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A Synergistic Approach to Process Innovation

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ABSTRACT With the continuing globalisation of the economy comes increasing number of competitors. Consequently, products lifecycles has continued to fall as companies strive to out-manoeuvre one another by introducing product and service innovations to meet the needs of increasingly choosy customers. This has created a business environment where change has become widespread and persistent. As processes are the engines that power organisations to deliver the values required by customers, it becomes imperative that to have competitive edge, or even survive in this sort of business environment, these processes need to be not only adaptable to the changes but also be capable of inducing the changes that would benefit the organisations. To investigate the feasibility of adaptable and change inducing processes, the research presented in this paper explores the synergies amongst three techniques for problems solving and process improvement: Theory of Inventive Problem Solving, which is more commonly known by its Russian acronym, TRIZ; Theory of Constraints (TOC); and Lean Manufacturing.

Keywords: Theory of Constraints, TRIZ, Systematic Innovation, Process innovation

Introduction

The continuing globalisation of the economy and the consequent increases in the number of competitors has resulted in a business environment where change has become widespread and persistent. As processes are the engines that power organisations to deliver the values required by customers, it becomes imperative that to have competitive edge, or even survive in this sort of business environment, these processes need to be not only adaptable to the changes but also be capable of inducing the changes that would benefit the organisations. In this paper, we explore the synergies amongst three techniques for problems solving and process improvement: Theory of Inventive Problem Solving, which is more commonly known by its Russian acronym, TRIZ; Theory of Constraints (TOC); and Lean Manufacturing with the aim of exploiting them to help companies to develop robust processes that can adapt to changing business environment and also induce the changes that would enable them prosper.

One way of looking at TRIZ is as a collection of tools that facilitate creativity and innovation in problem solving. The main premise of TRIZ is that creativity can be structured and repeated. The main premise of TOC is that the performance of a system is dictated by the performance of its biggest constraint. The message of TOC is that improvement efforts should be focused on the constraint where they would have the biggest impact on the overall goal of the company. The key philosophy of Lean is that the elimination of non-value adding activities, variability and inflexibility is imperative in order to deliver value to customers at the right time, quantity, quality and at minimum cost.

In the next section, some background information regarding each of the three techniques is provided, followed by a literature review of some of the works that have sought to explore similar synergies. The literature review is followed by a highlight of the commonalities amongst the techniques and how the synergies amongst the techniques might be utilised. The concluding part of the paper includes some recommendations on how these synergies might be adopted.

Background

Lean

The term 'Lean Production' was first coined by Krafcik (1988) and popularised by Womack et al. (1990), although the technique was pioneered by Eiji Toyoda and Taiichi Ohno at the Toyota Motor Company. Today, the technique is also known as 'Lean Manufacturing', 'Lean Enterprise' or just 'Lean' due to its applications beyond production and into other areas and industries such as service companies, hospitals, government departments.

The key philosophy of Lean is that the elimination of non-value adding activities, variability and inflexibility is imperative in order to deliver value to customers at the right time, quantity, quality and at minimum cost (Drew et al., 2004). Lean refers to non-value adding activities as wastes and identifies seven wastes: over-production; transportation; motion; over-processing; inventory; waiting and defects. The aim of a Lean implementation is to identify and eliminate these wastes, and there are five steps to achieving this (Womack and Jones, 2003).

i. *Specify value*
   Womack and Jones (2003) argue that the first step in eliminating non-value adding activities is to understand and specify what value means from the point of view of a customer. In other words, how does a specific product and/or service meet the needs of customers at a given time and price?

ii. *Identify the value stream*
   A value stream constitutes all the activities that take place in order to get a product from concept through to finished product and into the hands of a customer. A value stream is usually described using a value stream map (VSM) which provides a graphical presentation of the activities involved in a process. This helps to expose the wastes in the process and provides a basis for thinking

about ways to eliminate the wastes. A future state VSM is used to describe a new process where wastes have been minimised.

iii. *Flow*
Once the wastes have been minimised in step 2, the next step in lean thinking is to enable smooth flow through the remaining process steps described in the future state VSM. Flow implies rethinking the ways activities are performed across functional departments and looking at how they can be done within departments and by product teams.

iv. *Pull*
This step capitalises on the flexibility and responsiveness achieved through implementing flow but provides a framework to help a company to produce its goods and services according to customers' demand. In other words, it enables customers to pull goods and services from a company rather than a company pushing products to customers. Pull system in Lean is implemented using the takt time and kanban techniques.

v. *Perfection*
This step is a reminder that the above four steps are meant to be repeated over and over so that organisations can continue to reap the benefits of waste elimination.

Theory of Constraints

Theory of Constraints (TOC) was developed by Eliyahu Goldratt and was popularised in his novel, The Goal (Goldratt and Cox, 1989). The main premise of TOC is that the performance of a system is dictated by the performance of its biggest constraint, which is usually referred to as a bottleneck. As an organisation can be represented by a network of processes, TOC frequently uses the analogy of a chain to describe a process where the strength of the weakest link in the chain determines the strength of the whole chain. The fundamental message of TOC is that improvement efforts should be focused where they would have the biggest impact on the overall goal of the company, which is to "make more money now as well as in the future" (Goldratt and Cox, 1989). TOC takes a systems thinking approach by firstly utilising the constraint as a focal point for leveraging the performance of the entire system, and secondly by investigating and understanding how other parts of the system affect the performance of the constraint. For physical constraints such as resource constraints, TOC provides 5 focusing steps (Goldratt, 2003)—highlight in the following paragraphs:

i. *Identify the system's constraint*
This stage is about finding out which resource is limiting the ability of the system to achieve its goal of 'making more money'. Within a manufacturing organisation, this could be an internal resource or lack of some specific skill set.

