PHILIPPINE ENGINEERING JOURNAL
PEJ 2008; Vol. 29, No. 2: 17-46

DEMYSTIFYING TRIZ FOR ACHIEVING IDEALITY IN DESIGN OF TECHNICAL SYSTEMS

Nestor O. Raneses
Associate Professor of Industrial & Systems Engineering
Department of Industrial Engineering & Operations Research
College of Engineering, University of the Philippines Diliman

ABSTRACT

This paper describes the basic foundations of TRIZ in simple operational terms and affirms its empirical soundness in generating innovative solutions to inventive problems. Three actual case study applications are presented to demonstrate how the basic methods and tools of TRIZ can be used to structure and accelerate inventive solution finding. We conclude that assimilating TRIZ in design-oriented courses is a good anchor for introducing and diffusing TRIZ technology and innovative thinking in graduate design course and in capstone design courses in the undergraduate levels.

Keywords: Inventive problem. Ideality. Functionality. Resources. Contradictions. Inventive Principles. Su-F models. Technology evolution. ARIZ

INTRODUCTION

The creation and design of ideal and sustainable technical systems has become a daunting challenge for system design engineers in the face of ever-changing set of requirements and continuous barrage of technology growth and change. Technical systems encompass all types of human-made artifacts that include products, processes, systems, structures, equipment, networks, or their integration. There have been many cases of engineered technical systems designs falling short of expectations, barely meeting requirements, providing obvious and apparent solutions that are inutile, or even engendering new problems, resulting in dysfunctional and non-sustainable systems. When a design problem becomes insoluble or when its solutions create more problems, systems designers are confronted with what is called an inventive problem. By definition, an inventive problem is a problem with no known solution or problem for which the known or generally accepted solution creates other problems (Petrov, 2005). According to Altshuller (Altshuller, 1999) , the Russian patent engineer who studied the evolution and behaviour of patents, and recognized as the founder of the Theory of Inventive Problem Solving or TRIZ, about 95% of solutions are non-inventive. Figure 1 depicts the Pareto distribution of these types of problems. These solutions are casually obvious routine changes, apparent minor corrections, and at best, major improvement only on the system. The source of knowledge for these solutions are either personal, within the organization or at best within the industry where the organization belong. (Altshuller, 1999). They do not involve any novel breakthrough change or discovery of an innovative solution that dramatically improves the performance and behaviour of the system.

Correspondence to: Department of Industrial Engineering & Operations Research, College of Engineering, University of the Philippines Diliman, Quezon City PHILIPPINES 1101

Received: July 22, 2010
Revised: April 20, 2011
Accepted: June 15, 2011

In a more recent survey done by Lipototov (2008), it was found that 52% of all technical system problems in industry were solved by corporate technical know-how and common sense while the next 37% were cracked with simple psychology-based creativity methods and direct technology transfer. This leaves 11% for TRIZ-like solutions. Conventional problem approaches are generally unable in generating these types of solutions. They are powerless in providing ideal sustainable solutions for innovating technical systems. With respect to innovation, it is observed that it lacks systems and structures and relies heavily on psychological methods and serendipity. Rossi- Ciao (2006) reported that over 80% of innovations failed before they reached the market, 97% of the patents never paid back their initial cost, over 90% of innovations were delivered late and over budget and manufacturing averages only 1 successful product for every 3,000 generated idea .

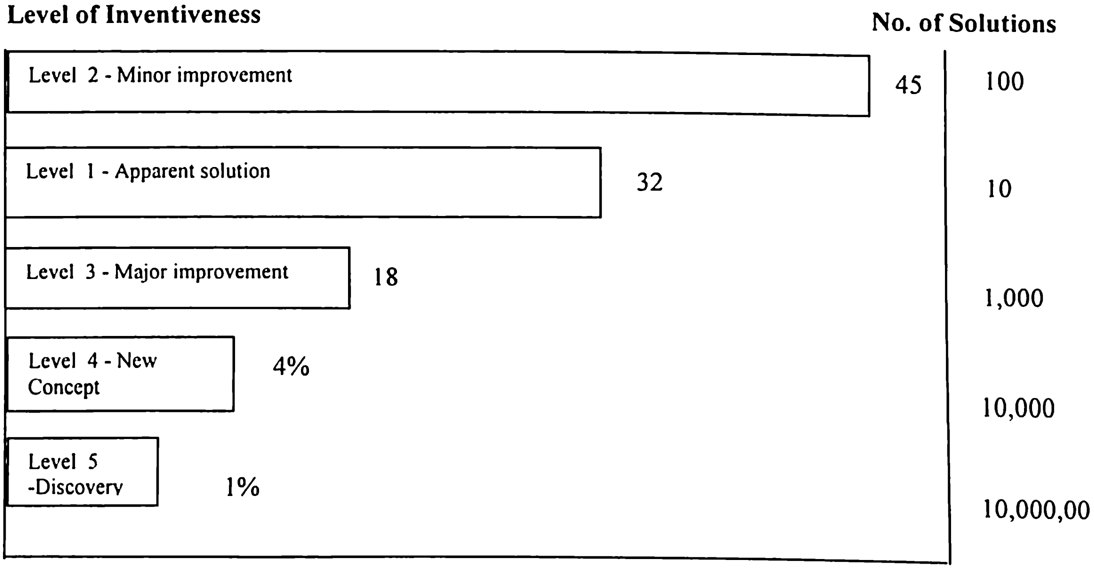


Figure 1: Pareto of Level of Inventiveness of Problems According to Altshuller (1999)

There are many advertised benefits of using TRIZ. Bukhman (2009) summarized the most prominent benefits of using TRIZ as 1) break the psychological inertia in solving problems, 2) reduce the number of trial and error iterations in finding solutions, 3) power knowledge with creative imagination, 4) make system, product, process more ideal and 5) accelerate innovation. Domb (1997) posited that TRIZ increases innovation velocity by a factor of 12X for inexperienced innovators and 3X for experienced innovators.

In terms of usefulness, Bukhman (2009) also presented the numerous applications of TRIZ in creating specification design, concept design, engineering design, product development and innovation, process design, manufacturing and equipment design, design for environment, design for reliability, design for ease of use, design for supportability, design for maintainability, and practically the whole gamut of system engineering including soft applications in marketing, operations and service management, finance, and human resources management. The on line *Triz Journal*, has also run a series of TRIZ real applications since it started publishing in 1996. Mathis (2009) and Bukhman and Brown (2005) presented two excellent comprehensive applications of TRIZ in product design and improvement. The former used TRIZ to improve the Mars bite-size candy pouch while the latter used TRIZ to design a repeatable process for improving sustainable wind turbine energy conversion system.

Souchkov (1997) in an experiment of TRIZ effectiveness reported a significant improvement in solution generation with TRIZ. A sample of 723 engineers with one week training of TRIZ generated 68% correct solutions versus 628 equally experienced engineers turning out only 2% correct solutions.

The main purpose of this paper is to provide a clear understanding of the basic philosophical underpinnings, structure, and operational implications of TRIZ as applied to improvement and design of technical systems. The overarching motivation is to present TRIZ in its simplest form so that it can be operationally integrated within the industrial system engineering perspective. The other corollary objective is to entice the academic community to assimilate the teaching of TRIZ for design oriented and creative courses and disciplines especially science, technology and creative professions.

The paper is organized into ten sections. The first section deals with the review of TRIZ literature and its historical evolution. The TRIZ literature was thoroughly scanned and critically scrutinized from the lens of pedestrian systems engineering. The second to seventh sections distill the essential elements of TRIZ based on the rubric of applicability, degree of inventiveness and innovation, compatibility with other problem solving tools, ease of operational use, minimal learning time and design for X-cellence criteria. The eighth section presents condensed case study TRIZ experiences by the author to demonstrate the operability and effectiveness of TRIZ application. The ninth section describes the specific osmosis of TRIZ knowledge and education in the academic environment to motivate engineering students and systems designers to broaden and sharpen their design toolbox. Finally, the paper concludes with an overall affirmation of the power of TRIZ to generate inventive solutions and recommended actions that will promote the natural use and integration of TRIZ in systems design among the design engineering community of students, faculty, practicing design engineers and other allied professionals engaged in sustainable and resource-constrained technical systems.

TRIZ Literature and Historical Evolution

The Theory of Inventive Problem Solving or TRIZ (acknowledged Russian acronym for *Teoriya Resheniya Izobretatel'skih Zadach*) provides a paradigm shift in thinking through a problem that provokes an innovative approach to generating solutions based on a rigorous scrutiny of the behaviour and common patterns of patents. Pioneered by Genrich Saulovich Altshuller (1926- 1998), the Russian patent engineer, TRIZ is considered as a dialectic way of understanding the problem of a system by imaging the ideal solution first and then overcoming contradictions to achieve ideality, excellence and sustainability. While TRIZ has yet to graduate as an "exact" formal science, Zlotin (2005), its theoretical foundations, structure, methods and tools are based on solid empirical science and technology principles Mann (2005). Since its inception in 1946, TRIZ has continued to evolve and transform into innovative problem solving and technology systems evolution. Mann (2007) reported that about 1500 person-years of research and systematic extraction of knowledge from almost 3 million of the world's finest patents have been spent to refine and grow TRIZ. Souchkov (2008) traces this evolution in an excellent brief of the historical morphing of TRIZ from its beginnings in 1946 to its many transformation and derivatives to the present as shown in Table 1.

Table 1: TRIZ Key Historical Milestones (Adapted from Souchkov, 2008)

Date/ Period	Historical Milestones
1946-1950	• G. Altshuller started developing TRIZ • G Altshuller conducted first TRIZ training sessions in Russia
1950-1954	• G. Altshuller imprisoned for criticizing Soviet state of inventiveness
1956	• G Altshuller introduced concepts of ***Technical Contradictions*, *Ideality*, *Inventive Systems Thinking*, *Technical System Completeness*, *Inventive Principles*** • G. Altshuller & Shapiro published "Technical Creativity" article in **Questions of Psychology Journal** • TRIZ algorithm with 10 steps and 5 inventive principles
1956-1959	• TRIZ algorithm with 15 steps and 18 inventive principles • Introduced ***Ideal Final Result (IFR)***
1963	• ARIZ introduced with 18 steps and 7 inventive principles. • Altshuller published *System of the Laws of Technical System Evolution*
1964	• TRIZ algorithm with 18 steps and 31 inventive principles • First version of the **Matrix for Resolving of Technical Contradictions** with generalized parameters (16x16 matrix)
1964-1968	• ***ARIZ*** version with 25 steps and 35 inventive principles. • **Matrix for Resolving of Technical Contradictions** (25x 25 matrix) • Developed teaching techniques for ***Creative Imagination Development*** • G Altshuller defined " ***Ideal Machine*** "
1969	• G Altshuller established first TRIZ training and research center in Russia • G Altshuller established the first nation-wide open source initiative in Russia
1971	• ***ARIZ-71*** with 35 steps and 40 inventive principles • ***Matrix for Resolving of Technical Contradictions*** *(39X 39 matrix)* • Introduced ***operator-time-size –cost (smart little people)*** • **Yuri Garin** introduced **database of Physical effects**
1974	• St Petersburg School of TRIZ under V. Mitrofanov
1975	• Introduced ***Substance Field Modelling*** with 5 ***Standard Solutions*** • ***ARIZ-75B with 35 steps including Physical Contradictions & Substance- Field Modelling*** • Altshuller shifted focus on solving *inventive problems by formulating and eliminating physical contradictions*
1977	• ARIZ-77 with 31 steps, physical contradictions at micro level, pair of conditioning components, operational time and operational zone. • Presented 18 inventive standards.
1979	• Altshuller published " ***Creativity as an Exact Science*** " book • Defined Theory of Technical Systems Evolution as a separate area of study
1982	• ARIZ-82 with 34 steps with ***X-concept, Mini-problem, Table of typical Conflicts, Table of Resolving Physical Contradictions, and Method of Little Men*** • Altshuller positioned ARIZ for solving non-standard inventive problems and Inventive Standard solutions for standard inventive problems • Excluded the ***Matrix of Resolving Technical Contradictions and 40 Inventive Principles*** from ARIZ • Presented 54 Inventive standards • Altshuller initiated research on ***biological effects*** • Extended TRIZ applications to Arts and Mathematics
1985	• ***ARIZ-85C*** with 32 steps with new rules and regulations, database of physical, geometric and chemical effects, 76 standard solutions, function cost analysis trimming, and systems of Laws of Tech. Evolution • ***76 Standard solutions organized in 5 classes*** • Developed ***database for physical, geometric and chemical effects*** • Altshuller concluded that ARIZ-85C was a complete tool for solving inventive problems • B. Zlotin, S. Litvin, & V. Guerassimov developed ***Function Cost Analysis (FCA)*** for analyzing technical systems and products • Conducted research on ***TRIZ Laws and Trends of Systems Evolution*** • Proposed new tools ***Subversion analysis, Functional Analysis of Inventive Situations, Alternative System Merging***
1986	• Altshuller shifted to "***Theory of Creative Personality Development***" from technical TRIZ • Developed TRIZ version for children
1989	• Released first TRIZ software " ***Invention Machine™*** " by Invention Machine Lab • Demonstrated database of technology effects that linked technical functions with specific technologies • Established Russian TRIZ Association

