Universidade do Minho
Escola de Engenharia

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Using TRIZ Methodology with Lean Production Techniques applying SMED method in Industrial Environment

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Master Thesis
Engineering and Industrial Management Integrated Master

Work performed under the guidance of
Professor Petr Lepsik
Professor Manuel Lopes Nunes

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DECLARAÇÃO

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ABSTRACT

Due to recognized benefits of Lean Production in the world, companies of all kinds and sizes are trying to implement the techniques to this production system. However, in their haste to reach short-term benefits of Lean Production, companies deploy sporadic and occasionally their tools without a clear link to global strategies. As a result, the majority fails in its attempt to be a Lean company and back to their old manufacturing systems.

Nowadays it can also be applied the Theory of Inventive Problem Solving (TRIZ) by proposing a new approach to the Japanese Method of Lean Production. Traditionally, the effectiveness of new process is unpredictable as process relies largely on inspiration and the past experiences of the producing system. By integrating TRIZ problem-solving tools and its knowledge base, it's proposed a new TRIZ-based approach to address this weakness in the processes. Through the case study, the combination of TRIZ methodology with Lean Production proposed model is verified. This demonstrates the helping relevance of TRIZ to the processes improving it. It is hoped that this case study will raise awareness among researchers so that more studies in this direction are conducted because TRIZ is a new approach methodology so it isn't yet too developed at this time.

Using both methodologies (Lean and TRIZ) the goal wasn't reached. It was supposed the changeover take less then 10 minutes and still more. Although it was a success using them together because the system improve. Using just SMED the system would improve "just" 56% but using SMED and TRIZ techniques the system was improved, using less 87% of the time taken in the beginning.

As a result, it was found that Lean is best used when the tools are applied in combination with TRIZ Methodology. Combining these two methods the production become quicker and effective reducing the waste.

KEY WORDS

Continuous Improvement. Lean Production. Production System. SMED. TRIZ.

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ABREVIATIONS AND ACRONYMS LIST

ATE	Automated Testing Equipment
BKM	Best Known Method
HMLV	High Mix Low Volume
I/O	Input/Output
JIT	Just-In-Time
LP	Lean Production
MPV	Main Parameters of Value
NVA	Non Value Added
PDCA	Plan-Do-Check-Act
QFD	Quality Function Deployment
ROI	Return On Investiment
SaO	Subject-Action-Object
SMED	Single Minute Exchange of Die
TP	Test Program
TRIZ	Theory of Inventive Problem Solving
VSM	Value Stream Mapping
WIP	Work In Process

1. Introduction

Is the scope of the master thesis of Industrial Engineering and Management (Mestrado Integrado em Engenharia e Gestão Industrial – MIEGI) by Minho University that this research project is developed during the second semester of the fifth year of the master studies in 2012/2013 and was realized at Technical University of Liberec – Czech Republic.

This chapter is related to the introdution of the work and also contemplates the framework, the objectives outlined, the research methodology applied and it ends with the structuring of this master thesis.

1.1 Framework

Nowadays, competition in the industry sector for better products is global. Companies are finding difficulties to compete with those outside that use cheaper labor, cheaper materials, and face fewer regulations while manufacturing similar products.

Some companies are embracing a business philosophy known as Lean Production to compete successfully in the global market. In the industry, the approach offers firms a management philosophy and business tools that help them become more efficient and, therefore, more competitive. While common industries such as automotive and aerospace, LP isn't widespread in other traditional sectors, which have been conservative in adapting new technologies and methods (Blanchard, 2010).

The challenge for the survival of organizations, together with the competitiveness and technological agility, did emerge new management techniques, which seek to keep the organizations in an environment of constant change, developing administrative systems efficiently agile and strong enough to the standards set by the new economic formation of society. Economic globalization and the rapid emergence of new technologies and continuous impose themselves as an way to mobilize organizations to obtain the maximum degree of competitiveness, modernity and quality, in order to ensure their survival and growth. As stated above, it's the concept of Lean Production (Reinertsen, 2005).

Although it started in the automotive industry, Lean Production philosophy is used in companies of various activities, from raw materials to the delivery of services to manufacturing.

Even the evolution of the technology and the sophistication of machinery the basic principle of this philosophy is to combine new management techniques using what already exists (resources, machines, etc) to produce more with fewer resources and less manpower. The Lean Production system, arrives from the need of Japanese companies in the automotive sector, in particular the Toyota Motor Company, developing different methods of manufacturing at vehicle industry against the ones used by American industry, where the highlight was the system of mass production of the Ford Company and General Motors, because they realized they could not compete on the same concepts. This resulted in a new model of production system, known as Lean Production System and the Toyota Production System (Lean Production) (Liker & Convis, 2011), (Levinson, 2012). The term "Lean" was originally coined in the book "The Machine that Changed the World" of Womack, Jones and Roos published in the U.S. in 1990. In this book, it is clear the advantages of performance Toyota Production System: large differences in productivity, quality, product development etc..and explains to a great extent, the success of Japanese industry.

A new aproach has been developed to be a help tool to other methods. This new russian method is called TRIZ. TRIZ is "Theory of Inventive Problem Solving" and it is based on the "Principles of Invention" extracted from the history of technological innovations. It has 2.5 Million patents over the world were analyzed for condensing their innovative essences.

TRIZ is an handy innovative problem solving method which, when correctly implemented, overrides the searching trial-and-error method to vulnerability-free definitions. TRIZ is frequently hybridized with other methods. In product development, many people use QFD (Quality Function Deployment) or other methods of studying the customers needs and wants, then combining that knowledge with TRIZ (especially patterns of evolution) to decide what to emphasize in the new product or system. Many articles can be found in the TRIZ Journal about Six Sigma, Lean or Theory of Constraint. These methods are used to understand the problem, then TRIZ is used to solve the problem (Kaplan, 1996).

TRIZ methodology is now applicable on personal computers with the software IHS Golfire which helps to find patents and ideas for innovative processes and products.

1.2 Goals

This master thesis has the objective to apply the technique of Single Minute Exchange of Die (SMED) of the Japanese Methodology of Lean Production to an Automated Testing Equipment (ATE). SMED in combination with the Russian Method of the Theory of Inventive Problem Solving (TRIZ) helps to reduce the changeover time at the industry of semiconductors.