ii. *Decide how to exploit the system's constraint*
Once the constraint of the system has been identified, the next step is to find out how to get more out of the constraint. The constraint of system is usually characterised by inefficiencies, quality issues and other forms of waste. This step is about making the constraining resource work at its peak performance.

iii. *Subordinate everything else to the above decision*
This is where TOC brings in systems approach to improvement. Due to the interdependencies amongst resources and processes, the subordinate step is about ensuring that all other parts of the system work in harmony to maintain the peak performance of the constraint as determined in step ii.

iv. *Elevate the system's constraint*
Elevating the system's constraint means increasing the capacity of the constraint. This step assumes that in the previous steps, the organisation has tried to squeeze out as much capacity as possible from the constraint before investing in additional capacity.

v. *If in a previous step a constraint has been broken, go back to step 1, but do not allow inertia to cause a system's constraint*
This last step ensures that there is a cycle for continuously boosting the performance of an organisation by using the constraint as a point of focus.

For policy constraints, TOC provides 3 focusing questions (Avraham, 2009a; Mabin and Davies, 2010) as follow:

i. *What to change?*
This is similar to step (i) in the 5FS and the purpose is to find out the major issues that are preventing the organisation from achieving peak performance such as company policies and rules, measurement systems, people behaviour, relationship issues etc. Obviously, in any organisation, there are numerous issues that may need to be addressed but this step is meant to identify the few that are preventing the organisation from achieving its goals. The Current Reality Tree (CRT) is frequently used to create a map of what the current scenario is regarding the issue on focus. CRT is basically a cause and effect mapping of a situation.

ii. *What to change to?*
Once the constraint is pinpointed, the next step is to create a future scenario that resolves the constraining issue, and to identify what needs to change in order to achieve the future scenario. TOC believes that most issues in any organisation are as a result of a conflict, and it uses an Evaporating Cloud (EC) to represent a conflict. The EC exposes not only the conflict but also the assumptions that are reinforcing the conflict. By identifying and replacing one or more erroneous assumptions, the conflict is broken. With the conflict broken,

a Future Reality Tree (FRT) is used to create logical representation of a future scenario.

iii. *How to cause the change?*
This step creates a roadmap of the actions that will be taken in order to go from current scenario to the future scenario as depicted in an FRT. Based on an FRT, a Transition Tree (TT) is used to create plan of actions that would enable the organisation to achieve the future state, and a Prerequisite Tree (PRT) is used to examine and overcome the risks that may affect the successful implementation of the plan.

TRIZ

TRIZ (Teoriya Resheniya Izobretatelskikh Zadatch) is a Russian acronym which, when translated into English, means Theory of Inventive Problem Solving (Terninko et al., 1998). TRIZ was initially developed by Genrich Altshuller and his colleagues after studying over 200,000 patents to identify the common patterns in the innovative solutions presented in the patents. The technique has since evolved as researchers have continued to study enhance its toolset. TRIZ can be seen as a means for increasing innovation (Terninko et al., 1998). TRIZ argues that the traditional approach of going from problems to solutions directly can lead to unending 'trial and error' situation, and to resolve this, it proposes a 'principle of solution by abstraction' (Kaplan, 2005). This principle, which is demonstrated in the figure 1, suggests that instead of going directly from a specific problem to a specific solution, it may be better to firstly identify an abstract form of the problem. This would then be followed by an identification of a possible solution(s) to the abstract problem and then translation of the abstract solution into a specific solution that solves the specific problem.

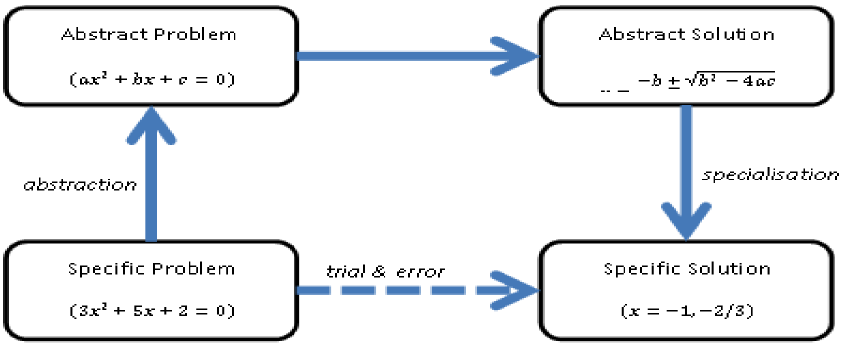

Figure 1. Problem of solution by abstraction (taken from Kaplan (2005))

A quadratic equation example, which was presented by Kaplan (2005), is ideal for explaining the principle. If one is asked to solve an equation such as $3x^2+5x+2=0$, there are three ways to proceed. The first is to try factorisation which can involve a lot of trial and error. The second approach is to complete the square which is quite an involved way and requires deep knowledge. The third approach is to use the formula which is basically a general representation of quadratic equations. Using the third option, one would abstract the equation to $ax^2+bx+c=0$, and then proceed to use the abstract solution $x=(-b \pm \sqrt{(b^2-4ac)})/2a$ to arrive at the specific solution of $x = -1, -2/3$.

One of the abstraction methods in TRIZ is the use of contradictions which, as Altshuller realised, are present in all inventive problems. There are two types of contradictions in TRIZ: technical and physical contradictions (Terninko et al., 1998; Kaplan, 2005). A technical contradiction occurs when one is trying to improve a parameter or attribute of a system and another parameter gets worse. An example is when one is trying to improve the strength of a component and the weight increases. As a way to resolve such conflict, Altshuller developed a 39x39 matrix of engineering parameters e.g. weight, area, shape etc. that utilises 40 inventive principles (i.e. abstract solutions).