1990	• Launched Russian language " *Journal of TRIZ*"
1990-1994	• G. Altshuller & I. Vertkin published book on " *A Life Strategy of a Creative Person* " • Released new TRIZ software " *Innovation Workbench*™" by Ideation International • Published database of "biological effects" by V. Timokhov.
1994-1998	• Russian TRIZ Association became International TRIZ Association • Launched on line ***TRIZ Journal*** in 1996. • G Altshuller died in 1998.
1998-2004	• Organizations with TRIZ expertise developed different versions of T*RIZ (I-TRIZ, xTRIZ, CreaTRIZ, TRIZ+, OTSM- TRIZ*) • Pre-1998 TRIZ of Altshuller referred as *Classical TRIZ* • Creax Belgium released ***TRIZ software " Innovation Suite"*** • Developed ***TRIZ for Business Management, Kids and Pedagogy.*** • ***Matrix for Resolving Technical Contradictions and 40 Inventive Principles applied to other areas, architecture, chemistry, chemical engineering, finance, operations management, etc*** • Introduced ***Simplified Inventive Thinking(SIT), Advanced Simplified Inventive Thinking (ASIT), and Unified Structured Inventive Thinking (USIT)*** • Established European TRIZ Association, French TRIZ Association and Italian TRIZ Association. • Established Altshuller Institute for TRIZ Studies in the US
2004-2008	• Introduced new tools for analyzing complex problems and management: ***Root Cause Analysis*** + for decomposing inventive problems & Prob***lem Flow Technology & Problem*** Networking for managing complex problems. • New tools based on previous studies emerged: ***Hybridization, Anticipatory Failure Determination, Function-Oriented Search, Functional Clues, Inventive Standards for Business Management & Radar Plot for Mapping of Technology Systems Evolution*** • Established ***Japan TRIZ Association*** • Experimental versions ***of ARIZ*** • ***Directed Evolution by Ideation International*** • Integration ***of TRIZ with QFD and DFSS , VE , DFM,***

Originally developed in 1946 by Altshuller, his research work culminated with the following key observations and findings (Altshuller, 1987, 1989):

1. Problems and solutions were repeated across industries and sciences.
2. Patterns of technological evolution were repeated across industries and sciences.
3. Innovative solutions used technical and scientific effects outside the field where they were developed.
4. Innovation is not a random process. It can be codified, classified, and systematically done.

TRIZ departs from the standard problem solving frame by removing artificial constraints , customarily arising from inherent biases, habits, beliefs, rules , history, tradition , education and training, and past experiences. It re-formulates a "problem" from a different paradigmatic perspective. It avoids the repeated trials and errors in design and systematizes the creativity and innovation process. Trade-offs and compromises are not tolerated and are no longer acceptable criteria for systems performance (Zlotin, 1998). Achieving perfection or ideality of the system has become the ultimate desideratum.

We can represent the basic TRIZ structure as a pantheon of destination point or goal, structural elements and foundational concepts and methods. This is shown in Figure 2.

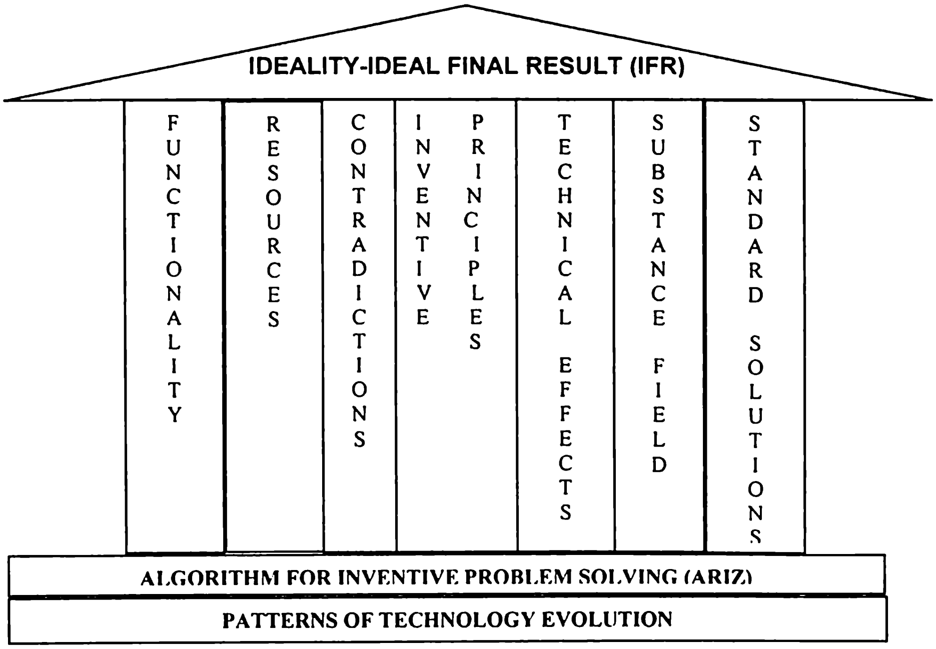


Figure 2: Pantheon Structure of Basic Classical TRIZ

Objective and Goal of TRIZ

In this section, we introduce the concept of ideality as the overarching goal and objective of TRIZ.

Ideality and Ideal Final Result (IFR)

The main objective of TRIZ is to achieve ideality in systems. Altshuller defined ideality as the quotient of the sum of all useful effects and the sum of all harmful effects (i.e. costs and harm) accruing from a system. In TRIZ nomenclature, ideality is a state in which performing a desired function or effect accrues without the physical existence of the system. (Altshuller,1999) The ideal system is a system that delivers the function without the system. Useful effects refer to value or benefits created by the functioning of the system while harmful effects are those undesirable effects comprising costs, material, space, energy , noise, pollution, etc).

(1) Ideality = $\sum$ useful functions / $\sum$ harmful functions.

In systems language, ideality is equivalent to systems value which is the aggregate measure of system performance. It is akin to the concept of "value" introduced by Lawrence D Miles who defined value as the ratio of sum of functions and the sum of costs. The higher this value the better is the system (Royzen, 1993).

One of the fundamental tenets of TRIZ is that as the system evolves, it increases its degree of ideality. The direction of evolution is toward improving benefits, improving functionality, decreasing negative effects, decreasing costs and decreasing harm. The ultimate goal of TRIZ is the ideal final result (IFR) which is the state where the useful functions are improved while the harmful effects are reduced to zero. (Altshuller, 1987). Mathematically, this translates to infinite useful functions or benefits with zero costs and harm, which converges as the ideal system. An ideal system is therefore a system that delivers functions at no cost, does not occupy space, does not consume energy, does not emit harmful gases, etc. Altshuller (1979) defined the ideal machine as the machine with no mass or volume but does the required work. The ideal method gets the necessary effect autonomously without spending energy or time. The ideal process is a process with the result without the process itself while the ideal substance is a no substance with the function done. As shown in Figure 1, the IFR is the intersection point of the best values of two contradicting functions as contrasted to an optimum trade-off point. As shown in the graph, the IFR is independent of the constraints of the original problem. In TRIZ, the IFR is the starting point for generating trajectories of potential solutions to a systems problem. The closer the solution is to the IFR, the better the system is. While IFR may not be achieved, ideality forces designers and problem solvers to expand the solution space beyond the restrictive limits of their experience domain thereby afford them the opportunity to discover innovative and inventive solutions, heuristically. Therefore, the IFR defines the ideal quality attributes of the system – absence of deficiencies and preservation of the advantages of the original system.

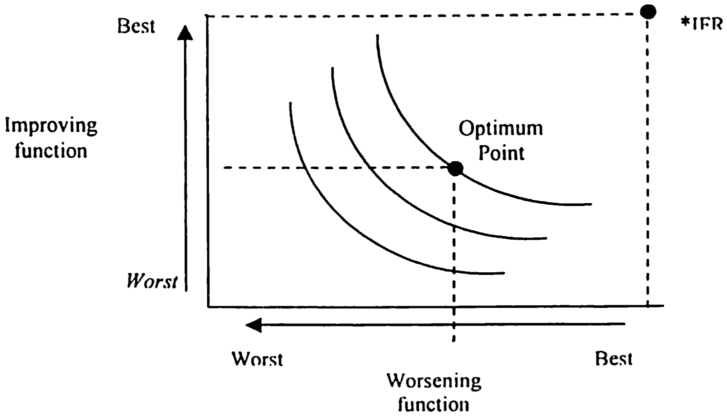


Figure 3: IFR vs. Optimum Point
Adapted from Mann (2003)

Terninko, Zusman & Zlotin (1998) enumerated six generic ways to improve ideality:

(1) Eliminate auxiliary functions. *Examples are unnecessary packaging in many products, redundant inspection work and multiple handling in numerous manufacturing operations, value meals, budget air travels, generics.*

(2) Eliminate elements and delegate elements to resources. *Examples are electronic ticketing, on-line check-in, video-conferencing, outsourcing, and virtual manufacturing.*

(3) Identify self-service. *Examples are modular furniture, electronic tag system, self-programmed instruction, vendo-type services.*

(4) Replace elements, parts or total system. *Examples are acoustic, visual, electronic sensors for mechanical devices, tele-commutingfor physical transportation, automatic storage and retrieval system (ASRS) for manual storage and retrieval,*

(5) Change or simplify the principle of operation of the system. *Examples are one –stop shop service facilities, kanban system, no-touch or single touch system, dock-to-stock system*

(6) Use resources. *Examples are waste recycling and re-use, waste heat recovery, co-generation, waste to energy conversion, 24/7 operation, flexible multi-skilling, multi-site electronic work cells, remote maintenance support system.*

It should be stressed that ideality is the metric that measures the progress toward the ideal final result. The closer the ideality to the IFR, the more ideal the system is.

Structural Elements and Fundamental Paradigms of TRIZ

We describe in this section the basic elements of TRIZ. We also discuss the fundamental paradigms that uniquely differentiate them from other concepts and other system improvement approaches.

Eight Patterns of Technology Evolution

The basic building block of TRIZ is the eight patterns of technology evolution which Altshuller identified during his original investigation of the commonality behaviour of about 200,000 patents (Altshuller, 1987). He observed that technical system that was designed to provide defined functions tended to evolve in a systematic way according to a generic pattern and trend behaviour over time. He specified eight patterns defining the trends of technology evolution that provide knowledge in predicting the behaviour of the system through time. Table 1 summarizes these eight patterns together with their corresponding theory.

