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A comparison between the Functional Analysis and the Causal-Loop Diagram to model inventive problems

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Abstract

The pressure of the market, the exigencies of the society, and the environmental restrictions ask for new problem-solving approaches. In this context, the Theory of Inventive Problem Solving (TRIZ) offers several advantages: it is a knowledge-based approach for problem-solving that links the problem requirements with some engineering models to guide the solving process. However, the learning process of TRIZ and its use with a practical purpose reveal many drawbacks. A significant problem, while using TRIZ, emerges when the user needs to analyze and formulate an inventive problem. To deal with this issue, a combination of TRIZ with other tools seems the best strategy. The use of the Functional Analysis (FA) is one of the best examples. Despite the usefulness of the FA technique, a difficulty remains: it is a complex task to model the causal relationship between several parameters or conditions within a system. However, a tool used in the System Dynamics Modeling deals well with this situation. The System Dynamics (SD) analyzes the nonlinear behavior of complex systems over time. Congruent with recent TRIZ advances, the SD is a computer aided-approach with an extended application domain, practically in any complex system-social, managerial, economic or natural system defined by some relationships, a flow of information, and some effects of causality. Hence, SD can produce useful information when there are several conflicts in a system, also called a problem network. SD uses a graphical tool to model the variables and states of a system: The Causal-Loop Diagram. This tool is helpful to explain a conflict, the change of a system, or merely the interactions that take place to obtain an effect. This article presents a comparison between the Functional Analysis and the Causal-Loop Diagram to model inventive problems.

Keywords: Modeling; Design method; Analysis

1. Introduction

The society, the pressure of the market, and the environmental restrictions ask for new problem-solving approaches capable of efficiently respond to more complex challenges. The Theory of Inventive Problem Solving (TRIZ) is useful when there is a need to solve problems that lead to an impasse or a situation where the available knowledge does not produce a satisfactory solution [1]. The TRIZ Toolbox can address different problems: (a) conflicts modeled as physical and technical contradictions [2], (b) situations modeled as functions via the Substance-Field Analysis (SFA) [16], and (c) situations where it is necessary to define the potential changes in a system via the Trends of Evolution analysis (ToE) [11]. However, some inventive problems demand a more in-depth and detailed analysis than that of the classic TRIZ tools. To respond to this challenge, a complementary tool capable of producing a synergy with TRIZ is the Functional Analysis (FA). FA is an analytical tool used in the Value Engineering (VE) approach and later modified to fit the TRIZ requirements for modeling technical systems through their functions and system components [13]. The FA objective is to analyze and

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represent graphically the relations that take place within a system to produce at least one primary function or desirable effect. This information uncovers new resources that are valuable to understand, analyze, and hierarchize the internal relations of the system. The FA leads to the identification of problems related to the operation of a system, to determine where are functions that do not add value to the system or where there is a superfluous utilization of available resources [13]. There are several works that apply FA. [8] Propose a new methodology for identifying necessary functions based on Function and Behavior Representation Language (FBRL), and a method to use the functional diagram. The result of this research is a new method for applying FA, and use it in the field of agricultural machinery. [19] Uses the methodology of the VE and the FA to find solutions to the water shortage in Egypt. This work includes the development of some ideas based on evaluation criteria, data collection, analysis of channel functions, and an economic study to analyze the feasibility of the project. The result of the investigation originated a potential solution based on the primary function of the system. [12] Models a system through the FA and analyzes the possibility of applying VE in road projects. The need arises because projects in this field frequently have a significant delay, the costs exceed the original budget, and the results are not efficient. Therefore, the methodology searches for solutions to the problem from different perspectives: the cost analysis, the time planning, and the application of original ideas. The results of the research revealed the possibility to reduce costs and to increase the yield of the project benefits based on the VE methodology. [9] Develops a model with the help of FA to apply the VE approach in the construction industry. The modeling effort focuses on the quality, cost, and positive impacts on the environment. In its search for sustainable applications and measures, the VE allowed a reduction of 20% to 30% on the costs and a reduction of 7% of the total energy consumption. [18] Proposes an FA model and applies the VE methodology to explain the effects of drainage coatings (DC) on the environment. Based on the product lifecycle cost methodology, it evaluates two alternatives for drainage: surface and crust. The results show the best alternative to reduce the environmental damage using VE. Despite its usefulness, the FA and the TRIZ tools have some significant limitations: (1) In both techniques, it is not possible to model problems that change concerning time; (2) it is not possible to see if a cause has a positive or negative effect on the variables included in a model, and (3) when there are multiple conflicts, these techniques cannot determine which problem is more relevant. Based on the above limitations, the research problem focuses on to demonstrate that it is feasible to model inventive problems and collect more information to facilitate the problem-solving process. The hypothesis of this work explains that it is possible to combine the TRIZ tools with an approach capable of addressing these limitations: The System Dynamics (SD) Modeling. It is necessary to underline that the combination of TRIZ with System Dynamics is an emergent research topic, a situation that emphasizes the originality of this work.

