A Proposed Classification and Process of Systematic Innovation

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Abstract

A classification for the field of systematic innovation is proposed. A Systematic Innovation Process (SIP) derived from observations of business practices is proposed and exemplified. Time-wise, the SIP is a series of phases and stages which link the planned business processes from business opportunity identification to technology details to cross-industry application exploitation of newly developed technology/tools/products. Resource-wise, the SIP provides a platform to integrate heterogeneous resources and tools such as TRIZ (Theory of Inventive Problem Solving), non-TRIZ tools, and more opportunity identification and problem solving techniques for systematic innovation. Unlike brain-storming type innovation activities which are often ad-hoc and highly dependent on luck, systematic innovation is regarding the systematic development of innovative problem solving and/or opportunity identification. The proposed SIP is based on authors' observations of industry practices and has not been described elsewhere before. The framework integrated the full phases of systematic innovation processes providing a structured process to enable companies systematically identifying business opportunities and key problems, solving problems, and leveraging developed tools/products/technologies for cross-industry exploitations. This SIP also allows for the integration of various tools and knowledge within the overall systematic and cyclic process to support systematic innovation.

Keywords: systematic innovation, systematic innovation process, TRIZ, non-TRIZ

1. Introduction

1.1 Importance of innovation to the industry and world economy

Science and technologies have been changing rapidly in the last fifty years. In this time of rapid changing and highly competitive world, innovation is a vital source of competitive advantage or even surviving necessity.

Every new product/process/service originates from a new idea. The active functions of executives, for accelerating of innovative ideas to market, shall include developing a means of stimulating the creation of innovative ideas, developing a way of processing these ideas into product/process/service and storing innovative information into a structured knowledge repository, developing a means of analyzing innovative idea viability, and implementing the innovative ideas to product/process/service for maximizing business performance (Stokic et al., 2003).

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1.2 Random innovation versus systematic innovation

In general, there are three types of innovative problem solving approaches:

(1) A flash of genius: It occurs to the innovator with a flash of genius, sometimes accidental. However, only a tiny percentage of people are genii. It is not a primary source of innovative problem solving approach.
(2) Empiric Path: This approach attacks problems by brainstorming or trial-and-error approaches. A great majority of innovation in the world are from this category of source. However, it is highly dependent on luck and fails to take into consideration of all existing/possible solutions for best selection.
(3) Methodical Path: A systematic process is used to reveal the total solution space. It can quickly converge to an optimal solution by systematic analysis. It also provides more comprehensive coverage of the solution space allowing selection of optimal solution. Systematic Innovation belongs to this kind of approach. The differences between systematic innovation and empirical trial-and-error approaches are depicted in Figure 1.

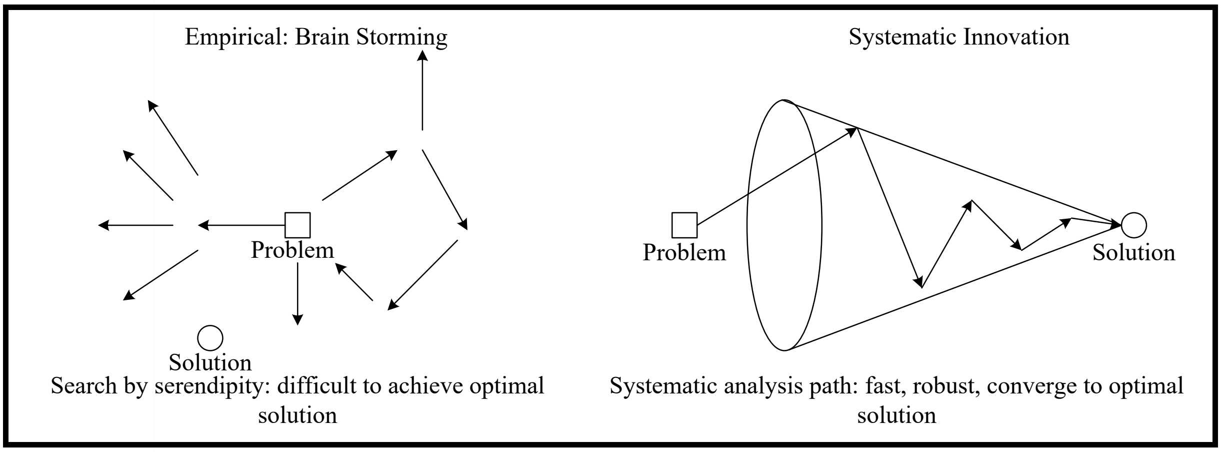

Figure 1. Differences between systematic innovation and try-and-error approach

Systematic Innovation (SI) is a field of studies which aims to enable us systematically identifying opportunities and/or solving problems innovatively. The sources of the SI primarily come from studies of human prior wisdom and/or inspiring problem-solving phenomena in the nature. The author's interpretation of systematic innovation can be described as: "Systematic ways of identifying innovative opportunities and/or problem solving innovatively". The discipline of Systematic Innovation is relatively new. Based on authors' observations of innovative business practices, this article proposes a way to classify the knowledge of systematic innovation and a structured process for systematic innovation which can facilitate innovative product/process/project development.

2. Related Work

2.1 Classification of systematic innovation

The proposed classification of systematic innovation is depicted in Figure 2. It includes Human-originated Systematic Innovation (HSI) and Nature-inspired Systematic Innovation

(NSI). The HSI can be divided into TRIZ (Theory of Inventive Problem Solving) and non-TRIZ systematic innovation systems. The TRIZ tools/knowledge can be divided into Classical TRIZ and TRIZ extension. They are extracted knowledge from patents. The patent-originated TRIZ knowledge/tools include: (1) Classical TRIZ - primarily, developed by Altshuller and his partners; (2) TRIZ-extension – are TRIZ tools/knowledge augments/developed by Altshuller's many disciples. The non-TRIZ systematic innovation knowledge/tools are extracted knowledge from other human studies/activities and knowledge developments such as 6 thinking hat, SCAMPER, etc. In the Nature-inspired SI domain, it consists of biologically inspired SI, known as Bionics/Biomimetics/biomimicry and non-biologically nature-inspired SI.

