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TRIZ in a bi-system with Lean Sigma

Master Thesis for defense of certification on Level 5 of MATRIZ certification program

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Introduction

The need for purposeful inventive activity increased dramatically with the beginning of agricultural evolution, when growth of population combined with the shortage of animal and plant resources made hunters and collectors search for new ways of gaining food. For example, corn ear (known to everybody since childhood) does not grow in wild, but is a product of human agricultural activity. According to different sources, this activity dates from the 8th to the 12th millennium B.C. Then the first handicraft industries appeared which also required innovative approach.

For a long period inventive activity remained intuitive and was a “business” of a small group of geniuses. The need for such activity was also insignificant. It is worth noting here that in family portraits of the Middle Ages the expression on the faces of 7-8 year old children does not differ from that on the faces of adults. One of the possible explanations is that the amount of knowledge existing at that time and necessary for survival was so small that the 7-8 years old children already possessed the whole volume of it.

This situation began changing during the Renaissance, when serious scientific studies, which were aimed at cognition of the surrounding nature, expanded on foundation laid in by ancient scientist.. Nevertheless, during a long period of time serious changes in science and culture occurred very rarely, so even a small number of inventors were sufficient to meet the need of society in creation of new things. This situation lasted until the beginning of the 20th century. But it was already in the first half of the 20th century that the need in inventive methodology emerged. The society demanded more frequent changes, which, in turn, tempted the appetite even more. It was only 70 years ago that people did not know washing machines, and used to dry their washing in open air. There was no television, no penicillin, and no immunization against poliomyelitis, no printers, no contact lenses, and no oral contraceptives. All these things appeared during a very short period of time. And in the last quarter of the 20h century, with the appearance of computers, the changes began occurring constantly, without stopping.

In the 1930s the research in the field of inventive activity psychology was started, because it was believed that the cause of genius lies in specific features of the thinking process. Brainstorming sessions, morphological table and, later, DeBono methods and a lot of other methodologies were aimed at mobilizing the creative thought. It should be mentioned that a certain success was achieved to some extent, but its level was definitely unsatisfactory.

At the end of 1940s, the inventive activity methodologies, based on the research-and-technology basis of that time, began appearing. These methodologies rested upon the regularities identified as a result of analysis of existing products and technological processes. At the same time, the activity in the field of exploration of systems and their behavior in different conditions became much more intensive. In the late 1940s, Larry Miles began his work on creation of Value-Engineering Analysis methodology. And it was at that same time that Genrich Saulovich Altshuller began creating his Theory of Inventive Problem Solving (TRIZ). Genrich Altshuller was one of the first to understand that inventive process is prohibitively time-consuming and does not meet the ever-growing demand for increasing the rate of innovation emergence.

It should be pointed out here that Altshuller was not the only one striving for developing a technology for inventive activity. At about the same time, several more attempts were made to create a similar technology. However, most of them concentrated on exploration of psychology and on the analysis of inventor's brain operation with the aim to create psychological techniques of inventive activity based on such studies. The common feature of virtually all works in this field was realization of the need for elimination of psychological inertia, which was believed to be the main barrier for innovative thinking.

Using TRIZ terminology, we could say that a Physical Contradiction was realized: an inventor needs to have a certain body of knowledge necessary for successful work; and at the same time, an inventor should have the brave mind of a child, not limited by psychological inertia, caused by the burden of knowledge. G. S. Altshuller succeeded in formulation and resolving of this contradiction from the engineering standpoint. And his success was much greater than that of his contemporaries.

In the late 1980s and early 1990s two new methodologies have emerged – Six Sigma and Lean Manufacturing. Yet, only TRIZ offers a systematic, repeatable process for breakthrough innovation. However, circumstances in business don’t often come together to create the opportunity for radical change. The established manufacturing and business processes, very large investment in equipment and people training quite often create barriers for innovation.

So, what is the answer? This work makes an attempt to provide such an answer.

General Characteristics of the Research Work

The author first became acquainted with TRIZ in April 1991. In late June, early July 1991 a first ever week long TRIZ Seminar in the USA was conducted by Simon Litvin, Vladimir Gerasimov and Igor Devoino, the author served as an interpreter. As a result, the author was completely sold on power of TRIZ for technical problem solving.

By the time of his acquaintance with TRIZ the author was well familiar with Six Sigma, the Theory of Constrains and Value Engineering/Value Management methodologies. Save for VE/VM, no other problem solving methodology was fully embraced by the industry. Then, in 1993 General Electric adopted Six Sigma, developed at Motorola, as their Quality Enhancement Methodology. This act was followed by the rapid growth of interest in Six Sigma, a large number of training and consulting companies, offering Six Sigma based services, sprang up almost overnight.

Six Sigma is a methodology for detection and fixing of defects in technological and business processes. Six Sigma methodology is based on well studied and tested statistical methods of quality control, data analysis and systematic training of the entire company’s personnel, involved in technological or business process. Six Sigma enables determination of the number of defects in any process or any step of the process.

Therefore, Six Sigma is a methodology for uncovering defects, inherent in various processes, based on statistical analysis of available data. Yet, this methodology does not offer many tools for elimination of these defects. A human is left to his/her own wits and, most often, brainstorming process, for resolution of found issues. On the other hand, in TRIZ, statistical data is used for discovery and use of the laws and patterns of technology. Integration of these approaches allow for development of an instrument, capable of broadening the capabilities of both methodologies.

A while ago, consultants, who practice Six Sigma and Lean Manufacturing, merged these methodologies, creating, the so called, Lean Sigma or Lean Six Sigma. Lean Manufacturing is methodology developed in Japan on the basis of Toyota Production System. The aim of this methodology is elimination of various wastes in technical and business processes. According to various sources, the number of most frequently occurring wastes is 7 to 10.

The author first thought about a merger of Six Sigma and TRIZ as a way to promote TRIZ in the industry. In other words, utilize Six Sigma as a towing system, similar to, say, a steam engine on a sail boat. At the time, it was a worthy undertaking as TRIZ providers had hard time selling their services. And for a very understandable reason. While Six Sigma providers promised a $170,000 economic benefit from a single Six Sigma supported project and Lean Manufacturing consultants operated with concrete numbers of economic benefits from Lean supported process improvements, TRIZ consultants were offering to solve problems… In addition, every other “improvement technique” was offered by a uniform, well structured process, while TRIZ offering differs greatly from provider-to-provider… However, while Six Sigma has a uniform process, regardless of the provider, Design for Six Sigma, DFSS, is a different story. The reason? DFSS is an attempt at creativity, which requires independent thinking in addition to some kind of algorithm.

Secondly, TRIZ is qualitative in nature. This is one of the major reasons TRIZ is a difficult subject to comprehend for engineers and scientists, who are used to operate with numbers in their work. Thus, “the digitization” of TRIZ became one of the topics of TRIZ research. And in particular, the digitization of the very moment when a solution is obtain. In many seminars the author was confronted with – well, the tools are understood, but how do you transit from a tool to a solution? The debate on this subject continues and escalates. The only reprieve is to work a problem, introduced by a team of students. Then, it happens naturally.

Thirdly, Six Sigma and Lean practitioners, faced with lack of creative approach in their methodologies, began “incorporating” TRIZ into their offerings. In every such case, TRIZ was presented as a contradiction matrix only, thus severely limiting the potential impact TRIZ tools could have in a particular problem solving process.

The relevance of the research topic

As any other system, TRIZ behaves according to the trends of the General Systems’ Theory. According to one of the trends, technological systems evolve in a general direction from mono-systems to bi- or poly-systems. Then the bi- and poly-systems convolute into mono-systems. TRIZ is not an exception to this trend. Today, TRIZ and a modified Value Engineering (VE) function analysis module comprise a mono-system of contemporary TRIZ as developed by the Leningrad TRIZ School. This school, led for many years by Voluslav Vladimirovich Mitrofanov, produced a number of excellent TRIZ practitioners and developers.

At a close view, TRIZ provides qualitative assessment and analysis of the system under consideration. Yet, in a technical systems' analysis, based on numerical representation of system's features, functionalities and problems, quantitative assessment is very important as it provides a universal valuation of system's capabilities and provides foundation for comparative analysis of the system and its environment.

Therefore, TRIZ based process would benefit greatly if accompanied by some kind of quantitative assessment. That there is such a need is supported by the fact that many TRIZ practitioners are attempting at inclusion of quantitative methods into TRIZ based problem solving process. For example, Alexander Kudryavtsev's Mater Thesis, presented to Dissertation Council in October of 2006, is devoted to "mathematisation" of TRIZ based problem solving process; GEN3Partners Company introduced Main Parameters of Value, or MPV, into analytical portion of a problem solving process; quite a few papers were presented at various websites, devoted to TRIZ and its Tools, most notably on website Metodolog.

Then, there are numerous attempts by Six Sigma and Lean Manufacturing practitioners to apply TRIZ tools into their process. In majority of these attempts TRIZ was represented exclusively by Contradiction Table, which is the best TRIZ tool because its capabilities are quite limited.

The goals and tasks of the research

The goal of this work is to examine the potential ways of using TRIZ in some kind of unified system with Lean Sigma. To this end the following steps were taken –

- Determine possibilities of integrating Lean Sigma and TRIZ;
- Develop a roadmap for application of newly developed bi-system;
- Test the newly developed process.

A review of the known approaches to systems' integration

The subject of systems' integration became a top priority in the General Systems Theory with realization of the need to analyze, develop and improve processes. To date, most integration efforts are aimed at assuring synchronous performance of different subsystems, which comprise an enterprise or a project.

Thus, system integration involves integrating existing (often disparate) subsystems. The subsystems will have interfaces. Integration involves joining the subsystems together by "gluing" their interfaces together. If the interfaces don't directly interlock, the "glue" between them can provide the required mappings. System integration is about determining the required "glue". System integration is also about adding value to the system, capabilities that are possible because of interactions between subsystems. In today's connected world, the role of system integration engineers is becoming more and more important: more and more systems are designed to connect together, both within the system under construction and to systems that are already deployed.

Several different integration methods could be used, depending on the situation. **Vertical Integration** (as opposed to "**horizontal**") is the process of integrating two, or more, systems according to their functionality by creating functional entities also referred to as silos. The benefit of this method is that the integration is performed quickly and involves only the necessary steps; therefore, this method is cheaper in the short term. On the other hand, cost-of-ownership can be substantially higher than seen in other methods, since in case of new or enhanced functionality, the only possible way to implement (scale the system) would be by implementing another silo. Reusing these systems to create another functionality is not possible.