2. Background

Forrester proposed the SD in the 1960s [6]. SD is a technique for analyzing and modeling temporal behavior in complex environments. It is based on the identification of feedback loops between elements, as well as delays in information and materials within the system. SD proposes a four stages methodology for creating dynamic simulation models: (1) Conceptualization, (2) Formulation, (3) Evaluation, and (4) Implementation [7,14]. One of the steps within the conceptualization stage is the development of the Causal Loop Diagram (CLD). A causal diagram in its simplest form is an oriented graph. An arrow represents the causal link between the variables that it connects. A link has a polarity, which denotes the type of influence, either positive or negative. The use of signs in a relation is useful to propose dynamic hypothesis that will guide the constructions of some scenarios (problem solving paths). In a CLD there are positive (feedback) and negative (balancing) loops. The first type is in charge of feeding the system, while the latter stabilize it. Some works use SD to model the innovation process. [20] Develop an SD model that integrates the concept of innovation engines with the notion of "transition paths" as part of a multi-level thinking. [4] propose a two-stage technology foresight approach. During the first stage, critical technologies are evaluated and identified by national experts through Delphi surveys. In the second stage, an SD simulation model is used to estimate how critical parameters can impact the achievement of foresight and planning objectives. [21] Use SD for the creation of a model that analyzes the urban eco-economic system that includes economic sub-models, population, and sub-systems applied in the analysis of Beijing's sustainable development under different scenarios. The CLD diagram is part of the SD methodology, while the FA belongs to the VE analysis. However, both tools have a common purpose: to analyze the relationship between variables to represent the system behavior. The next section describes, as a case study, the analysis of an object where there are some conflicts. Table 1 shows a comparison between FA and CLD methodologies.

Table 1. Comparison between FA's and CLD's methodologies [14,22]

Phase	FA	CLD
1) Identification	● Identify functions. ● Classify functions.	● Identify level and auxiliary variables.
2) Analysis	● Function Models ● Establish Function Worth	● Establish causal relationships between variables.
3) Description	● Cost Functions ● Establish Value Index	● Define polarity between causal links. ● Identify feedback loops and roll loops.
4) Modeling	● Build FA diagram. ● Select Functions for study	● Build CLD diagram and use it to make Forrester Diagram.

The case study compares the modeling process between the FA and the CLD through the model of an everyday object. The purpose is to identify some advantages and limitations of both modeling approaches. The object described is a dry-erase marker. A market study demonstrates that the users have new requirements. The problem consists of increasing the useful lifespan of the object without negatively impacting its current dimensions. Thus, the enterprise that produces the object needs to design a new model to substitute the actual product in the market. The case study describes the two different modeling strategies to demonstrate the improvement areas of each approach. The first section of the case study utilizes the FA to model the dry-erase marker functions. Before to describe the model it is necessary to explain the terminology. It is important to underline that it is a common practice to use the nomenclature of the Substance-Field Analysis to build the Function Analysis diagram. The reason behind this decision is the possibility to link both techniques and connect the modeling stage with the solving process. Another advantage is the possibility to classify a relationship with the purpose to produce useful information to start the solving process. Table 2 shows the nomenclature used in the SFA. Each arrow has a particular meaning according to the modeling.