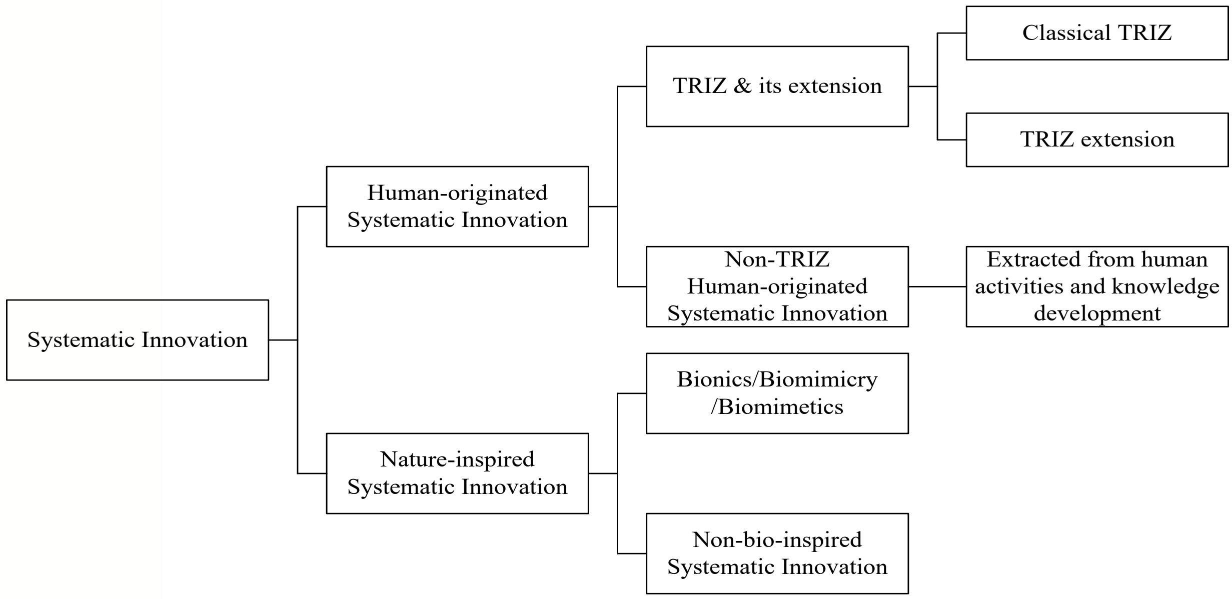

Figure 2. Classification of systematic innovation domain

2.2 TRIZ and non-TRIZ tools

Probably, the set of most important systematic innovation tools is TRIZ. TRIZ is the acronym for the Russian phrase, "Teoriya Resheniya Izobreatatelskikh Zadatch," roughly translated into English as "Theory of Inventive Problem Solving." Genrich Altshuller and his colleagues in the former USSR started TRIZ research in 1946. The three primary findings of TRIZ research are as follows (The TRIZ Journal):

(1) Problems and solutions were repeated across industries and sciences.
(2) Patterns of technical evolution were repeated across industries and sciences.
(3) Innovations used scientific effects outside the field where they were developed.

At the heart of the TRIZ theory, there are five key concepts which make TRIZ very valuable for innovative problem solving:

(1) Ideality, which defines the goodness of any product or system.
(2) Resources, which inspires us to use existing resources and to turn harm into help.
(3) Functionality, which helps us focus on the primary function and inspires us to create simplicity design.
(4) Contradiction, which profoundly indicated that:
   a. The underlying factor that blocks human advancement is contradiction.
   b. Innovation is, in essence, out of solving at least one contradiction.
(5) Space/time/interface, which facilitates us to see problems from various space/time/interface allowing us to solve problem easier and more innovatively.

There are many TRIZ publications which describe the TRIZ theories and provide numerous successful applications. (Altshuller 1984, 1997, 1999; Kaplan, 1996; Fey and Rivin 1997; Terninko et al. 1998; Zlotin et al., 1999; Savransky, 2000; Rantanen and Domb, 2002; Mann, 2002; Clausing and Fey 2004, 2005)

Hua et al. (2006) surveys TRIZ integration into other creativity tools, methods and philosophies using a literature review of publications, most of them are from proceedings and the TRIZ Journal, from 1995 to 2006. In their review, there are many problem-solving tools, techniques and philosophies that have been integrated or compared with TRIZ, such as Quality Function Deployment, Six Sigma, Design For Manufacture and Assembly, Robust Design, Axiomatic Design, Theory of Constraints, etc. Rantanen and Domb (2002) used TRIZ to enhance Six Sigma, Constraints Management, Supply Chain Management, QFD, and Taguchi methods to gain innovative and technological competitive advantages. To link the OTSM-TRIZ theory with concurrent engineering, Eltzer et al. (2004) proposed guidelines to analyze and synthesize the resulting complex contradiction network in a single inventive redesign task for the parametric design model and cause-effect relationships. Akay et al. (2008) presented the applications of the adaptation of TRIZ into human factors problems and revealed the benefits. Many TRIZ success cases can be found in the articles published in the TRIZ Journal. However, non-TRIZ systematic innovation tools are also useful and can be integrated with TRIZ tools for the process of systematic innovation. Yamashina et al. (2002) presented an innovative product development process by integrating non-TRIZ tool, Quality Function Deployment, and TRIZ and enables the effective and systematic creation of technical innovation for new products.

This article proposes a classification of the knowledge/tools of systematic innovation and a Systematic Process which can provide a framework to guide the integration of various innovation tools to facilitate the full life cycle of systematic innovation.

2.3 Related Work on Systematic Innovation Processes

Since the late 1990s, knowledge management has been the core of contemporary R&D management. The keyword is intellectual property, and the essence is innovation.

In the past, innovation ideas are mostly from brainstorming or trial-and-error. This is largely dependent on luck. There is a need to bring structure and systematic processes to innovation. As quoted by Strategos' Directors Loewe and Chen (2008): "an innovation process is critical to bringing structure to a fundamentally unstructured activity" - anonymous. One attempt at describing the latest development within the systematic innovation field is shown in Figure 3.

Refer to Figure 3. Mann (2002) proposed a four-step Systematic Creativity Process (SCP), namely, Define, Select Tool, Generate Solutions and Evaluate. The process starts with a perceived need for something to happen, followed by a clear definition of the right problem (conflicts), selecting the most appropriate tools to help people to solve it, solving by the TRIZ tool-kit, and finally identify the best solution (ideality) from the ones generated during the preceding 'solve' part. This process emphasizes the adaptation of the concepts and tools of TRIZ to carry out design activities. The conflict-based model and tools are applied to support the decision-making. Mann also proposed a 4-phase process to solve problems which covers Problem Identification Phase, Problem Selection Phase, Solution Generation Phase, and Solution Selection Stage. Mann's models did not cover the early stage of opportunity definition, and subsequent stages of implementation and further exploitation of newly developed technologies/products.