A physical contradiction occurs when there are two opposing requirements for a single parameter. For instance, a situation that requires the weight of a component to be high and low. To facilitate the use of TRIZ in business and management, technical and physical contradictions are referred to as conflicts and contradictions respectively (Mann,2007). An example of a conflict in business is when one is trying to improve the quality of a product and the cost increases. An example of a contradiction is when there is a need for inventory to be both low and high.

Some other abstraction mechanisms in TRIZ include Ideality and Substance Field (Terninko, 1998; Kaplan, 2005; Mann 2002 and 2007). Beyond the abstraction basis of TRIZ, there are other philosophical concepts to TRIZ thinking. These include Resources, Functionality, Space-Time-Interface (Mann, 2002, 2007). The concept of Resources directs attention to the effective and creative use of things within and outside a system even seemingly negative resources; Functionality encourages focus on the functions required from a system; Space/Time/Interface encourages users to analyse systems from different spatial, temporal and interface contexts.

Literature review

Over the past few decades, a range of techniques have been developed and used to enable businesses respond to the challenges in the business environment such as, but not limited to, TQM, Business Process Reengineering (BPR), Lean, Agility, TOC. Unfortunately, most of these techniques have been degenerated to 'flavour of the month' as businesses continue to search for the panacea technique. However, as each of these techniques has helped businesses realise business benefits, it means that each of the techniques has something to offer. Realising this and the need for more encompassing solutions to business problems, researchers started to explore various combinations of these techniques to help provide more holistic business improvement approach.

A majority of the research have looked at integrating Lean and Agility techniques. Lean facilitates efficiency and cost reduction while agility enables rapid responsiveness to various changes in the business environment. The argument for integrating Lean and agility is to enable businesses to get the best of both worlds. Elmoselhy et al (2013) discusses the application of the hybrid approach to the automotive manufacturing sector. The work extracts the technical attributes of Lean and agility and devises a combination that would be suitable for the automotive industry. Katayama and Bennett (1999) explore the combination of Lean, Agility and Adaptability while Azevedo et al (2012) propose an Agiliean index for determining the agility and leanness of companies in the automotive supply chain. The index is computed from a set of lean and agile behaviours and practices. An interesting research by Stratton and Warburton (2003) sought to integrate lean and agile supply chain using separation principles of TRIZ and evaporation cloud of TOC.

The key benefit of these works is that they provide a form of high level or strategic views and directions regarding the ways lean and agility could facilitate improvement in business operations. What is missing in most of these works are the ways to leverage lean and agile tools in a systematic way to bring about a specific blend of operational activities in order to achieve specific objectives. Some other research have sought to fill this gap by combining Lean and TOC tools. Dettmer (2001) explores the similarities and differences between Lean and TOC and sought to use the differences to enrich both techniques. He argues that the main difference between Lean and TOC is that Lean seeks to eliminate waste in an entire value stream simultaneously. On the other hand, TOC seeks to find out the parts of the system that constrains the overall performance of the system and apply improvements to these constraints in a sequence that would result in the highest and quickest benefits. Dettmer (2001) provides a framework that shows how TOC and Lean tools can be used within the 5 focusing steps of TOC. Moore and Scheinkopf (1998) carried out similar work but in their framework, the 5 focusing steps of TOC are preceded by two steps: “adopt the throughput world perspective”, and “define the system to be improved, its purpose and the measures of its purpose”. Both works focused on utilising Lean within a TOC framework. Other similar works include the works of Avraham (2009b) and Vorne (2013). However, the work of Avraham (2009b) sought to integrate TOC, Lean and Six Sigma.

Some other works explored the synergies of TOC and TRIZ such as the work of Stratton and Mann (2003). In this work, the discussions were on the viewpoints of TRIZ and TOC with regards to conflicts and contradictions, and also on the commonalities of the underlying principles. Lebepe and Emwanu (2013) provide a comparison of TRIZ and TOC in relation to the effectiveness of the tools in a production environment. Similarly, Conradie and Consultores (2005) combine TRIZ and TOC in solving a forest harvesting problem. Domb and Dettmer (1999) apply TOC and TRIZ in resolving an aircraft problem. Moura (1999) discuss the combination of TOC trees and TRIZ. Pfeifer and Tillmann (2003) explore how TRIZ and TOC can be combined to optimise manufacturing processes. The results of these works show that there are some benefits to be derived by exploring the synergies amongst these tools.

Other research works explored the synergies between Lean and TRIZ including the works of Bligh (2006), Iyer (2006) and Ikovenko and Bradley (2004). Also, Martin (2010) provides a very brief description of the commonalities between TRIZ and TOC, and between TRIZ and Lean. He also suggests the combination of the three techniques as a way forward. The main drawback of this work is the lack of details. To the best of our knowledge, this unpublished work by Martin (2010), which is under three pages in length, is the only work that has attempted to consider the synergies between TRIZ, TOC and Lean.

Commonalities amongst TRIZ,TOC and Lean

Philosophical basis

One of the main philosophical basis of TRIZ is that increasing ideality is the overriding trend of evolution of systems, and the concept of ideality can be represented as (Mann, 2007):

$$\text{Ideality} = \text{Benefits} / (\text{Harm} + \text{Costs})$$

This means that as a system evolves, it would progressively deliver more of what it considers as *Benefits* and less of *Harm* and *Costs*. TOC has a similar expression which is based on the concept of the 'Goal' of a system. The philosophical basis of TOC is that the success of an organisation depends on how well it achieves its goal, and the goal of organisations is to 'make more money now as well as in the future' (Goldratt and Cox, 1989). In TOC, the goal of an organisation is represented as (Moore and Scheinkopf, 1998):

$$\text{Goal} = \text{Throughput} / (\text{Inventory} + \text{Operating Expenses})$$

Where *Throughput* is the rate at which the organisation makes money, *Operating Expenses* is all the money the organisation spends in order to turn inventory into throughput, and *Inventory* is the money that the organisation spends on things it intends to turn into throughput.