Table 2. The nomenclature used in the SFA [5,10].

Analysis	Nomenclature
1) Application	
2) Desired effect	
3) Insufficient desired effect	
4) Excessive	
5) Harmful effect	
6) Inexistent effect	
7) Transformation of model	
8) Uncontrolled effect	

3. Case study

The object selected for the case study is a dry-erase marker. It has eight components: the plug, shape, information, case, gripper, blocker, absorbent medium and ink (see Figure 1). Table 3 shows a brief description of each component. The names proposed are generic but the technical terminology is available in the patent US006048121A [3].

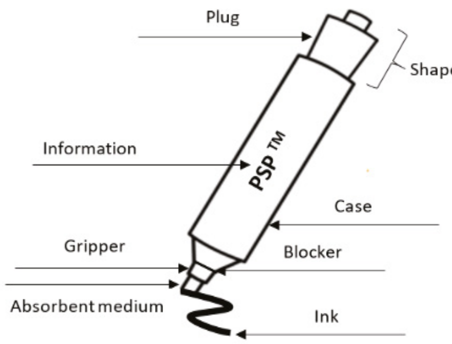

Fig. 1. Physical parts of a dry-erase marker

Table 3. Description of each one component and its function

Part	Description and function
Plug	It is the piece that isolates the top of the dry-erase marker. Function: to cover and contain.
Shape	Refers to the plug design pattern. Function: to hold
Information	Text or symbols printed on the surface of the dry-erase marker that includes recommendations, trademark, and instructions, among other information. Function: to transmit basic data
Case	It is the container that forms the body of the object. Function: to contain
Gripper	Small piece with a shape that fixes the absorbent medium into the case. Function: to contain
Blocker	Small notch whose function is to apply pressure to the plug to avoid axial movement. Function: to deform to produce pressure.
An absorbent medium	Spongy body that by capillarity retains and doses the ink. Function: to contain.
Ink	Colored liquid used to make a register on a surface such as glass, acrylic plastic or other surfaces. Function: to move over a surface.

3.1. Application of FA's methodology

According to Table 1, the construction of an FA diagram demands four phases. Next points describe each phase.

Identification: The primary function or mains useful function of the object is the reason to exist or the design intention of an object. Thus, any system will have at least one useful function. In the case study (dry erase marker) is to create an ink register on a non-absorbent surface to record some information. In turn, each component has a specific function that collaborates to produce the primary function. In addition to the description of the components, Table 3 also described the function of each item.

Analysis: All design process involves the identification of requirements. Table 4 or planning table allows the identification of the client's needs and represents them in an easy and simple format. The planning table combines the attributes of the product with the data offered by the client to rank all requirements.

Description: The study of cost functions and value index requires an analysis of primary, secondary functions, and the relative importance of the value added (frequently expressed as a percentage). This information is usually obtained with a market study [15]. This analysis allows the identification of the relative importance of each one of the demands and characteristics (primary and secondary of the product). Table 4 shows the characteristics, their weight, and importance through the planning table.

Table 4. Planning table.