Star Integration or also known as **Spaghetti Integration** is a process of integration of the systems where each system is interconnected to each of the other systems. When observed from the perspective of the system which is being integrated, the connections are reminiscent of a star, but when the overall diagram of the system is presented, the connections look like spaghetti, hence the name of this method. The cost varies due to the interfaces which systems are exporting. In a case where the systems are exporting heterogeneous or proprietary interfaces, the integration cost can substantially rise. Time and costs needed to integrate the systems increase exponentially when adding additional systems. From the feature perspective, this method often seems preferable, due to the extreme flexibility of the reuse of functionality.

Horizontal Integration or Enterprise Service Bus (ESB) is an integration method in which a specialized system is dedicated to communication between other systems. This allows cutting the number of connections (interfaces) to only one per system which will connect directly to the ESB. The ESB is capable of translating the interface into another interface. This allows cutting the costs of integration and provides extreme flexibility. With systems integrated using this method, it is possible to completely replace one system with another system which provides similar functionality but exports different interfaces, all this completely transparent for the rest of the systems in a merger. The only action required is to implement the new interface between the ESB and the new system.

The horizontal scheme can be misleading, however, if it is thought that the cost of intermediate data transformation or the cost of shifting responsibility over business logic can be avoided.

At the present, the most tools for systems' integration and process development/improvement exists within Information Technology, IT, domain. As a result, a lot of resources being wasted on futile attempts to fix various system's issues with a software package, which is not applicable to a particular situation.

For the purposes of integrating TRIZ and Lean Sigma the author explored Vertical Integration as it appears the best suited for the required outcome.

Scientific novelty of the research

There is no dispute over the mono-bi-poly trend of systems' evolution. This research addresses certain ways for integrating TRIZ with Lean Sigma in accordance with this trend. In particular, the author considers the following as new contributions:

- ✓ A physical contradiction – TRIZ must be described by mathematical apparatus and TRIZ can't be described by mathematical apparatus, is resolved by separating these mutually exclusive requirements in time and in space. Thus, an application of statistical approaches, contained within Lean Sigma, allows an increase in "digitization" of TRIZ based problem solving process.
- ✓ Developed a process of Situation Analysis, based on concurrent use of TRIZ and Lean Sigma. TRIZ was mined for tools, enabling application of the resources, required for non-conventional solutions. Lean Sigma was mined for tools, which enable quantitative assessment of most problematic nodes in technical and business processes.

✓ Created a foundation for continuing development of TRIZ/Lean Sigma integration process, where TRIZ plays the leading role.

What is Six Sigma and Lean?

What is Six Sigma

Six Sigma is a business management strategy, originally developed by Motorola that today enjoys wide-spread application in many sectors of industry. Six Sigma seeks to identify and remove the causes of defects and errors in manufacturing and/or service delivery and business processes. It uses a set of management methods, including statistical methods, and creates a dedicated infrastructure of people within the organization who are experts in these methods. Six Sigma aims to deliver "Breakthrough Performance Improvement" from current levels) in business and customer relevant operational and performance measures. Business or operational measures are elements like:

- Customer Satisfaction Rating Score
- Time taken to respond to customer queries or complaints
- % Defect rate in Manufacturing
- Cost of executing a business process transaction
- Yield (Productivity) of service operations or production
- Inventory turns (or) Days of Inventory carried
- Billing and Cash Collection lead time
- Equipment Efficiency (Downtime, time taken to fix etc.)
- Accident / Incident rate

Time taken to recruit personnel and so on…

Six Sigma initiatives are planned and implemented in organizations on "Project by Project" basis. Each project aims not only to improve a chosen performance metric but also sustain the improvement achieved. Each Six Sigma project carried out within an organization follows a defined sequence of steps and has quantified financial targets (revenue increase, cost reduction or profit increase)

Six Sigma – Historical background

Six Sigma was originally developed as a set of practices designed to improve manufacturing processes and eliminate defects, but its application was subsequently extended to many other types of business processes as well. In Six Sigma, a defect is defined as anything that could lead to customer dissatisfaction and / or does not meet business set specifications. The elements of the methodology were first formulated by Bill Smith at Motorola in 1986. Six Sigma was heavily inspired by six preceding decades of quality improvement methodologies such as quality control, TQM, and Zero Defects, based on the work of pioneers such as Shewhart, Deming, Juran, Ishikawa, Taguchi and others.

Like its predecessors, Six Sigma asserts that:

- Continuous efforts to achieve stable and predictable process results (i.e. reduce process variation) are of vital importance to business success.
- Manufacturing and business processes have characteristics that can be measured, analyzed, improved and controlled.
- Achieving sustained performance and quality improvement requires commitment from the entire organization, particularly from top-level management.

How is Six Sigma different?

Features that differentiate Six Sigma apart from previous quality improvement initiatives include –

- A clear focus on achieving measurable and quantifiable financial returns from any Six Sigma project.
- An increased emphasis on strong and passionate management leadership and support
- A special organization infrastructure of "Champions," "Master Black Belts," "Black Belts", "Green Belts" etc. to lead and implement the Six Sigma approach
- A clear commitment to making decisions on the basis of verifiable data, rather than assumptions and guesswork.
- The term "Six Sigma" is derived from a field of statistics known as process capability study. It refers to the ability of processes to produce a very high proportion of output within specification. Processes that operate with "Six sigma quality" over the short term are assumed to produce (long-term) defect levels below 3.4 defects per million opportunities (DPMO).Six Sigma's implicit goal is to improve all processes to that level of quality or better. In recent years, Six Sigma has sometimes been combined with lean manufacturing (management) to yield a methodology named Lean Six Sigma.

What is Lean?

Lean is a philosophy and set of management techniques focused on continuous "eliminating waste" so that every process, task or work action is made "value adding" (the real output customer pays for!!) as viewed from customer perspective. Lean “waste elimination” targets, among others, the following “Wastes”:

- Overproduction – Making more than what is needed by customer / market demand
- Over-processing - Doing more to a product/service (but not perceived as value by customer)
- Waiting – For material, information, people, equipment, procedures, approvals and more
- Transportation – Movement of products / items during or after production
- Defects – Errors, mistakes, non-complying products, services, documents, transactions
- Rework and Scrap – Products, transactions or outputs not meeting specifications and have to be fixed, redone, rectified, marked down or scrapped / unusable.
- Motion – Mainly people, document movement, searching etc.
- Inventory – Buffer stocks or resources (Raw, Work in process, FG, Bench staff etc.)
- Unused Creativity – People knowledge and skills that are not utilized by the company

Wastes make the organization slow, inefficient and uncompetitive. Lean methods help to remove / reduce waste and contributes to driving “business agility” (velocity) through smooth work flow across the organization resulting in rapid fulfillment of customer needs in an optimum manner.

Six Sigma Methodologies

Six Sigma has two key methodologies: DMAIC and DMADV both inspired by Deming's Plan-Do-Check-Act Cycle.

- DMAIC is used to improve an existing business process;
- DMADV is used to create new product or process designs.

DMAIC

- The basic DMAIC methodology consists of the following five steps:
- Define process improvement goals that are consistent with customer demands and the enterprise strategy.
- Measure key aspects of the current process and collect relevant data.
- Analyze the data to verify cause-and-effect relationships. Determine what the relationships are, and attempt to ensure that all factors have been considered.
- Improve or optimize the process based upon data analysis using techniques like Design of Experiments.

- Control to ensure that any deviations from target are corrected before they result in defects. Set up pilot runs to establish process capability, move on to production, set up control mechanisms and continuously monitor the process.

DMADV (also known as DFSS – Design for Six Sigma) – the basic methodology consists of the following five steps:

1. Define design goals that are consistent with customer demands and the enterprise strategy.
2. Measure and identify CTQs (characteristics that are Critical To Quality), product capabilities, production process capability and risks.
3. Analyze to develop and design alternatives, create a high-level design and evaluate design capability to select the best design.
4. Design details, optimize the design, and plan for design verification. This phase may require simulations.
5. Verify the design, set up pilot runs, implement the production process and hand it over to the process owners.

Six Sigma Implementation roles

One of the key innovations of Six Sigma is the professionalizing of improvement management functions. Prior to Six Sigma, quality and improvement management in practice was largely relegated to the production floor and to statisticians in a separate quality department. Six Sigma borrows martial arts ranking terminology to define a hierarchy (and career path) that cuts across all business functions and a promotion path straight into the executive suite.

Six Sigma identifies several key roles for its successful implementation

- Executive Leadership includes the CEO and other members of top management. They are responsible for setting up a vision for Six Sigma implementation. They also empower the other role holders with the freedom and resources to explore new ideas for breakthrough improvements.
- Champions are responsible for Six Sigma implementation across the organization in an integrated manner. The Executive Leadership draws them from upper management. Champions also act as mentors to Black Belts.
- Master Black Belts, identified by champions, act as in-house coaches and subject matter experts on Six Sigma. They devote 100% of their time to Six Sigma. They assist champions and guide Black Belts and Green Belts. Apart from statistical tasks,

their time is spent on ensuring consistent application of Six Sigma across various functions and departments.

- Black Belts operate under Champions and Master Black Belts to apply Six Sigma methodology to specific projects. They devote 100% of their time to Six Sigma. They primarily focus on Six Sigma project execution, whereas Champions and Master Black Belts focus on identifying projects/functions for Six Sigma.
- Green Belts are employees who undertake Six Sigma implementation along with their other job responsibilities. They operate under the guidance of Black Belts and Champions Stated Six Sigma Benefits.

Leading companies have implemented Six Sigma and realized gainful results. Motorola has reported over US$17 billion in savings from Six Sigma as of 2006. Other early adopters of Six Sigma who achieved well-publicized success include Honeywell International and General Electric (introduced by Jack Welch). By the late 1990s, about two-thirds of the Fortune 500 organizations had begun Six Sigma initiatives with the aim of reducing costs and improving quality.

To sum all this up, Six Sigma and Lean Manufacturing, combined, became the generally accepted Continuous Improvement Methodology and Productivity Enhancement Tool. As such, Lean Sigma was selected by the author for integration into TRIZ based situation analysis and problem solving process.

