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How could the TRIZ tool help continuous improvement efforts of the companies?

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Abstract

This paper objective is to explore TRIZ tool as a tool that could be helpful during Lean implementation, in particular, during the continuous improvement process efforts. Attending to the already published papers regarding Lean and TRIZ, at least since 2004, this synergy is viable and sustainable. This paper presents TRIZ principles and discusses their relation with Lean Production principles. Additionally, presents some TRIZ tools and explain how they can be useful in the context of the methodology in development to be applied in Textile and Clothing Industry.

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Keywords: Lean Production, TRIZ, Continuous improvement;

1. Introduction

Lean Production (LP) is a well-known production model that has its roots in Toyota Company as Toyota Production Systems [1]. LP is focused on the customer, seeking the elimination of waste (activities that adds no value to the products) and on time quality products, materials and information deliveries, attending to the people and environment respect. To achieve this, a continuous improvement effort must be formally implemented. In order to implement LP in a company, many tools, procedures need to be implemented, demanding a methodology that helps in this process. A methodology is being developed, and described through the paper, recurring to known tools used to diagnose, analyze, improve, and report the system status, before and after LP implementation.

In this paper, the authors study the TRIZ tool as a useful tool and with a role in this methodology. It is also addressed this role by discussing when and how the tool can be used.

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2. Context study and motivation

This work will support a Lean Production methodology being developed by the authors to implement in Textile and Clothing Industry (TCI). This industry represents a considerable weight on socio-economic structures of Portugal. It is one of the few industries which contribute positively to the Portuguese balance of trade and it is the most exposed to competition, with significant impact on the volume of employment and reduction of sales margins. It is also an industry constituted by many small companies (SME) and very vulnerable to the strong competition and global market. For this reason, many companies already closed their doors, launching to the unemployment hundreds of workers.

Simultaneously, it is an industry with many productivity problems due to materials flow confused, workers without multi-skilling competences, high rate of defects, sewing lines without a consistent and uniform flow, high level of work in process (WIP), among others.

The TCI is also an industry strongly seasonal and fashionable, depending on clients' behavior. The customers demand change significantly and in short time span appealing to companies' leanness and agility. For these reasons, the methodology in development includes the tools to diagnose the problems referred and, at the same time, must have tools that allowdeveloping new products and new processes or improving the existent ones.

3. TRIZ principles and tools

According to The Altshuller Institute for TRIZ Studies [2], TRIZ is the Russian acronym for *Teoria Rechenia Izobretatelskih Zadatchi* (TRIZ) that in English means Theory of Inventive Problem Solving (TIPS). This theory, created in 1946 by a Russian engineer and scientist Genrikh Altshuller, was applied to engineering technical problem solving. Altshuller, after studying the patents process, concluded that in this process it was possible to found out a pattern. From this theory, the author concluded that inventiveness and creativity can be learned. Following this author, others promoted the TRIZ tool and inserted it in engineering curriculum, either in Mechanical Engineering [3, 4] or in Textile Engineering [5, 6].

Stratton and co-authors [4], referred that there are three premises on which TRIZ methodology is based in order to inventive problems being codified, classified and solved methodically, as other engineering problems. These premises are: 1) the ideal design with no harmful functions is a goal; 2) an inventive solution involves a partial or total elimination of a contradiction and 3) the inventive process can be structured.

According to these authors, the first premise implies finding the ideal solution to a needed effect or function with no additional resources or negative secondary effects. It is referred in TRIZ circles as Ideality which means dividing all useful effects or functions by all harmful effects or functions. Although "ideality" is an unreachable state, the search for this state provokes incremental improvements and a continuity of innovative solutions. Finding the ideal solution takes advantage of the resources already available in the system. The second premise has to do with the classification of the inventive solutions into five levels, as described in table 1 [4].