Primary Characteristics	Primary Weight	Secondary Characteristics	Secondary Weight	Weighted Importance
Portability	0.20	Storable	0.35	0.07
		Shape	0.30	0.06
		Size	0.25	0.05
		Weight	0.10	0.02
Practicality	0.16	Ergonomics	0.19	0.03
		Weight	0.72	0.11
		Simplicity	0.08	0.01
Air tightness	0.20	Level pressure	0.63	0.13
		Adjustment	0.26	0.05
		Weight	0.11	0.02
Long useful life	0.14	Ink level	1.00	0.14

		Balance	0.67	0.09
Stability	0.13	Weight	0.24	0.03
		Support	0.09	0.01
Hardness	0.06	Resistance	0.83	0.05
		Design	0.17	0.01
		Type of ink	0.36	0.02
Environmental impact	0.05	Cover material	0.40	0.02
		Clean process	0.16	0.01
		Body material	0.08	0.00
		Color	0.66	0.02
Esthetic	0.03	Design	0.19	0.01
		Texture	0.16	0.01
Non-toxic smell	0.02	Type of ink	1.00	0.02
Summation	1.00			1.00

The planning table provides information about the weighted importance of each attribute and is used to make better decisions.

Modeling: A generic way of relating the system parts (Figure 1) with a conflict or desired state is through the nomenclature of Table 2. During the development of the FA diagram, are included verbs to denote the action that each component has on another. A relation represents then the function of each component. Figure 2 shows the FA diagram of the object.

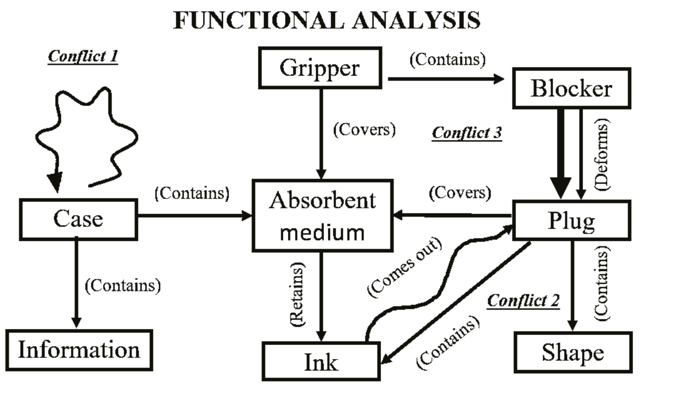

Fig. 2. FA diagram

The FA enables a graphical perception of the inventive problems in the system. Figure 2 suggests several inventive problems:

1. Conflict one: The enterprise wants to increase the useful function of the object in time. Hence, to increase the useful function means to increase the volume of ink stored in the absorbent medium inside the case. Nevertheless, this partial solution increases the total volume of the object, the production cost, and the image of the product in the market. Thus, the case should be bigger to increase the durability of the useful function but should be small to assure the object portability.
2. Conflict two: The plug must cover the top of the absorbent medium, which is the part that interacts with the surface to avoid damage or an undesirable contact between the ink and another surface. However, it should not cover the top to facilitate the useful function.
3. Conflict three: The plug must cover the top of the absorbent medium firmly to avoid accidental leakage of ink but must also be soft to be practical for anyone.

3.2. Application of CLD's methodology

Similarly to the creation of the FA diagram, the construction of the CLD encompasses four stages.

Identification: There are level and auxiliary variables within SD. According to Forrester and Sterman [7,14], an analogy to explain how dynamics modeling works within a system: let´s consider the system as a network of interconnected tanks. Each tank has an amount of water, an input rate, and an output flow that change over time. Hence, the variable level represents a container and has inputs and outputs. The flow and its rate vary depending on some inflows and outflows represented as valves and controls. The level per unit of time results from a differential equation. The valves are based on rates or parameters that consist of auxiliary variables that do not change in time. The identification of the level and auxiliary variables have an important role since it allows a classification of the variables that change in time and those that remain constant throughout the model.

Analysis: In this phase, it is necessary to define the causal relationships identified in the previous stage. The level variables have a primordial role because they generate feedback and balancing loops, which determine how the system changes over time. The level variables represent a differential equation regarding the time that elapses in each time interval.