The above inference did not flow from purely theoretical thought process. As usual, in the case of application sciences, first there was a successful project, in which TRIZ was used in conjunction with Six Sigma. Thus, it is fare to say that practice preceded theory in this case.

Personal contributions of the applicant

Majority of the offerings in the Scientific Significance of the Research are personal contributions of the author. At the same time, the authors owes to a large number of TRIZ practitioners, who at various times provided constructive critique and sound advice.

A comprehensive formulation of the issues

Today, 20 years after TRIZ was introduced to the West, it is still not accepted as a preferred problem solving methodology. Mainly due to its incompatibility with traditional project management approaches and insufficient integration with other productivity enhancement tools. In addition, the functional analysis, as we know it, is a very capable tool for revealing useful and harmful functions/interactions. However, it does not determine the key issues within the system. Thus, there is a need for additional step(s) or an additional tool. It is believed that the integration of TRIZ with Lean Sigma may help improve both situations.

The methods of resolving the formulated issues

In TRIZ based systems' theory systems may form a bi or poly system, consisting of several seemingly unrelated systems. There is also a notion of some systems, as they were introduced into technological or transactional space, taking advantage of the position of an established system in such a way as to enhance new system's acceptance. Yet, there is very little available in terms of successful integration of improvement methodologies, save for integration of VEA analysis and TRIZ, and not very well structured integration of Six Sigma and Lean Manufacturing.

Considering the fact that one of the issues deals with TRIZ not being integrated with other productivity enhancement tools, the author looked for a suitable methodology, which may be a suitable partner for such integration. At the time, Six Sigma was getting widely accepted in the USA as a premier quality and productivity enhancement methodology. Secondly, Six Sigma was touted as process improvement tool and TRIZ, combined with VE, was addressing process related issues. Once again, Six Sigma is a methodology for uncovering defects, inherent in various processes, based on statistical analysis of available data. Yet, this methodology does not offer many tools for elimination of these defects. A human is left to his/her own wits and, most often, brainstorming process, for resolution of found issues. On the other hand, in TRIZ, statistical data is used for discovery and use of the laws and patterns of technology. Integration of these approaches allow for development of an instrument, capable of broadening the capabilities of both methodologies.

Thus, it appears that, in a first approximation, TRIZ and Six Sigma may be considered alternative systems.

How it started

The situation, which led to the first experience with integrated use of TRIZ and Lean Sigma, involved insufficient information flows in a medium size manufacturing company, where the author worked as Vice President of Engineering.

At the time the author started to work for this company it took 14-18 weeks from order entry to delivery of a complete system. The systems were in a form of a skid unit, consisting of a pressure vessel, a pump, a few mechanisms of various complexity and functionality, and a control system, complete with control box and operational software. Although most of system's components were standard, the configuration and final assembly was customer depended. Therefore, each order stood on its own, requiring a lot of interface between various company departments. The attempts of installing a concurrent engineering process failed for some reason or other.

A few months after starting working for this company, the author, along with a few others, came up with an idea of Models and Options system. After nearly two years of concentrated effort this system was put into place. As a result, the lead time for order completion was reduced to 8-10 weeks, a reduction of almost 1/2 of initial lead time. The engineering department developed a set of design documentation for some 60 variations of this system – Models. The Models consisted of Options – Subsystems.

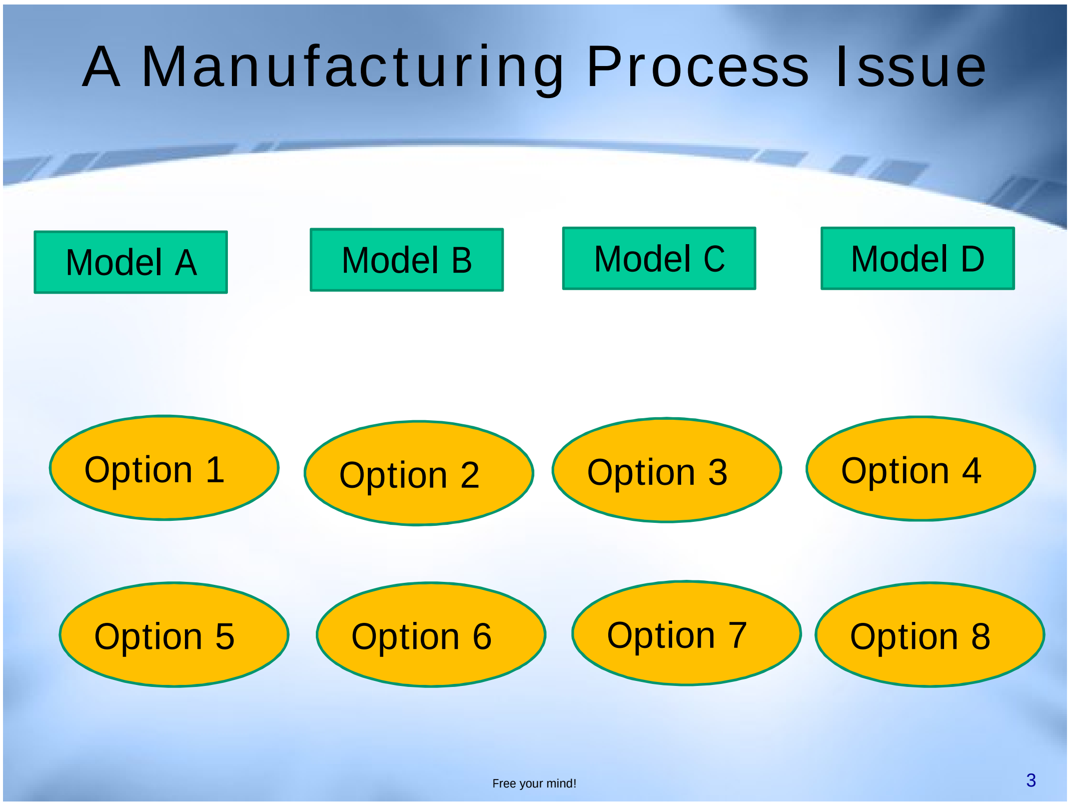

Fig. 1 – a representation of Models and Options

Each Model was formed based on process and productivity requirements. Therefore, there were Models with different number of working chambers, pump sizes, add system configuration, etc. Each set of design documentation consisted of drawings, bills of materials, manufacturing process instructions and so forth. In other words, once a Model was sold, and based on manufacturing availability, it took 2-3 days to start processing an order.