Table 1. Five levels of solution, according to Stratton et al.[4]

Level	Solution	Percentage (%)
1.	Standardization: solution by methods well known within specialty	32
2.	Improvement: improvement of an existing system, in the same field	45
3.	Invention inside technology: improvement in existing system, usually from other fields	18
4.	Invention outside technology: new generation of a system, using science not technology	4
5.	Discovery: new system usually based on major discovery	1

These inventive solutions are centred on eliminating contradictions, being contradictions performance trade-offs. Examples may be identified as follows: strength vs. weight, speed vs. efficiency, etc., which were denominated as technical contradictions by Altshuller [4].

3.1. The 40 principles

From over 1,500,000 world-wide patents, Altshuller extracted 39 standard technical characteristics that causeconflict, called the 39 Engineering Parameters [7]. The Altshuller's Contradiction Matrix based on these 39 technical parameters is combined with 40 inventive principles (Table 2) that are used to solve the technical contradictions [8, 9]. Other contradictions are the physical contradictions that include, for example, fast vs. slow contradiction and these contradictions are solved with others principles and tools (separation of contradictory requirements in time or space, etc.).

Table 2. The 40 Principles of TRIZ, based on Altshuller [8]

The 40 Principles of TRIZ			
1. Segmentation	11. Beforehand cushioning	21. Skipping	31. Porous materials
2. Taking out	12. Equipotentiality	22. Blessing in disguise	32. Colour changes
3. Local quality	13. "The other way round"	23. Feedback	33. Homogeneity
4. Asymmetry	14. Spheroidality-Curvature	24. Intermediary	34. Discarding and recovering
5. Merging	15. Dynamics	25. Self-service	35. Parameter changes
6. Universality	16. Partial or excessive actions	26. Copying	36. Phase transitions
7. Russian dolls	17. Another dimension	27. Cheap short-lived objects	37. Thermal expansion
8. Anti-weight	18. Mechanical vibration	28. Mechanics substitution	38. Strong oxidants
9. Preliminary anti-action	19. Periodic action	29. Pneumatics and hydraulics	39. Inert atmosphere
10. Preliminary action	20. Continuity of useful action	30. Flexible shells and thin films	40. Composite materials

3.2. TRIZ tools

These 40 inventive principles are one of the tools used by TRIZ methodology, being others exposed by the Institution of Mechanical Engineers [10] as Oxford Creativity TRIZ toolkit that includes 10 tools:

1. Thinking in Time and Space
2. Eight Trends of Technical Evolution
3. Contradictions
4. Forty Principles
5. Seventy-six Standard Solutions
6. Resources
7. Ideality
8. Functional Analysis
9. Smart Little People
10. Size-Time-Cost

TRIZ methodology involves a body of knowledge and a time-consuming learning process but its essence, according to Nakagawa [11], resumed to these 50 words: *"Recognition that technical systems evolve towards the increase of ideality by overcoming contradictions mostly with* ***minimal introduction of resources****. Thus, for creative problem solving, TRIZ provides with a dialectic way of thinking, i.e., to understand the problem as a system, to make an image of the ideal solution first, and to solve contradictions."*

4. Lean, TRIZ principles and other related concepts

Lean and TRIZ share a main idea: design and delivery products to the clients that they really want. In order to achieve this, both use principles and tools having in mind reducing the waste or minimizing the usage of new resources and both uses a procedure of continuous improvement. Some authors already established the relation between the Lean Thinking principles, the seven wastes and the lean tools [12, 15].

According to Bligh [13], TRIZ and Lean Thinking have common points: improvement of the operations of a system; need some time to define the problem, analyze the current state of the company to predict the future state and optimize the use of available resources.

These common points begin in the engineering parameters considered in the contradiction matrix with particular emphasis to the: waste of energy; waste of substance; waste of time; amount of substance; reliability; and productivity. Wasted energy, water and natural resources, and the increase of pollutants are some of the effects of the seven wastes of Lean that have a direct impact in environmental performance [16]. They are also a concern in TRIZ principles presented and previously identified in table 2, related with the engineering parameters and the way that products are designed. These synergetic relationships are explained in following.