Description: The CLD uses oriented graphs to identify feedback loops. In this graph, an arrow represents the causal link between some variables. It also has a polarity that denotes the type of influence, whether positive or negative. Figure 4 depicts the relations between two variables and its polarity.

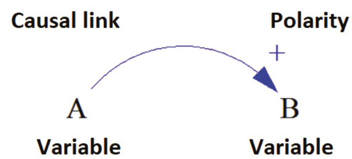

Fig. 3. Polarity between two variables

Figure 3 represents the basic structure of a CLD. There is a causal link between variable A and B with positive influence. Hence, if the variable A increases, the variable B will also do so. On the contrary, if the variable A decline, so will B. Moreover, if the influence is negative the relationship is different: if the variable A increases, then the variable B would decrease. Hence, if the variable A decreases, the variable B would increase. The identification of polarities within the CLD represents an important step in the construction of a CLD because the cohesion of variables depends on it. Once the variables are related, it is possible to identify the feedback and balancing loops.

Modeling: Finally, the coherent combination of all elements results in the construction of the CLD. Figure 5 shows the CLD of the dry-erase marker in the case study. Within the SD methodology, the CLD plays an essential role because it is the basis for the creation of the Forrester Diagram (FD). The dynamic simulation uses FD to create models of continuous variables that are measured per unit of time.

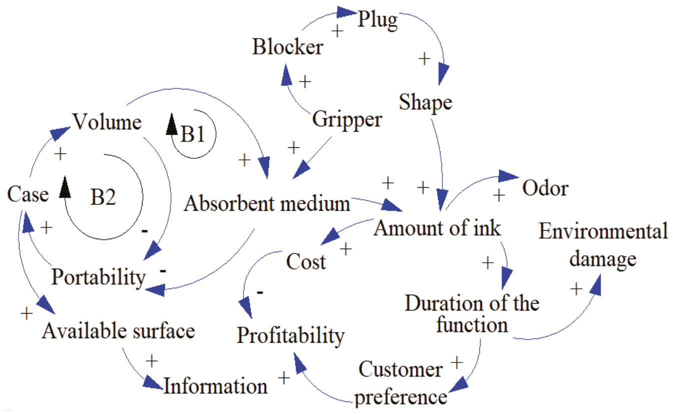

Fig. 4. Causal Loop Diagram (CLD)

From the CLD in Figure 4 is possible to formulate some inventive problems:

1. If the portability increases the case will also increase producing an augmentation in the volume of the system, which in turns will affect the portability negatively. Hence, it is necessary to improve the portability without increasing the volume.

2. If the goal is to increase the useful function of the object, it is necessary to increase the amount of ink in the product, which demands a bigger absorbent medium, resulting in a volume augmentation.

3. If the amount of ink increases, the cost-effectiveness gets reduced.

It is possible to observe in the CLD the causal relationships among parameters and variables in the system. There are two balancing loops. According to Figure 5, loop B2 is inside B1. The relationship between the variables that form B1 and B2 is the most important within the CLD. The portability and their relationships with the volume and the absorbent medium encompass the main factors to propose some changes in the product design.

4. Discussion and results

Currently, the FA diagram and the CLD evolve from a different approach, as they are part of the VE (and later from TRIZ) and the SD that are far apart from each other. However, some papers mention the ability to create a synergy between TRIZ and SD. [5] affirm that by combining both approaches, it is possible to propose a new way of modeling and solving inventive problems. In this combination, TRIZ obtains a dynamic modeling tool based on continuous simulation, and SD adds the capacity to model and solve inventive problems in its toolbox. Table 5 shows a comparison between both techniques. Table 5 underlines the capacities and limitations of both approaches and also supports the feasibility of a potential synergy, generating an opportunity for research.

Table 5. Comparison between TRIZ and SD approaches [5].