Table 2 : Eight Patterns of Technology Evolution

Pattern	**Description**
Evolution Toward Increased Ideality	*Every system generates both useful and harmful effects. Over its lifetime, every system will achieve its ideal state.*
Technology Evolution Stages – Life Cycle	*Every system follows a cycle of birth, grow, maturity, and decline according to an S-curve pattern*
Non-uniform Development of System Elements	*Each system component has its own S-curve. Each component evolves at different velocities, reaching technology limits at different time points those results in contradictions.*
Evolution Toward Increased Dynamism & Controllability – Dynamization	*Through time, systems become more flexible and become easier to control and monitor.*
Evolution Toward Increased Complexity, then Simplification and Integration – Multiplication	*Over time, systems tend to add more functions that initially build complexity, then collapse into simpler systems and then combine to provide more functions.*
Evolution with Matching and Mismatching Elements – Synchronization	*To improve system performance or compensate for undesirable effects, evolving system elements are matched or mismatched. Matched elements are system components with the same nature and function.*
Evolution Toward the Micro-level and Increased Use of Fields – Scaling Up or Down	*Through time, systems tend to transition from macro to micro systems. To improve performance and control during the transition different energy fields are used.*
Evolution Toward Decreased Human Involvement-Automation	*Over time, systems become more and more automatic obviating human involvement.*

Adapted from Domb (2000) and Petrov (2005)

Recognizing the generic patterns, regularities, and trends of evolution enables the designer to map and forecast future qualitative trajectories and successive transformations that systems undergo in delivering functions toward ideality. Barriers to systems performance can be overcome by invoking similar or analogous evolutionary patterns from other systems. For example, the "instant pre-mix technology " in the food industry has percolated into modular fabrication in construction, on-line on- demand delivery for service systems, and virtual manufacturing and servicing .

Functionality

In systems engineering, a function refers to a specific action or series of actions necessary to achieve a given objective. Analogously in TRIZ, a function is defined as the natural or inherent action performed by a system. The most important function is called the main useful function (MAU). It is the primary reason for the existence of the system and must always exist. There are also secondary useful functions. These functions are either secondary functions or non-basic but beneficial functions. While they are not basic work functions, they provide benefits and other useful effects to the users. In addition, there are supporting functions that support the main basic functions. Assisting functions assist other useful functions while correcting functions rectify the negative effects of another useful function. Supporting functions are useful, but do not provide benefits directly to the user and incur cost. Harmful functions are unwanted function, create undesirable effects, are not useful, and do not provide any benefits at all.

To describe a function, TRIZ uses the substance–field (Su-F) representation or more simply a subject-action/field-object template as shown in Figure 4. Any technical system or its components can be modelled as a number of substances interacting with each other via six types of fields – mechanical, acoustic, thermal, chemical, electrical, magnetic, and electro-magnetic. Satisfactory interaction implies normal useful actions between and amongst the substances. Disfunctionality means unsatisfactory interactions amongst the substances. These unsatisfactory interactions can be categorized as:

(1) *Insufficient useful action.* Not enough to achieve desired function
(2) *Excessive useful action.* Produce more action than required.
(3) *Harmful action.* Necessary interaction producing positive effects but results in a side negative effect.
(4) *Missing useful action.* Interaction is necessary but how to introduce it in the system is unknown.

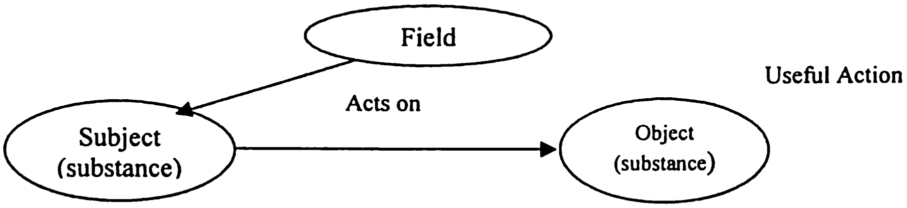


Figure 4: Substance-field model

Resources

In TRIZ, a resource is defined as anything in the system that is not used to its optimum potential. Terniko, Zusman & Zlotin (1997) categorized resources as readily available, substance, or derived resources. Readily available resources are resources that can be used in their existing state. Substance resources comprise materials that compose the system and its environment. They can be physical raw materials, waste, by- products, elements of system, and substances from surrounding environments, harmful and altered substances from the system. Derived resources are those hidden resources resulting from combining, transforming, accumulating, concentrating or interfacing readily-available resources. Readily-available and derived resources can take the form of fields or energy resources, space resources, time, information and knowledge resources, functional resources, environment and interactions of the system with the environment. On a more operational level, Yang (2005) categorized and segmented resources as substance, field, space, time, information and knowledge and functional resources. Field resources include energy within and outside the system, energy from system waste and energy that can be built upon existing sources. Space resources can come from empty space, space at interface of the different systems, or space created by vertical, nested or re-configuration of existing system elements. Time resources can originate from system pre-work & post- work periods, or time freed from concurrent processing, just-in-time operation, or efficient flow scheduling and sequencing. Information and knowledge covers knowledge of all substances, all available fields, past, present and future knowledge, other people knowledge and knowledge of operation. Functional resources include un-used or under-utilized existing system main functions, secondary functions and harmful functions.

In TRIZ, to achieve ideality in a structured and repeatable manner, everything becomes a resource for the inventive solution. The challenge is to look for abundant, cost-effective, ready and easy-to-use resource that can maximize benefits while minimizing undesirable effects.

Contradictions and Inventive Principles

TRIZ introduced two basic types of contradiction: (1) technical contradiction and (2) physical contradiction.

A technical contradiction is a condition where improvement in some attributes of a system leads to the simultaneous deterioration of other technical attributes. For example, increasing speed consumes more fuel or increasing strength increases weight in transport vehicles or increasing capacity utilization increases cycle time in manufacturing flow systems. A typical solution to this technical contradiction is to find a trade-off or compromise between the two contradictory demands or an "optimum point". However, this solution does not eliminate the contradiction. It retains the harmful or undesired action or shortcoming of the system. TRIZ, on the hand, believes that by eliminating the technical contradictions, both contradictory attributes can be improved dramatically thereby elevating the performance of the system to a significant level. Altshuller screened 40,000 patents from 200,000 patents and formulated technical contradictions between technical attributes of systems (Altshuller, 1997). He identified 39 engineering parameters and codified about 1250 typical system contradictions. Shown in Table 3 is the list of these 39 engineering parameters together with their descriptive definitions.

Table 3: Altshuller's Thirty-nine Engineering Parameters.

Parameter Name	Definition/ Description
Weight of Moving Object	Mass of a moving object in a gravitational field. Force that the body exerts on its support or suspension or on the surface on which it rests
Weight of Non – moving Object	Mass of a stationary object in a gravitational field. Force that the body exerts on its support or suspension or on the surface on which it rests
Length of Moving Object	Any one linear dimension of a moving object
Length of Non- moving Object	Any one linear dimension of a stationary object
Area of moving Object	Geometrical characteristic described by the part of a plane enclosed by a line. Part of the surface occupied by the moving object.
Area of non- moving Object	Geometrical characteristic described by the part of a plane enclosed by a line. Part of the surface occupied by the stationary object.
Volume of Moving Object	Cubic measure of space occupied by a moving object.
Volume of Non- moving Object	Cubic measure of space occupied by a stationary object.
Speed	Velocity of an object. Rate of a process or action in time.
Force	Force measures the interaction between systems. It is any interaction that aims to change the condition of an object.
Stress	Force per unit area. Tension.
Shape	External contours, appearance of a system.
Stability of Object	Wholeness or integrity of the system. Relationship of the system's constituent elements. Increasing entropy decreases stability.
Strength	Resistance to breaking. Extent to which object is able to resist changes in force.
Durability of Moving Object	Time the moving object performs the action. Service life. Mean time between failures. Shelf-life.
Durability of Non- moving Object	Time the stationary object performs the action. Service life. Mean time between failures. Shelf-life.
Temperature	Thermal condition of the object or system.

Brightness	Light flux per unit area. Illumination.
Energy Spent by Moving Object	Measure of the moving object's capacity to do work. Energy required doing a particular job.
Energy Spent by Non-moving Object	Measure of the stationary object's capacity to do work. Energy required doing a particular job.
Power	Rate of use of energy. Time rate at which work is performed.
Waste of Energy	Use of energy that does not contribute to the job done.
Waste of Substance	Partial or complete, permanent, or temporary loss of some of a system's materials, substances, parts or subsystems
Loss of Information	Partial or complete, permanent, or temporary loss of data or access to data in or by a system
Waste of Time	Time is duration of an activity. To improve loss of time is to reduce time. 'Cycle time reduction' is a common term.
Amount of Substance	Number or amount of a system's materials, substances, parts or subsystems which may be changed fully, partially, permanently or temporarily.
Reliability	Ability of the system to perform its intended function under stated time and conditions.
Accuracy of Measurement	Closeness of the measured value to the actual value of a property of a system.
Accuracy of Manufacturing	Extent to which actual characteristics of the system or object matched the required or specified characteristics
Harmful Factors Affecting on Object	Susceptibility of a system to externally generated effects
Harmful Side Effects	Effects resulting from the operation of the system that reduce efficiency or quality of the functioning of the object or system
Manufacturability	Ease of manufacture. Degree of facility, comfort or effortlessness in manufacturing or fabricating system or object
Convenience of Use	Ease of operation. Simplicity. "Easy" processes require less people, less steps, etc.
Reparability	Ease of repair. Quality characteristics such as convenience, comfort, simplicity, and time to repair faults, failures, faults or defects in a system.
Adaptability	Versatility. Extent to which a system or object positively responds to external changes.
Complexity of Device	Number and diversity of elements and element interrelationships within a system.
Complexity of Control	Difficulty of detecting and measuring. Complexity and cost of measuring and monitoring a system.
Level of Automation	Extent at which a system or object performs its functions without human involvement.
Productivity	Number of functions or operations done by a system per unit time. Output per unit time. Cost per unit output.

Adapted from Altshuller (1996,1999)

To resolve these technical contradictions, Altshuller compiled and developed the forty inventive principles with 86 sub-principles. These forty inventive principles propose the most promising solution to overcoming the technical contradiction. However, they do not directly provide the solutions. The Matrix for Resolving the Technical Contradictions comprising these 39X 39 engineering parameters are populated with the recommended inventive principles that can be used to generate solutions that will eliminate the technical contradictions. A subset of the Contradiction Matrix containing the corresponding inventive principles is shown in Table 4 to illustrate how to it is structured and how it is used. Given a technical contradiction, identify the improving parameter and the worsening parameter, then using the Table of Contradiction Matrix, the intersecting cell of these parameters contain the inventive principles to use to overcome the contradiction. For example:

Improving Parameter	Worsening Parameter	Inventive Principles
1-Length of moving object ↑	5-Area of moving object ↓	29-Pneumatics or hydraulics
		17-Another dimension
		38-Boosted interactions
		34-Discarding and recovering

Table 4: Subset of 39 x 39 Matrix of Technical Contradictions (pc-physical contradictions)

Improving Parameter/ Worsening Parameter	1- Weight of a moving object	2- Weight of a non Moving object	3- Length of a moving object	4- Length of a non Moving object	5- Area of a moving object	:	:	35- Adaptability or Versatility	36- Device Complexity	37- Diffi - culty of detecting	38- Extent of an automation	39- Productivity
1-Weight of a moving object	Pc	-	15, 8, 29, 34	-	29, 2, 40, 28	:	:	29, 5, 15, 8	26, 30, 36, 34	25, 29, 26, 32	26, 35, 18, 19	35, 3, 24, 37
2-Weight of a non-moving object	-	Pc	-	10, 1, 29, 35	-	:	:	19, 5, 29	1, 10, 26, 39	25, 28, 17, 15	2, 26, 35	1, 28, 15, 36
3-Length of a moving object	8,15, 29, 34	-	Pc	-	15, 17, 4	:	:	14, 15, 1, 16	1, 19, 26, 24	35, 1, 26, 24	17, 24, 26, 16	14, 4, 28, 29
4-Length of a non-moving object	-	35, 28, 40, 29	-	Pc	-	:	:	1, 35	1, 26	26	-	30, 14, 7, 26
5-Area of a moving object	2,17, 29,4	-	14, 15, 18, 4	-	Pc	:	:	15, 30	14, 1, 13	2, 36, 26, 18	14, 30, 28, 23	10, 26, 34, 2
:	:	:	:	:	:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:	:	:	:	:	:
35-Adaptability or versatility	16, 15, 8	19, 15, 29, 16	35, 1, 29, 2	1, 35, 16	35, 30, 29, 7	:	:	Pc	15, 29, 37, 28	1	27, 34, 35	35, 28, 6, 37
36-Device complexity	26, 30, 34, 36	2, 26, 35, 39	1, 19, 26, 24	26	14, 1, 13, 16	:	:	29, 15, 28, 37	Pc	15, 10, 37, 28	15, 1, 24	12, 17, 26
37-Difficulty of detecting	27, 26, 28, 13	6, 13, 28, 1	16, 17, 26, 24	26	2, 13, 18, 17	:	:	1, 15	15, 10, 37, 28	Pc	34, 21	35, 18
38-Extent of automation	28, 26, 18, 35	28, 26, 35, 10	23,	17, 14, 13	-	:	:	27, 4, 1, 35	15, 24, 10	34, 27, 25	Pc	5, 12, 35, 26
39-Productivity	35, 26, 24, 37	28, 27, 15, 3	18, 4, 28, 38	30, 7, 14, 26	10, 26, 34, 31	:	:	1, 35, 28, 37	12, 17, 28, 24	35, 18, 27, 2	5, 12, 35, 26	Pc

TRIZ 40 and TRIZ-SITE provide excellent presentation and treatment of the use and application of the Contradiction Matrix (TRIZ40, TRIZ-SITE) . The interested reader is strongly advised to use these two excellent online TRIZ websites for applying the Table of Contradiction Matrix. Table 5 summarizes the classical Altshuller normative description of the forty inventive principles.