4.1. TRIZ principles and eco-efficiency factors

TRIZ principles are also totally akin to the eco-efficiency factors launched by the World Business Council for Sustainable Development [17]:

1. Reduce the material intensity of its goods and services
2. Reduce the energy intensity of its goods and services
3. Reduce the dispersion of any toxic materials
4. Enhance the recyclability of its materials
5. Maximize the sustainable use of renewable resources
6. Extend the durability of its products
7. Increase the service intensity of its goods and services

Applying these factors combined with inventive principles of TRIZ for product design, will promote the production of high eco-efficiency in products or services [18] and thus, promote the cleaner production towards sustainable production and consumption patterns [17]. Related tools are: Design for Manufacturing, Design for Assembly/Disassembly, Design for Recycling and/or Design for Environment or all DFX tools that must base the contemporary design in order to promote more Environmentally Conscious Manufacturing (ECM). This deals with green principles that are concerned with developing methods for manufacturing products from conceptual design to final delivery to consumers and ultimately, to the End of Life (EOL) disposal that satisfy environmental standards and requirements [19]. The principle 1, Segmentation, is totally related with this when intends to make an object easy to assemble or disassemble.

Principle 3, the principle of Local quality, whose main objective is to make each part of an object fulfill a different and/or complementary useful function to a product like a Swiss-army knife. The principle 6, Universality, is related to making a part, or object, be able to perform multiple functions; eliminating the need for additional parts or objects reducing in this way, the necessary materials. There are many examples of application of this principle like a sofa and a bed in the same object, child car safety seat converts to a stroller among others [9]. Employing mechanical vibration (principle 18) or gravity, when possible, will save energy.

A pertinent aspect for this discussion is the use of Pareto analysis to prioritize actions when not all can be achieved with the available resources presented in principle 16, Partial or excessive actions [9]. The principle 20, Continuity of useful action, has an aspect related with making all parts of an object or system work at full load or optimum efficiency all the time, resulting in less wasted energy.

Another important TRIZ principle for elimination of wastes is the principle 22, Blessing in Disguise, because it is allied with the use of energy wasted on engines to other utilizations (co-generation process), the recycle of wasted materials of one manufacturing process as raw materials in another process like the manufacturing of clothes from recycled materials such as PET products (Nike did this for EURO2012 T- shirts football players) and the transformation of old clothes in paper sheets for weddings invitations or paper bags for shopping or use an organic waste from cooking the meals as a compost fertilizer. These kinds of actions are also included in principle 25, Self-service, which includes giving to the objects some self-services like self-cleaning glass.

Use of alternative materials as a solution to natural materials will help to preserved the bio-diversity of species, mainly, the ones in risk of disappearing. This is included on the principle 26, Copying, that promotes the use of simpler and inexpensive copies and replacement of objects by optical copies. Some of these aspects are discussed elsewhere as well as some projects related with how this is happen in Textile industry [21, 22].

Some recent examples of alternative materials and reuse are: a new eco-friendly uniform developed for MacDonald's workers, which have a "closed-loop", meaning that old or damaged textiles, instead of going to the landfill, will simply be remade into new ones. This uniform will appear for the first time at the London for Olympics games.

Other example is the 'world's most sustainable suit' by Marks & Spencer (M&S), made with organic wool; lining made from recycled plastic bottles; canvas made from recycled polyester; reclaimed buttons; pockets and waistband made from reclaimed fabric; and labels made from recycled polyester. In another first, M&S has also added a 'QR' code to the suit label which can be scanned using a mobile phone so customers can download information on the suit and the materials it is made from. M&S wants to launch this suit during this year as being part of their strategy, called Plan A. Plan A is Marks & Spencer's environmental and ethical program which aims to make M&S the world's most sustainable major retailer by 2015. Launched in 2007 and extended in March 2010, it takes a holistic approach to sustainability focusing on involving customers, engaging all areas of the business and tackling issues such as climate change, waste, raw materials and health and well-being a fair partner.