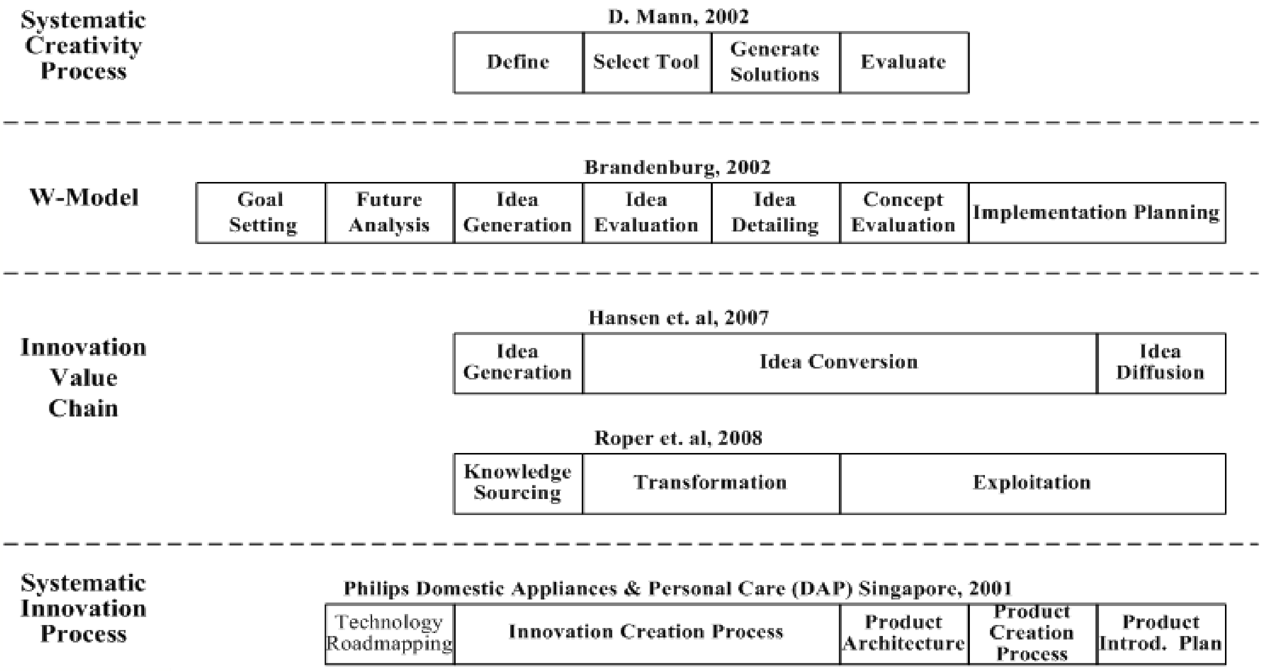

Figure 3. Literature review of systematic innovation process

Brandenburg (2002) proposed a seven-stage W-Model which forms a continuous circle that brings about recurring innovation activities on a strategic level. The final output of the W-Model is an Innovation Roadmap, which identifies future innovations and immediate innovations with a lot of potential for success, as well as innovations that should be investigated in more detail or at a later stage. The W-Model thus builds in strategic planning for immediate and future innovation projects, and creates a further input for the W-Model. The W-model did not cover the actual implementation and further exploitation of developed new products/technologies.

Hansen and Birkinshaw (2007) recommended viewing innovation as a value chain comprising three phases, namely, Idea Generation, Idea Conversion and Idea Diffusion. The aim of Idea Generation phase is to generate ideas from various sources: internal, external and cross-unit collaboration. During Idea Conversion phase, the major tasks are screening and funding of ideas and developing ideas into viable products, services, or businesses. In the Idea Diffusion phase, the developed ideas are spread within and outside the company to receive buy in.

Roper et al. (2008) modeled the innovation value chain for manufacturing firms highlighting the drivers of innovation, productivity and firm growth. This process includes

Knowledge Sourcing, Transforming, and Exploitation phases. Their model highlights the structure and complexity of the process of translating knowledge into business value and emphasizes the role of skills, capital investment and firms' other resources in the value creation process.

The innovation value chain models proposed by Hansen and Robert, et al., provide conceptual interpretational links between the upstream and downstream stages. Yet, no actionable methods were provided to facilitate the innovation processes.

Philips Domestic Appliances and Personal Care unit of Singapore (2001) presented a Systematic Innovation Process as indicated at the bottom of Figure 2. The first stage of its Systematic Innovation Process is Technology Road Mapping (TRM), which defines the needs and technological directions required for future R&D. The result of TRM is a series of innovation projects, which ranges from breakthrough product concepts to developing new technologies. Following the TRM is the Innovation Creation Process (ICP) where consumer needs and technological opportunities are developed into working prototypes to test the feasibility of concepts. Project teams are assigned to carry out the innovation projects arising from the TRM. Once innovation projects are proven to be feasible with functional prototypes, new concepts are further developed into standard technical modules. This structure is implemented in product design and process design for flexible manufacturing. The introduction of new products is managed via a Product Creation Process (PCP). The progress of this process is marked by milestones at which management reviews the results and decides on whether the project should continue. Multi-disciplinary project teams are formed to undertake PCP projects in a concurrent engineering environment. The SIP proposed provides good guidelines for company's current product development process. However, there is no mention on technology exploitation and no development tools were provided or linked for the proposed SIP.

The authors' proposed process of systematic innovation was based on the observations of innovative product and process development. Time-wise, it provides a logical framework to cover the systematic innovation processes from initial problem to opportunity and problem identification, to problem solving and to technology/product exploitation and forms a full cyclic life cycle of the innovation processes. Resource-wise, the proposed SIP provides a framework upon which various tools and knowledge can be integrated to facilitate the innovation processes. The tools/knowledge which can be used to fulfil the process of innovation include TRIZ tools and non-TRIZ tools.

3. The Proposed Process for Systematic Innovation

Refer to Figure 4. The proposed process of systematic innovation consists of five linked phases and eight stages. The proposed five phases are Opportunity Definition, Problem Definition, Solution Definition, Project Execution, and Application Exploration in that order. For each of the three definition phases, there is a diverging stage followed by a converging stage as shown in the Figure. The corresponding tools identified so far for the various phases and stages are listed in Figure 5. Acronyms in the figure are explained in Appendix. It is noted that the tools listed are the ones identified so far. There may be other tools which are yet to be explored under the umbrella of the proposed systematic innovation process. Because the interfacing inputs into and outputs from the connecting stages are well defined regardless of whatever tools/resources used in each stage, this framework allows integration of heterogeneous tools/resources in each stage for the process of systematic innovation. The brief functional descriptions for the listed tools in Figure 5 are in Appendix for cross reference.