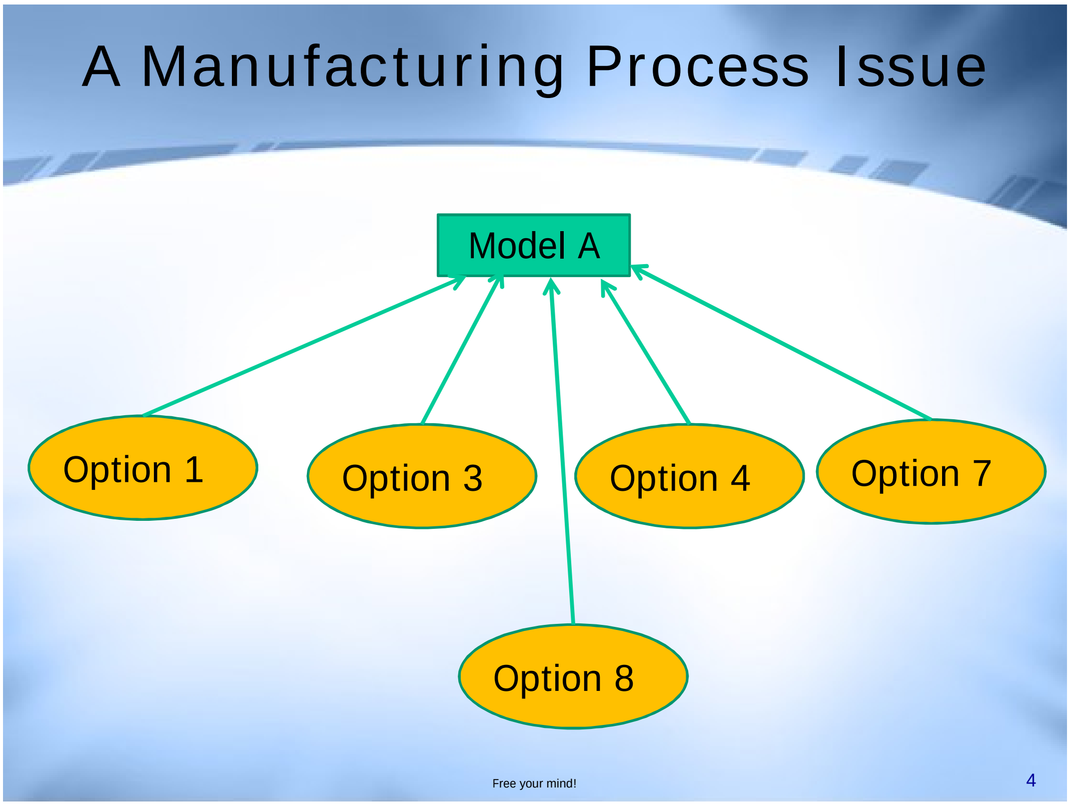

Fig. 2 – Model A

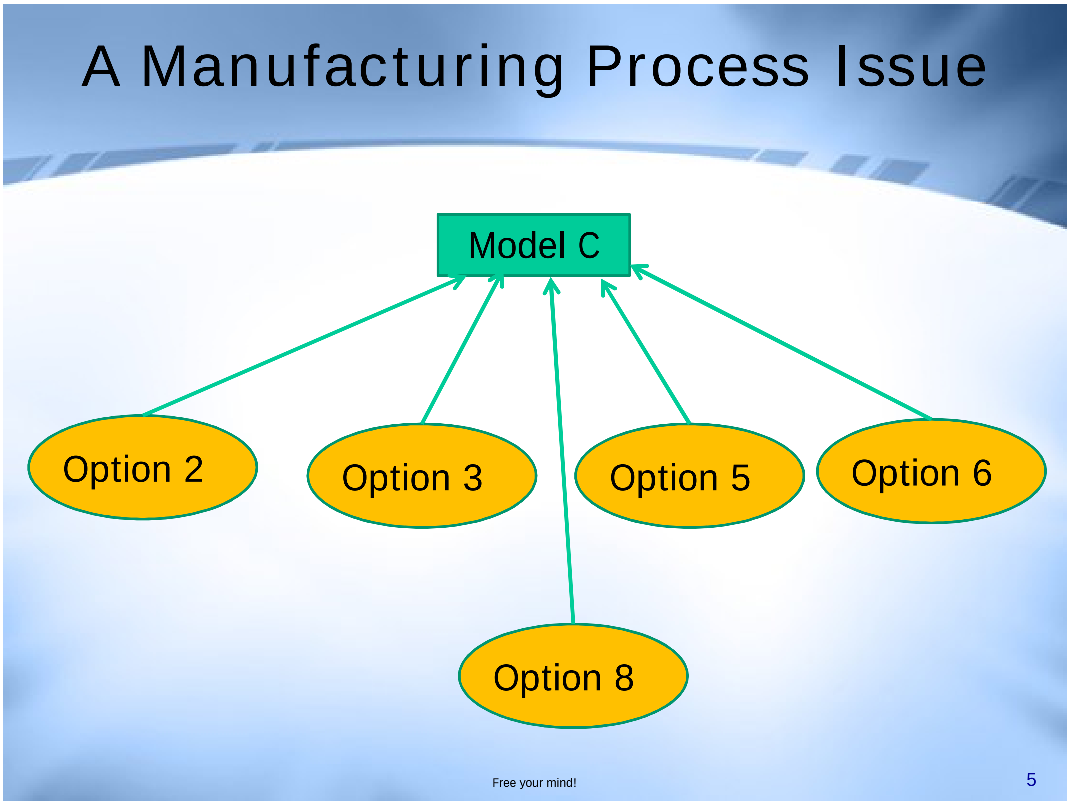

Fig. 3 – Model C

For about 6 months everyone was really happy. Then, engineering overtime started to escalate out of reason. The engineering time allocation and the associated numbers of hours were recorded on a weekly basis. So there was sufficient data for application of Six Sigma process analysis tools. We had Key Process Input Variables, KPIVs, and Key Process Output Variables, KPOVs, required for analysis of the situation. The KPOVs were insufficient as Engineering Department was expending too many overtime hours.

The Pareto analysis revealed, as can be seen from Fig. 4, something we were not ready for – 20% of all engineering hours were expended on support of Models & Options system. This situation was absolutely unacceptable as it added too much burden to overhead component of the price structure.

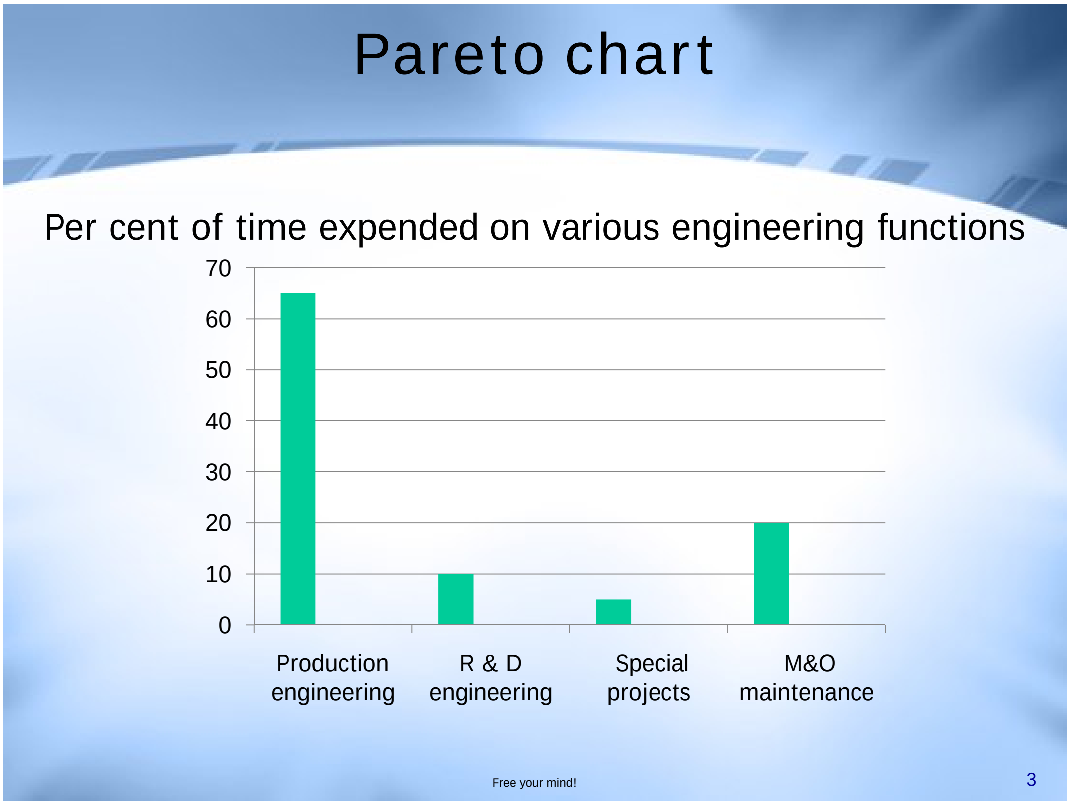

Fig. 4 – Pareto chart of engineering time breakdown

Subsequent analysis helped with understanding the reason for this unexpected result of otherwise very successful implementation of process improvement innovation.

The MRP, Material Requirements Planning, software was designed in such a way that it did not allow a simple substitution of one part in any Option for another. For example, if for any reason a ½” bolt was to be replaced with ¾” bolt, a designer could not just pull a part number from the BOM, Bill of Materials, structure and insert a different part number. The BOM structure would have to be rebuilt from bottom up for every substitution of a part number. Since BOM was providing information vitally required by purchasing and manufacturing for performance of their jobs, BOM must be correct and up to date. Therefore, accumulating BOM changes and making a global revision, say, once a month was not an option.

As could be seen from Fig. 3 and Fig. 4, any Option could be a part of a number of Models. Thus, a change in any of the Options led to a revision of design documentation for a number of Models. And this was very laborious process. Thus, a huge increase in Engineering Department overtime.

Here we were dealing with a clear case of incompatibility between the systems and associated processes. And the old prophesy – majority of the problems in a system result from the attempts to improve it, rang true with vengeance. We were facing a number of System (Technical) Contradictions – improvement in one part of the system leads to deterioration in another part of the system. Namely: improvement in overall order completion process resulted in overload in Engineering Department; improvement in structural integrity of an assembly resulted in more work for Engineering Department; etc. To short cut the process of TRIZ based analysis, associated with this issue, in the end, we came up with a Physical Contradiction – the Model and Options set up must be in place to improve overall performance of the company as a whole, and must not be in place so it will not overload Engineering Department. The solution should be of such nature as not to trigger a lot of resistance from the rest of the company departments. In other words, the solved state should not differ much from the existing set up.

The decision/solution was to reverse hierarchy of the Models and Options system. The resulting structure is illustrated in Fig. 5.

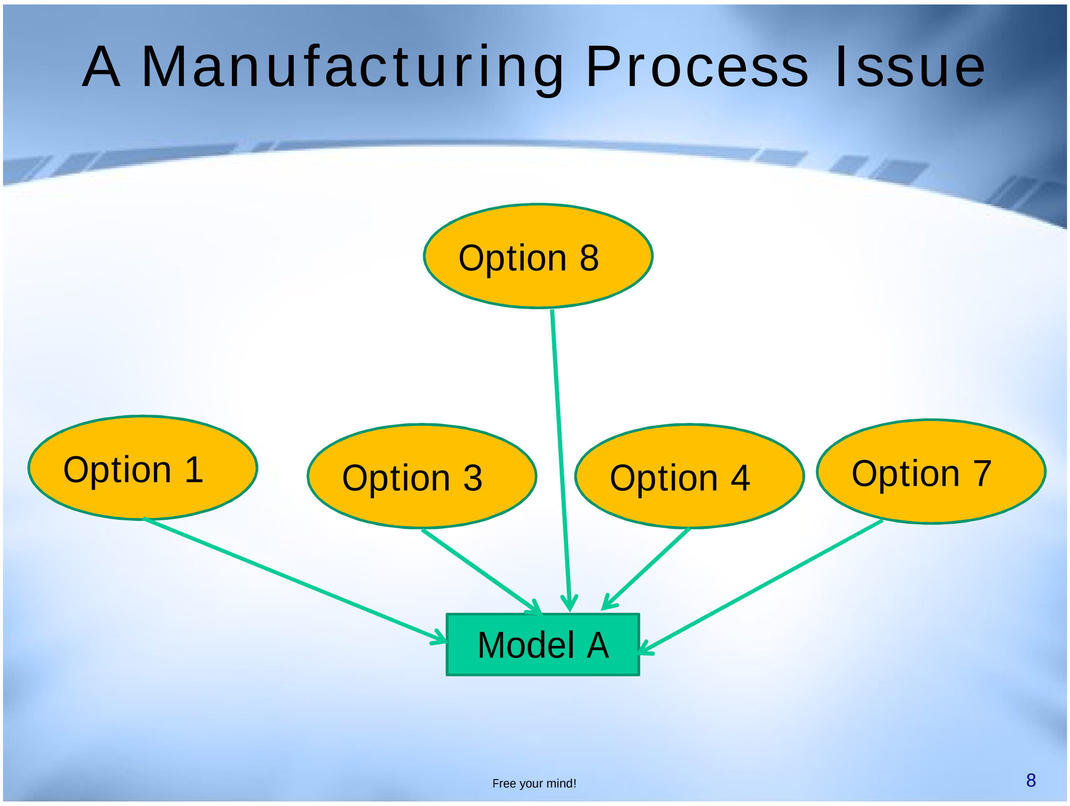

Fig. 5 – Model A

In other words, the Models and Options have exchanged their relative system hierarchy position. If initially the Options were serving as subsystems to a system represented by a Model, the new structure puts the Model into position of a subsystem to a number of supersystems – Options.

This development enables individual Option revisions without any impact on any other design documentation. Each Model is now custom made for a specific order and becomes an archive item upon delivery of ordered system to a customer. If any of the Options, comprising this particular order, is revised, it does not affect the archived design documentation.