Advantage	TRIZ	SD
Conflict resolution capacity	X	-
Ability to model complex systems	X	X
Use mathematical models	-	X
Solving inventive problems	X	-
Use simulation	-	X

In turn, FA diagram and CLD have differences and similarities in their respective approaches. The comparison shown in table 6 allows seeing the scope of both tools and in turn the possibility of being used simultaneously in the design of new processes.

Table 6. Comparison between FA diagram and CLD

Advantage	FA diagram	CLD
Causality representation	-	X
Allows the use of verbs	X	-
Ability to model functions	X	X
It allows relating components	X	X
Polarity analysis	-	X
Effects analysis (based on SFA nomenclature)	X	-

Table 6 shows the advantages of each modeling approach. Also, it reveals that there is some compatibility between both approaches, and then, the possibility to use both techniques simultaneously to model and later involve other tools for solving inventive problems.

According to table 5 and table 6, both techniques are complementary. Despite their differences, both techniques produce valuable information that is useful to model and solve inventive problem. Also, their common characteristics show a similar pattern in their modeling as shown in table 1.

The case study shows that a simultaneous interaction between FA diagram and CLD allows a better comprehension of the components of a product and their relationships. FA diagram produces a graphic that explains the nature of the effect or action that one component or parameter has on another. In turn, CLD provides the user with the systemic approach proposed by Forrester [6] and described by Sterman [14] that leads to causality.

Another important advantage when using the FA diagram is that the model creates a link with some TRIZ tools that can solve the problem. If the conflict involves a component or parameter that demands two mutually exclusive states or conditions, then the conflict is a physical contradiction. If the problem affects two different components or parameters, then it is a technical contradiction. The concept of contradiction is a useful strategy to model problems [1]. If a conflict involves several components or functions, then the Substance-Field Analysis is useful to model and solve the problem [2]. The analysis of physical and technical contradictions and the Substance-Field Analysis require a functional study of the objects to select the right tool for a specific situation. In turn, the creation of the CLD is paramount within the SD methodology. Establishing the causal relationships between variables allows the creation of the Forrester diagram, and through software, the diagram provides the user with the ability to create dynamic simulation models. Consequently, the CLD in combination with the Forrester diagram produces the ability to test dynamic hypotheses that represent potential solution paths.

A significant contribution of the FA diagram to the user is the ability to analyze functions in the system, while the CLD allows the evaluation of the causality and with it, the mathematical relations that enable the measurement of the effect of one variable concerning another using dynamic simulation. The consequence of combining both approaches leads to a different structure that allows a more accurate analysis that provides the user with valuable information for decision-making.

5. Conclusion and future work

The simultaneous use of the FA diagram and the CLD to model conflicts in a system produces information that gives the user the ability to connect variables and components. The FA diagram provides information to facilitate the selection of a potential tool for solving the inventive problems identified in the diagram, while the CLD produces information to explore the potential impact of any modification in the system. Currently, both tools work independently and have proven to be effective in their respective areas. However, Table 6 shows that both approaches are complementary. Also, the resulting advantages are potentially useful to model and solve the intrinsic conflicts of the design process.

Future work suggests that is necessary to propose a methodology. At present, both tools are used independently. Thus, a methodology for combining the FA and the CLD is desirable, and also to deploy it in different scenarios to obtain experiences. The application of both approaches for designing new services it is also a relevant challenge. There are many questions to solve in this issue. How can we deal with the intangibility, heterogeneity, and simultaneity of services in the modeling stage?

Despite the usefulness of TRIZ in several technical domains, the TRIZ toolbox demands a huge adaptation effort to deal with the service design. This challenge starts in the modeling stage. The use of the FA and the CLD is an interesting alternative to face this defy. As complexity increases, for instance, in the design of Sustainable Product-Service Systems (SPSS), the need for modeling more complex or even hidden relations and effects will demand new approaches [17]. Consequently, the use of the CLD and the FA diagram in the SPSS represents a research opportunity.