Table 5: Altshuller's Forty Inventive Principles with their Descriptive Actions

	Principle Name	Descriptive Actions
1	Segmentation	1. Divide system into independent parts 2. Make system easy to disassemble 3. Increase degree to fragmentation or segregation 4. Transition to micro-level
2	Taking out	1. Separate interfering parts or single out only the necessary part
3	Local quality	1. Change structure from uniform to non-uniform Or change external influence from uniform to non-uniform 2. Make part best suited for operation 3. Make part do different & useful functions
4	Asymmetry	1. Change shape from symmetrical to asymmetrical 2. Change degree of asymmetry
5	Merging	1. Combine identical or similar systems or assemble identical or similar parts 2. Make operations contiguous, parallel, bring together in time 3. Agglomerate system to bi- and poly-system

6	Universality	1. Do multiple functions 2. Standardize features
7	Nesting	1. Place system inside another 2. Let part pass through a cavity in the other
8	Anti-weight	1. Merge with other systems that provides lift 2. Make system interact with the environment
9	Preliminary Anti-Action	1. Do anti-actions to control harmful effects 2. Create prior stresses to oppose undesirable working stresses
10	Preliminary action	1. Do action before it is needed 2. Pre-arrange system without losing time , convenience and ease of operation
11	Beforehand cushioning	1. Prepare prior contingency actions to compensate for low reliability
12	Equipotentiality	1 Limit position fields
13	Inversion	1. Invert actions used to solve problems 2. Make movable parts or external environment fixed or fixed parts Movable 3.Turn system upside down
14	Spheroidality	1. Use curvilinear parts for rectilinear parts or surfaces, spheroids for flat surfaces & ball-shaped structures for cubes 2. Use rollers, balls, spirals & domes 3. Use rotary motion 4. Use centrifugal forces
15	Dynamics	1. Design characteristics to optimize operating conditions 2. Divide system into parts capable of movement relative to each other 3. Make rigid or inflexible system movable or adaptive 4. Increase degree of free motion
16	Partial or excessive action	1. Use "slightly less" or slightly more" if 100% objective is not achievable
17	Another dimension	1. Move system into 2-dimensional space 2. Move system into 3-dimensional space 3. Use multi-story arrangement of a system 4. Tilt or re-orient system. Look from another angle. 5. Use another side of a given area. 6. Use another scale.
18	Mechanical vibration	1. Make system oscillate or vibrate 2. Increase frequency 3. Use system resonant frequency 4. Use external elements to create oscillation/vibration
19	Periodic action	1. Use periodic or pulsating actions instead of continuous actions 2. Change frequency of periodic actions 3. Use pauses between impulses to perform different actions
20	Continuity of useful actions	1. Make system work at full-load all the time. Carry out work continuously. 2. Eliminate idle or intermittent actions or work.
21	Skipping	1. Conduct process or certain stages at high speed
22	"Blessing in disguise" or "Turning Lemons into Lemonade"	1. Use harmful factors to achieve a positive effect. 2. Eliminate primary harmful action by adding it to another harmful Action to resolve problem 3. Amplify a harmful factor to such a degree that is no longer harmful
23	Feedback	1. Introduce feedback to improve process or action 2. Change magnitude or influence of feedback
24	Intermediary	1. Use intermediary carrier article or intermediary process 2. Merge system temporarily with one another
25	Self-service	1. Make system serve itself by doing auxiliary useful functions 2. Use waste or lost resources ,energy or substances
26	Copying	1. Use simpler and expensive copies of systems 2. Replace system with optical copies 3. Use appropriate "out of the ordinary" illumination and viewing. Move to infrared or ultra-violet.
27	Cheapshort-living objects	1. Replace expensive system with multiple inexpensive systems
28	Mechanics substitution	1. Replace mechanical means with sensing (acoustic, optical, taste or smell) means 2. Use electric, magnetic, and electromagnetic to interact with system 3. Change from static to movable fields, from unstructured to structured fields
29	Pneumatics & hydraulics	1. Use gas or liquid parts instead of solid parts
30	Flexible shells and thin films	1. Use flexible shells and thin films instead of 3-dimensional structures 2. Isolate system from external environment using flexible shells and their films
31	Porous materials	1. Make system porous or add porous elements 2. Use pores to introduce useful substances or functions in porous systems

32	Color changes	1. Change color of a system or external environment 2. Change transparency of a system or environment 3. Use color additives or luminescent elements to improve observability 4. Change emissivity properties
33	Homogeneity	1. Make system interact with a given system of the same material
34	Discarding and recovering	1. Dissolve or modify portions of system that have fulfilled their functions 2. Restore consumable parts or system directly in operation
35	Parameter changes	1. Change system's physical state 2. Change concentration or consistency 3. Change degree of flexibility 4. Change temperature 5. Change pressure 6. Change other parameters
36	Phase transitions	1. Use phenomena occurring during phase transitions
37	Thermal expansion	1. Use thermal expansion (contraction) of materials
38	Boosted Interactions (Strong Oxidants)	1. Replace common air with pure oxygen 2. Replace enriched air with pure oxygen 3. Expose air or oxygen to ionizing radiation 4. Use ionized oxygen 5. Replace ionized oxygen with ozone 6. Insert an active ingredient
39	Inert environment	1. Replace a normal environment with an inert one 2. Add neutral parts or inert additives to system
40	Composite structure	1. Change from uniform to composite (multiple) structure

Adapted from Mann and Domb (1999) and Mann and Winkless (2002)

Evidently, the 40 inventive principles appear to be the easiest element of TRIZ due to its prescriptive nature and the abundance of examples for each of the principle. The TRIZ literature teems with various applications and examples of the forty inventive principles in both technical and non-technical systems starting with the seminal examples of Domb and Kate (1997). For technical systems, Mann (2001) developed the forty inventive applications in architecture; Hipple (2005) in chemical engineering; Grieson, Fraser, Morrison , Niven, and Chisholm (2003) in chemistry; Retseptor (2002) in micro-electronics; Mann and Winkless (2001,2002) in food technology; Rea (2001) in softwares; Jones and Harrison (2001) in eco-innovation; Tepliskiy and Kourmaer (2005) in construction technology and Kaplan, Tschirhart and Hipple (2010) in human factors and ergonomics. For non-technical systems, the applications of the forty inventive principles for business were developed by Mann and Domb(1999); social examples by Terninko (2001), quality management by Retseptor (2003); service operations management by Zang and Tan (2003) ; finance by Dourson (2004); education by Marsh, Water and Marsh (2004); marketing, sales and advertising by Retseptor (2005); customer satisfaction enhancement by Retseptor (2007) and even the elimination of the severe acute respiratory syndrome (SARS) virus in Singapore by Belski, Kaplan, Shapiro, Vaner and Wai (2003). Interestingly, these applications made TRIZ easy to understand.

Physical contradiction occurs when an element of a system conflicts with itself. To perform a particular function, it must have this attribute but to perform another function it must not have the attribute. For example, coffee should be hot enough to enjoy it but not too hot to enable you to hold the cup. Physical contradictions are easier to solve than technical contradictions. Hipple (1999) described methods on how to overcome physical contradictions using the four separation principles of TRIZ:

(1) *Separate in Time. Separate action/part/system causing the physical contradiction. Example, traffic light separate vehicles in time.*

(2) *Separate in space. Physically move action/part/system to resolve contradiction. Clover-leaf, overpass or underpass separate flowing traffic in space.*

(3) *Separate between parts and whole. Break action/part/system into small parts. Combine action part/system into a whole. Rotunda flow is an example of separation between parts and whole.*
(4) *Separate by condition. Handle action/part/system differently based on condition. Express lane or electronic-pass lanes are examples of separation by condition.*

Inventive Standard Solutions

When there are unsatisfactory interactions in the system, TRIZ recommends specific rules that can improve the system by modifying the physical model of the system. The modification can be done by introducing new components, replacing existing components, modifying existing components or changing structure of the system. The system is formulated using substance-field models (SFMs).

Mann (2001) indicated that from 1975 to 1985, G Altshuller and his cohorts compiled and classified 76 standard solutions addressed to systems needing improvement, specifically level 3 inventive problems. As described earlier, Level 3 inventive problems are problems requiring paradigm shifting, changes in physical effects and with technical contradictions resolved.

The standards specified the condition of the problem situation and defined the framework of the solution concept. In accordance with the laws of technical system evolution, these standard solutions suggest directions for the transformation of the initial technical system toward an improved level of system ideality. These were derived from analogous systems of variations in substances in substance –field models (SFMs).

The 76 standard solutions are divided into 5 cases:

Case 1 - Improve the system with no or little change in the system – 13 standard solutions
Case 2 - Improve system by changing the system – 23 standard solutions
Case 3 -Transition systems to super system or micro-level - 6 standard solutions
Case 4 - Detection and Measurement – 17 standard solutions
Case 5 - Strategies for simplification and improvement of the other standard solutions – 17 standard solutions.

For a detailed description of the 76 standard solutions with their corresponding normative actions ,the interested reader is strongly encouraged to review Terninko, Domb and Miller (2000).

Database of Scientific & Technical Effects

The catalogue of physical, chemical, geometric and other scientific effects maps technical functions to physical effects, principles, and phenomena. Pointers of effects and phenomena are specifically organized information registries. Effects are repeated interactions of elements between inputs and outputs of processes or systems. These effects are natural results and phenomena known in physics, chemistry, geometry and biology. Kucharavy (2006) traced the evolution of pointers of effects starting from 1969 to 1985 with the first publication of physical effect pointer in 1971. The whole spectrum of effects covers plain effect (one input –one output), complex effect (multiple inputs- single output or single input- multiple outputs), reversible effect (elastic deformation), irreversible effect (plastic deformation), connected effect (series of effects) and combined effects (chain of connected effects)

With the use of the effects knowledge database, many alternative options for satisfying and delivering the required system function become readily available. More importantly, the easy

With the use of the effects knowledge database, many alternative options for satisfying and delivering the required system function become readily available. More importantly, the easy access to this database, compresses time for searching them. A sample effects subset is shown in Table 6 below:

Table 6: Sample Effects Subset

Function	Effects
Separate mixture	:Electrical separation. Magnetic separation. Centrifugal forces. Absorption. :Diffusion. Osmosis.
Move solid object	: Magneto-restriction .Thermal expansion. Vibration.
Stabilize object	: Electrical effect. Magnetic effect. Viscosity. Jet motion. Gyroscopic effect.

ARIZ – Algorithm for Inventive Problem Solving

In this section, we describe the step by step methodology for solving inventive problems otherwise known as ARIZ. ARIZ is considered as the heart of TRIZ. The overall framework is starting with a specific problem, we convert into a generic problem by abstraction, then we generate a generic solution by analogy and from this generic solution, we converge into a specific solution. This overall high-level problem structure is shown in Figure 5.