Some of the goals of this project were:

- Reduce the setup time;
- Reduce wastes;

- Reduce delivery time;
- Reduce the defects caused by the start of the process;
- Improve start up process;
- Increase productivity;

1.3 Research Methodology

To a project be successful is needed to predefine a guideline (Figure 1), being necessary define the research methodology to use.

To define the research methodology, it should take into account the specificity of the scientific object. After knowing the scientific object, must be passed the basic principles involving the planning of research and then characterize the basic rules and techniques that lead to the preparation and writing of scientific work. Therefore, starts the development of scientific work (Saunders, Lewis, & Thornhill, 2002).

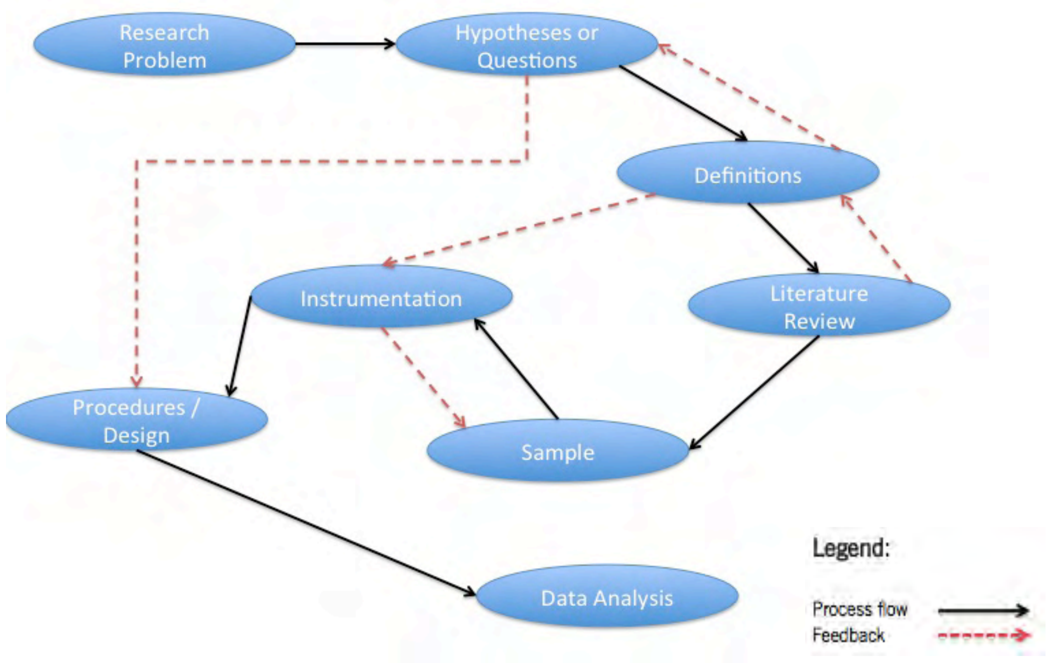


Figure 1 - The Research Process

In this project, the following methodology was a research of surveys and case studys (Figure 2). The choices made in the methodology should be the pretense of describing the main features of the TRIZ methodology which is a new methodology and poorly publicized.

In order to know more about the methodology has been chosen an exploration object which has the most common questions such as "how?" so it has arguments to respond to. With these surveys must also be based on case studys to explore and try to somehow complete studies already made with personal touch, formulating new hypotheses and making improvements.

The advantages of this process is the existence of direct knowledge of reality, quantification and quickly due to the availability of data. But there are also disadvantages. Generalization is the principal one due to the limited control of external variables (cause-effect relationships) and might occur weak perception due to the assimilation of evolutionary phenomena (cross-sectional) (Gilham, 2000).

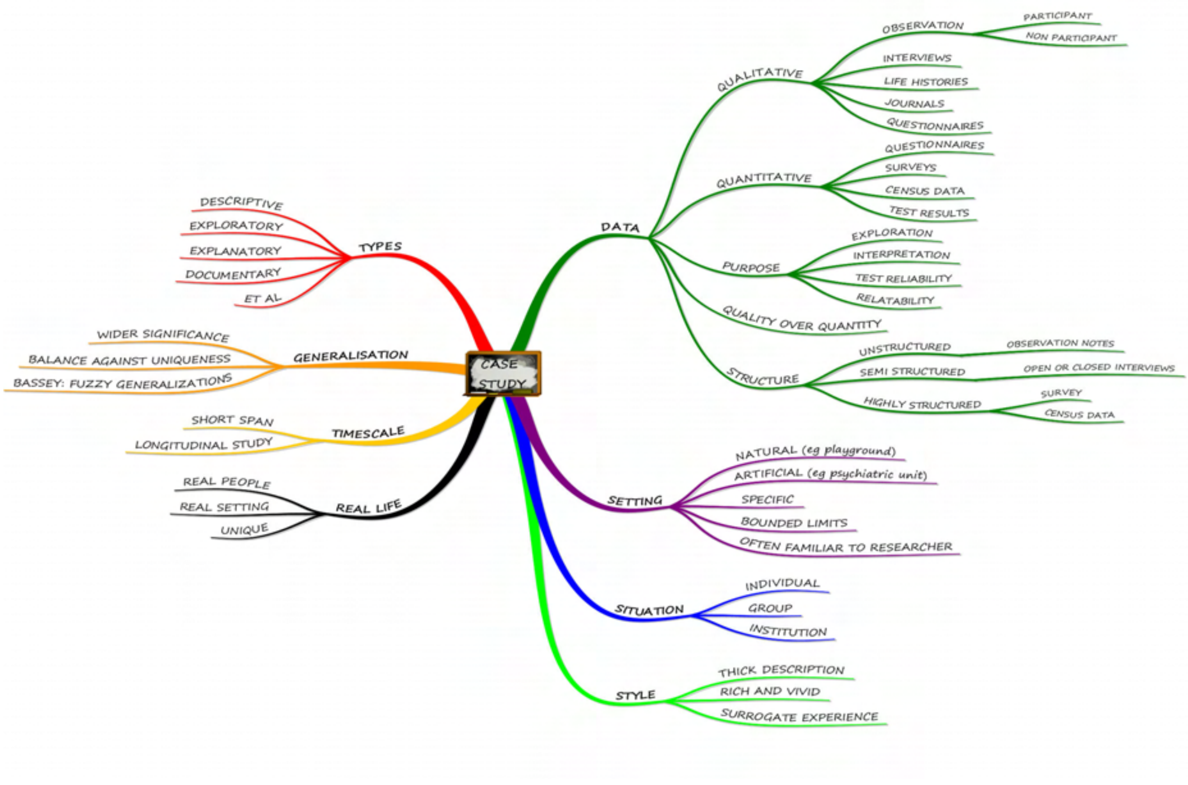


Figure 2 - Case study

1.3.1 Primary Data

The primary data are those which are collected afresh and for first time and thus happens to be original in character. There are 4 most used types of primary data collection:

- Direct observation;
- Interviews;
- Questionnaires;
- Scheduled methods.