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References

[1] Altshuller G. Creativity As an Exact Science. Amsterdam, Netherlands: CRC Press; 1984.
[2] Altshuller G. The Innovation Algorithm. Worcester, Massachusetts: Technical Innovation Center; 2007
[3] Carver JW. Dry Marker and Eraser System. US Patent 6,048,121, 11 April 2000.
[4] Chena H, Yub J, Wakelandb W. Generating technology development paths to the desired future through system dynamics modeling and simulation. Futures. 2016, 81: 81-97.
[5] Delgado-Maciel J., Cortes-Robles G., Jiménez M. E., Sánchez-Ramírez C., García-Alcaraz J. Application of the Systems Dynamics Approach to Model Inventive Problems. In: Martínez de Pisón F., Urraca R., Quintián H., Corchado E., editors. Hybrid Artificial Intelligent Systems. Lecture Notes in Computer Science, Springer, Cham. 2017; 10334: 494-506.
[6] Forrester J. Industrial Dynamics. 1st ed. Cambridge, Massachusetts: The MIT Press; 1961
[7] Forrester J. Principles of Systems. 1st ed. Portland, Oregon: Productivity Press; 1988
[8] Makino K, Sawaguchi M, Miyata N. Research on Functional Analysis Useful for Utilizing TRIZ. J Sci Procedia Engineering 2015; 131: 1021-1030.
[9] Rachwan R, Abotaleb I, Elgazouli M.The Influence of Value Engineering and Sustainability Considerations on the Project Value. J Sci Procedia Environmental Sciences 2016; 34: 431-438.
[10] Salamatov Y. TRIZ: the Right Solution at the Right Time: A Guide to Innovative Problem Solving. 2nd ed. Krasnoyarsk, Russia: Institute of Innovative Design; 1999
[11] Savransky S. Engineering of Creativity: Introduction to TRIZ Methodology of Inventive Problem Solving. 1st ed. New York: CRC Press; 2000
[12] Schneiderova R. Possibility of Using Value Engineering in Highway Projects. J Sci Procedia Engineering 2016; 164: 362-367.
[13] Souchkov V. Research and Practice on the Theory of Inventive Problem Solving (TRIZ). In L. Chechurin editor. Linking Creativity, Engineering and Innovation. Springer; 2016.
[14] Sterman, J. Business Dynamics: Systems Thinking and Modeling for a Complex World. 1st ed. Boston, Massachusetts: McGraw-Hill Education; 2000.
[15] Terninko J. Step-by-Step QFD: Customer-Driven Product Design. 2nd ed. Boca Raton, Florida: CRC Press. Taylor & Francis Group; 1997.
[16] Terninko J, Zusman A, Zlotin B. Systematic Innovation: An Introduction to TRIZ (Theory of Inventive Problem Solving). 1st ed. Boca Raton, Florida: CRC Press LLC; 1998
[17] Vezzoli C, Ceschin F, Diehl J et al. New design challenges to widely implement 'Sustainable Product–Service Systems'. Journal of Cleaner Production 2015; 97: 1-12.
[18] Walaa Y. Effect of drains coverings on environment by using value engineering. Alexandria Engineering Journal 2017; 55(3): 327-332
[19] Walaa Y, Hussien A. Value engineering for canal tail irrigation water problem. J. Ain Shams Engineering Journal 2017; In Press, Corrected Proof — Note to users.
[20] Walrave B, Raven R. Modelling the dynamics of technological innovation systems. J Sci Research Policy 2016; 45(9): 1833-1844.
[21] Wei F, Haizhong A, Huajiao L et al. Accessing on the sustainability of urban ecological-economic systems by means of a coupled emergy and system dynamics model: A case study of Beijing. J Sci Energy Policy 2017; 100: 326-337.
[22] Wixson J. Function Analysis and Decomposition Using Function Analysis System Technique. Paper presented at International Council on Systems Engineering Annual Conference (INCOSE '99). INEL/CON-98-01072, 6-10 June 1999