Similarly, Lean can be expressed in a similar way based on its concept of 'value'. The main proposition of Lean is to deliver customer value with minimum waste and cost. This may be represented as:

$$\text{Lean} = \text{Value} / (\text{Waste} + \text{Cost})$$

Conceptual abstraction

From the expressions for Ideality, Goal and Value above, it is easy to see that there is an obvious parallel amongst TRIZ, TOC and Lean, and one can argue that Throughput and Value are special cases of Benefits. One can also argue that '*Inventory & Operating Expenses*' and '*Wastes & Costs*' are special cases of '*Harm & Costs*'. In other words, *Ideality* can be seen as an abstraction of TOC's *Goal* and Lean's *Value*.

Problem abstraction

In addition to conceptual abstraction, there is also similarity amongst the three tools with regards to problem abstraction. In problem solving, abstraction can be seen as a way to classify problem types. As discussed ealier, contradictions are a class of problems in TRIZ and a company's problem of wanting to "increase speed but vibrations increases" is a specific form of contradiction. Similarly, TOC uses constraint in an abstract manner in such a way that a company's specific resource constraint problem is a special form of TOC constraint. In the same way, Lean uses wastes in an abstract manner.

Perfection and on-going improvement

Both Lean and TOC encourage a process of continuous improvement. This is evident in the last step, step 5, of each technique. Lean says 'Seek perfection' and TOC says 'if the bottleneck is broken, go to step 1', and TOC refers to this as a Process of On-going Improvement (POOGI) (Goldratt and Cox, 1989). TRIZ's ideality expression also implies the seeking of perfection. This commonality is self-evident once we appreciate the argument that TOC's Goal and Lean's Value are special cases of TRIZ's Ideality.

Thinking tools

The techniques are seen as consisting of thinking tools and this has led to the use of phrases such as Lean thinking and TRIZ thinking. TOC is special in this sense because its tools such as Current Reality Tool, Evaportation Cloud etc are referred to as thinking processes (Avraham, 2009a).

Commonalities between TRIZ & TOC

Focus on elimination of conflicts/contradictions as key to improvement

TOC believes that the ability of an organisation to achieve its goal depends on the performance of the constraint. Resource constraints manifest themselves in the form of bottlenecks, and policy constraints manifest as conflicts that forces the organisation to continue to make compromises and trade-offs. TOC believes that taking a careful look at the assumptions behind the conflicts using Evaporating Clouds will lead to reconciliation that breaks the conflict.

Similarly, TRIZ believes that strong solutions to problems often arise from the identification and removal of conflicts. In TRIZ, the contradiction matrix is the main tool for identifying the best strategies to facilitate the removal of conflicts, and the separation principles are the tools for resolving contradictions (Mann, 2007).

Commonalities between Lean and TOC

Value, value stream and systems thinking

Both TOC and Lean recognise the interdependencies amongst all the activities involved in delivering value to customers. TOC uses the chain analogy to illustrate the choking effect of constraints on the outcome of an entire process. Lean conceptualises the interconnection of the activities as value stream and uses value stream mapping as a description and analysis tool.

Flow and pull system

Both Lean and TOC advocate the importance of flow and they also utilise pull systems to control the flow of products. Lean uses Kanban as a tool to implement the pull system, TOC uses Drum-Buffer-Rope system.

Commonalities between Lean and TRIZ

Trimming

Lean advocates doing more with less and Trimming in TRIZ encourage users to think about reducing the complexity of a system while maintaining its functionality.

Maximisation of Resource Utilisation

Lean seeks to maximise the utilisation of resources and TRIZ also encourages the identification of all resources within and outside a system to maximise their uses. However, TRIZ advocates the creative use of waste Resources in such a way that they become useful e.g. the use of waste heat to re-heat buildings in heat recovery systems.

Synergistic use of the three techniques

This section explores how the three techniques can be combined for better results. The idea is to use one technique as a base framework or a starting point and then investigate how the other two techniques may be used to supplement the base framework. Specifically, it explores how to incorporate: Lean and TRIZ tools within a TOC framework; TOC and TRIZ tools within a Lean framework; and TOC and Lean tools within a TRIZ framework.

Using Lean and TRIZ tools within a TOC Framework

The work presented in the following paragraphs utilises the 5 focusing steps of TOC and draws from the works of Dettmer (2001), Moore and Scheinkopf (1998) and Vorne (2013).

i. *Identify the constraint*

   Lean

   Value stream mapping (VSM)—VSM helps to provide an overall picture of a process and conventionally helps to identify wasteful activities in the process. When used within a TOC framework, VSM can be help to identify resource constraints in a system.

Gemba visits - visiting the shop floor and having conversations with shop floor workers is one of the conventional ways of identifying bottlenecks in TOC. Coincidentally, Lean advocates a similar approach commonly referred to as 'go to the gemba'. The idea is that supervisors and shop floor worker have better ideas about where the bottleneck lies.

TRIZ

Conflicts/Contradictions—TOC advocates the identification of conflicts within a system and most often this is achieved using CRT and evaporation cloud. This can be supplemented using TRIZ which has some tools that are equally effective but less rigorous than CRT such as 'root contradiction analysis' tool (Mann, 2007) and 'why-what's stopping' tool (Basadur, 1995; Mann, 2007).