In this case was used the direct observation in “Gemba”, a Japanese word that literally means "the real place", used in business process improvement contexts to refer to the place where value is added, such as a manufacturing area or a workshop. A related term, "Gemba Kaizen", is used in Japanese process improvement initiatives to mean continuous improvement on the shop floor, where production takes place.

The goal of gemba is to add value to products, to fully understand the gemba behaviors and the current reality of the situation more clearly, from a direct observation and also observe the wastes might be happening in the productive system to try improve the quality control system which by Dr. Kaoru Ishikawa "consists of developing, designing, producing, marketing and servicing products and services with optimum cost-effectiveness and usefulness, which customers will purchase with satisfaction" (Ishikawa, 1990).

Respect others and strengthen the culture. Gemba requires direct interaction with employees as they work. This can easily cause tension between upper management and employees if the employee feels uncomfortable about being observed if work incorrectly. However, to get the full value of gemba one must engage themselves with the employee directly while they work, not from a distance. Keeping an equal respect for everyone should be commonsense, especially in the gemba (Figure 3).

Figure 3 - Team Member Feedback

The observer should do all the tasks also himself to understand better the process so he could have a better knowledge of what he should change. He'll have a better idea how each step function, the time each step takes and the failures it can exist to improve them.

Interviews with the workers are also too important because are the workers who are day by day making the processes. Better then no one they know their difficulties and also they could have ideas of what to change to make their work easier and quicker.

1.3.2 Secondary Data

Secondary data means that are already available, so they refer to the data which have already been collected and analyzed by someone else. When the researcher utilizes secondary data, then he has to look into various sources from where he can obtain them. In this case he is certainly not confronted with the problems that are usually associated with the collection of original data. This data can be obtained by some ways like:

- Historical data review;
- Literature review;
- Technical studies database;
- Worker skills.

To successfully manage an improvement it’s important to use historical reviews performing a complex juggling act of time, budget, and resources without dropping any of these elements. If something goes well or fails it's critical for to record and build on that knowledge in order to improve future results. It helps to develop better estimates, and reduce hours invested in document creation by leveraging templates from past data.

Research literature reviews can be contrasted with more subjective examinations of recorded information. When doing a research review, you systematically examine all sources and describe and justify what you have done. This enables someone else to reproduce your methods and to determine objectively whether to accept the results of the review. There should be clear links between the aims of your research and the literature review, the choice of research designs and means used to collect data, your discussion of the issues, and your conclusions and recommendations.

The technology database is meant to represent an important scientific and didactic source for the subject technology. The further intention is to include the latest results of research, including that gained from all over the world technical learning processes, and to maintain user experiences in the form of evaluated samples.

Employees value meaningful work over other retention initiatives. Survey respondents who reported their companies use their skills effectively are more likely to report they plan to stay with their current employer and help him to go further.

1.3.3 Overall Flow

The overall flow is showed in the next figure (Figure 4) in fluxogram:

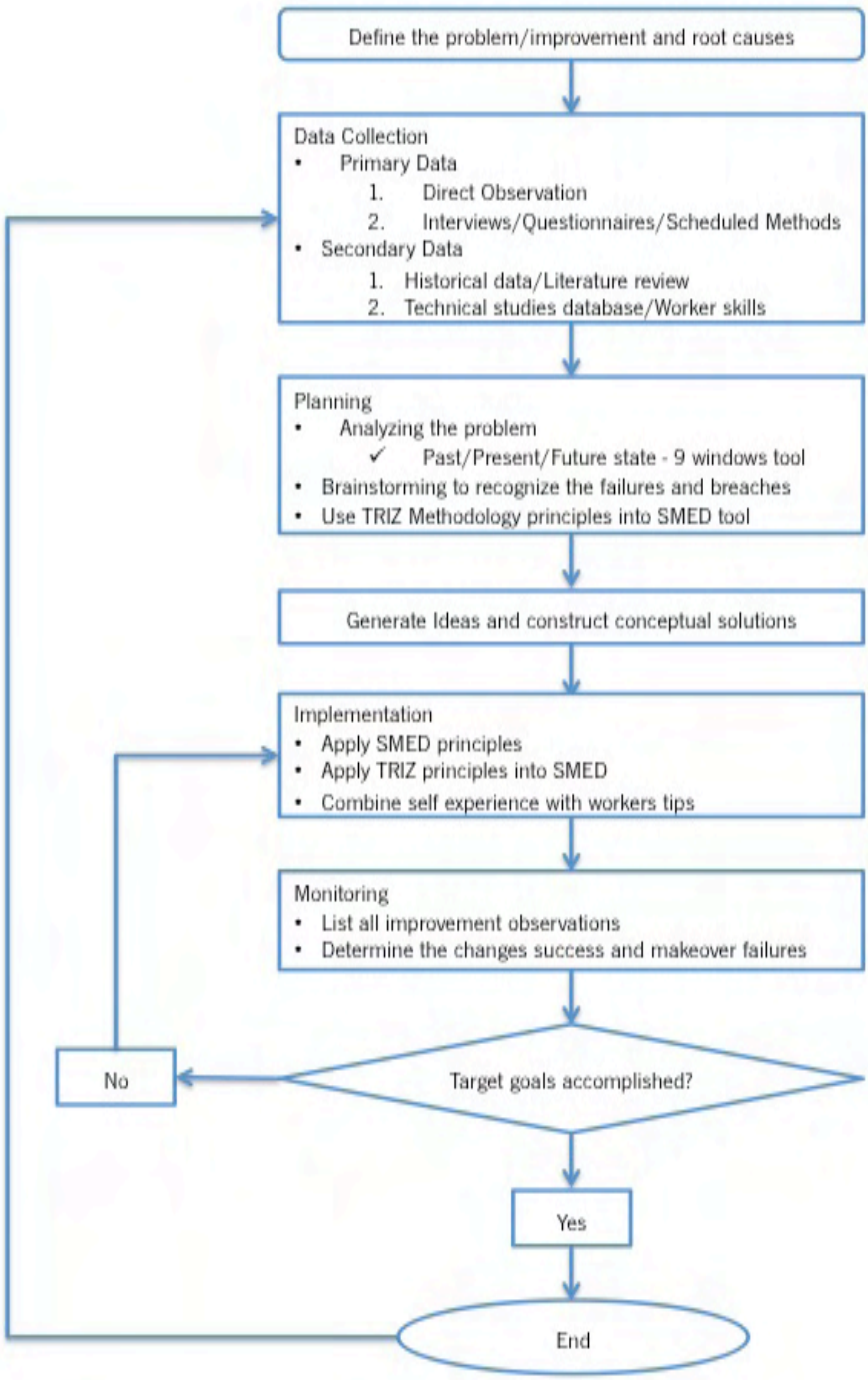


Figure 4 - Overall Research Flow Process

1.4 Thesis Organization

This thesis is organized into seven chapters. The first chapter is the introduction of the thesis which gives the framework of the study, also has its goals, characterizes and gives the justification of the investigation methodology and reports the thesis organization.

The second chapter is about the literature review where the theoretical foundation is written. This chapter will focus on the theory of Lean Production methodologies and TRIZ methodologies.

The third chapter is about the research methodology explaining how the data was collected and what type of data it is to know how to use it, ending with the overall flow.

The forth chapter is the identification of the problem based on the data we collect. Here it's explained the past/present situation of the system and why to change what it's already done followed by the detailed review of the case study and ending with an explanation of the current situation changeover process.

In the fifth chapter the countermeasures will be exposed with the improving proposals to overcome some problems found.

The sixth chapter present the results and discussions of the application of the countermeasures to improve the changeover process splited by hardware, process and human dynamics passing by the overall improvement of the system. Then it has a brief of an economical analyse of the changes by the improvements and then a critical evaluation of the new changeover system finishes this chapter with further suggestions for future improvements.

The last chapter is about the conclusion of the case study and thesis goal.

2. Literature Review

This chapter concerns to literature review and begins with a brief historical of Lean Production approaching their principles and wastes, defining then the identified tools which are focusing with more detail of SMED. The last part is an introduction to the TRIZ Methodology with its tools and principles.

After some research and analyzing techniques used in articles and texts of combination of Lean and TRIZ with more focus to SMED technique it was concluded that the most used tools/techniques/principles of TRIZ combined on Lean were 40 Principles, Functional Analysis and Trimming. Less than these 3 but also with some focus were Standard Solutions and Thinking in Time & Space (Figure 5).

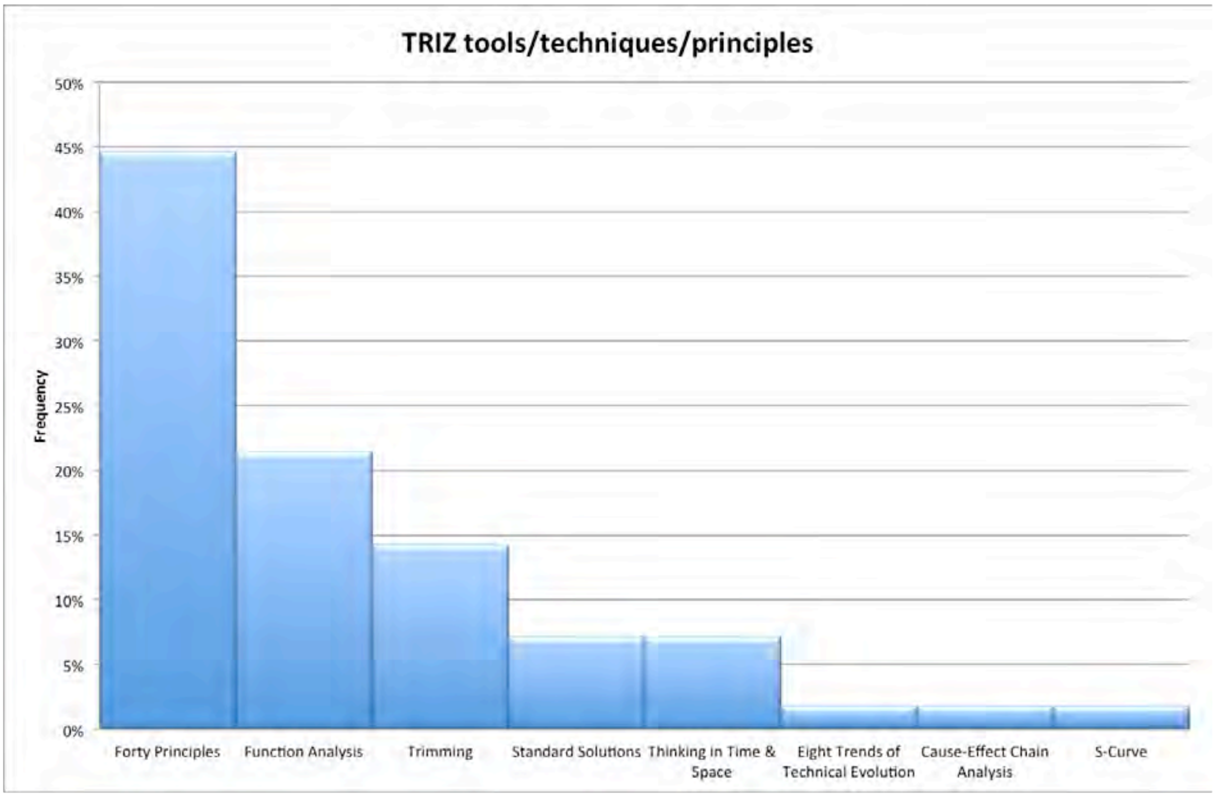


Figure 5 - Frequency of TRIZ tools/techniques/principles combined with Lean

In Lean the goal is to eliminate waste. The goal of TRIZ is to provide innovative ideas/solutions to improve the system or at least to minimize the waste. In title of ending, the summary of this master thesis, it can be concluded that TRIZ is an helpful methodology to Lean and a big complement to fill the gaps which Lean can't reach so well (Figure 6).