4.2. TRIZ principles, SPC and Lean Six-Sigma

Modifying a process means knowing the process and how it works, which imply getting feedback on this behavior. Principle 23, Feedback, has this concern. Statistical Process Control (SPC) can help on the measurement of this process. In this context, Six-Sigma, or more recently, Lean Six-Sigma is also combined with TRIZ methodology to improve quality and service process performance, even in the services sector like as described in Wang & Chen [20].

4.3. TRIZ principles and system improvement

Another relevant principle that is more related with the system improvement and minimizes wasted activities is the principle 5, Merging, make objects or operations contiguous or parallel; bring together on time. This requires a reconfiguration of the system production in production cells or flow lines. The principle 10, Preliminary action, in pre-arrange objects in order to their fluidity and right place without waste time in unnecessary transport or looking for tools or materials in spite of putting the machine to work. Also the principle 20, Continuity of useful action, has another aspect related with eliminating all idle or non-productive actions or work, being necessary housekeeping tasks or 5S Lean tool which results in less downtime of machines.

4.4. TRIZ principles and QFD

Bicheno [23] referred that the waste of making the wrong product efficiently is the eighth waste, being a restatement of the first lean principle "Value" [24]. This means that delivery a good quality product not wanted by the clientis a waste that the companies want to avoid because they invest money, resources and time in a product that will be keep in the shelf. Quality Function Deployment (QFD) has been traditionally used to translate customer´s specification into production requisites. Some authors, namely as in [7, 25], considered that QFD could be enhanced with TRIZ principles and tools, helping in this way to identify new functions and performance levels of quality.

4.5. TRIZ principles and Lean solutions

The TRIZ principles explained could also help the lean consumption vision of Womack & Jones [24] that goes to a totally opposed direction of mass production and consumption environment in which "one format fits all". Some principles towards to this vision of a lean consumption which joins the consumer view with provider view. In order to have this lean consumption, it is necessary: 1) solve our problem completely; 2) don't waste our time; 3) provide exactly what we want; 4) provide value where we want;

5) provide value when we want; 6) provide the value we really desire, not just the existing options; and 7) solve our complete problems permanently. Lean solutions will have benefits for the environment, by reducing materials and resources needs; and for the society, by employing highly skilled people through a Lean work environment propitious to develop thinking skills and create thinkers [26].

5. TRIZ in the Textile and ClothingIndustry Lean Production methodology

The authors are developing a methodology to implement Lean Production in Textile and Clothing Industry (TCI) (LPmodTCI). The Fig.1 shows a three-phase framework of the proposed methodology to implement Lean Production in TCI [22].