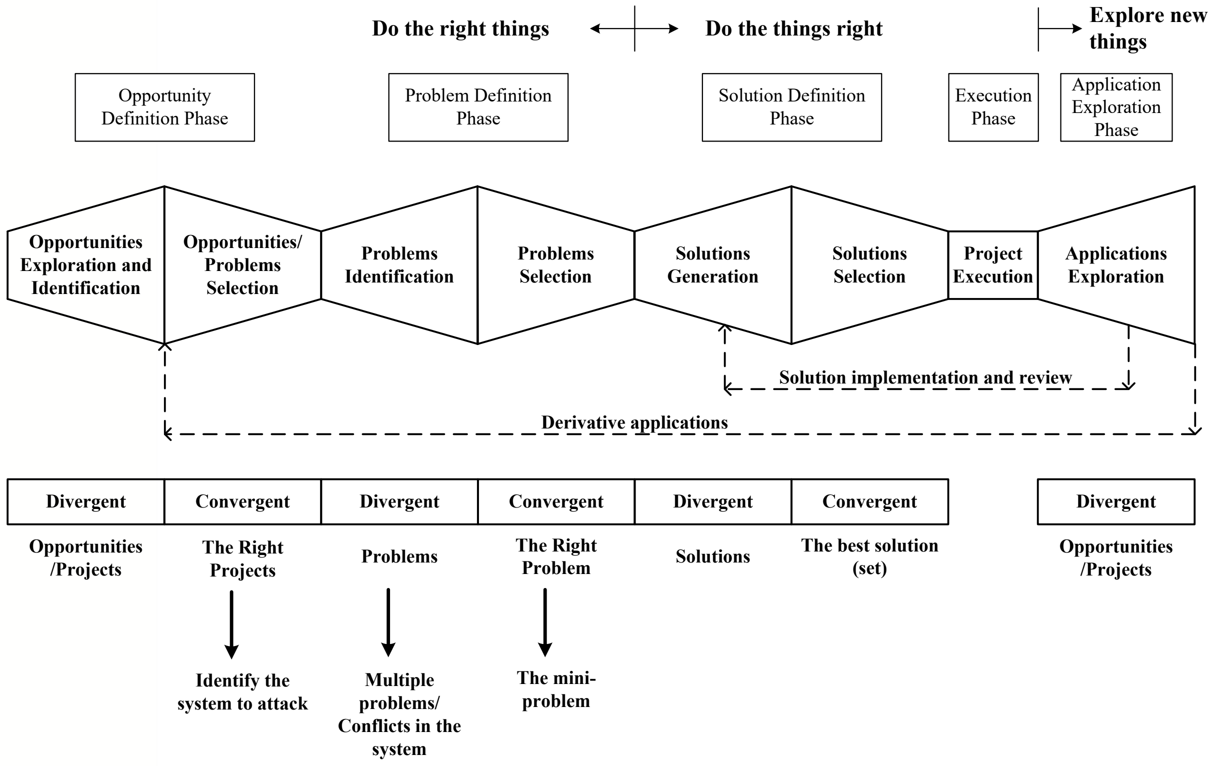

Figure 4. Systematic Innovation Process

Refer to stage designations in Figure 5 for descriptions below.

Stage (1) and (2):

The Opportunity Definition Phase consists of a divergent Project/opportunity Identification Stage followed by a convergent Project/opportunity Selection Stage. An input to the beginning stage is a current problem spotted. This initial stage enables wide-open opportunity explorations which may lead to solving the current problem without actually dealing with the current problem or locating other business opportunities/projects to work on.

In this stage, the initial problem is analyzed using the TRIZ and/or Non-TRIZ tools as listed in the lower part of Figure 4 to find out all possible business opportunities or projects/products to work on. Refer to Appendix, the tools for this Opportunity Definition Stage can be further divided into two classes:

a. **Wide-open opportunity exploration tools:** These tools include Problem Hierarchy, Ideal Final Result, and 9/12 Windows analysis. These tools allow the users to go beyond the space/time/interface of the current problem and identify relevant possible opportunities in other space/time/interface. Often times, a problem is difficult to solve at the current space/time/interface and can be better and easier solved in a different and maybe non-obvious space/time/interface. This is liken to the essence of Fourier Transform. Instead of solving a difficult time-domain differential/integral problem, the Fourier Transform is able to convert the original time domain problem to frequency domain (Wikipedia on Fourier Transform). Then, solving the difficult differential/integral problem in time domain becomes solving a much easier minus/plus problem in frequency domain. The three tools listed in this paragraph can systematically take the users to analyze the current problem from different perspectives and hopefully identify better position to solve the current problem and locate many opportunities for innovation.

b. **Tools for opportunity exploration within a given product/service direction:** These tools include Ideal Final Attribute (IFA), Omega Life View (OLV), Perception mapping, Voice of Customer Table (VOC), and Quality Function Deployment (QFD), etc. The IFA can systematically help us identify conflicts between customers and providers or among features/functions/attributes of the product/service we provide. Since conflicts are opportunities for innovative product or service, these tools can help us identify innovation ideas systematically within the direction of our given products or services.

The outputs of the Opportunity Exploration Stage are the multiple projects/opportunities which can be explored to solve the current problem or create new business opportunities. These outputs then feed into the convergent Project Selection Stage of the Opportunity Definition Phase to select the best opportunity/project to attack using the corresponding tools listed in the Opportunity Selection Stage as indicated in Figure 4. Though not listed here, many more tools such as project selection methods are available to screen the identified opportunity and converge the wide-open opportunities into a best project for further studies.

	Opportunities Exploration and Identification (1)	Opportunities/ Problems Selection (2)	Problems Identification (3)	Problems Selection (4)	Solutions Generation (5)	Solutions Selection (6)	Project Execution (7)	Applications Exploration (8)
TRIZ tools	▪ Problem Hierarchy ▪ 9/12 Windows ▪ Ideal Final Results (IFR) ▪ Ideal Final Attributes (IFA) ▪ Evolution Potential Anal	▪ S-curve Analysis)	▪ F(A)A ▪ CECA ▪ Root Contra. Analysis (RCoA) ▪ Func. Rel Anal ▪ Size-Time-Interface-Cost (STIC) ▪ Problem Hierarchy ▪ 9/12 Windows ▪ Flow Analysis ▪ IFA ▪ SFA		▪ Inventive Principles ▪ Inventive Standards ▪ Trends ▪ Patent DB ▪ FOS ▪ Func / Attr. DB ▪ Patent Circum. ▪ Trimming ▪ Smart Little People ▪ Feature Transfer ▪ Resources			
Non-TRIZ tools	▪ Omega Life Views (OLV) ▪ VOC ▪ QFD ▪ Perception Mapping ▪ 6 Thinking Hats	▪ Benefit Analysis ▪ Constraint Analysis ▪ Resource Analysis ▪ Pugh Matrix ▪ Feasibility Study	▪ Red Team Analysis ▪ Kepner Tregoe method ▪ 6 Thinking Hats	▪ Root Cause Anal. (RCaA) ▪ Red Team Analysis ▪ Pugh Matrix ▪ Kepner Tregoe method	▪ Anticipatory Failure Anal. ▪ Lateral Thinking ▪ SCAMPER ▪ Oblique Strategy	▪ Multi-Criteria Decision Analysis ▪ Axiomatic Design ▪ Pugh Matrix	▪ Proj. mgmt tools ▪ Six Sigma ▪ Lean Prod-uction	▪ VOC/QFD ▪ Product Platform Analysis (PPA) ▪ Product/ Technology Roadmap