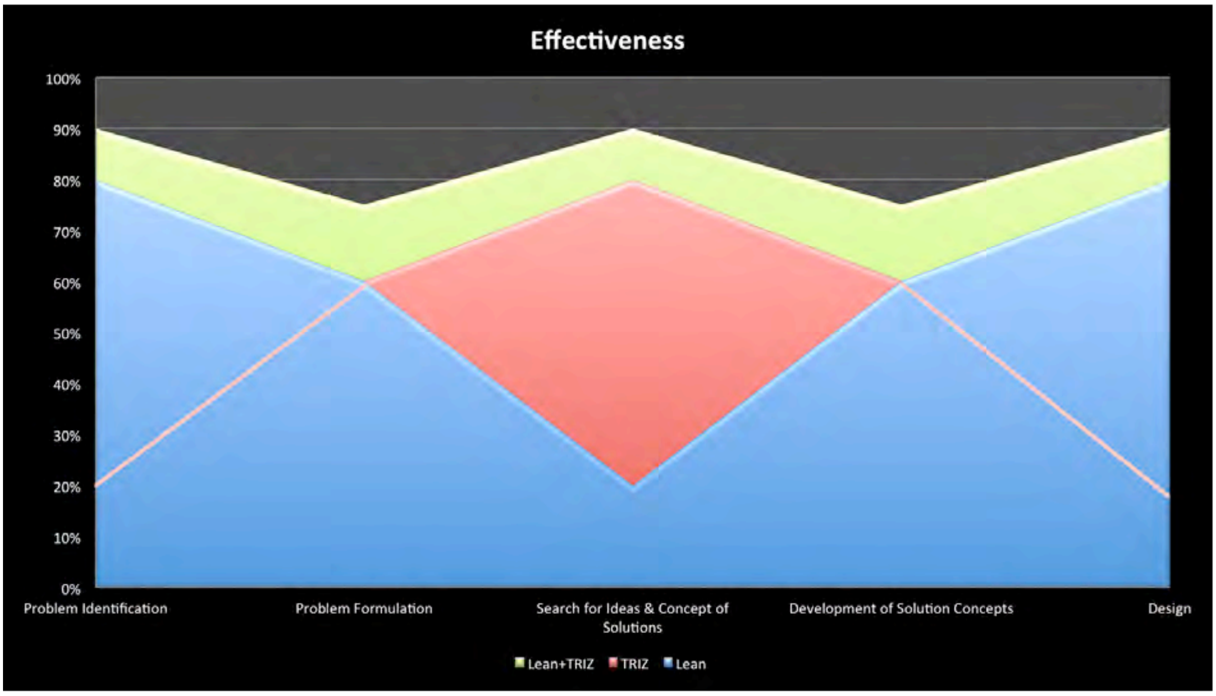


Figure 6 - Effectiveness of the combination between Lean and TRIZ

2.1 Lean Production

The Lean Production originated in Japan in the period after World War II, whose prominent application was at Toyota Motor Company. Devastated by war, Japan hadn't the resources to carry out high investments required for the deployment of mass production that characterized the system implemented by Henry Ford and General Motors (Pascal, 2007). Furthermore, in the country were other series of problems and challenges to be overcome as limited domestic market and demanding wide variety of products, labor, organized labor, the existence of several vehicle manufacturers in the world, interest in joining Japan between others. From there came the need to create a new management model, rising thus the Toyota Production System or Lean Production (LP), structured by Taiichi Ohno, Vice-President of Toyota.

The fundamental goals of this new system characterized by quality and process flexibility, expanding their ability to produce and compete on the international stage. The concept of Lean Production has spread across the world and there are several definitions of this philosophy, as shown below:

> *"The elimination of waste and unnecessary elements in order to reduce costs, the basic idea is to produce only what is needed, when needed and in the required amount" (Ohno, 1997).*

"The search for a production technology that uses the least amount of equipment and hand labor to produce goods without defects in the shortest possible time, with minimum intermediate units, understanding how waste is any element that does not contribute to service quality, price or time required by the customer. Eliminate all waste through concerted efforts of management, research and development, production, distribution and all departments of the company" (Shinohara, 1988).

"There confer maximum number of functions and responsibilities all workers who add value to the product line, and adopt a treatment system defects immediately triggered the each problem identified, capable of achieving its root cause" (Womack et al, 1990).

2.1.1 Lean Production Basis

The basis of LP is the combination of management techniques to produce more with fewer resources. LP differs both from craft production as mass production. In craft production, highly skilled workers, using hand tools, manufacture each product according to the buyer's specifications, made one at a time. Already in mass production, specialized professionals design products that are manufactured by unskilled or semi-skilled operator expensive equipments with specific purposes, producing standardized products in large quantities. In mass production, the idle time needs to be avoided, because the machinery has a very high cost. The management then adds a "reservation" in the form of extra inventory and workers to ensure the availability of inputs or the production flow is not slowed. Due to the high cost of investment in machinery, adaptation to manufacture new products is prevented and the consumer is the one who benefits from low prices at the expense of variety (Black & Miller, 2008).
However, Lean combines the advantage of handcraft production, while avoiding the high cost, with mass production, avoiding the inflexibility by using some tools (Figure 7). To achieve these production objectives, management brings together teams of workers with various skills at every level of the organization, to work alongside machines, producing small quantities with a large variety of goods of choice. The production can be called as Lean because it uses less of everything compared to mass production – less human effort in the factory, smaller footprint, lower investment in equipment (Ndahi, 2006).