S-Curve analysis—S-Curve is known in a number of fields of work to represent the way in which a wide range of systems evolve. A good example is 'product life cycle' which can be represented by an s-curve in figure 2. In the diagram, a product goes from conception, birth, growth, maturity and decline. There is an argument that all systems evolve in this manner. Carrying out an s-curve analysis on the different aspects of a process might help to identify the aspects that have reached their limits on their s-curves or those that are near.

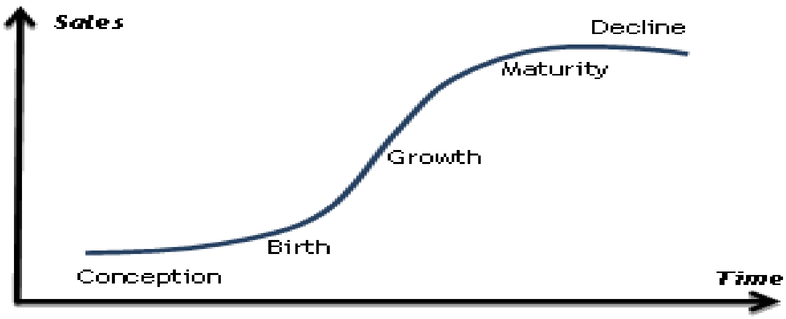

Figure 2. An S-curve of a product life cycle (adapted from Mann, 2007)

Function/Attribute Analysis (FAA) (Mann, 2007)—FAA is a graphical technique for analysing how a system works by mapping the functional interrelations amongst the components of system. Different types of arrows are used to show different functional relationships such as effective, insufficient, excessive, missing and harmful relationships. This kind of mapping could be very useful in identifying the constraint of a system.

ii. Decide how to exploit the constraint
Lean
A number of Lean tools are applicable in this step of TOC. These tools include (not exhaustive): Kaizen, 5S, Standardised Work, Pokayoke, Visual Manage-

ment, Single Minute Exchange of Die (SMED), Jidoka etc. Any of these, or their combinations, could be used to maximise the performance of the constraint.

TRIZ

Ideality – employing the ideality concept in this step would help to envision an ideal situation for the constraint. TRIZ argues that incremental improvements are strongly affected by the law of diminishing returns. TRIZ advocates the use of ideality to encourage people to envision an ideal situation first and then work back, if necessary, to the most practical situation. The main benefit of this is that it facilitates 'out of the box' thinking because when one is thinking about an ideal situation, they are not bound by the constraints of the current situation and the psychological inertia that impedes free thinking. The incremental and ideality thinking approaches are illustrated in figures 3(a&b).

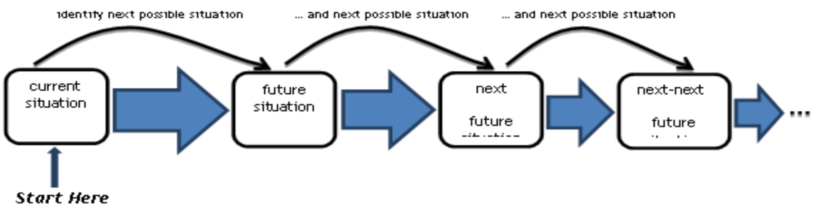

Figure 3(a). Incremental improvement approach (adapted from Mann, 2007)

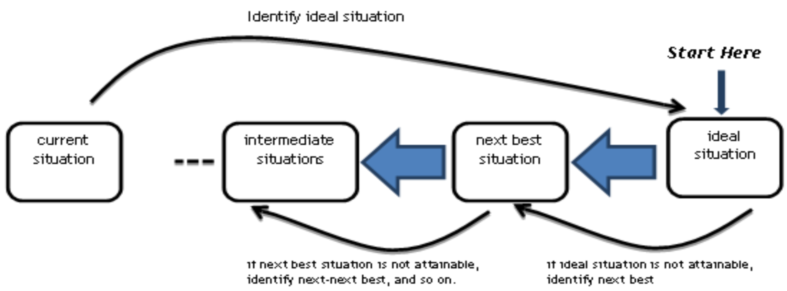

Figure 3(b). Ideality approach (adapted from Mann, 2007)

Contradictions—within a system, there may be conflicts and contradictions that prevent the constraint from reaching its maximum performance. This step in TOC is an ideal place to utilise TRIZ contradiction resolution methods because as one tries to improve the constraint, it may well be that something else gets worse.

Trends of evolution—the concept of trends of evolution (Mann, 2002) is based on the premise that the stages of evolution of systems are identifiable including the stages of development of the systems' components. And once the current stage of a system is identified along a particular trend, the future stages of evolution of the system can be predicted. There are 35 trends in TRIZ which could be examined to identify the trends that are relevant to the constraint. For each of the relevant trends, the current stage of the constraint along the trend's evolution path could be identified. Together, these trends would provide directions on how to exploit the constraint.

S-Curve—if, for example, the s-curve analysis in step (ii) suggests that the constraint has reached its limit, then there is no point in trying to squeeze out anymore from it. The focus should then be on transitioning to a new S-Curve. In TRIZ, transitioning to a new S-Curve usually results in innovative solutions.

iii. Subordinate everything to the constraint

Lean

Kanban for non-bottlenecks—kanban is an approach for controlling the flow of materials or work through a process. It uses a system of cards to visually signal the need for materials. Kanban can be used within this step in the TOC framework to regulate the flow of materials from upstream resources to the constraint.

The other lean tools mentioned in step (ii) such as kaizen, 5S, standardised work, TPM etc. can also be applied to non-constraints to ensure that the non-constraints have the capability to appropriately serve the constraint.

TRIZ

Functional/Attribute Analysis—FAA can also be used at this stage to help understand the interrelationships amongst the components of the system and to identify the harmful, insufficient and missing actions that may exist.