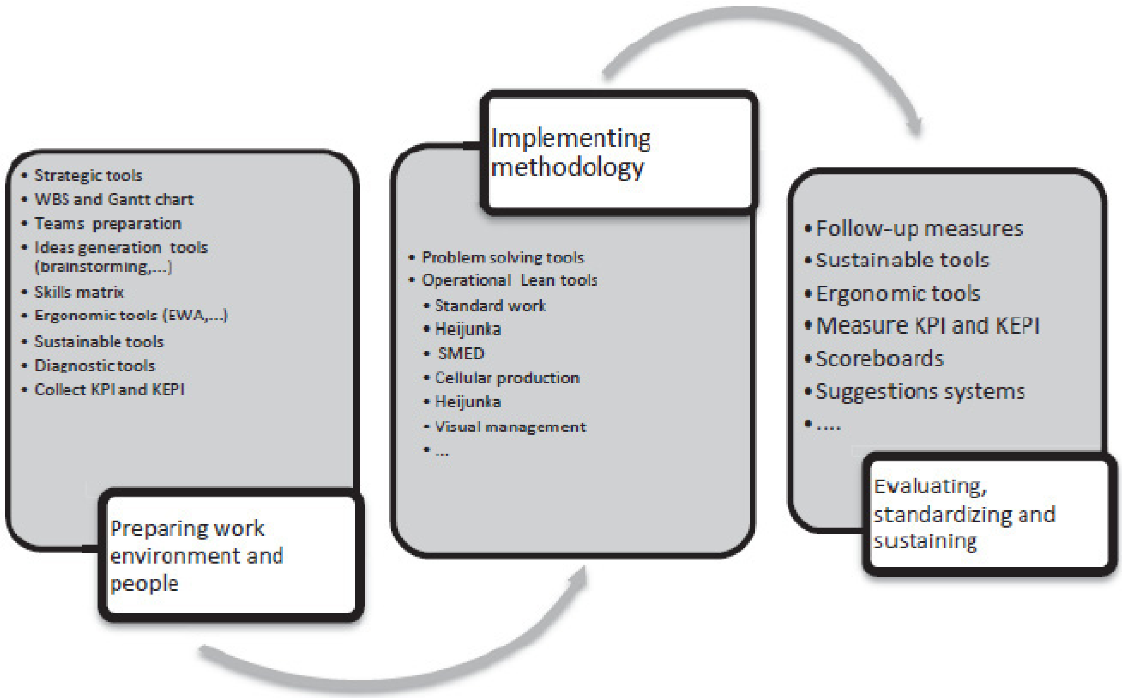

Fig. 1. Framework of the methodology to implement Lean Production in TCI

During Lean Production implementation many problem solving tools can be used, like the ones identified in the table 3, to support the team work of discover and solve problems in a continuous improvement effort.

Table 3. Problem solving tools

Problem solving tools		
Histogram	Radar chart	Man-machine chart
Affinity diagram	Arrowdiagram	P/Q analysis
Cause-effect diagram (fishbone or Ishikawa diagrams)	Paretodiagram	8D method
Gantt chart	Control chart	DMAIC
Scatter diagram	Relations diagram	PDCA cycle
Tree diagram	Display chart (pictograph)	A3 report
Pie chart	Process analysis sheet	VSM
Graph	Cycle time analysis sheet	Spaghetti diagram
Check sheet	Work combination chart	Eight wastes tool
Matrix diagram	Process flow diagram	Root cause analysis

Many of these tools could also be used for diagnosis the system in the first phase of the methodology and be combined with some others tools to promote the ideas generation: brainstorming, 6M1E (Man, Machine, Methods, Material, Measurement, Management information and Environment) checklist, the asking "Why" five times (5Whys) technique, the 5W2H (What, Why, Where, When, Who, How, How much/many) checklist and Osborne´s checklist (use it another way; borrow an idea from something similar; change or replace it; expand it; reduce it; use alternatives; replace it; reverse it; and combine it). These tools help to raise the right questions in the search for causes of problems [27].

The TRIZ tool is one more tool that could be added to this tools base and help the companies in a Lean journey implementation. This will support the efforts of continuous improvements, through the systematic new products development and problem discover and solution search and/or generation. TRIZ support on the new products development is possible at two levels: in supporting the innovation team to develop eco- friendly and ergonomic productswith less natural resources, water, energy and pollutants emissions in less time, according to the already principles and engineering parameters discussed in the previous section, and in providing access to a database of causes/effects built based on experiences from others companies and industries.

In order to achieve this, there are several techniques associated with TRIZ that can be beneficial and also could be used in all phases of methodology. These techniques are included in the tools presented in section 3 and are explained in the context of the LPmodTCI.

In *Thinking in Time and Space* tool it is used a nine-box tool or nine-windows tool [14] that is applied in three different ways at various stages of the problem understanding and solving process: set the system context, define its environment (super-system) and all the details (subsystems). This also can be applied to the supply chain to understand who the distributors (super-system) are and the suppliers (subsystems), understanding in this way the company's position in the market and also where the company has been and where it is going tracking a current state map [13].