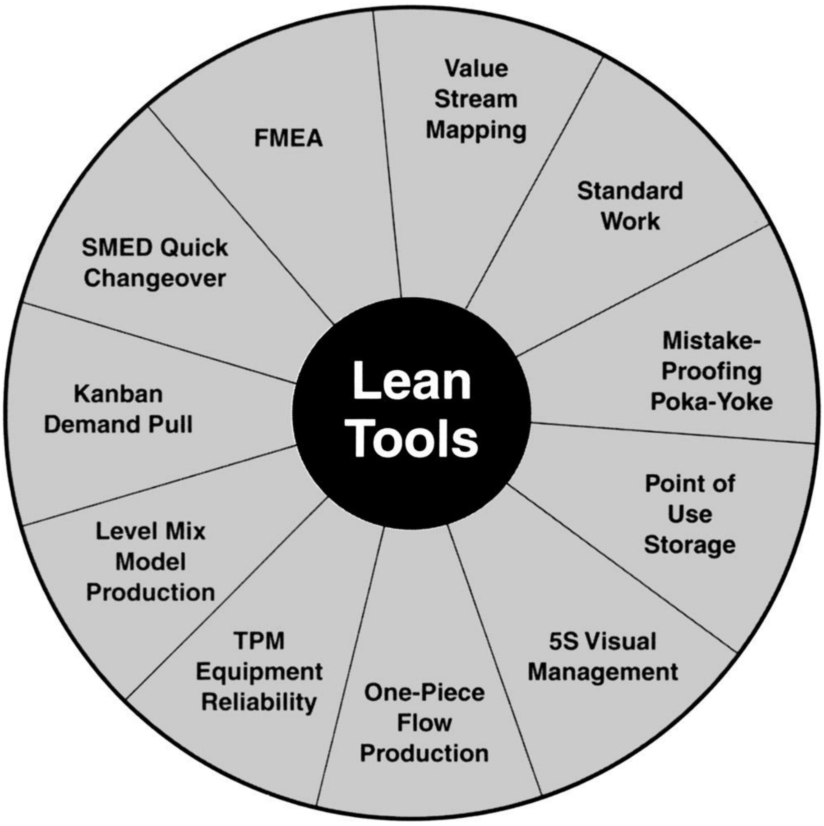


Figure 7 – Some Lean Tools

One of the fundamental concepts of LP is continuous improvement (Kaizen), considered the key to the success of Japanese methods of production. The Japanese production system is set up to encourage change and constant improvement as part of daily operations. To achieve Kaizen, management leverages the collective experience of all its employees and values the solution of problems together. The LP emerged as an integrated manufacturing system or methodology whose focus is to optimize the processes and procedures through continuous reduction of waste, for example, excess inventory between workstations and high wait times (Imai, 1986). Its main objectives are:

- Integration and optimization of the manufacturing system (Figure 8) : it‘s necessary to integrate all parts of the manufacturing system, always seeking to optimize the system as a whole. Any process or activity that does not add value to the product is waste and must be eliminated. Integration and optimization of a manufacturing system is a continuous process of reducing the number of stagnation steps, necessary to complete a particular process (Imai, 1997).

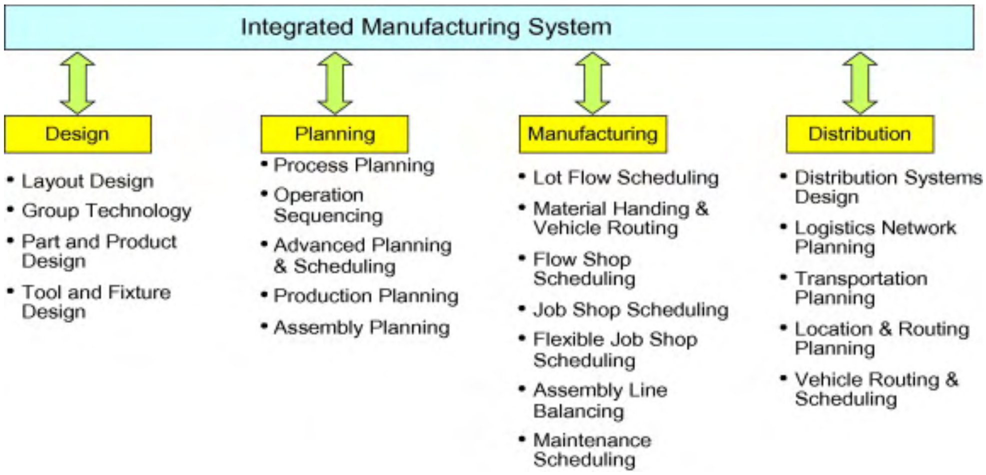


Figure 8 - Integrated Manufacturing System

- Quality (Figure 9): pull system requires a precise and productive environment that provides quality products. Each production process must pass quality products to the next step, i.e. the quality should be ensured throughout the whole process. The Lean Production requires that each person involved in the production process be educated and trained to accept responsibility for the level of quality of their work (Besterfield, 2003).

Figure 9 - Quality cycle

- Process flexibility (Figure 10): is to minimize the restriction factors in production. Being flexible is the ability to quickly obtain materials and preparing a production process in short time and with minimal cost, that is, be able to withstand variations in demand (Ortiz, 2009).
- Production according to the demand (Figure 10): the company has to organize its production according to customers' requests, for they are the reason for a company. It makes no sense to produce what customers do not want (Kirchner, 2013).

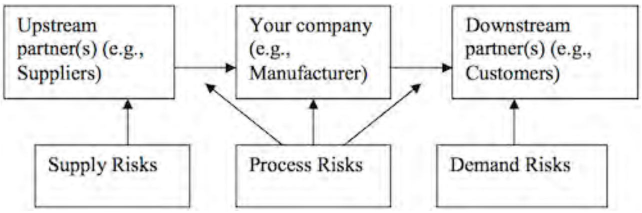


Figure 10 - Supply and demand chain

- Maintain commitment to customers and suppliers (Figure 7): keep appointments is the final link that allows individual manufacturers to join in a continuous manufacturing process. Suppliers, customers and employees need a clear position of senior management that the company wants to remain competitive in the market. Plan to keep appointments is a process to determine the steps necessary to meet the delivery plans, quality levels and profit margins (Modarress, Ansari & Lockwood, 2005).
- Reducing the cost of production (Figure 11): the goal is more obvious and feasible with the implementation of LP, declaring "war" to waste and so determined and sustained cost reduction seeking of the manufacturing process as a whole (Huda & Preston, 1992).