One of the unplanned benefits of this system modification was much improved flexibility company's salesmen enjoyed while developing a system/quote to customer's specifications. Prior to the new product structure, a salesman had to record customer's specification, take it to the Engineering Department; the Engineering Department developed a set of design documentation, which was then priced by estimators. Depending on Engineering Department load, this could stretch into 2-3 weeks ordeal. Now, a salesman comes to a customer's office with a laptop, connects to the mainframe computer via the internet, and develops a custom model based on required options/functionality and the rules of interactions for the Options. Since every Option is priced individually and all the interactions are priced as well, the quote is produced automatically as soon as the system is configured. The entire process takes 2-3 hours.

Next steps

The results of the Models and Options process improvement formed the foundation of continued research on the subject of TRIZ and Lean Sigma integration. Armed with newly acquired knowledge, the author started to look for opportunities to test this newly created algorithm, which, at first, was very simplistic –

1. Determine "trouble" node in a system – use an appropriate analysis technique
2. Quantify "troubles" with Lean Sigma tools
3. Select the more "troublesome" node for improvement
4. Select an appropriate TRIZ tools for "trouble" elimination
5. Test "solved state" for inadvertent problems

The continued research on this topic reinforced the initial opinion – TRIZ and Lean Sigma can enhance each other in an integrated system. In addition, the author and his team tested the newly created bi-system in a number of projects.

One of the projects dealt with a flat panel – a cover for a control box. This panel was manufactured on a fully automated production line, where the panel was moving from station to station by robotic conveyor. At some time, the number of glitches in this manufacturing process reached unacceptable magnitude. The lack of reliable transfer of the panel from station to station caused process stoppages and high maintenance costs.

Again, using Six Sigma tool, Analysis of Variances, ANOVA, it was determined that in one particular transfer area the number of disconnects exceeded the rest of the disconnects almost 4 times. Thus, the aim of "attack" was clearly established. As in most of cases, where unexplained failure presents itself, the author used "Subversion Analysis" method, first developed by Boris Zlotin as an extension of his work relative to Solving of Scientific problems. Here, I used a series of "WHY?" type questions, employed in Six Sigma and, in slightly different manner, by "Subversion Analysis".

1. What is required to cause a body to transit from a state of relative rest to a slate of relative movement? The answer here is a Force.
2. What kind of forces may be involved? The answer here is External Forces and Internal Forces.
3. Since no External Forces were obvious, the next question – What constitutes an Internal Force? One of the possibilities here – a shift in the Center of gravity.
4. What could cause a shift in the Center of Gravity? One of the possibilities – an addition of a mass to the body.

Further, it was determined that the most "troublesome" transfer takes place after "Paint Station", where an equal, within a range, coats of enamel paint was applied to both sides of the panel by design. A simple test revealed that the spray guns on both sides delivered unequal amount of material outside of range. Thus, a condition for a shift of Center of Gravity was created. Once the reason for this failure was determined the fix was simple.

Again, a combined application of Lean Sigma and TRIZ enabled much more efficient problem solving process.

Melding TRIZ and Lean Sigma

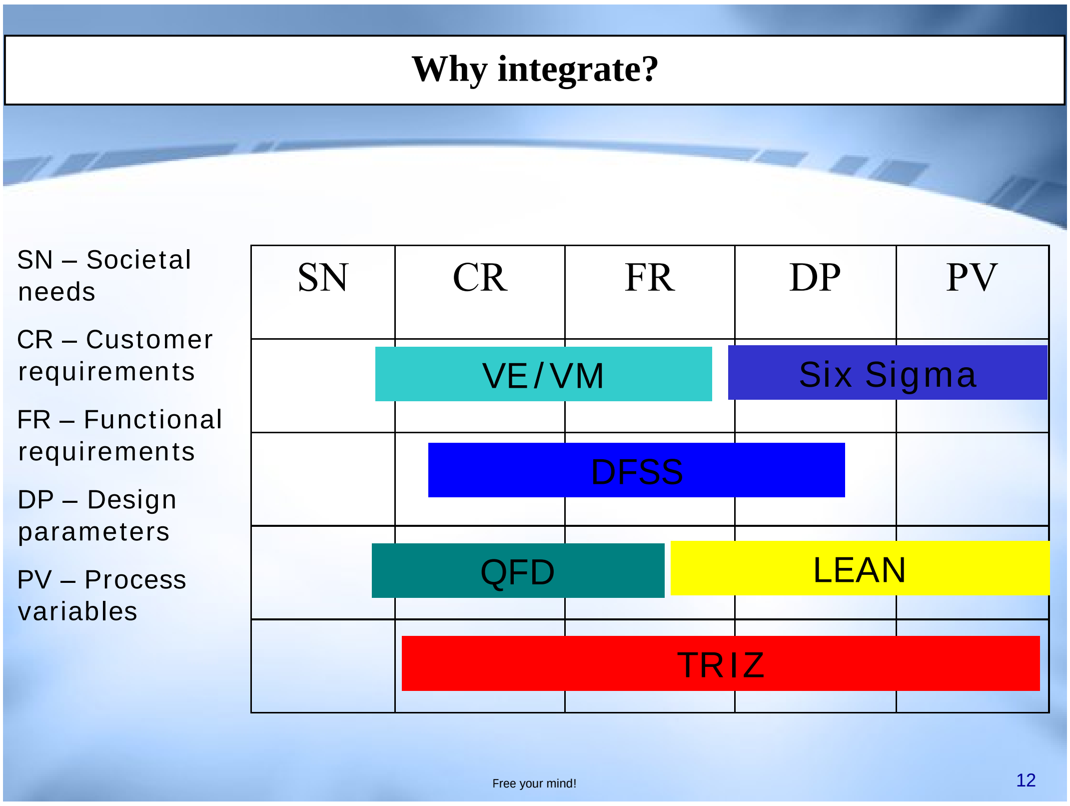

Fig. 6 – Why integrate?

Lean Sigma is a bi-system, organized along the lines of process improvement. TRIZ, on other hand, is focused on product improvement/development. Lean Sigma is about data collection and analysis, utilizing precise quantitative procedures. TRIZ is about qualitative assessment of the system/situation, utilizing a plethora of analytical tools, aimed at weakening mental inertia of an innovator. Lean Sigma is firmly embedded in corporate structure of many medium and large size companies. TRIZ is talked about a lot, but not as widely accepted. Lean Sigma consists of Lean Manufacturing + Six Sigma. Lean is based on Toyota Production System, Six Sigma started as a Quality Improvement methodology at Motorola. TRIZ was started in the late 1940s and in the 1970s it absorbed a large segment of Value Engineering. Thus, the contemporary TRIZ is a mono system, which grew out of bi-system consisting of TRIZ and Value Engineering.

- *The main idea behind Lean Sigma is that quality of an offering should be improved based on evolutionary transformation, avoiding abrupt changes in product or service.*
- *The main idea behind TRIZ is that evolutionary transformations are effective up to a appoint, then revolutionary transformations are in order through resolution of defined contradictions.*

With all the differences, these methodologies have, there is at least one thing in common – both are utilized for process improvement.

Lean Sigma, in use for many years, occupies a certain methodological niche. A lot of people in many companies are employed in the field of Lean Sigma application and training/certification. In other words, Lean Sigma is a flagship in the field of process improvement.

However, the practice of applying TRIZ showed the following. Once the initial resistance of managers and specialists dissipates and the real work starts, the phenomenal performance of TRIZ based process quickly converts most of naysayers into believers. As a result, the management is mystified by a situation where a small TRIZ team outperforms Lean Sigma establishment. Naturally, all sorts of ideas for reorganization of innovation process spring to life.

On the surface, the easiest way to accomplish such reorganization is by merging TRIZ tools into Lean Sigma process, notably into DFSS, which is often the case. The main idea of such a merger is to strengthen DFSS in its creative part, in the idea generation module. To date, this approach produced much better results than TRIZ-less DFSS in any rendition. TRIZ-DFSS union proved to be very effective for improving the quality of products.

However, the effectiveness of such union could be improved dramatically by eliminating the main obstacle of an effective merger between TRIZ and Lean Sigma – the difference in approaches.

Lean Sigma is obviously biased towards the evolutionary development of the product/process. Here, any idea that involves a radical change in any subsystem of a product or process is rarely accepted. A solution to a "mini-problem" (in the terminology of TRIZ), provides minor changes in a system under consideration, optimizing its parameters and resolving minor conflicts that arise during the development of its subsystems. Application of TRIZ techniques can provide both an evolutionary change in the system, optimization, and substantial transition to a new, improved system (i.e. - the solution of a "maxi-problem"). On a company level the second possibility is often overlooked, and Six Sigma experts persistently, but ineffectively struggle for the improvement of product quality, although higher level quality may be easily achieved by a qualitative change in selected subsystems of a system they are trying to improve.

However, an attempt to mend these two is like an attempt to harness together a Shire horse and a race horse. One can pull a heavy cart, while another – to run much faster. How to reconcile these two?

Looking at the situation from a TRIZ perspective reveals the following contradiction:

DFSS, even reinforced with TRIZ, seeks to improve the existing situation without significant changes in the system or process;

On the other hand, TRIZ enables evolutionary improvements of the system, as well as a transition of the original system to a higher level.

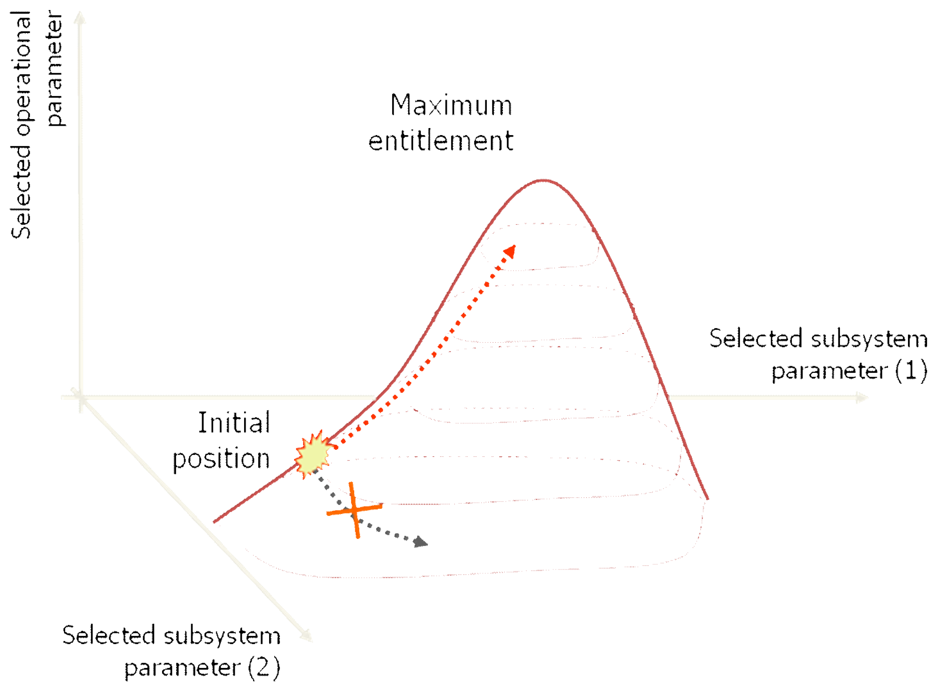

Fig.7 – The three dimensional dependency of an operational parameter on two selected parameters of a sub-system

To resolve this contradiction, let's take a look at the development of a real system.