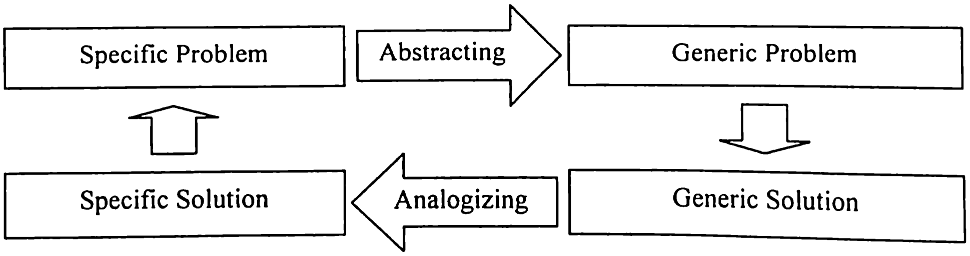


Figure 5: TRIZ Generic Problem Solving Framework

At the operation level, there exist many versions of ARIZ which evolved from 1970 to 1985. We present here a simplified hybrid version of ARIZ that highlights the unique tools and techniques of TRIZ which we believe is easy to use and implement in a design and improvement environment.

Step 1. Define the technical system
    What is the main useful function?
    What is the objective of the system?
    What is the goal of the system?
    What are the resources?
    What is the operating environment?
    What are the costs associated with the system?
    What are the ideal results?
Step 2. Identify the ideal final result (IFR)

Step 3. Compare and contrast the existing system with IFR
    How far is the existing system from the IFR?

Step 4. Establish ideality equation
    What are the benefits?
    What are the harm and costs?

Step 5. Identify the system level contradictions

What are the physical contradictions?
What are the technical contradictions?
Can the technical contradictions be converted to physical contradictions?

Step 6. Use the Contradiction Matrix to resolve contradictions
Use separation principles to resolve physical contradictions
Use inventive principles and the contradiction matrix to overcome for technical contradictions

Step 7. Compare existing system with solution ideality

Step 8. Evaluate solution. Compare with IFR. If not acceptable, go to step 10

Step 9. Implement solution.

Step 10. Create system model.

Step 11. Identify super system/subsystem contradictions

Step 12. Create substance- field models of the system parts that has problem
- 12.1. Use trimming for redundant function
- 12.2. Use functional improvement for absent useful function
- 12.3. Use standard solutions for elimination for harmful function
- 12.4. Use separation principles for physical contradictions.
- 12.5. Use inventive principles to resolve technical contradictions
- 12.6. Use physical, chemical, and geometric effects database to create and introduce useful functions that are unknown .

Step 13. Go back to Step 7.

Clearly, except for the specific and unique TRIZ tools embedded in the step-by-step problem solving structure, ARIZ is a variant of the applied scientific method of problem solving.

Case Study Application

We presented in this section an abridged case study applications of TRIZ experienced by the author in the course of his assimilating TRIZ in his graduate courses in industrial engineering and total quality management and his previous quality improvement work in semiconductor manufacturing . These cases illustrate how TRIZ can simplify and accelerate the generation of innovative solutions to inventive problems.

Case Study Application 1: Inventive automotive battery design (Cuaresma, Dalawis, Lodriguito, Raneses, 2010)

Situation

A battery is an electrochemical device that converts chemical energy into electricity, by a galvanic cell. A galvanic cell is a fairly simple device consisting of two electrodes of different metals or metal compounds (an anode and a cathode) and an electrolyte.

The current vented or flooded type battery uses corrosive liquid sulfuric acid, electrolyte is pretty corrosive, vents dangerous explosive gases, must be installed upright and heavy. These are undesirable attributes that users wish to minimize or get rid of.

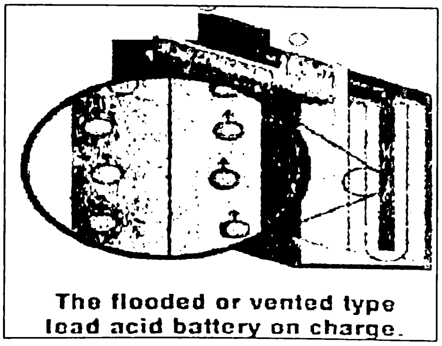


Figure 6: Current Battery: Flooded or vented Type

Problem Formulation

Table 7: TRIZ Problem Formulation of Auto Battery

Engineering system	High-capacity, long life, safe, easy to use, auto battery that can be installed in any angle.
Operating environment	6-8 engine starts per day, normal vehicle electrical load, normal driving cycles, tropical temperature conditions, normal road conditions with occasional speed bumps and coarse road conditions.
Resource requirements	Plates, Separators, Electrolyte, Electrical field, Chemical reaction, Vibration and Space
Primary useful function	Start engine, Provide power and Stabilize voltage
Harmful effects	Corrode auto parts, Add weight, Consume space, Emit fume or gas, Generate heat, Cost of materials and Use lead
Ideal results	High-capacity, reliable , light, re-chargeable, leak-free, maintenance –free, pollution-free
Ideal Final Result (IFR)	Lead-free, leak-free, maintenance-free, pollution-free, fully-rechargeable

Generic Problem

The generic problem is how to come up with a cost-effective, reliable, high-capacity, light, rechargeable, leak-free, maintenance free and pollution –free auto battery to be used under normal operating driving cycles of 6-8 engine starts per day with warranty of at least 5 years

Technical Contradictions and Inventive Principles

The first contradiction is improving the capacity of battery and battery life implies increasing active material consumption (thicker plates + more electrolytes). This would make the battery a lot heavier. Translating this to parameters found in the contradiction table, the improving parameter is *strength* and the worsening parameter is the *weight of fixed object. From the Table of Contradiction matrix, there are 4 feasible inventive principles, namely,* #40-Composite Materials, #26 –Copying. #27-Cheap short living and # 1-Segmentation. Among these four inventive principles *the most applicable is principle 40 – use composite materials. The most appealing solution concept is to* convert separator to fine ,highly porous micro-fiber glass which as the following effects, increases current, decreases electrical resistance, resists vibration, does not emit explosive gas and does not permit spillage or leakage and allows installation in any angle.

The second technical contradiction is the longer the life of the battery, the more the parts become unstable with the stratification of acid. Translating this to parameters found in the contradiction table, the improving parameter is *duration of moving object* and the worsening parameter is the *objects composition stability. From the Table of Contradiction Matrix, the feasible inventive principles are #13- the other way around, #3 local quality and #35 parameter changes. The most appropriate principle is to change the parameter. Change the physical state of liquid electrolyte to solid type. Add fume silica to immobile the electrolyte.*

Inventive solution

The absorbent glass material (AGM) battery which is high capacity, lighter, vibration-free, safe, maintenance-free and can be installed in any angle is an inventive solution . This type of battery is also cost-effective, durable due to less wear and tear and could last for at least 5 years.

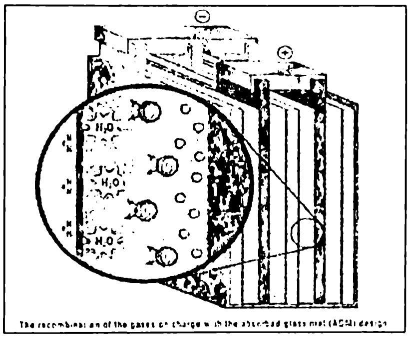


Figure 7: Inventive solution: Absorbent glass material battery

Case Study Application 2: Improvement Design of Pump Shoes for Working Women (Raneses, Abdul, Panabang, Revil, 2010)

Situation

High-heeled pumps are one of the favorite footwear among working women due to their versatility and elegance. They lend a touch of class and feminity to the wearer's appearance. These are two of the main reasons why women buy and wear high-heeled pumps despite the pain they inflict on women's backs as well as on ankles and calves in the form of blisters. Common causes of blisters are incorrect fit, the weight of the wearer, the height of the heels, and the type of materials used.

Generic Problem

The desire is to engineer pump shoes for working women that are designed for fashion, designed for comfort, fit for use, easy to wear, and long lasting .

Problem formulation

Table 8: TRIZ Problem Formulation of Pump Shoes for Working Women

Engineering system	Pump shoes for working women designed for fashion, fit-for–use, designed for comfort, easy –to-wear, and long-lasting
Operating environment	Worn by working women at least three times a week to work
Resource requirements	Durability of materials and Pressure from heels
Primary useful function	Protect feet from forces of the ground and from extreme temperature
Harmful effects	Foot blisters, Pain and calluses on toes and Cost of materials
Ideal results Ideal final result	Durable, stylish, comfortable and affordable pump shoes without causing foot blisters. Personalized, customized, blister-free and pain-free but still stylish/ fashionable

Technical Contradictions and Inventive Principles

The shoes need to be light weight to reduce stress from walking. Sole and heel contribute the most weight to the shoes. As the weight of the shoe heels become lighter, durability of the shoes worsens creating a technical contradiction. The feature to improve is #2, weight *of the non-moving object* while the parameter that is conflict is #16, *durability of a non-moving* object as seen from the Table of Contradiction Matrix. The most appropriate inventive principle is # 2, *taking out*. Single out the sole and the heel since they contribute the most weight to the shoes. Choose light material for both of them. Light wood and latex foam soft leather cushion for heel and light rubber for sole.

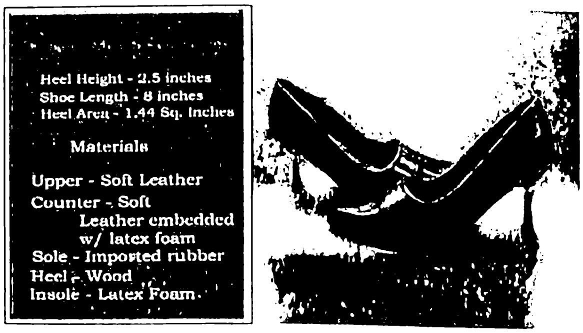
To look fashionable, the shoe heel must be taller. However, as the heel height increases, pressure on the feet increases, causing blister formation. This translates to another technical contradiction. The improving parameter is # 4, *length of a moving object*, while #11, *tension/pressure*, is the worsening parameter. From the Table of Contradiction Matrix, inventive principle #14, *curvature,* is the most applicable. Instead of using rectilinear parts, surfaces or forms, use curvilinear ones; move from flat surfaces to spherical ones; from parts shaped as a cube to ball-shaped structures. The solution concept is to change the heel from thin and straight to a curved one and increase the diameter of the top lift.

Furthermore, to be more fashionable, the shape of the upper part of the shoe needs to be thinner to appear stylish. However, the pointed toe cap /upper causes blister formation on the ball of the feet. This translates to a technical contradiction of #12, shape as the improving parameter and #31, harmful side effects as the worsening parameter. From the table of contradiction matrix, inventive principle #35, parameter change, change the degree of flexibility as the most appropriate. The solution is change the hard, rigid material of the upper to soft, elastic material such as soft leather or latex foam.

The force applied on the feet caused by the shoe parts in contact with the feet directly affects the stress on the ankle, toes, and ball of the feet of the wearer. This converts into a contradiction between # 10, *force /intensity* and #11 *pressures or stress*. The most applicable inventive principle to nullify this contradiction is # 11, *beforehand cushioning*. The most attractive solution is to place a cushion in between the sole and the lining especially those areas that are in contact with the feet points that are prone to blisters especially the ball of the feet and the heel.

Inventive Solution:

The inventive solution is pump shoes with a defined heel height and area and shoe length. Material is soft leather for upper, rubber for sole, wood for heel and latex foam for insole.



Heel Height - 2.5 inches
Shoe Length - 8 inches
Heel Area - 1.44 Sq. Inches

Materials

Upper - Soft Leather
Counter - Soft
Leather embedded
w/ latex foam
Sole - Imported rubber
Heel - Wood
Insole - Latex Foam.