Figure 11 - Strategic Source Planning

All the above objectives have been established aiming to expand the company production capacity to compete in this global scenario. The goals posed by LP for the various production problems are: zero defects, zero preparation time (setup); zero inventory, zero movement, zero breaks batch unit (one piece) and zero lead time.

Thus, the essence of the Toyota Production System is the relentless pursuit of eliminating any and all loss. At Toyota this principle is known as "the principle of non-cost". By traditional logic, the price was set by the company that added the cost of producing the profit (Net Price = Cost). However, with the increasingly fierce competition and increasingly demanding consumers, the price shall be determined by the market (Price - Cost = Profit). Analyzing the second formula, we arrive at the conclusion that the only way to increase or maintain profit is reducing costs (Kirchner, 2010).

For disposal of these wastes and to reach the goals established, Lean Production makes use of a set of techniques and tools such as Cellular Layout, Kanban, the Value Stream Mapping, among others (Middleton, Taylor, Flaxel & Cookson, 2007).

2.1.2 8 Wastes

In Ohno's (1997) view, Lean Production is the result of the elimination of seven types of waste classics, also called losses existing within a company. Nowadays, it's known one more waste which it wasn't considered at that time.

Below is Figure 12 relating the seven types of losses described by Ohno (1997) plus the eighth wastes with people, quantity and quality.

Figure 12 - 8 wastes

It's observed from the figure that the quality of the product, quantity produced and people are directly linked to the eight types of loss. Losses for processing, for motion and waiting time are related to hand labor. Already losses for overproduction, transport and stock are being influenced by the quantity of production. Finally, the loss due to reworking defective products and refers to the quality of the product. Shigeo Shingo says that **"The most dangerous kind of waste is the waste we do not recognize"** (Shingo, 1985).

Therefore, focusing on these three points, people, quality and quantity, it is possible to minimize, if not eliminate, the types of losses in the process (Bicheno, 1994).

Overproduction loss

The loss may be by overproduction quantity (Figure 13), which is output beyond the scheduled volume (leftover pieces), or by anticipation, that is the loss by producing prior to the time necessary for manufactured products that will be stored awaiting the opportunity to be consumed or processed by later steps. This type of loss is the worst because, besides being very difficult to eliminate, creates a countless number of other waste, such as storage area, deterioration, energy costs, maintenance of equipment, hided from operational and administrative problems through "safety stocks".

Lean Production infers to produce only what is needed at the moment, and with this, reduces the setup time, which synchronize with the output demand, which is compact plant layout, and so on (Hoeft, 2007).

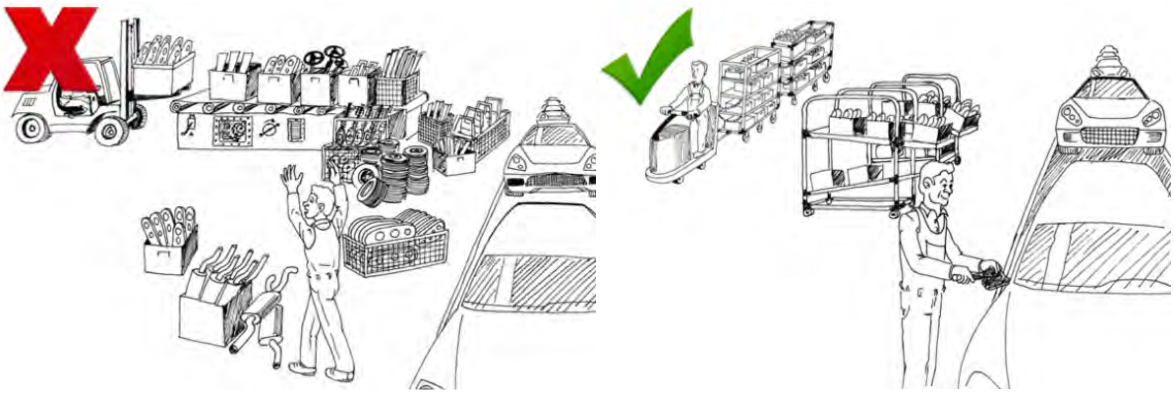


Figure 13 - Overproduction

Waiting time loss

This type of loss is the time when no processing, transportation, or inspection is performed (Figure 14). There are three types of loss expected: in the process, when there is a failure or delay in the raw material and a whole lot is waiting for the machine to start production lot; when parts have gone through the same process and have to wait by all other parts of the lot and the operator to be able to follow the next step, when the worker remains idle, watching a machine in operation. Some tools are used to eliminate the expected loss, for example, the rapid exchange of tools developed by Shingo (1996) and Kanban technique for synchronizing the output. Moreover, the versatility of workers also contributes to minimizing such loss (Harbert, 2006).