Figure 5. TRIZ vs non-TRIZ Tools in SIP

Stage (3) and (4):

The selected best project is then fed into the divergent Problem Identification / Selection Stage of the Problem Definition Phase to identify all possible problems/conflicts in the project/product to attack. Again, the corresponding problem identification tools listed in Figure 4 can be used to identify conflicts. Each conflict constitutes a problem to attack, as described in the TRIZ concept. The identified problems are then fed into the convergent Problem Selection Stage of the Problem Definition Phase to select the right problem for attack. The selected problem is a “mini-problem” in the TRIZ problem solving term as we now focus on a minimal critical area to attack one at a time.

Stage (5) and (6):

The right problem is then fed into the Solution Generation Stage of the Solution Definition Phase for generation of all possible solutions. Classical TRIZ tools as listed in Figure 4 are very powerful means to generate innovative solutions. Non-TRIZ tools can also be used to solve problems.

The resultant multiple solutions are then fed into the Solution Selection Stage of the Solution Definition Phase for the best set of solution(s) to use. Few TRIZ tool is available for this stage. However, non-TRIZ tools such as those listed in Figure 4 are available for solution selections.

Stage (7):

The selected best set of solution(s) is then executed at the Project Execution Stage to solve the target problem and to review the results. No TRIZ tools are available for this stage of the SIP. Abundant typical project management tools are available for this stage.

Stage (8):

After product launched, one should balance the introduction of revolutionary products with incremental improvements in others so as to maintain a steady flow. The product models evolve from a core product. The core product system will express the generic technology system, and higher- or lower-priced versions will differ in the subsidiary technologies of features. The product family planning is especially important to deal with competitive conditions of shortened product life cycles, which can decrease profits. By having a comprehensive view of one’s initiatives over time, one can avoid either overwhelming or underwhelming the marketplace.

Upon completion of the project, it is likely that new technologies, tools, and/or products may be created. However, the innovation process should not stop here. These newly produced technologies/tools/products can be further exploited in the Application Exploration Stage to extend their applications across different industries for innovations. No TRIZ tool is available to help the application exploration stage. However, some non-TRIZ tools are available to help systematically explore new opportunities for exploitations within and across industries as indicated in Figure 5 and explained in Appendix. There are rooms to develop tools for this stage to aid the systematic exploitation of new technologies/tools/products.

Refer to Figure 4. The identified opportunities for application exploitation can be further fed back into the entry point of the Opportunity Selection Stage of Opportunity Definition Phase for further studies and analysis. This forms a cyclic life cycle of the Systematic Innovation Process. In addition, while in the Solution Generation Stage of Solution Definition Phase, it is helpful to obtain ideas from across industry by utilizing new technologies/products/tools available in the Application Exploration Phase of other projects possibly from a heterogeneous industry. This is indicated by a dashed line linking from Application Exploration Phase to the Solution Generation Stage in Figure 4.

The proposed SI framework provides a full-stage SI roadmap to enable companies systematically identifying business opportunities/key problems, solving problems, and leveraging developed tools/products/technologies for cross-industry exploitations.

Time-wise, along the horizontal track, the proposed SIP provides visibility that allows a firm to pace the introduction of new products and services and exploitation of developed technologies/tools. It provides a logical roadmap in series of connected stages w/ clear purposes for each stage to guide the full life cycle of the systematic innovation processes.

Resource-wise, as listed in Figure 5, the proposed SIP provides pointers to the library of tools/knowledge in each stage and a platform to integrate heterogeneous tools for opportunity identification and problem solving. This framework allows integration of heterogeneous resources such as TRIZ tools and non-TRIZ tools to support continuous and cyclic systematic innovation process. This framework also allows for integration of TRIZ & non-TRIZ tools under a unified umbrella. The results from any TRIZ or non-TRIZ tools can be integrated at the end of that stage and feed to relevant tools in the ensuing stage. The individual results developed by any tools in the previous stage can be further "operated" by any TRIZ or non-TRIZ tools in the ensuing stage. By the logical nature of the proposed SIP, it can be used to guide the development of comprehensive computer-aided systematic innovation tools.

The proposed SIP covers not only the problem solving part but also connecting from the abundant business opportunity exploration/identification and tying to applications explorations of developed technologies/products/tools. The bases for this new set of innovation process are a broader systematic view for business opportunities and problem solving and a feedback system structure. This SIP is a platform for integrating heterogeneous resources, from marketing research to technology details. The broader view of SIP brings more business opportunities, more tools, TRIZ and non-TRIZ tools, more solution techniques and even more research opportunities.

The proposed model of systematic innovation process hopefully can:

(1) Guide the full life cycle of innovation process effectively and efficiently;
(2) Provide a platform to integrate TRIZ and non-TRIZ SI tools allowing complementary supports between tools.

Although innovation may often be accidental in practice, the proposed SIP can facilitate systematic processes for destined innovations in a full cyclic life cycle.

4. Case Study: Simulator I/O System Update

This case study illustrates an application of the Systematic Innovation Process on energy supply issues. The overall journey of this case is illustrated in Figure 5.

(0) Initial problem: The typical operating license period of nuclear power plant is forty years. The training simulator system's computer system for nuclear power plant operator is gradually obsolete. Simulator is an essential system not only for new operator training and qualification, but also for operator on-the-job training. One key part of simulator computer update project is the input/output system, which interconnects simulator computer and simulator control panels.

4.1 Opportunity Definition Phase

(1) Opportunity Identification Stage (TRIZ Tools – 9/12-window analysis and Ideal Final Results): Refer to Figure 6, the present system relevant to the Simulator I/O system is RTP system which provides data communication function. The 9/12-window analysis indicated the problems/issues on the super-system/system/sub-system and alternative system levels covering time frame from past/present/future.