Say, the operational parameter of the system, we are attempting to improve, depends on two chosen parameters of its subsystems, as shown in Figure 7 (in reality, the number of these parameters is much higher, but we consider the simplest case). Initially, the system is at some point, below the point of extreme maximum performance. Every improvement in a sub-system's parameters is aimed at an increase in the value of the system's operating parameter.

And this is the main goal of Lean Sigma methodology. The optimization process is very complex; it requires large investments of time and effort. These investments grow exponentially when a system approaches optimal point. However, the current practice forces optimization efforts regardless of cost/benefit reality. This is true regardless of which optimization methodology is used. Still, the most effective here are TRIZ enhanced DFSS and other methodologies, based on TRIZ evolutionary tools.

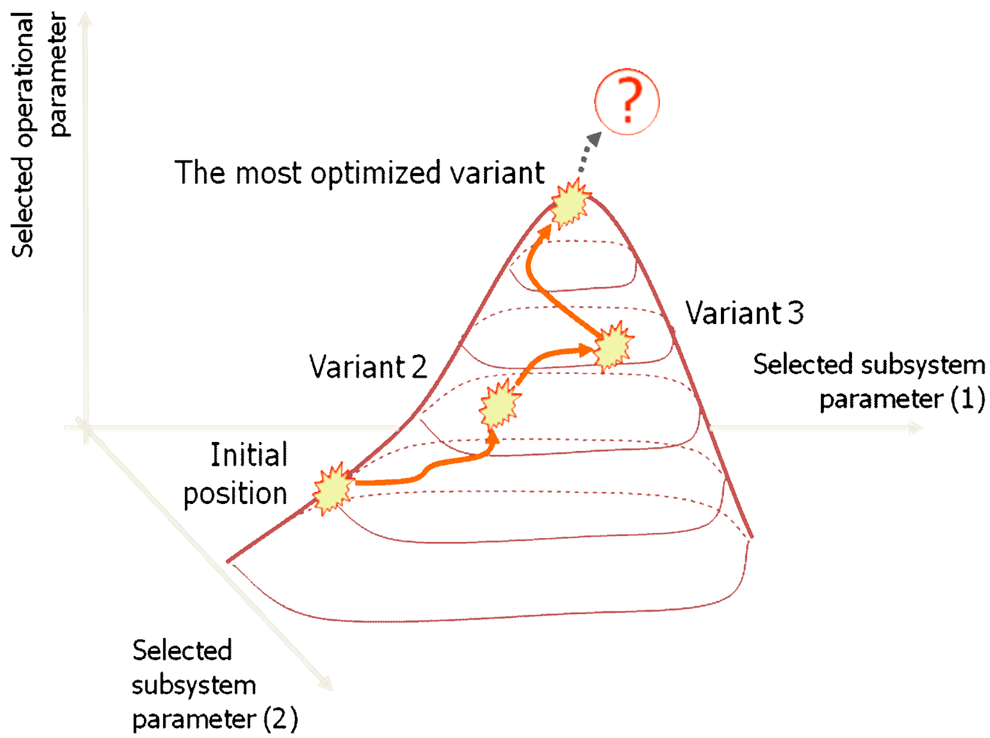

Fig. 8 – If the system is at the intermediate optimum, its evolutionary recourses are completely exhausted

But ... what do we do if the system is at an intermediate optimum? Figure 8 shows that any change in the parameters of the subsystems now leads to deterioration of performance parameters. The evolutionary resources are completely exhausted. The law of diminishing returns dictates evolutionary stagnation. This condition is especially hard to overcome when there is an undetected, thus unresolved, contradiction, which prohibits continued improvement. This situation is not inherent in technical systems alone; it affects non-technical, i.e. business, systems as well.

Under these conditions, the only way to improve a system/process is a qualitative transition (Fig. 9). That is, it is necessary to formulate one or more of the key contradictions, which prohibit the system's ability to evolve. Then, exacerbate them to an extreme and resolve those contradictions to define a new version of the system, capable of continued improvement, based on newly found resources for development. That's where TRIZ is indispensable as its main strength is in formulating and resolving various contradictions.

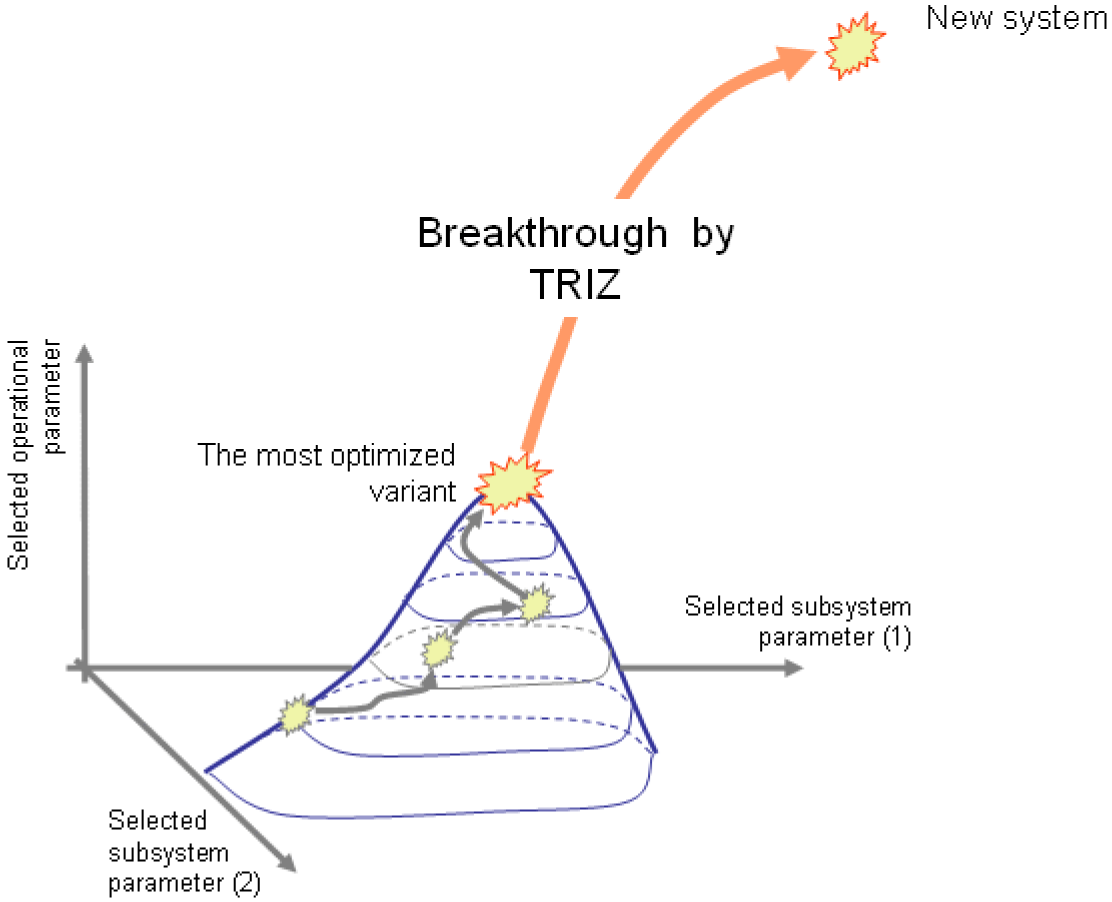

Fig. 9 – The transition to a new system that has additional resources for development

Obviously, the solution of the problem with breakthrough methods of TRIZ can not immediately produce a system with optimum operational parameters. Now, this task could be performed by using optimization techniques, primarily methods, which comprise DFSS (Fig. 10). In fact, most of products and services evolve through alternation of optimization and "leap-frogging" activities (Figure 11).

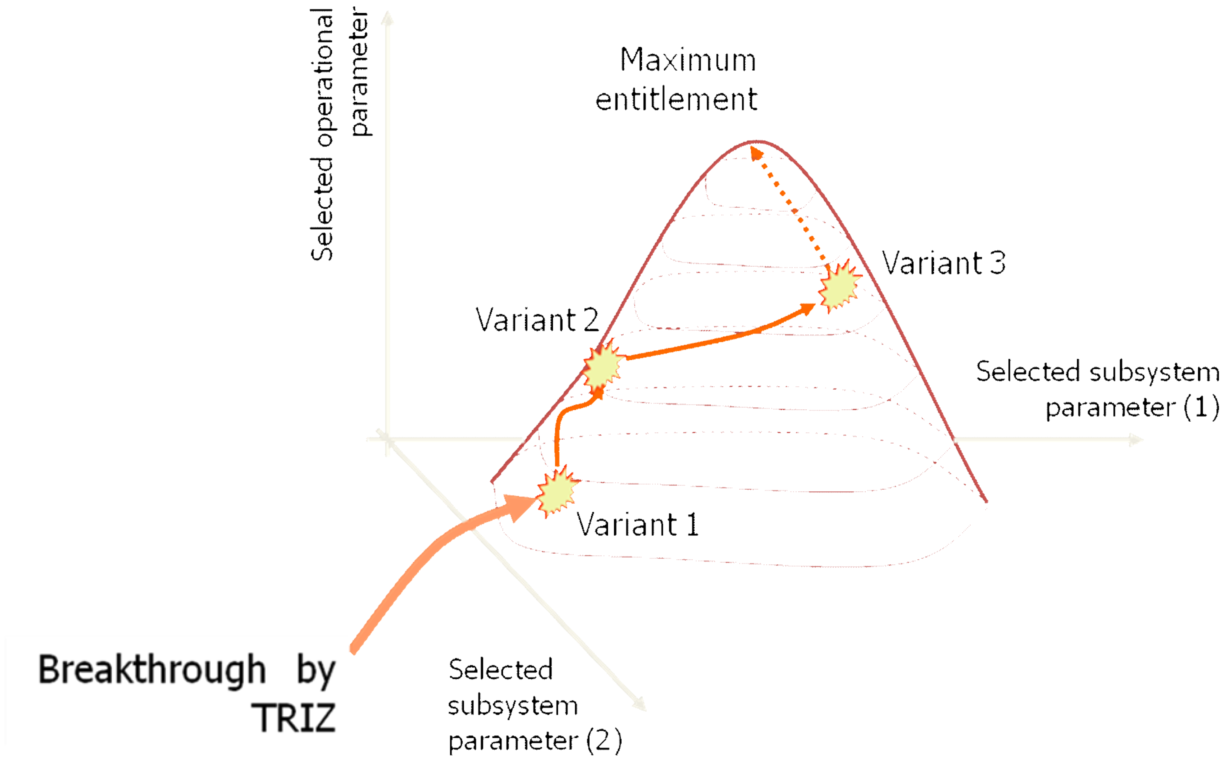

Fig. 10 – Selected system, obtained after the resolution of conflicts, needs further optimization

Turns out that the contradiction between these requirements, optimization and “leap-frogging”, is resolved by separation in time.