Space-Time-Interface (Mann, 2007)—this is tool is an attention focusing devise that encourages users to examine the system from different spatial, temporal and interfacing perspectives. For instance, one may examine the constraints spatially from the sub-system, system and super-system points of view. And when looking at the system spatially, the tool encourages users to examine the interfaces amongst different parts of the sub-system, system and super-system. One may also examine the constraint temporally by looking at the constraint from past, present and future perspectives to understand how changing times would affect the constraints and the non-constraints.

iv. Elevate the system's constraint

Lean

Lean tools such as SMED, TPM and Jidoka can be used to significantly improve the performance of the constraint.

TRIZ

S-Curve—it might be necessary to think about transitioning to a new S-curve whether or not the constraint has reached its limit.

Trends of Evolution – moving onto another step on a trend's path could also help to elevate the constraint.

Space-Time-Interface – examining how the constraint could change over time may suggest ways to elevate the constraint.

v. *Return to step 1.*

Using TOC and TRIZ tools within Lean framework

i. *Identify value*

TOC

TOC goal—in addition to identifying value from the perspective of the customer, this step in Lean can be complemented with an important aspect of TOC which is about identifying the goal of the system in order to maximise throughput. As mentioned above, throughput in TOC is rate at which a business makes money from sales.

TRIZ

Ideality—ideality thinking in this context is about considering customer value from an ideal point of view. Looking at the ideality expression earlier, one can see that ideality can be enhanced by either increasing the benefits or by reducing the costs/harm or both. Thinking of value from these points of view would enable users to gain broader sense of the concepts of value which would help to refine the direction of Lean implementation. In other words, it is not just about finding ways to minimise wastes (costs/harm) but also about asking the question: How ideal is the value that we provide to customers?

ii. *Map the value stream*

TOC

This step can be complemented with TOC tools such as Current Reality Tree (CRT) and Future Reality Trees (FRT) to identify any policy constraints that affect the behaviour of the system.

Importantly, in this stage of Lean framework, a constraint/bottleneck mindset may be adopted to help prioritise improvements.

TRIZ

Function/Attribute Analysis—this step could also be complemented with FAA to gain deeper insight into the inter-relationships that exist amongst the components of a system.

Ideality—it may also be necessary to think about future value streams in terms of ideal value stream. This will help to break away from thinking about making an incremental improvement to thinking about radically changing the system. This way of thinking would help 'out-of-the-box-thinking'.

iii. *Create flow*

TOC

TOC bottleneck concept is very applicable in this step to help identify resource and policy constraints that are impeding flow. TOC's tools such as CRT, FRT and evaporating cloud can be used to achieve this.

TRIZ

Trends of evolution—can be used to understand where the system/process is at different evolution paths. Some trends that may be applicable include: Space Segmentation, Trimming, Dynamisation and Action Co-ordination (Mann, 2002).

Conflicts/Contradictions—it may be beneficial to seek out the conflicts and contradictions that block flow.

Inventive principles—there are 40 inventive principles in TRIZ that represent problem solving strategies that have resulted in innovative solutions (Terninko, et al,. 1998; Mann, 2007). Identifying the applicable inventive principles that would support the work in this stage can be very beneficial. This may be as part of conflict/contradiction resolution using the contradiction matrix.

iv. *Establish pull*

TOC

In this step of lean, it is possible to use the DBR system instead of kanban system or as a complementary set of tools. Please see Avraham (2009b) for further details regarding DBR and also comparison of DBR and Kanban systems.

TRIZ

Trends of evolution – the following trends could be applicable in this step of Lean: Action Co-ordination, Rhythm co-ordination, Controllability (Mann, 2002).

v. *Seek perfection*

Using Lean and TOC within a TRIZ framework

The discussion about using Lean and TOC in TRIZ framework will take a slightly different approach from the foregoing discussions. In this section, the focus is to explore how TRIZ problem solving routine can support Lean and TOC implementation. In literature, there are different TRIZ problem solving routines but this section will be based on the routine developed by Mann (2007). There are four steps in the routine: define problem; select tool; generate solutions; and evaluate solutions.

i. *Define problem*

   In every problem-solving situation, understanding and defining the problem is a very crucial step and this is the purpose of this step. One of the key elements of creativity is lateral thinking—the ability to generate alternatives (De Bono, 1990) not just in finding solutions but also in problem definition. So, TRIZ's focus on problem abstraction can be very useful in stimulating creativity in problem definition. The abstraction of business and process problems may provide valuable means for examining problems from various vantage points, and combining the problem classes from Lean, TOC and TRIZ could help in providing a range of alternatives in problem definition:

   a. *Wastes;*
   b. *Constraints;*
   c. *Conflicts;*
   d. *Contradictions;*
   e. *Inflexibility;*
   f. *Variability;*
   g. *Reliability;*
   h. *Robustness;*
   i. *Cost;*
   j. *Risk;*
   k. *Missing, Insufficient and excessive actions*

ii. *Select tool*

   With a clear understanding of the type of problem at hand from the problem definition step, the 'select tool' step guides the user through a process of identifying which techniques, strategies or tools are most applicable for the problem at hand. For example, if the predominant problem is 'waste', the 'select tool' may point to the direction of utilising Lean as a base framework. The select tool would utilise descriptions of different types of problem situations and opportunity situations with recommendations about which tools are most relevant.

iii. *Generate solutions*

   This step focuses on generating potential solutions using the tool(s) selected in step (ii). In lean, this could be creating a number of future state VSM options. In TOC, this could be creating a number of FRT options and evaporations clouds. Emphasis here is on creating a number of solution options rather than creating one solution.

iv. *Evaluate solutions*

The purpose of this step is to identify the most suitable solution from the solution set. In Lean, the various future state VSMs can be subjected to analysis to identify the best VSM. In TOC, this would involve the analysis of different FRTs to identify the most appropriate.