The analysis indicated alternative opportunities for improvements or problem handling. We can improve system, sub-system or super system. While considering any system to attack, the 9/12-window helps us to consider the life cycle situations of each system we will attack. The tools in the first stage help us analyze one initial problem and diverge to alternatives, virtual reality, as indicated in the opportunity identification stage of Figure 5. The Structured Thinking Questionnaires (Table 1), a technique of IFR, provides a step by step questionnaire to elicit the right opportunity direction.

(2) Opportunity Selection Stage (Non-TRIZ Tool – Constraint Analysis): Taking the multiple opportunities into consideration, one should consider cost-benefit analysis, resource availability, design capability/flexibility, etc. Obviously, from the 9/12-window analysis, there are two basic requirements, the necessity of continuous improvement and the license renewal shall be met. While virtual reality is attractive this may cause incompatible with real nuclear power plant operating environment. Considering systems cost, design engineering, development cost and maintenance issues, the preferable candidate is a mature industrial I/O communication system.

Table 1. Structured Thinking Questionnaires

Questions	Answer
1. What is the final aim of the system?	To keep the simulator system working.
2. What is the Ideal Final Result outcome?	Simulator can work without I/O system.
3. What is stopping you from achieving this IFR?	The I/O system has to match the current simulator hardware system.
4. Why is it stopping you?	The cost is too high to get a new simulator system.
5. How could you make the thing stopping you disappear?	Change the I/O system. Function desired: keep I/O working and provide spare capacity Attribute desired: low cost I/O system
6. Has anyone else been able to solve this problem?	PC-based industrial I/O system
7. What resources are available to help create these circumstances?	PC, Industrial I/O bus system.

	Past	Present	Future
Super System	Power plant construction, people preparing to utilize	Power plant sys. People	License renewal, life extension
System	Manufacturing, shipping, prepared for data comm.	RTP sys. being used for data communication	Continuous system upgrading
Subsystem	Manufacture of components	PCB, wire, power supply, case.	Compatible for H/W & S/W upgrading
Negative/ Alternative System	Advanced 3D visual technology	Virtual reality system	No physical parts, comp..

Figure 6. 9/12-window analysis of Simulator I/O system problem

4.2 Problem Definition Phase

(3) Problem Identification Stage (TRIZ Tool – Root Contradiction Analysis): The next question is what kind of problems behind this potential opportunity? How do we define them and focusing the right problem? For any industrial application system, the basic design philosophy is to maximize the system performance at lowest cost. Simulator I/O system also follows this philosophy.

The Root Contradiction Analysis tool can help us search for conflicts in a system, i.e., the right problem. By Root Contradiction Analysis (Table 2), for meeting communication performance, we need more I/O modules, but more I/O modules mean higher cost, consequently, we have conflict. The conflict identified by the analysis is between data communication capability and materials, or data communication capability and space, or data communication capability and cost. Other tools can also help us identify other conflicts. For the sake of brevity, they are omitted.

Table 2. Root Contradiction Analysis

Subject: To achieve high performance at low cost, what is stopping us?

Why	Answer	Parameter involved	Improve (desirable)	Worsen (undesirable)
What is our problem/sore point for I/O system?	We want to increase I/O system data communication capability.	Data communication band.	Data communication band.	
Why? What stopping us?	To increase I/O capability we need more I/O systems. To get more I/O systems, we need more I/O modules to increase data communication capability.	materials		Materials
Why? What stopping us?	To put more modules we need more I/O systems to place it.	I/O systems		spaces
Why? What stopping us (to get more space)?	More I/O systems cost more	cost		cost
Conclusion: We have conflicts: Between data communication band and materials; or data communication band and space; or data communication band and cost.				

(4) Problem Selection Stage (Non-TRIZ Tool – Feasibility Study): How do we deal with the conflicts from the above Root Contradiction Analysis? A Feasibility Study can provide analysis to the problem and recommendation for the best alternative (Wikipedia on Feasibility Study). A comparison of technical feasibility for the conflicts in "data communication capability and materials", "data communication capability and space", and "data communication capability and cost" is given in Table 3. It appears that the modern data communication technology can solve the above mentioned conflicts.

Table 3. Feasibility Study

	Data communication band and Material	Data communication band and Space	Data communication band and Cost
Technology	Data communication efficiency depends on industrial communication protocol, and there are feasible technologies in firmware form.	Current technology is more advanced than the existing old system. Current technology can solve data communication band and space conflict.	Current technology can solve data communication band and cost conflict.

4.3 Solution Definition Phase

(5) Solution Generation Stage (TRIZ Tools – Inventive Principles and Patent Database): The next question is how do we resolve the contradiction? A number of tools maybe available as listed in Figure 4. In this case, the 40 Inventive Principles are appropriate TRIZ tools to generate solutions.

The number 5 inventive principle, Consolidation/Merging can reduce material usage while providing needed functions, and the number 20 inventive principles, Continuity of useful action, can provide most efficient work for all elements at all time. For improving the data communication efficiency, from space view, we can utilize new communication technology by advanced materials, e.g. firmware. By internet search and/or more specific domain literature review, there are many options available, for instance, RS-485、RS-422、IEEE-488，token ring、token bus, …etc.

For time effectiveness, we can utilize time division or frequency division technology to promote data communication performance in a fixed time frame and reduce the quantity of material. The switching technology, by switching between host system and backup system, can provide continuity of useful action, and also reduce the quantity of material.

(6) Solution Selection Stage (Non-TRIZ Tool – Multi-Criteria Decision Analysis): Considering the multiple decision criteria, including maturity of technology, cost, physics, engineering feasibility and compatibility of existing simulator system, maintainability, etc., the final solution is a RS-4xx switching data communication system. The new system will interconnect the existing control panel RTP interface and the new PC server host computer system, to replace the obsolete ENCORE host computer interface I/O system.