1. During the optimization phase, system’ parameters are improving steadily through relentless efforts. Minor changes to the system are accompanied by optimization of its sub-systems. At this stage of development, DFSS and evolutionary TRIZ tools work real well. Due to depletion of substance, information and field resources the development of the system slows down and eventually stops...

2. This is the most opportune moment for a breakthrough to a new and improved version of the system. As a rule, by this time the company's management is looking for a new ways of system’s development and is ready to accept the idea of a qualitative transformation of the system. Therefore, now is the time to use the “heavy artillery” of TRIZ tools, based on the concept of contradiction.

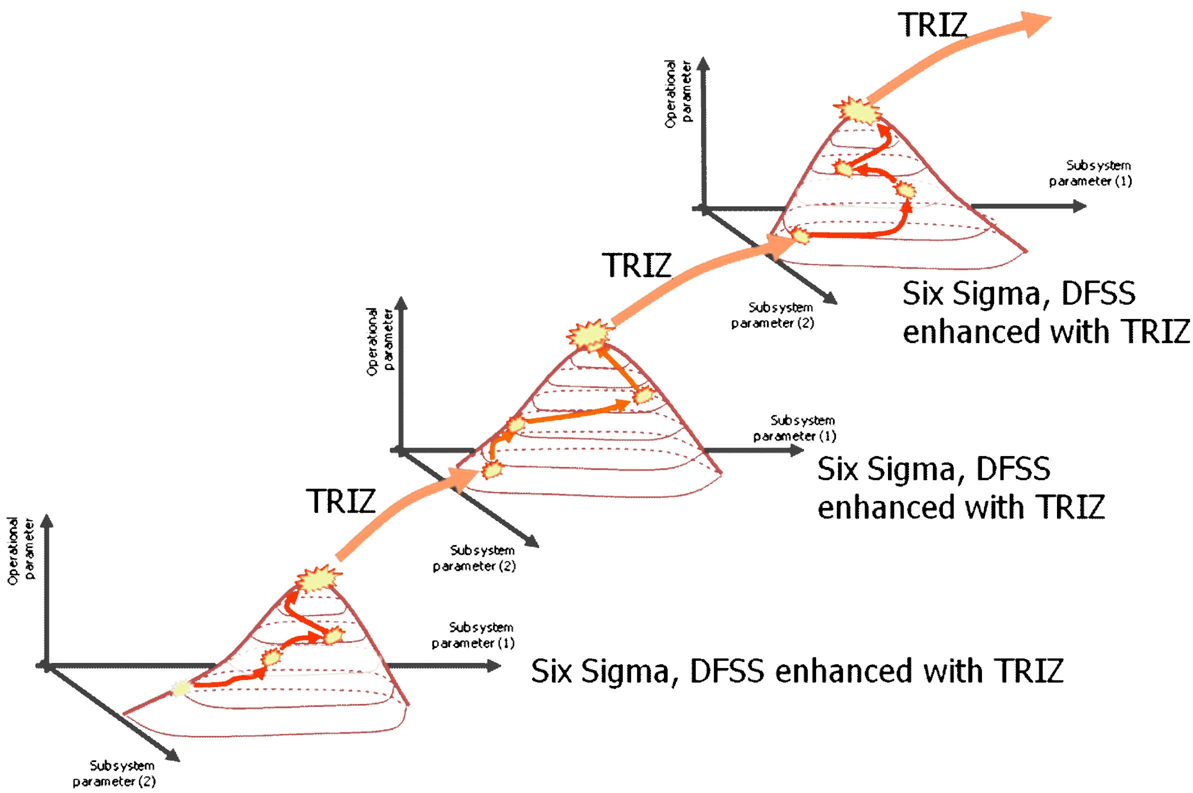

Fig. 11 – A potential sequence of system' development

We examined two approaches to innovation: Optimization and Disruption. How to select the one appropriate in a given situation?

For a best answer to above question we need to remember that any problem solving process must start with some kind of analysis of the situation. The analysis should identify, among other things, the position of the system on the S-curve and the available resources. Here, one should utilize qualitative as well as quantitative analysis tools. For example, analysis of variations, a Lean Sigma tool, should be used along with TRIZ tools for identification of various resources.

If the resources are available, the optimization may be in order. If the resources are exhausted, a disruptive approach is preferable. After all, the contradictions are most often result from lack of available resources.

From the above statement follows an idea of proper application of Lean Sigma and TRIZ, based on system's position on S-curve. S-curve is conditionally split into 3 areas:

1. Birth of system
2. Rapid growth
3. Maturity and decline

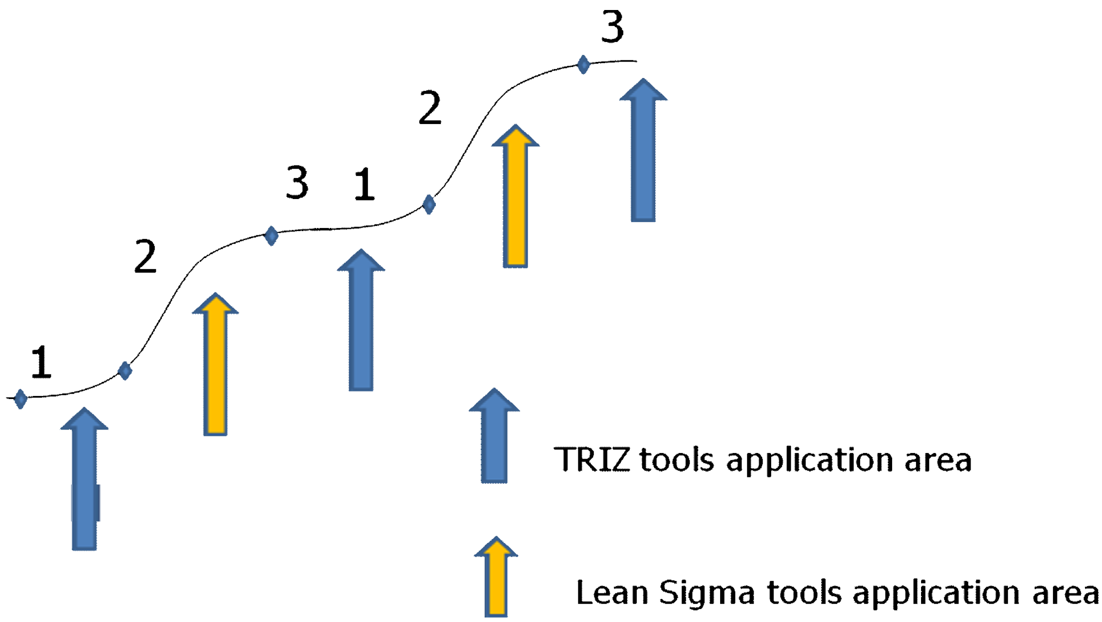

Fig. 12 – Areas of Lean Sigma and TRIZ tools periodic application

Understandably, at stage 1 the system is not formed yet. Thus, nothing to improve. The inventiveness is in order. At stage 2 the system is in full bloom, the resources are there for incremental improvements. Thus, Lean Sigma is a preferred methodology here. At stage 3 the resources are mostly depleted, the inventiveness is in order once again. And so forth.

On General Systems' Theory (GST)

If we recall that Lean Sigma is a methodology for uncovering defects, inherent in various processes, then we are dealing with process analysis and improvement. If we consider that systems engender process, then we need to study systems, their structures and functionalities. Systems theory was first introduced by biologist L. von Bertalanffy in the 1930s as a modeling device that accommodates the interrelationships and overlap between separate disciplines. The reality is that when scientists and philosophers first tried to explain how things worked in the universe, there were no separate disciplines. There were simply questions to be answered. But as we started understanding more and more, the sciences broke down into chemistry, physics, biology, and then biophysics, biochemistry, physical chemistry, etc. so that related components of a problem were investigated in isolation from one another. The Systems Theory introduced by von Bertalanffy reminds us of the value of integration of parts of a problem. Problems cannot be solved as well if they are considered in isolation from interrelated components. Enormous advantage systems analysts have in knowing the definitions of systems theory is that they present us with ideal guidelines for our initial familiarization with a new problem, which of course is a new system.

Russ Ackoff – an authority in systems thinking – gave the following elegant and beautiful illustration of the above statement (1971 unpublished speech, *The Second Industrial Revolution*), cited by Dannemiller Tyson Associates, *"Whole-Scale Change: Unleashing the Magic in Organizations"* (Berret Koehler, San Francisco, CA: 2000):

"Let me try to give you a feeling of why that [systems thinking] is so, by giving you an example rather than trying to give you a generalized proof. I would like you to go through the following thought experiment. I read in the New York Times the other day that there are 142 makes of automobiles available in the United States. So let's get one of each and bring them into a large garage – 142 cars.