Figure 8: Inventive Pump Shoes for Working Women

Case Study Application 3: Mechanical Damage Elimination during Electrical Testing of micro lead frame package, 32-lead, 7X 7 integrated circuit package (Alolod, Pantisma, Raneses, 2008)

Current Situation

In semiconductor manufacturing, micro lead frame (MLF) packages are considered as the cutting edge package technology of the future. However, owing to their small and thin dimensions, these packages alias no lead quad flat packages (NQFP) or quad flat no leads (QFN) integrated circuit packages are very susceptible to both external and internal mechanical damage during electrical testing. Mechanical damage physically manifests as scratches on package, pad, or leads, package crack, tool marks, chip outs or die cracks. Any evidence of package crack, die crack or tool mark on the unit is rejected. Scratches or laceration on the body surface exceeding 50% of the body surface is also rejectable. When the exposed base metal or the depth exceeds 25% of the plastic body thickness of a chip-out, the unit is likewise rejected.

The equipment uses gravity / free fall for moving units during testing. Units are loaded on tubes from the topmost of the handler via the loading module, then singulated and dropped towards the test chambers for temperature soaking. Singulators, control the unit movement, stopping and releasing of unit one by one. Figure 9 shows the diagram of the path of the units as they traverse the automated gravity-fed handler during electrical testing. Figure 10 shows the unit to unit movement of stopping and releasing. Also shown in Figure 11 is the physical example of chip out visible at 30X magnification.

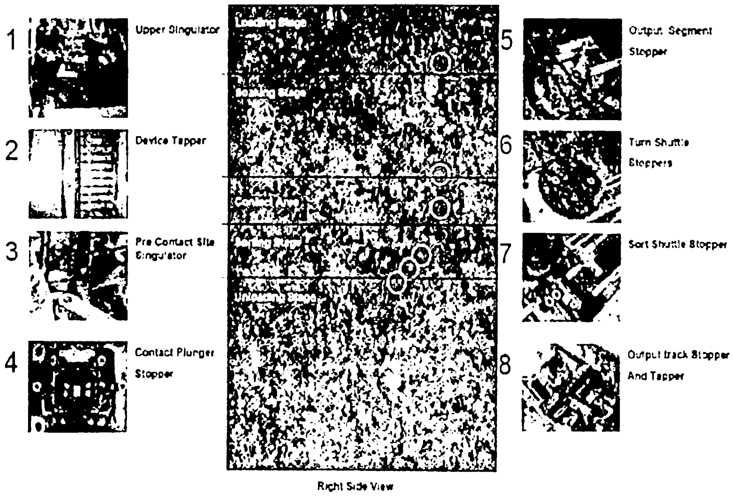


Figure 9: Automated Gravity-Fed Handler Diagram Indicating IC Contact Points

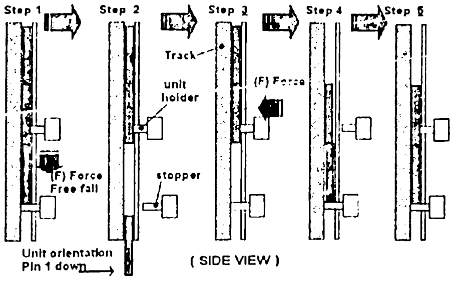


Figure 10: Singulator stopping and releasing unit. Unit holder force is perpendicular to the unit body

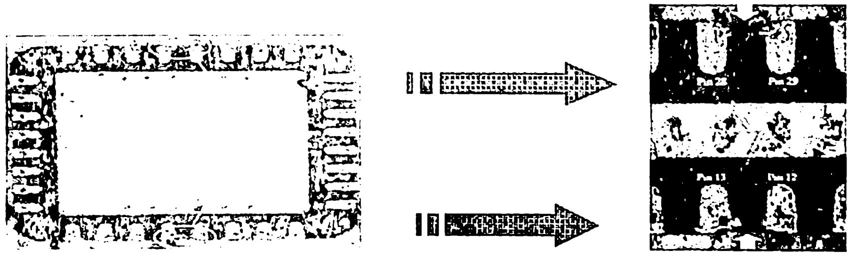


Figure 11: Chip-out on two side of the package visible on 30x magnification

Problem Formulation

Table 9: TRIZ Problem Formulation of the Mechanical Damage Elimination of the MLF/ QFN/ NQFP IC Package during Gravity –Fed Handling

Engineering system	Handler kit singulator stopping and releasing system handling small and thin no lead quad flat pack (NQFP) 32-lead , 7X 7 integrated circuit package resistant to mechanical damage during automated electrical testing
Operating environment	Tube-loaded ,gravity feed using automated handling equipment sliding sequentially at different temperatures ambient (25C) and at hot (130C), cold (- 40C) average of 4 insertions and maximum of 30 insertions
Resource requirements	Singulator stopping and releasing unit , Weight of unit , Temperature, Friction between units, Area of contact , Force free fall , Unit orientation , Force on the unit and Contact surface of unit with stopper
Primary useful function	Move unit Singulate unit (Control unit flow)
Harmful effects	Cost of re-insertion, Scrap, Consume space , Consume time , Damage unit and Jamming
Ideal results	No mechanical damage, no package crack, no tool mark, no chip out, no die crack during gravity-handling and testing
Ideal Final Result (IFR)	Mechanical damage- free nqfp/mlf/qfn package after testing

Generic Problem

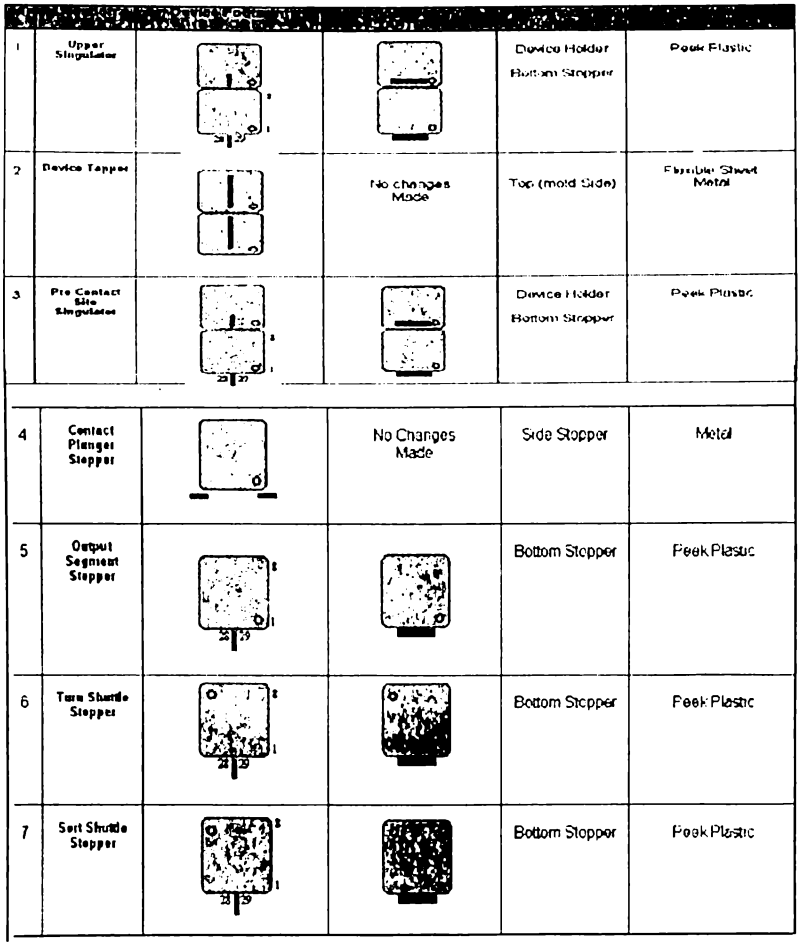
Re-design the handler kit singulator–holder system of the gravity–fed handler such that mechanical damage of mlf devices during gravity-fed handling is eliminated.

Technical Contradiction and Inventive Principles

The increase force (parameter # 10, force, and improving parameter) on the IC package results in increasing stress (parameter #11, worsening parameter) on the contact area with the stopper resulting in more friction and damage to the unit. The most appropriate inventive principle is # 11, cushioning. One solution concept is changing the stopping material from metal to peek (poly –ether- ether ketone). Peek material is thermoplastic, light weight, known to be softer than metal, and has greater elasticity than stainless metal. The other solution concept is shimming that controls the depth of the pressing of the unit to the socket. A shim is a replaceable sheet of material. The other contradiction is that as the weight of the unit increases, the reliability of the unit decreases since the stress increases causing mechanical damage to the unit. The improving parameter is the weight of the moving object while the deteriorating parameter is the reliability of the unit. The appropriate inventive principles are #11, cushioning, # 27 cheap disposable and #3 local quality. For cushioning, we have the peek material solution. For cheap disposable, we have the shim solution and for local quality, we zeroed in on the contact area between the unit and the unit holder and stopper. To decrease the stress, we increased the area of contact between the stopper and the holder.

Inventive Solution

The inventive solution was to change the stopper and holder material from stainless steel to peek and enlarge the area of contact between the unit and the stopper and holder. For additional cushioning, single shimming was provided. The changes are shown in Figures 12 and 13 indicating the foot print of area of contact improvement. Subsequent finite element analysis and accelerated life tests of the proposed solution confirmed the effectiveness of the solution. Mechanical damage was eliminated during the implementation of the solution.



1	Upper Singulator			Device Holder Bottom Stopper	Peek Plastic
2	Device Tapper		No changes Made	Top (mold Side)	Flexible Sheet Metal
3	Pre Contact Site Singulator			Device Holder Bottom Stopper	Peek Plastic
4	Contact Plunger Stopper		No Changes Made	Side Stopper	Metal
5	Output Segment Stopper			Bottom Stopper	Peek Plastic
6	Turn Shuttle Stopper			Bottom Stopper	Peek Plastic
7	Sort Shuttle Stopper			Bottom Stopper	Peek Plastic

Figure 12: Handler Block Diagram with Indicated Contact Changes and Material Changes

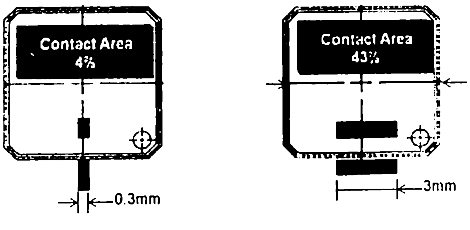


Figure 13: Enlargement of the Contact Area between the Unit and the Stopper and Holder.

Diffusion of TRIZ knowledge in Academic Education

In this section, we describe our experiences in teaching TRIZ in design-oriented courses in the graduate and advanced graduate level in Industrial Engineering (IE) and total quality management at the University of the Philippines Diliman.

To encourage the use of TRIZ in formal education, the author began introducing TRIZ in his graduate course in Total Quality Management (TM 225) at the University of the Philippines Technology Management Center since 2005. TRIZ is taught as a 3-hour learning module in structured innovation problem solving and creativity focusing on TRIZ basic concepts and structure, contradiction matrix, inventive principles, TRIZ in eco-innovation and a caselet on TRIZ application. Since then, more than 200 technology management students have learned the rudiments of TRIZ. In the graduate program of Industrial Engineering at the University of the Philippines College of Engineering, the TRIZ methodology has been assimilated in an advanced course in production systems (IE 245) more intensively with a nine-hour allocation, approximately 25% of the course content since 2007. TRIZ content is a mixture of theory and application focusing on the basic pillars of TRIZ: ideality, functionality, resources, technology evolution, contradiction matrix, inventive principles, substance-field analysis, standard solutions, algorithm for inventive problem solving (ARIZ), TRZ applications in product /service design, process and manufacturing design, design for environment with eco-design and design for X–cellence. This culminates with a mini-term project on TRIZ application melded with other design methods. TRIZ basic concepts, contradictions, inventive principles and ARIZ model for product and service design and manufacturing process design are likewise introduced in the core course on Analysis of Production Systems (IE 231) allowing students to appreciate the structured innovation approach in analyzing production-related issues and problems. This was started in 2008. A full-blown special problem/topic 45-hour course on TRIZ was offered in 2009 with 6 students covering in more detail the structured innovation pillars of TRIZ, ideality and ideal final results, technology system evolution, contradiction matrix, inventive principles, substance-field analysis, standard solutions, technical and scientific effects, algorithm for inventive problem solving, TRIZ applications in industrial engineering - product design and development, process design and improvement, manufacturing and supply chain design and improvement, human factors and work system design, design for reliability, sustainability and eco-innovation and team-based comprehensive term project. The results were encouraging. The projects were presented during the Mini Symposium on TRIZ organized by the Philippine TRIZ Interest Group at the University of the Philippines College of Engineering on March 10, 2010, attended by about 250 industrial engineering students and faculty from several universities.