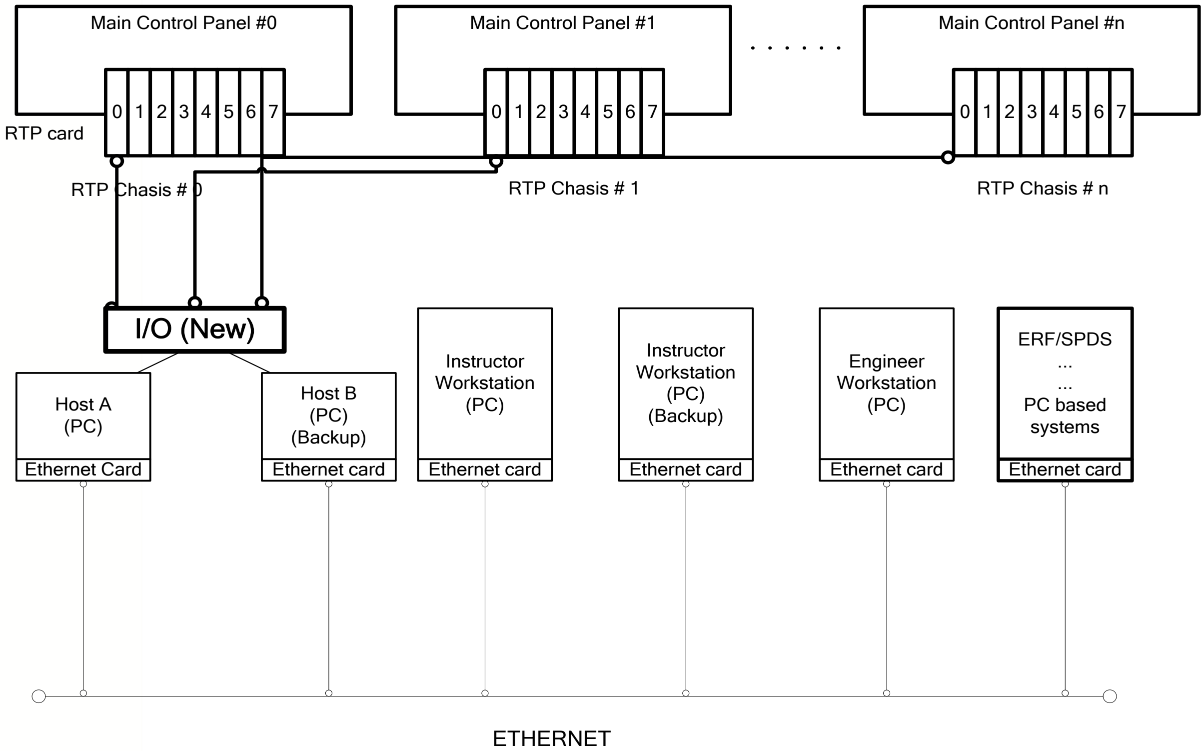

Figure 7. New data communication system solution

4.4 Execution Phase

(7) Project Execution Stage (Non-TRIZ Tool – Project management tools): Project management tools such as Work Breakdown Structure (WBS), Critical Path Method, project monitoring and control tools can be used to breakdown the project tasks, establish project schedule and monitor and control project performance, schedule, and costs.

4.5 Application Exploration Phase

(8) Application Exploration Stage (Non-TRIZ Tool – Product Platform Analysis): When an innovation project is finished, often times some new technologies/products/tools are developed out of the project. It will be a pity if the company stops at this point. The newly developed technologies/products/tools can further be used either within the same industry or

across industries to maximize their usefulness. It is these cross-industry applications that create most innovative and often high-impact results.

Through the product structure analysis, which is associated with market segment and product family, the niche can be achieved by the development of the product platform and its associated processes and production planning. Derivatives of the simulator I/O product platform, the product families, Boiling Water Reactor (BWR) power plant applications, Pressurize Water Reactor (PWR) power plant applications and Fossil power plants applications have addressed one or more of the market segments.

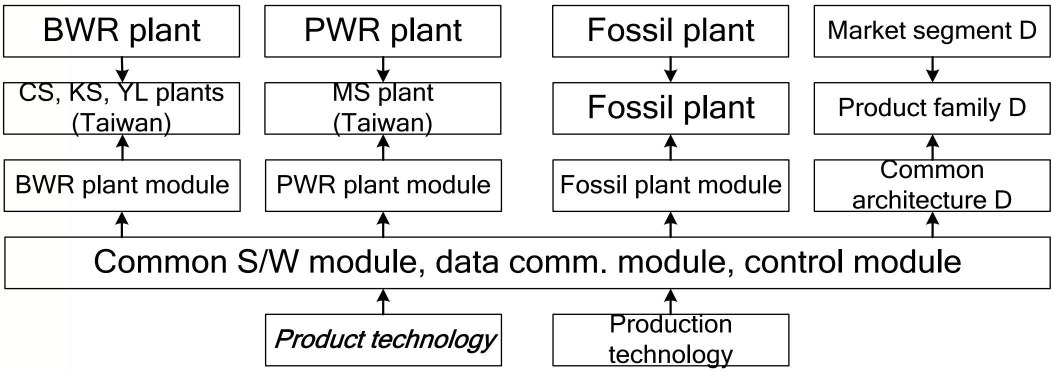

Figure 8. Product platform analysis

5. Conclusions

Unlike brain-storming type innovation activities which are often ad-hoc and highly dependent on luck, systematic innovation is regarding the systematic development of innovative problem solving and/or opportunity identification. A Systematic Innovation Process (SIP) has been constructed and exemplified. The proposed SIP is a series of phases and stages which link the planned business processes from business opportunity identification to technology details to cross-industry application exploitation of newly developed technology/tools/products. The proposed SIP provides a process to facilitate and pace the systematic innovation and a platform to integrate heterogeneous resources and tools, such as TRIZ and non-TRIZ tools, for synergetic utilizations. The SIP provides not only problem solving techniques but also opportunity identification and application exploitation for systematic innovation.

It is believed by the author that although innovation may be accidental, Systematic Innovation is destined (Sheu, 2008). The Proposed Process of Systematic Innovation provides a possible way for destined innovations.

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Appendix SIP tools and functions (Excerpted from D. Sheu class notes, 2008)

Tools	Functions
(1.a) Wide-open Exploration of possible projects/problems/ products/ services	
• 9/12 Windows Analysis	It offers a simple and effective way of encouraging problem solvers to see their problem situation from different perspectives. By changing perspectives among different space/time, the tool opens up opportunities at the different space and time. The contents to be placed in the various windows are often functions/attributes relevant to that window.
• Ideal Final Result	Get to the best possible right project/system for the current problem. It enables users to jump out of psychological inertia of the current problems and constraints.
• Problem Hierarchy	The Problem hierarchy tool helps us to see related problems at different problem levels. It consists of upward thinking and downward thinking. The downward thinking helps users to focus on the root causes of the problem allowing solving the current problem at its root. It is the upward thinking that challenges the existence of the current problem and helps us to find a better problem at a higher level to solve. This effectively solves the current problem without dealing with itself.
(1.b) Explore opportunities within given product/service direction	
• Ideal Final Attribute (IFA)	Identify conflicts between customers, between customer and provider, and between attributes of the subject product for business opportunities. (Maan, 2007)
• Omega Life View (OLV)	Examine extreme people's viewpoints for product/service ideas
• Evolution Potential Analysis	We can use evolution potential relevant to the current product of interest to explore opportunities for improvements.
• Voice of Customer Tables (VOC)	Tools to identify customers' needs and wants.
• Quality Function Deployment (QFD)	It allows us to deploy from customer requirements to design specifications for products. The customer requirements and product specifications are leads to innovative opportunities.
• Perception Mapping	By mapping out perceptions of various stakeholders, people can clarify issues and conflicts thus identifying project opportunities.
(2) Screening for right projects	
• Benefit Analysis	Used to screen out unnecessary projects. (Sanity check)