Some recommendations on utilising the synergies

Some recommendations are presented in this section to assist users in utilising the synergies amongst the three techniques.

i. *User preference and competence*—the way to exploit these synergies will depend on the preferences of the user. For instance, someone who is more comfortable with Lean may prefer to use Lean as the base framework, and similarly someone who is more versed in TOC or TRIZ may use TOC or TRIZ, respectively, as the base framework. Someone else may try each framework as a base.

ii. *Utilise TRIZ framework*—TRIZ framework discussed earlier can be used at two different levels. At a higher level, TRIZ steps can be used to decide which technique or toolset is the most appropriate for the problem at hand. This means that it could guide a problem solver from problem definition to identifying whether to solve the problem using Lean tools, TOC tools or TRIZ tools. At the lower level, it could be used within each framework or technique to identify the tools that are most appropriate for solving individual problems within the overall problem. For instance, it could be used to decide whether to use VSM or 5S.

iii. *Aim/purpose of improvement*—the aim of an improvement may also provide guidance on the technique to be used and some possibilities are presented in table 1.

Aim	*Suggested Technique*	*How?/Possible tools*
Change inducing	TRIZ & TOC	S-Curve, Trends, Ideality, Constraints
Develop foresight	TRIZ	Ideality, Trends
Anticipate changes	TRIZ & TOC	Space-time-interface, trends anticipate the movement of constraint
Process evolution	TRIZ & TOC	Conflicts/contradictions, constraints
Regular process leaps for business growth	TOC	Identifying and exploiting constraints
Process efficiency	Lean, TOC & TRIZ	Lean – minimising wastes TOC/TRIZ – eliminating conflicts and trade-offs TRIZ – creatively utilising wasteful resources
Control and stabilise processes	Lean and TOC	Pull systems
Protect against uncertainty	Lean, TRIZ, TOC	Space-time-interface, trends anticipate the movement of constraint, pull systems

Table 1 – Selecting the right technique based on the aim of improvement

Concluding remarks

This paper explored the synergies among three techniques for process improvement and problem solving (Lean, TOC and TRIZ). Each of the technique has its inherent strengths: TOC brings focus and logical thinking to process improvement; Lean facilitates waste elimination and process stability; and TRIZ enables lateral thinking, creativity and foresight. However, as each of the techniques has a rich toolset, employing the synergies may be difficult or overwhelming for some. Although some recommendations have been provided above to help make it easier but for people with relatively little experience of each of the techniques, the synergies may appear a huge undertaking. This view is also shared by Avram (2009b) who, in the context of integrating Lean, Six Sigma and TOC, identified three reasons for lack of uptake including: lack of effective integration process; perception of each tool as being best for particular uses; and lack of expertise in all the techniques. The first and second issues are something that this research has made an initial attempt to address, and the third issue can be addressed through training.

Nonetheless, these issues should not be allowed to detract from the potential benefits of the synergies. Hickey et al (2003) report their findings from an analysis of a number of companies that have combined Lean and TOC. Two of the companies, Brush Wellman and Gunze Electronics Manufacturing Division, achieved dramatic results by utilising TOC to identify the system constraints and using Lean to exploit and elevate the constraints. For Brush Wellman, cycle time reduced by 53%, on-time shipment increased 73%, capacity availability increased 25% and inventory turns increased 31%. For Gunze Electronics, inventory quantity decreased 372%, lead-time decreased 425%, and due date performance increased 17%.

There is also a fourth issue which was mentioned by Avram (2009b) and Hickey et al (2003) regarding the potential danger that the synergies could be seen as another 'flavour of the month' by employees. The two companies mentioned in the report by Hickey et al (2003) addressed the issue through effective communication to the employees explaining that the intention is to leverage the strengths of both techniques. The report went on to explain that the companies found the implementation of the combination to be logical and straightforward.

What this paper has done is to extend current research in this area and add the creativity dimension, using TRIZ, to help stimulate lateral thinking that would lead to process innovation. This paper has also discussed that utilising TRIZ tools such as ideality and trends of evolution can enable foresight in process innovation in such way that the processes can be used to induce changes that are beneficial to an organisation. The details presented in the paper are the initial outcome of the research and more work is already on-going to refine and improve the approach.

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References

Avraham Goldratt Institute (2009a) *The Theory of Constraints and its thinking processes: a brief introduction to TOC* [Online]. Available at: http://www.goldratt.com/pdfs/toctpwp.pdf (Accessed: 8 August 2013)

Avraham Goldratt Institute (2009b) *Combining Lean, Six Sigma, and the Theory of Constraints to Achieve Breakthrough Performance* [Online]. A velocity white paper. Available at: http://www.goldratt.com/pdfs/CombiningLSSandTOC.pdf (Accessed: 8 August 2013).

Azevedo, S.G., Govindan, K., Carvalho, H., and Cruz-Machado, V. (2012) An integrated model to assess the leanness and agility of the automotive industry. *Journal of Resources, Conservation and Recycling*, 66, 85-94.

Basadur, M. (1995) *The power of innovation: how to make innovation a way of life and put creative solutions to work*. London: Pitman Publishing.

Bligh, A. (2006) *The Overlap Between TRIZ and Lean* [Online]. Available at: http://www.innovation-triz.com/papers/TRIZ_Lean.pdf (Accessed: 8 August 2013).

Conradie, I. and Consultores, I. (2005) *TOC and TRIZ: Using a dual-methodological approach to solve a forest harvesting problem* [Online]. Available at: http://www.srs.fs.usda.gov/pubs/ja/ja_conradie001.pdf (Accessed: 8 August 2013).

De Bono, E. (1990) *Lateral Thinking*. London: Penguin Books.