In the context of *the Eight Trends of Technical Evolution*, TRIZ will help to predict new markets and new products [10]. TCI is a strongly fashioned industry, deeply dependent on people desires but also on climate. Being climate changes one of the 15 Global Challenges facing humanity [28] that will bring drastic changes to seasons due to global warming, the textile companies had to change their business strategies as a way to satisfy the market. Therefore, the demand for certain items, such as finer knitwear during the winter and even tops, will appeal to companies rethink their management strategies all the time.

Uncovering and Solving *Contradictions* will give the company experience and structure for problem solving successful. Combined these contradictions with the *Forty Principles* to develop new products and solve problems will the benefits already discussed on section 4. *Standard Solutions* for Problem Solving constitutes a knowledge base that anyone (designers, managers, workers …) can access and use, reducing the time design and cost.

Tool *Resources* deals with the identification of available resources and the idea is to find the right resources and/or systems and overcome constraints. Find the available resources needed give a good, cost-effective, environmentally friendly solution to the problem in hands. *Ideality* is related with understanding what the clientwant and it is deeply related with the lean consumption behavior explained early. Presented in the section 3, in the Ideality function it is intended the complete reduction of denominator, i.e., the harmful effects and in the context of client demand this means eliminate all the things the client do not want. The *Functional Analysis* is applied to modeling and analysis of the system and searches for the negative, ineffective and excessive interactions in the system. Doing this, companies will have a proper understanding of the problems and potential solutions. Function-based thinking and Ideality can help in creating an improved understanding of value (and thereby waste) [14].

Smart Little People is a tool for people think in a different way facing a problem. This technique can be used with the separation principles or the 40 principles once the conflict has been identified and it is especially useful in brainstorming sessions during the first phase of the methodology. The idea is to broken down into smaller the system in more understandable parts. Another tool useful in brainstorming sessions is the *Size-Time-Cost* that guides the problem solver to imagine the system at extremes, i.e., a totally free system or an infinite budget to spend [10]. Additionally, for brainstorming, idea generation and solution evaluation it can be used *Six Thinking Hats* technique (Fig.2, adopted of Mann [29]).

Fig. 2. Six Thinking Hats technique, adopted of Mann [29]

These six hats are related with different modes of people thinking according the task to develop. Each color have a different mode of thinking: **white**, requiring an objective look at data and information; **red**, associated with feelings, hunches and intuition; **black**, associated with caution, judgment, and looking logically at the negative aspects of a problem (often described as the "devil's advocate"); **yellow,** examining the feasibility and benefits of a given situation and looking logically at the positive aspects; **green**, generating new ideas, creative and lateral thinking; and **blue**, associated with the overall control and organization of the thinking processes. This technique can be integrated into any TRIZ inventive problem solving situation – from the initial assessment to problem-definition and solution [29].

6. Concluding remarks

This paper reviewed some tools of TRIZ methodology that could be used in the phases of a methodology to implement Lean in Textile and Clothing Industry (LPmodTCI) in development by the papers authors.The synergetic relationship between Lean and TRIZ was also described, emphasizing that Lean as much as TRIZ aims the elimination of wastes as some authors already had point out. In this way, TRIZ can be included in LPmodTCI as a tool for finding solutions to problems that systematically and continually appear in companies, for helping designergonomically and nature-friendly eco-products and/or develop/improveproduction systems in a sustainable manner.

Additionally, TRIZ methodology with Lean-Green Production and eco-efficiency concepts helps to save resources (energy, raw material, water) and provide the leanness and agility demanded by Textile and ClothingIndustry to attend the needs of customers demand that suffers changessignificantly and in short time span.

In summary it is concluded that TRIZ can be a very useful tool to LP and important to be includedand considered in LPmodTCI, allowing pursuing the continuous improvement and worrying about sustainable development.

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