Tools	Functions
• Constraint Analysis	Locate business/technical constraints in 9-windows
• Resource Analysis	Locate resources in 9-windows. The resources available help us to screen out projects which do not have resource supports.
• S-curve Analysis	S-curve indicates the development maturity of the current system. Different projects are likely to succeed at different maturity level of S-curve thus allowing us to determine which type of projects more is like to succeed at the present stage. The S-curve can be effectively used as filter to screen out projects which are less likely to succeed.
(3) Problem Identification	
• 9/12 Windows	Same tool as in the first phase. However, the contents of the 9 windows can be the problems seen from the various windows.
• IFA	Same as the IFA in Phase I. It allows the users to identify conflicts between attributes and between customers/providers for problem to attack.
• Function (Attribute) Analysis (FAA)	Function Analysis or Function Attribute Analysis (FAA) decomposes a system into its components, analyzes the functional/attributes relationships among the components enabling prompt focusing on the core problems. It is also used as a preliminary analysis for future problem solving.
• STIC (Size-Time- Interface-Cost)	Think about the extreme very big/small cases in size, time, interface, and cost to help up locate problems.
• Problem Hierarchy	Explained previously. Here the downward thinking is used for problem identification.
• Substance-Field Analysis (SFA)	Classify problems by the type of conflict configuration between the 2 substances, its fields, and the function between the substances. SFA is the prelude of Standard Solutions. Certain types of standard solutions can solve certain types of SFA problems. SFA is a way of analyzing problems.
• Root Contradiction Analysis (RCoA)	The Root Contradiction Analysis combines the concept of "Sore-point Analysis" and "Ask Why 5 times" to identify the underlying contradiction of the subject problem. It starts with the sore points felt and ask why to identify either the cause of the problem or the stopping factor to inhibit us from solving the problem. The cause and the stopping factor then constitute a contradiction.
• Red Team Analysis	Red Team analysis is to look at problems from the perspectives of the adversary and various stakeholders. This can help us to explore new problems and aid their selection.
• Kepner Tregoe Method (KT Method)	It is a formalized problem definition tool, used to help problem solvers to identify what has changed in a system: the delta between healthy state and problem state helps to find the root cause of a problem.
(4) Problem Selection	
• S-curve Analysis	S-curve analysis can be used to determine which problems are better solved by which tools or techniques.
• Root Cause Analysis (RCaA)	Root cause analysis analyzes the constituent causes of the problem. It allows user to select appropriate cause to attack and to solve the problem. It is both a problem identification and solution generation tool.
• Red Team Analysis	The Red Team Analysis provide critical viewpoint which can also be used to screen problems.
• Kepner Tregoe Method	Stated previously. It can also be used to aid problem selection.
(5) Solution Generation	
• Inventive Principles	Altshuller's 40 inventive principles provide trigger solutions to problems. The inventive principles can be used with or without Contradiction Matrix.
• Inventive Standards	Matched with the SFA stated previously to provide ways of problem solving.
• Trends	Trends of technical evolutions relevant to the current problem can be used as solution trigger for the current problems.
• Resources	The concept of resources can help us to locate existing resources without additional cost and to turn harm into help
• Patent Database (PD)	PD allows us to search previous problem solving methods possibly across industry to solve our problem innovatively.
• Function/Attribute Database	TRIZ organize solutions according to functions served or attributes hold. As

Tools	Functions
	such, the user can use the database to search for solutions based on functions/attributes desired.
• Smart Little People (SLP)	Looking at the problem at micro level and from the problem itself provides another perceptive for problem solving.
• Anticipatory Failure Determination (AFD)	By intentionally trying to find out ways to make the system fail, it allows us to identify all possible problems and help us to find ways to avoid it.
• Lateral Thinking	Lateral thinking is characterized by the shifting of thinking *patterns*, away from entrenched or predictable thinking to new or unexpected ideas. This provides ideas for solutions outside of regular thinking.
• SCAMPER	It is used as brainstorming aids to make the thinking more systematically. SCAMPER stands for: S - Substitute: components, materials, people C - Combine: mix, combine with other assemblies or services, integrate A - Adapt: alter, change function, use part of another element M - Modify: increase or reduce in scale, change shape, modify attributes P - Put: put to another use E - Eliminate: remove elements, simplify, reduce to core functionality R - Reverse: turn inside out or upside down.
• Oblique Strategy	This is essentially a deck of cards with solution triggers to get problem solvers thinking out of the box. Details can be found in http://www.rtqe.net/ObliqueStrategies/
(6) Solution Selection	
• Multi-criteria decision analysis	Multi-criteria decision analysis allows for selection of best solution considering multi-criteria.
• Feature Transfer	The Feature Transfer module allows transferring of desirable features from one system to another. By transfer multiple features from multiple systems to one system, it effectively generates the best solution which combines multiple desirable features.
• Axiomatic Design	Axiomatic design is a systems design methodology using matrix methods to systematically analyze the transformation of customer needs into functional requirements, design parameters, and process variables. The design principles or Axioms of Axiomatic Design can be used to screen out infeasible solutions and determine appropriate solutions.
(7) Project Execution	
• Project Management Tools	Many project management tools can be used to monitor/control the execution of the project and to review the project performance either it is a product or service innovation project.
• Six Sigma (6σ)	A method and philosophy to achieve product or process quality to within at most of 4.3 errors in 1 million error opportunities. The essence includes 1) reduce process variability; 2) increase design tolerance thus the 6 sigma reliability can be achieved.
• Lean Production (Lean)	The essence is to manufacturing the same product with minimum resource inputs and zero waste.
(8) Application Exploration	
• VOC/QFD	By using the VOC and QFD as stated previously, the user may locate other applications which suit customers' desire.
• Product Platform Analysis (PPA)	The PPA plans the expansion of derivative products.
• Product/Technology Roadmap	The roadmaps laid out the expansion of product derivatives and technology usage.

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