"We'll hire ourselves a good group of first rate automotive engineers and fist ask them to do the following: Inspect those 142 cars, test them, do any damn thing you want to, but come out and tell us which one has the best carburetor. So they run a series of tests and they come out and say the Buick has the best carburetor. So we make a not – Buick carburetor.

"Then you say fine, now we would like you to do the same thing on transmissions. So they test the transmissions and they come out and say the Mercedes has the best transmission – we make a note – Mercedes transmission. What is systems thinking?

"You say okay, take the distributor, and they run through and they come out and say the Dodge has got the best distributor.

"Then one by one, we take every part until we have every part required for an automobile and we have identified the best parts available. Now when that is done, we tell them to take those parts off those cars and assemble them, because then we ought to get the best possible automobile.

"But, do you get it? You don't even get an automobile. And for a very obvious reason.

"Because it turns out that the parts don't fit, and that's what systems thinking is all about.

"It says that the performance of the whole is not the addition of the performance of the parts, but it is a consequence of the relationship between the performance of the parts. It is how

performance relates, not how it occurs independently of the other parts. That is what systems thinking is about. What is systems thinking?

“So, synthesis is a different way of thinking and looking for explanations. It tries to find it by looking at wholes, the larger whole, of which things are a part rather than by taking things apart.”

With that we can move on to –

Definition of a System

Although there is no single, agreed upon definition of a system, simply put, a system is an organized collection of parts (or subsystems) that are highly integrated to accomplish an overall goal via interaction of its parts. The system has various inputs, which go through certain processes to produce certain outputs, which together, accomplish the overall desired goal for the system. So a system is usually made up of many smaller systems, or subsystems. For example, an organization is made up of many administrative and management functions, products, services, groups and individuals. If one part of the system is changed, the nature of the overall system is often changed, as well -- by definition then, the system is systemic, meaning relating to, or affecting, the entire system. (This is not to be confused with systematic, which can mean merely that something is methodological. Thus, methodological thinking -- systematic thinking -- does not necessarily mean systems thinking.)

Systems range from simple to complex. There are numerous types of systems. For example, there are biological systems (for example, the heart), mechanical systems (for example, a thermostat), human/mechanical systems (for example, riding a bicycle), ecological systems (for example, predator/prey) and social systems (for example, groups, supply and demand and also friendship). Complex systems, such as technical or social systems, are comprised of numerous subsystems, as well. These subsystems are arranged in hierarchies, and integrated to accomplish the overall goal of the overall system. Each subsystem has its own boundaries of sorts, and includes various inputs, processes, outputs and outcomes geared to accomplish an overall goal for the subsystem. Complex systems usually interact with their environments and are, thus, open systems. These concepts are well summarized in one of TRIZ tools – System Operator.

In addition, a high-functioning system continually exchanges feedback among its various parts to ensure that they remain closely aligned and focused on achieving the goal of the system. If any of the parts or activities in the system seems weakened or misaligned, the system makes necessary adjustments to more effectively achieve its goals.

A pile of sand is not a system. If you remove a sand particle, you have still got a pile of sand. However, a functioning car is a system. Remove the carburetor and you no longer have a working car.

Systems thinking is an approach to integration that is based on the belief that the component parts of a system will act differently when isolated from the system's environment or other parts of the system. Standing in contrast to positivist and reductionist thinking, systems thinking sets out to view systems in a holistic manner. Consistent with systems philosophy, systems thinking concerns an understanding of a system by examining the linkages and interactions between the elements that comprise the whole of the system. When you encounter situations which are complex and messy, then systems thinking can help you understand the situation systemically. This helps us to see the big picture - from which we may identify multiple leverage points that can be addressed to support constructive change. It also helps us see the connectivity between elements in the situation, so as to support joined-up actions.

From here follows what is called –

Super effect

There is a notion in TRIZ literature of Super Effect. First discussed by Gerasimov and Litvin, it means that whenever TRIZ tools are used to achieve stated purpose, there will be an additional, not preplanned benefit of a TRIZ based process. In my opinion, the Super Effect of this research is a hypothesis on TRIZ role in General Systems Theory (GST). According to GST, systems are very similar in their structures and methods of accomplishing goals. The functionalities would vary greatly, depending on the goal. Yet, underlying patterns of systems’ performance and evolution are almost identical.

G. S. Altshuller and his followers deliberately restricted the area of TRIZ application to technical systems. However, today, we can see how social, social-technical and technical systems interact and integrate. The most telling is integration of “human” with various technical systems. Those, who lost their limbs for various reasons, are being fitted with electro-mechanical prosthesis. Recently, an artificial arm, which is connected to biological human system in such way that it can move its artificial fingers in response to a signal from human brain, was developed. A human in an automobile soon will be able to control the vehicle with direct signals from human brain, bypassing arms and legs. The prototype of such integrated system is already built and tested in Germany.

And here is the hypothesis. TRIZ, in GST, may play role, similar to that of mathematics in natural sciences field. Natural sciences flow in parallel, subject to diffusion along the borders. Mathematics runs in perpendicular to the rest of natural sciences, providing common methods of research and analyses. A parallel flow of various systems, subject to diffusion along the borders, is pierced by TRIZ, which provides common methods of research and analyses. The difference is in that while mathematics operates with numbers and precise formulas, TRIZ operates with images. This hypothesis is illustrated in Fig. 13

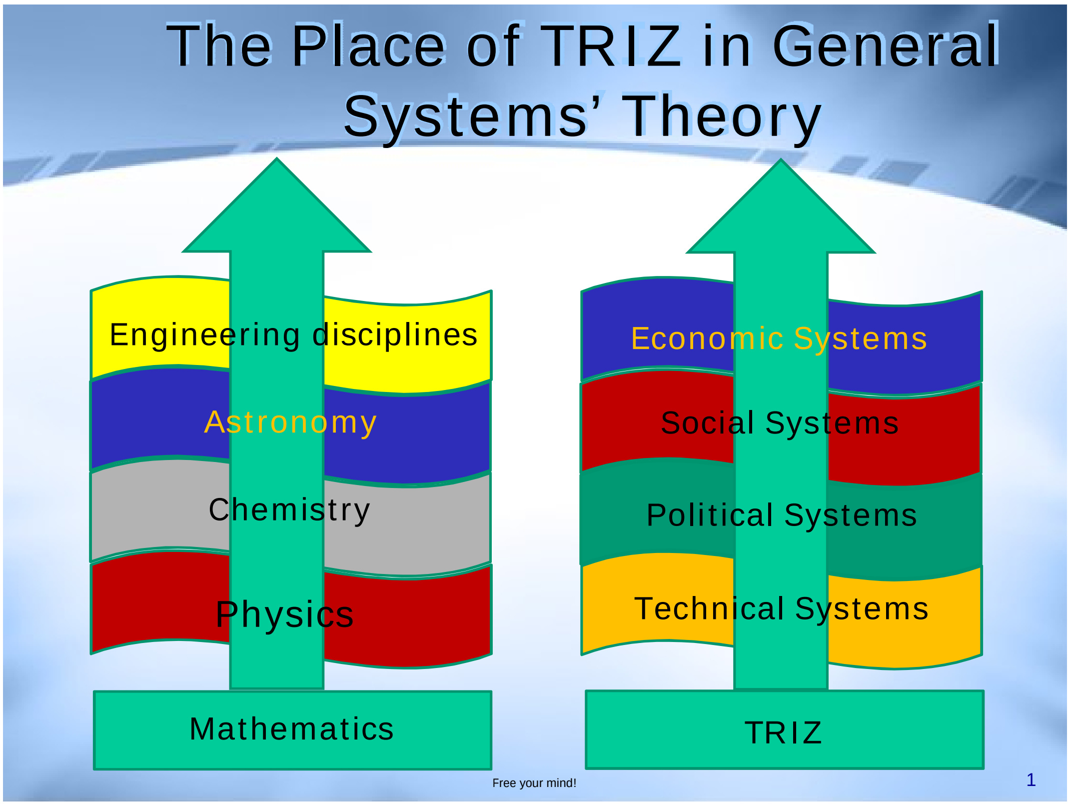

Fig. 13 – A place of TRIZ in GST

This analogy is supported by following observations:

Math's methods offer sciences and engineering ways to model a system under consideration (replace the system by a set of formulae and initial conditions) and to prognosticate its future behavior (using numerous mathematical methods). A set of math's methods is the means to:

a) Describe (model) systems' behavior (Sciences)

b) Predict systems' behavior (Sciences and Engineering)

c) Optimize systems' behavior (Engineering).

Math's methods have been heavily exploited in thousands of computer-based simulators for engineers and scientists.

TRIZ is a set of tools that offer ways to analyze systems, identify directions of evolution of systems and to exploit resources to discover most appropriate improvement for a system under consideration. A set of TRIZ tools offer the means to:

a) Apprehend problematic situations and model systems (Situation Analysis, Su-Field, Contradiction Table, ARIZ, and ARIP)

b) Exploit system's resources (Situation Analysis, Su-Field, Contradiction Table, ARIZ, ARIP)

c) Identify directions of systems' development (Laws, IUR, MIR, fields of MATCEMIB)
d) Conduct extensive search for solution ideas (most of the tools)
TRIZ tools have been exploited in a number of computer-based tools for system improvement.

Results and conclusions

The results:

1. Reviewed practical applications of TRIZ/Lean Sigma integrated method
2. Proposed theoretical foundation and algorithm for integration of TRIZ with Lean Sigma
3. Proposed the method of selected application of TRIZ and Lean Sigma
4. Offered a hypothesis of the role of TRIZ in GST

The conclusions:

1. TRIZ enhanced Lean Sigma methodologies work effectively in the presence of resources, required for system optimization.
2. TRIZ based tools for solving contradictions are effective when there are no available resources for system or process optimization and a qualitative change, a paradigm shift, is required for an advancement in system evolution.
3. The proper use of optimization and disruption techniques may increase the efficiency of both, Lean Sigma and TRIZ.

4. TRIZ tools, with some modifications, may be applied for system improvement across various fields of human activity.
5. It is preferable to employ holistic approach for system analysis and improvement. This way, the inadvertent problems in a system, resulting from various improvement activities, may be avoided. This point is well illustrated by Fig. 14.

Fig. 14 – Systemic approach to innovation

Here, a company is represented as a system with 7 interwoven areas, subject to innovation activities. It is quite obvious that no single area of the company may be advanced without concurrent advances aт the rest of the company.

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