We have also started cascading the TRIZ concepts in our advanced undergraduate industrial engineering course and capstone industrial systems design course since 2008 (IE 197/IE 198 Special Problems Topics on Design for Lean Six Sigma; IE 155 Industrial Systems Design). About 250 students were given a 3-4 hour lecture discussion on the basic pillars of TRIZ and selected IE applications of the forty inventive principles in industrial, operations, human factors, and product and systems design. In the UP Department of Chemical Engineering, TRIZ is also discussed in innovation and creativity in chemical engineering design for both graduate and undergraduate chemical engineering students .

Shown in Appendix 1 is a summary of the TRIZ assimilation in IE and TQM courses at the University of the Philippines.

Based on these experiences, we have found out that students find it easy in assimilating the TRIZ concepts in design. It was also evident that students overturned conventional design archetypes that are inhibiting breakthrough thinking and inventive problem solving once exposed to TRIZ .

Conclusions

We have presented TRIZ in a simplified format as a set of scientifically-based approach of generating innovative solutions to inventive problems comprising core concepts of idealist, functionality, resources, contradictions , inventive principles, standard solutions, technical and scientific effects knowledge database and a robust algorithm for solving inventive problem. We have established that indeed, TRIZ has a solid empirical structure and tenable methods and tools that can be used as a stand-alone approach or can be synergized or inserted with other problem solving paradigms.

We have also shown three case study applications that evidenced how TRIZ can easily structure and accelerate the breakthrough thinking and systematically generating inventive solution to product re-design and improvement and solving a quality problem. We have also shown the power of functionality, resources, technical contradictions and inventive principles in re-formulating the problem and coming up with an inventive solution.

We have also shared our experiences in assimilating TRIZ in our graduate courses in total quality management, advanced production systems, and in special topics/ problems in innovation and creativity in design to entice more breakthrough and innovative thinking in design. We conclude that assimilating TRIZ in design-oriented courses is a good anchor for diffusing TRIZ know-how in formal education.

Finally, while we recognize the power of TRIZ in systematizing innovation, it is not a panacea for all inventive problems. However, it is definitely one of the most efficient, comprehensive, systems-oriented and disciplined innovation models nurtured in a non-academic environment. We believe that academic interest and further researches in TRIZ will snowball as the innovation revolution engulfs the academic community. We anticipate more osmosis in creative engineering designs and applications of TRIZ in more practical settings.

Acknowledgment

We acknowledge the UP IE Alumni Association for the financial support of this research paper. We also thank the referees for their many helpful comments. We also appreciate the many insights of my graduate students on how TRIZ can be applied operationally.

Appendix 1: TRIZ Assimilation in IE Courses and TQM

Course	Course Title	No. of Hours	Content	No. of Students
TM 225 (graduate) – AY 2005- 2010), 10 academic semesters	Total Quality Management	3	TRIZ as Structured Innovation Approach ; Contra- diction Matrix; Inventive Principles; TRIZ in Eco- Innovation and TRIZ Case let	200
IE 297 (graduate), one academic semester - 2nd Sem, 2009-2010	Special Problems : TRIZ Applications in IE Systems Design	45	Definition of Inventive Problems; Structured Innovation; Pillars of TRIZ; Structure of TRIZ ; Evolution of TRIZ; Ideality & Ideal Final Results (IFR); Function Analysis (FA) & Resources; Technical and Physical Contradictions; Contradiction Matrix & 39 Engineering Parameters and Forty Inventive Principles: Engineering Design; Total Quality Management; Production and Operations Management; Human Factors & Ergonomics Substance-Field Analysis; Seventy-Six Standard Solutions ARIZ-Algorithm for TRIZ and TRIZ Applications: Eco-Innovation; Product Design; Process & Systems Design; TRIZ Application Design Project	6

IE 245 (graduate), 3 academic semester (2nd sem 2007-2008, 2nd sem 2008-2009; 2nd sem 2009-2010)	Advanced Production Systems	9	TRIZ in Innovative Product & Systems Design; Ideality & Ideal Final Results (IFR); Function Analysis (FA) & Resources; Technical & Physical Contradictions; 39X 39 Contradiction Matrix; Forty Inventive Principles; Substance-Field Analysis (Su-F); ARIZ; TRIZ Synergy with DFSS, QFD Value Engineering; QFD/ TRIZ/ VE Integrated Proj.	21
IE 231 (graduate), 4 academic semesters, 1st Sem 2007-2008, 2008-2009, 009-2010, 2010-2011)	Analysis of Production Systems	3	TRIZ in Product and Service Design; Ideality, Functionality, Resources, Contradictions, & Technology Evolution; Contradiction Matrix & Inventive Principles; TRIZ Application in Product, Packaging & Manufacturing Process Design	80
IE 155 (undergraduate); 2 academic semesters (2nd sem 2008-2009, 2nd sem 2009-2010)	Industrial Systems Design	3	Introduction to TRIZ; Technical Systems and Inventive Problems; Technology Evolution ; TRIZ Generic Problem Solving; Ideality, Functionality, Resources, Contradictions & Inventive Principles; Forty Inventive Principles Applications in IE Systems Design	180
IE 197 (3 semesters), AY 2009-2010, 1st Sem 2010-2011	Lean Six Sigma Certification	4	TRIZ in DFLSS; Technical Systems and Inventive Problems; Technology Evolution; TRIZ Generic Problem Solving; Ideality, Functionality, Resources, Contradictions & Inventive Principles; Forty Inventive Principles in Design for X-cellence in DFLSS and DFLSS Case let & Application	50

References

1. Alolod, R. and Pantisma, R. (2008) , Stress and Strain Analysis in Qualifying NQFP Packages, AMIS Engineering Forum & 18th ASMEP Technical Symposium, June 30 ,2008. (unpublished)
2. Altshuller, G. (1994), "The Art of Inventing (And Suddenly the Inventor Appeared)". Translated by Lev Shulyak. Worcester, MA, Technical Innovation Center. ISBN 0-9640740-1-X.
3. Altshuller, G (1987), "Creativity as an Exact Science ". Translated by Anthony Williams. "Gordon & Breach Science Publisher", New-York, London, Paris, 1984, 1987.
4. Altshuller .G. (1999), "The Innovation Algorithm. TRIZ, Systematic Innovation and Technical Creativity. Technical Innovation Center, Inc. Worcester, MA. USA.
5. Altshuller G., Zlotin B., Zusman A. and Philatov V (1999). "Tools of Classical TRIZ "Ideation International Inc.
6. Altshuller, G (1997), 40 Principles: TRIZ Key to Technical Innovation. Translated and edited by Lev Shulyak and Steven Rodman. Worchester, Massachusetts: Technical Innovation Center.
7. Altshuller, G (1996) Genrich. And Suddenly the Inventor Appeared: TRIZ, the Theory of Inventive Problem Solving. Translated by Lev Shulyak. Worchester, Massachusetts: Technical Innovation Center.
8. Belski, I, Kaplan, I., Shapiro, V., Vaner, L., and Wai, W.P., (2003), SARS and 40 Principles Eliminating Technical Contradictions: Creative Singapore ", T*he TRIZ Journal* (June 2003 issue), http://triz-journal//archives/2003/06.html.
9. Zlotin, B. And Zusman, A. (1999), "Directed Evolution: Philosophy, Theory and Practice ". Ideation International Inc.
10. Bukhman, I. (2009), "TRIZ Overview and Global Experiences", First Israeli TRIZ Conference: TRIZ Theory and Applications, Holon Institute of Technology, November 23, 2009.
11. Bukhman, I. and Brown S. (2005), "The TRIZ Give Way to the Wind Away: A Repeatable Process for Improving Sustainable Wind energy Conversion ", Proceedings of TRIZCON 2005, Altshuller Institute, Brighton, MI, USA. April 2005.
12. Chang, H-T., and Chen, J.L.(2003), " Eco-innovative Examples for 40 TRIZ Inventive Principles ", The *TRIZ Journal* (August 2003 issue), http://www.triz-jounral.com/archives/2003/07.html
13. Chen, J.L., and Liu, C. (2001), "An eco-innovative design approach incorporating the TRIZ method without contradictions analysis", *The Journal of Sustainable Product Design*, vol 1, pp 263-272.
14. Clarke, D. (1997), "TRIZ: Through the Eyes of an American TRIZ Specialist; A Study of Ideality, Contradictions, and Resources. Ideation International Inc.
15. Cuaresma, A., Dalawis, A., Lodriguito, A. and Raneses, N, " Battery Re-Design Using an Integrated QFD, TRIZ, and Value Engineering ", Paper Presented during the *Mini Symposium on TRIZ* ", College of Engineering, University of the Philippines, Diliman, Quezon City, March 10, 2010 .

16. Domb, E. (1997), " Contradictions: Air Bag Applications ", The TRIZ Journal (July 1997 issue), http://www.triz-journal.com/archives/1997/07.html
17. Domb, E. (1997), " IFR Tutorial", The TRIZ Journal (February 1997) , http://www.triz-journal.com/archives/1997/02.html
18. Domb, E. (1997) " How to Help TRIZ Beginners Succeed", The TRIZ Journal (April 1997 issue), http://www.triz-journal.com/archives/1997/04.html
19. Domb, E. (2000) " Strategic TRIZ and Tactical TRIZ- Using the Technology Evolution Tools", The TRIZ Journal (June 2000 issue), http://www.triz-journal.com/archives/2000/06.html
20. Domb, E. and Tate K. (1997) , " 40 Inventive Principles with Examples" The TRIZ Journal (July 1997 issue) , http://www.triz-jounral.com/archives/1007/07.html
21. Dourson, S. (2004), "The 40 Inventive Principles of TRIZ Applied to Finance ", *The TRIZ Journal* (April 2004 issue), http://www.triz-journal.com/archives/2004/04.html.
22. Dull, B. (1999) "Comparing and Combining Value Engineering and TRIZ Techniques", S*AVE International Proceedings*, pp 71-76.
23. Fey , V. (2001), " Glossary of TRIZ", The TRIZ Journal (March 2001 issue), http://www.triz-journal.com/archives/2001/03.html
24. Fey, V and Rivin, E. (2001), Fundamentals of TRIZ Course Book, Wayne State University, Detroit, MI, USA.
25. Fey, V., and Rivin, E. (1997). The Science of Innovation A managerial overview of the TRIZ methodology. The TRIZ Group, 82 pp. ISBN 0965835901.
26. Filmore, P. (2008), "Developing Highly Effective Engineers: The Significance of TRIZ ", TRIZCON2008, Kent State University, Ohio, USA, 13-15 April 2008.
27. Filmore, P. (2007), "Teaching TRIZ as a Systematic Problem Solving Method: Breaking Mindset ", TRIZCON2007, Louisville, Kentucky USA, 23-25th April 2007. http://www.triz-journal.com/archives/2008/02/html. .
28. Goel, P. And Singh, N. (1998), "Creativity and Innovation in Durable Product Development ", Computers and Industrial Engineering, Vol 35, #1-2, pp 5-8.
29. Grierson, B., Fraser, I, Morrison, A, Niven, S., and Chisholm, G. (2003), " 40 Inventive Principles –Chemical Illustrations", Th*e TRIZ Journal* (July 2003 issue), http://www.triz-journal.com/archives/2003/07.html
30. Hipple, J. (2002), "Using TRIZ to Find Fault with the Future", World Future Society, Philadelphia, PA, USA.
31. Hipple, J., (1999), "The Use of TRIZ Separation Principles to Resolve the Contradictions of Innovation Practices in Organizations," *The TRIZ Journal*, (August Issue), <<http://www.triz-journal.com/>>, (10 December 2001).
32. Hipple, J., (2005), " 40 Inventive Principles with Examples for Chemical Engineering ", *The TRIZ Journal* (April 2005 issue), http://triz-jounral.com/archives/2005/04/html
33. Hua, Z., Coulibaly, S. and Zhang, B. (2006) "Integration TRIZ with Problem Solving Tools: A Literature Review from 1995 to 2006", *Int. J Business Innovation Research*, Vol 1. Nos.1/2, pp. 111-128.
34. Ina, B- K. (2000), "A comparison of the Global 8-D Process and TRIZ", *TRIZ Journal , July* ,http://www.triz-journal.com/archives 2000/07/c/index/.htm
35. Indardaya, A., Panabang, M., Revil, M.S., and Raneses, N., "Improving the Design For Fit of Pump Shoes for Working Women Using TRIZ " Paper Presented Mini- Symposium on TRIZ, College of Engineering, University of the Philippines, Diliman, Quezon City, March 10, 2010. (unpublished)
36. InnoSutra, (2007), "Tools for Developing Innovative Solutions", Inno Support Transfer-Supporting innovations in SME, August 2007.
37. Jones, E. and Harrison , D.(2000), " Investigating the Use of TRIZ in Eco-innovation ", *The TRIZ Journal* (September 2000 issue), http://www.triz-journal/archives/2000/09/html
38. Jones,E, Harrison, D, and Stanton, N.(2001), " The Applications of TRIZ Tools in an Econ-innovation Process,", Proceedings of World Conference on TRIZ Future 2001, November 7-9, 2001, Bath, UK, pp. 57-78.