Dettmer, W.H. (2001) *Beyond Lean Manufacturing: Combining Lean and Theory of Constraints for Higher Performance* [Online]. Goal System International. Available at: http://www.goalsys.com/books/documents/TOCandLeanPaper-rev.1.pdf (Accessed: 8 August 2013).

Domb, E. and Dettmer, H. W. (1999) 'Breakthrough Innovation in Conflict Resolution: Marrying TRIZ and the Thinking Processes' *Proceedings of the APICS Constraint Management Special Interest Group*. Available at: http://www.triz-journal.com/archives/1999/05/b/ (Accessed: 8 August 2013).

Drew, J., McCallum, B. and Roggenhoffer, S. (2004) *Journey to Lean: making operational changes stick*. Basingtoke: Palgrave Macmillan.

Elmoselhy, S.A.M (2013) Hybrid Lean-Agile Manufacturing System Technical Facet in Automotive Sector, *Journal of Manufacturing Systems*, 32, 598-619.

Goldratt, E.M. and Cox, J. (1989) *The goal*. Revised edn. Great Barrington: North River Press.

Goldratt, E.M. (2003) *Production the TOC way*. Revised edn. Great Barrington: North River Press.

Hickey, P., DaCruz, M., Seaver, S., Simpliciano, S., and Liker, J. (2003) *Benchmarking lean manufacturing and theory of constraint implementations* [Online]. Naval Air Systems Command, Industrial Operations Group, NAVAIR Depot Maintenance System Program Management Office, Bearing Point Report. Available at: http://www.public.navy.mil/airfor/nae/AIRSpeed%20Documents/Benchmarking%20Lean%20and%20TOC.pdf (Accessed 5 February 2014).

Ikovenko, S. and Bradley, J. (2004) 'TRIZ as a Lean Thinking Tool', *ETRIA TRIZ Future Conference*, Florence, Italy.

Iyer, K. (2006) *Holistic Value Framework – Creating right value streams using TRIZ and other concepts*. Crafitti Consulting. Available at: http://www.aitriz.org/articles/InsideTRIZ/3230313130322D69796572.pdf (Accessed: 8 August 2013).

Kaplan, S. (2005) *An Introduction to TRIZ: the Russian Theory of Inventive Problem Solving* [Online]. Ideation International Inc. Available at: http://www.trizasia.com/docs/2005-Intro_to_TRIZ%20--%20for%20printer.pdf (Accessed: 8 August 2013).

Katayama, H. and Bennett, D. (1999) Agility, adaptability and leanness: A comparison of concepts and a study of practice. *International Journal of Production Economics*, 60-61, 43-51.

Krafcik, J. F. (1988) 'Triumph of the lean production system', *Sloan Management Review*, 30(1), pp. 41-52.

Lebepe, B.A. and Emwanu, B. (2013) 'Comparing Theory of Constraints (TOC) with TRIZ in solving production problem in South Afrika – a case study', *SAIIE25 Proceedings*. Stellenbosch, South Africa 9 – 11 July 2013. Available at: http://conferences.sun.ac.za/index.php/saiie/SAIIE25/paper/viewFile/638/210 (Accessed: 8 August 2013).

Mabin, V.J. and Davies, J. (2010) 'The TOC thinking processes: their nature and use – reflections and consolidation', in Cox, J.F and Schleier, J.G. (eds.) *Theory of constraints handbook*. USA: McGraw-Hill, pp. 631-669.

Mann, D.L. (2007) *Hands-on systematic innovation for business and management*. 2nd edn. Bideford: Lazarus Press.

Mann, D.L. (2002) *Hands-on systematic innovation*. Kuala Lumpur: CREAX Press.

Martin, A. (2010) *TRIZ, Theory of Constraints and Lean* [Online]. Available at: http://www.triz.co.uk/files/triz_toc_and_lean.pdf (Accessed: 8 August 2013).

Moore R. and Scheinkopf, L. (1998) *Theory of Constraints and Lean Manufacturing: Friends of Foes?* [Online]. Chesapeake Consulting, Inc. Available at: http://www.tocca.com.au/uploaded/documents/lean%20and%20toc.pdf (Accessed: 8 August 2013).

Moura, E. C. (1999) *TOC Trees Help TRIZ*. TRIZ Journal. Available at: http://www.triz-journal.com/archives/1999/09/e/ (Accessed: 8 August 2013).

Pfeifer, T. and Tillmann M. (2003) 'Innovative Process Optimisation – Utilising the Tools of TRIZ and TOC for Manufacturing', *ETRIA World Conference*. Aachen, Germany, November 2003. Available at: http://www.triz-journal.com/archives/2004/02/2004-02-04.pdf (Accessed: 8 August 2013).

Stratton, R. and Mann, D. (2003) 'Systematic Innovation and the Underlying Principles behind TRIZ and TOC', *Journal of Materials Processing Technology*, 139(1–3), pp.120–126.

Stratton, R. and Warburton R.D.H. (2003) The strategic integration of agile and lean supply. *International Journal of Production Economics*, 85, 183-198.

Terninko, J., Zusman, A. and Zlotin, B. (1998) *Systematic Innovation: an introduction to TRIZ (Theory of Inventive Problem Solving).* Florida: CRC Press LLC.

Vorne Industries Inc. (2013) *Theory of Constraints*. Available at: www.leanproduction.com/ theory-of-constraints.html (Accessed 8 August 2013).

Womack, J.P., Jones, D.T. and Roos, D. (1990) *The machine that changed the world*. New York: Rawson Associates; Oxford: Maxwell Macmillan.

Womack, J.P. and Jones, D.T. (2003) *Lean thinking: banish waste and create wealth in your corporation*. London: Simon & Schuster.