Increasing controllability,
6. Increasing complexity, followed by simplicity through integration,
7. Matching and mismatching of parts,
8. Transition from macrosystems to microsystems, and
9. Decreasing human interaction and increasing automation [8].

The nine evolution patterns allow VE team members to transform a subjective system improvement process into a search for the steps to fill the gap between the existing system and the desired system.

Therefore, the eight patterns of evolution may be applied to improve the solutions originated from other TRIZ tools and techniques. The following provides an example of how to deploy the patterns of evolution to improve the solution from the Su-field analysis for harmful interaction "Environment: Reduce green area by building a park in the center of circle."

1. Building the park with water distribution and cleaning system. This idea may be prompted by pattern of evolution (2) - systems evolving toward ideality. There is daily requirement for every park to clean area and water for growing plants.
2. Upgrading the material of the park. This idea may be prompted by pattern of evolution (3) - uneven evolution of system components. Growing problems of plants is major concern for park. To reduce this upgrades the soil and use domestic fertilizers.
3. Fencing to entire Park for increasing the dynamism and controllability of the park. This idea may be prompted by pattern of evolution (4) - increasing dynamism and

controllability.

4. Automating the whole park's water distribution system. This idea may be prompted by pattern of evolution (8) - decreased human interaction and increased automation. Installing automatic sprinkler or drip irrigation system for the water distribution will enhance the efficiency and effectiveness in operating the park.

Table 4 summarized the TRIZ general and recommended solutions to other harmful functions for the system intersection of roads.

V. CONCLUSIONS

VE has been practiced for half a century in the construction industry, which is still practicing VE in the same fashion as it was 50 years ago. The creative phase of the VE workshop determines the success or failure of a VE study. There is a need to improve the efficiency of the VE practice for better outcomes. This paper discuss modified VE workshop session by incorporating TRIZ techniques into the creativity phase traditional VE exercise.

TRIZ is a methodology and tool set for generating innovative ideas and solutions for problem solving. These tools provide systematic approaches and generic principles to formulate and analyze problems, generate creative ideas, and forecast the evolution trend of a system or project. These include:

1. 40 inventive principles for resolving technical contradictions,
2. Four inventive principles for physical contradiction elimination,
3. Seven generalized standard solutions for substance-field analysis, and
4. Nine laws and trends of technology evolution.

A case study of intersection of road for highway construction has been conducted to demonstrate the proposed workshop procedures and the application of the TRIZ tools and techniques. The case study indicates the workability of the modified VE creativity phase procedures and the usefulness of TRIZ tools and techniques in efficiently and effectively creating innovative ideas.

Appendix: 39 Features and 40 Inventive Principles (Spain 2004 & Apte 2008)

List of the 39 Features	List of the 40 Inventive Principles
1. Weight of moving object	Principle 1. Segmentation
2. Weight of stationary object	Principle 2. Taking out
3. Length of moving object	Principle 3. Local quality
4. Lengths of stationary object	Principle 4. Asymmetry
5. Area of moving object	Principle 5. Merging
6. Area of stationary objects	Principle 6. Universality
7. Volume of moving object	Principle 7. "Nested doll"
8. Volumes of stationary object	Principle 8. Anti-weight
9. Speed	Principle 9. Preliminary anti-action
10. Force	Principle 10. Preliminary action
11. Stress or Pressure	Principle 11. Beforehand cushioning
12. Shape	Principle 12. Equipotentiality
13. Stability of the object's composition	Principle 13. The other way round
14. Strength	Principle 14. Spheroidality - Curvature

- | | |
|---|--|
| 15. Duration of action by a moving object | Principle 15. Dynamics |
| 16. Duration of action by a stationary object | Principle 16. Partial or excessive actions |
| 17. Temperature | Principle 17. Another dimension |
| 18. Illumination intensity | Principle 18. Mechanical vibration |
| 19. Use of energy by moving object | Principle 19. Periodic action |
| 20. Use of energy by stationary object | Principle 20. Continuity of useful action |
| 21. Power | Principle 21. Skipping |
| 22. Loss of Energy | Principle 22. Turn Lemons into Lemonade |
| 23. Loss of substance | Principle 23. Feedback |
| 24. Loss of Information | Principle 24. 'Intermediary' |
| 25. Loss of Time | Principle 25. Self-service |
| 26. Quantity of substance/the matter | Principle 26. Copying |
| 27. Reliability | Principle 27. Cheap short living objects |
| 28. Measurement accuracy | Principle 28. Mechanics substitution |
| 29. Manufacturing precision | Principle 29. Pneumatics and hydraulics |
| 30. External harm affects the object | Principle 30. Flexible shells and thin films |
| 31. Object-generated harmful factors | Principle 31. Porous materials |
| 32. Ease of manufacture | Principle 32. Color changes |
| 33. Ease of operation | Principle 33. Homogeneity |
| 34. Ease of repair | Principle 34. Discarding and recovering |
| 35. Adaptability or versatility | Principle 35. Parameter changes |
| 36. Device complexity | Principle 36. Phase transitions |
| 37. Difficulty of detecting and measuring | Principle 37. Thermal expansion |
| 38. Extent of automation | Principle 38. Strong oxidants |
| 39. Productivity | Principle 39. Inert atmosphere |
| | Principle 40. Composite materials |

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