39. Kaplan, S.,(1996) , *An Introduction to TRIZ: The Russian Theory of Inventive Problem Solving,* Ideation International, Inc., Southfield, MI. USA
40. Kaplan, S, Zlotin, B. And Zusman, A. (1999), "New Tools for Failure and Risk Analysis" Ideation. International Inc., Southfield, MI. USA
41. Kaplan, S. (1996), an Introduction to TRIZ; the Russian Theory of Inventive Problem Solving. Ideation International Inc. ., Southfield, MI. USA 44 p.
42. Kaplan, S., Tschirhart, M., and Hipple, J. (2010), "40 Inventive Principles with Examples: Human Factors and Ergonomics ", *The TRIZ Journal* (February 2010 issue), http://www.triz-jounral.com/archives/2010/01/html.
43. Kosse, V (1999). Solving Problems with TRIZ; an Exercise Handbook." Ideation International Inc., ., Southfield, MI. USA
44. Kucharavy (2006), TRIZ Methods and Tools, LGECO, Laboratory of Engineering Design, INSA Strasbourg Graduate School of Science and Technology, Strasbourg, Cedex, France.
45. Livotov, P., (2008)," TRIZ and Innovation Management ", I*nnovator* (08/2008) ISSN 1866-4180. TrisEurope, pp2-29.
46. Mann, D., (2002) "TRIZ for Everyone (Even Those Who do not want to Spend a Year Learning It)," *The TRIZ Journal*, (January Issue),http://www.triz-journal.com/archives/ 2002/01/ html.
47. Mann, D. (2002) 'Hands on Systematic Innovation ', CREAX Press.
48. Mann, D. and Domb, E. (1999) "40 Inventive (Management) Principles with Examples", *TRIZ Journal,* www.triz-journal.com/archives/1999/09/a/index.html.
49. _Mann, D., (2002), "Evolving the World's Best Creativity Methods", *TRIZ Journal (April 2002 issue), htpp://www.triz-journal.com/archives/2002/04/html.*
50. Mann, D., and Domb, E., (1999), "40 Inventive (Business) Principles with Examples, "The *TRIZ Journal, (*September Issue*), http://www.triz-journal.com/archives/1999/03/html.*
51. Mann, D and Jones, E. (2002) "Sustainable Services and Systems (3S) Through Systematic Innovation Methods", *the Journal of Sustainable Product Design,* Vol 2, pp. 131-139.
52. Mann, D. and O'Cathain, C. (2001) " 40 Inventive (Architecture) Principles with Examples", The TRIZ Journal (June 2001 issue), http://www.triz-jounrnal .com/archives/2001/06.htm
53. Mann, D and Winkless B. (2001) "Food Development and the 40 Inventive Principles" The *TRIZ Journal* (May 2001 issue), http://www.triz-journal .com/archives/2001/05/html.
54. Mann, D and Winkless B. (2002), " 40 Inventive (Food) Principles with Examples ", *The TRIZ Journal* (October 2002 issue), http://www.triz-journal .com/archives/2002/01.htm
55. Marsh, D., Waters, F., and Marsh , T. (2004), " 40 Inventive Principles with Applications in Education", *The TRIZ Journal* (April 2004 issue), http://www.triz-journal.com/archives/2004/04.html
56. Mathis, F. (2009) , " TRIZ Used to Improve the Mars Bite-size Candy Pouch " *The TRIZ Journal* (January 2009 issue), htpp://www.triz-journal.com/archives/2009/01.htm
57. Mazur, G. (1993), "Theory of Inventive Problem Solving (TRIZ), www.mazur.net/triz/.
58. Nakagawa, T.(2001), "Essence of TRIZ in 50 Words", The TRIZ Journal (June 2001 issue), http://www.triz-journal.com/archives/2001/06.html
59. Nakagawa, T. (1999), "Let's Learn TRIZ – A Methodology for Creative Problem Solving", Plant *Engineer*, Vol. 31 (August 1999) pp. 30-39.
60. Nakagawa, T., (2001), "Introduction to TRIZ (Theory of Inventive Problem Solving) ", 23rd Annual Symposium of Japan Creative Society, Toyo University, November 3, 2001.
61. Quinn, R. E., 1988, *Beyond Rational Management: Managing the Paradoxes and Competing Demands of High Performance*, Jossey-Bass, and San Francisco, CA.
62. Petrov, V. (2005), "The Structure and Functions of TRIZ ", ISBN 965-7127-00-9. 1980-2005.
63. Raneses, N., " Demystifying TRIZ- The Theory of Inventive Problem Solving " Paper Presented during the 10th PIIE National Congress & 4th IE Research Conference, Mandarin Oriental Hotel , March 11-12, 2010 .
64. Rantanen, K and Domb, E. (2002) "*Simplified TRIZ: New Problem Solving Applications for Engineers and Manufacturing Professionals* ", St Lucie Press, CRC Press, Boca Raton, USA.

65. Rantanen, K and Domb, E.(2008), "*Simplified TRIZ: New Problem Solving Applications for Engineers and Manufacturing Professionals* ", Auerbach Publications, Taylor and Francis Group LLC, Boca Raton, USA.
66. Rea, K. (2001), " TRIZ and Softwares- 40 Inventive Principles Analogies Part 1 ", *The TRIZ Journal* (September 2001 issue) , http://www.triz-journal .com/archives/2001/09.htm
67. Rea, K (2001) , " TRIZ and Softwares- 40 Inventive Principles Analogies Part 2 ", *The TRIZ Journal* (November 2001 issue), http:// www.triz-journal.com/archives/2001/11.htm
68. Restseptor, G. (2005), " 40 Inventive Principles in Marketing, Sales and Advertising ", *The TRIZ Journal* (
69. Retseptor, G. (2002), " 40 Inventive Principles in Micro-electronics ", *The TRIZ Journal* (August 2002 issue), http://www.triz-journal.com/archives/2002/07/index.html
70. Retseptor, G. (2003), "40 Inventive Principles in Quality Management ", *The TRIZ Journal,* March issue), http://www.triz-journal.com/archives/2003/03/index.html.
71. Royzen, Z. (1993), "Application TRIZ in Value Management and Quality Improvement ", Society of American Value Engineers (SAVE) Annual Proceedings, Fort Lauderdale, Florida, USA.
72. Ruchti, B., and Livotov, P., (2001), "TRIZ-Based Innovation Principles and a Process for Problem Solving in Business and Management," *The TRIZ Journal*, (December Issue), <<http://www.triz-journal.com/>>, (7 January 2002).
73. Salamatov Yuri. TRIZ: The Right Solution at the Right Time: A Guide to Innovative Problem Solving. Insytec, the Netherlands, 1999. 256 pages.
74. Savransky, S. (2000) , "Engineering of Creativity: Introduction to TRIZ Methodology of Inventive Problem Solving .CRC Press LLC 2000 , Boca Raton, FL, USA. , 394 pages, ISBN 0849322553.
75. Scheweizer, T. ( ) "Problem Solving with TRIZ: Historical Perspective and Improving Ideality.
76. Scheweizer, T. (2002), "Integrating TRIZ into the Curriculum: An Educational Imperative ", *TRIZCON 2002 Conference Proceedings*, Altshuller Institute of TRIZ Studies.
77. Slocum, M.S. (2003), "Total product/process development system when six sigma meets TRIZ and QFD "Proceedings *of ETRIA World Conference: Triz Future 2003.* Aachem, Germany.
78. Slocum , M.S., Domb, E. and Lundberg, C. (2003), " Solution Dynamics as a Function of Resolution Method (Physical Contradiction and Technical Contradiction) ", The TRIZ Journal (January 2003 issue), http://www.triz-journal.com/archives/2003/01.html
79. Souchkov V. (1997), Integrated Technology of Conceptual Design, Industrial Design Solutions, Netherlands, B.V.
80. Terninko, J., Dob, E., and Miller, J. (2000), " The Seventy-six Standard Solutions with Examples Class 1 ", The *TRIZ Journal* (February 2000 issue) , http://www.triz-jounral.com /archives /2000/02.html
81. Terninko, J., Dob, E., and Miller, J. (2000), " The Seventy-six Standard Solutions with Examples Class 2 ", The *TRIZ Journal* (March 2000 issue) , http://www.triz-jounral.com /archives /2000/03..html
82. Terninko, J., Dob, E., and Miller, J. (2000), " The Seventy-six Standard Solutions with Examples Class 3 ", The *TRIZ Journal* (May 2000 issue) , http://www.triz-jounral.com /archives /2000/05.html
83. Terninko, J., Dob, E., and Miller, J. (2000), " The Seventy-six Standard Solutions with Examples Class 4 ", The *TRIZ Journal* (June 2000 issue) , http://www.triz-jounral.com /archives /2000/06.html
84. Terninko, J., Dob, E., and Miller, J. (2000), " The Seventy-six Standard Solutions with Examples Class 5 ", The *TRIZ Journal* (June 2000 issue) , http://www.triz-jounral.com /archives /2000/07.html
85. Terninko, J., Zusman, A., and Zlotin, B., (1998) "Systematic Innovation: An Introduction to TRIZ (Theory of Inventive Problem Solving), St Lucie Press, 153 pages. ISBN 1574441116.
86. Terninko J., Zusman A., Zlotin B. (1997), "Step-By-Step Triz: Creating Innovative Solution Concepts. 1997

87. Tepliskiy, A. and Kourmaer, R. (2005), "Application of 40 Inventive Principles in Construction ", Advanced Technologies International, Richardson, Tx, USA.
88. TRIZ40, "Interactive TRIZ Matrix and 40 Inventive Principles", http://www.triz40.com/
89. TRIZSITE.com, TRIZ, http://www.trizsite.com/onlinetools/default.asp.
90. Yamashita, H and Kawata, H (2002), "Innovation product development process by integrating QFD and TRIZ ", International *Journal of Production Research.* Vol 40, no. 5, pp 1031-1050.
91. Yang, K., Zhang, W. (2000) "A Comparison and Axiomatic Design", *Proceedings of ICAS 2000, First International Conference on Axiomatic Design*, Cambridge, Massachusetts, USA, June 21-23, 2000. pp 235-242.
92. Zhang, J., Tan, K.C., and Chai, K.H. (2003), "Systematic Innovation in Service Design through TRIZ", *The TRIZ Journal* (September 2003 issue) pp.1-12, http://www.triz-journal.com/archives/2003/09/index.html.
93. Zlotin, B, and Zusman, A. (2005), "Various Aspects of TRIZ Evolution ", Ideation International, Southfield, MI, USA (July 2, 2005).
94. Zlotin, B., & Zusman, a (2001), "Directed Evolution: Philosophy, Theory and Practice". Ideation International Inc. Southfield, MI, USA.