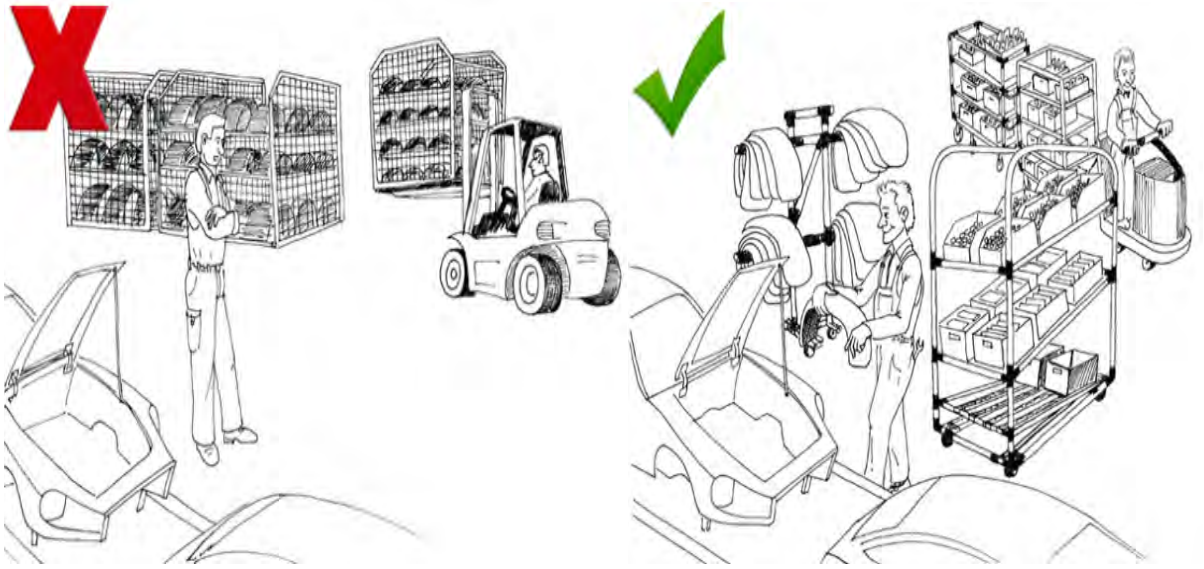


Figure 14 - Waiting Time

Transport Loss

Loss on transport is one that is made unnecessary travel or temporary stockpiles (Figure 15). Seen as a waste of time and resources, the activities of transport and handling must be eliminated or reduced to the maximum, by developing appropriate physical arrangement that minimizes the distances to be covered. In addition, transportation costs can be reduced if the material is delivered to the place of usage (Rodriguez, 2012).

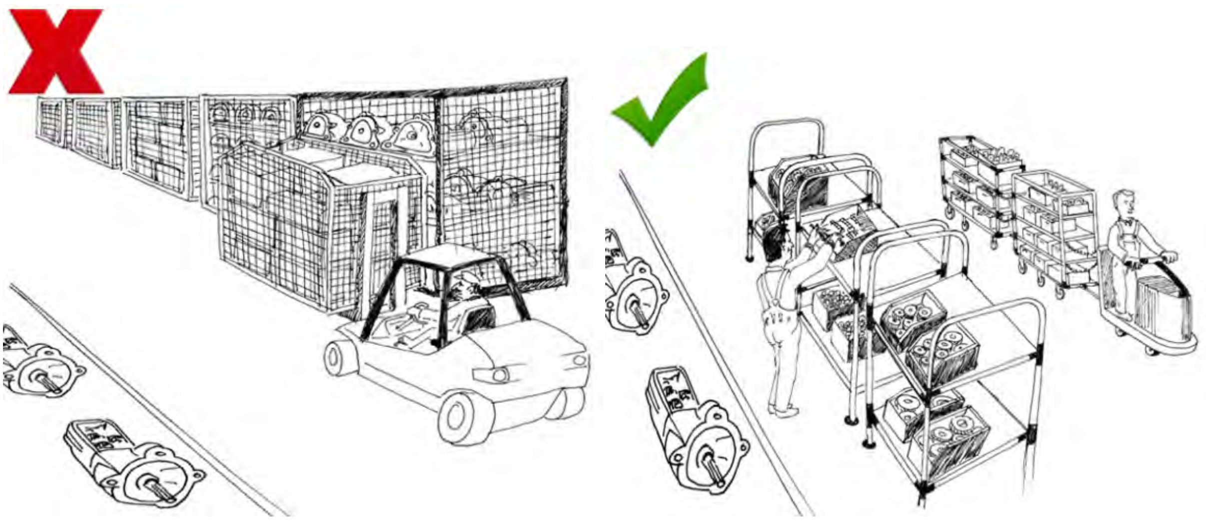


Figure 15 - Transport

Processing loss

Loss on processing consists of machines or equipment used improperly as the capacity or capability to perform an operation (Figure 16). In this sense, it is important to apply the methodologies of engineering and value analysis, which are important tools to minimize this waste, which does not affect the basic functions of the product (Anderson, 2001).

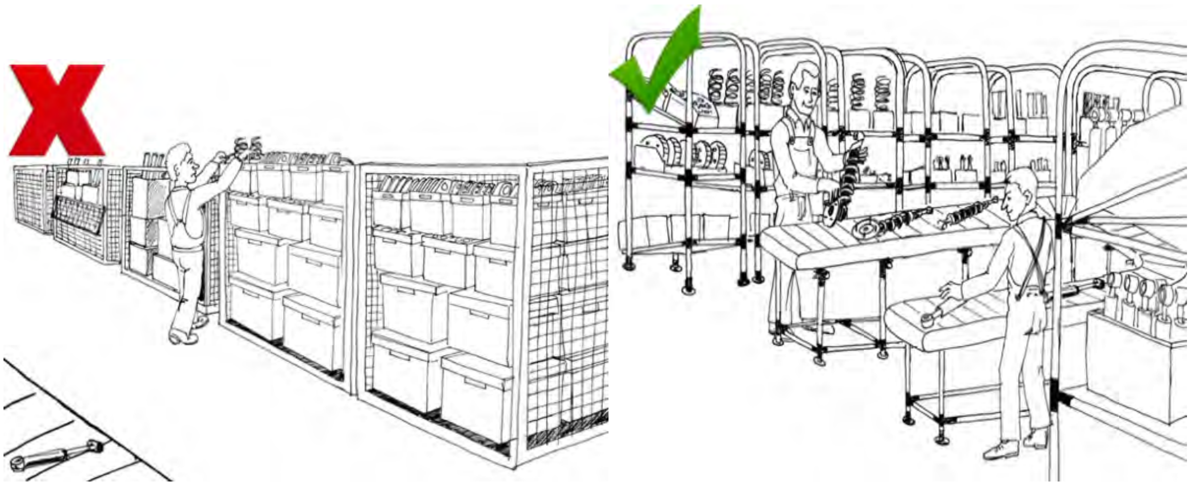


Figure 16 - Processing

Handling operation loss

This loss occurs as the difference between work and movement (Figure 17). Relate to unnecessary movements made by operators in the execution of an operation. For example, is the action of those who perform some sort of check or demand parts on the workbench or any movement of a team member or machine which does not add value. The techniques of time study and methods are important to eliminate this waste. The rationalization of the movements in operations is also obtained by automating operations. However, it is noteworthy that the mechanization of operations is recommended after they have exhausted all possibilities of improvement in the labor movement and in routine operations (Harry, 2004).

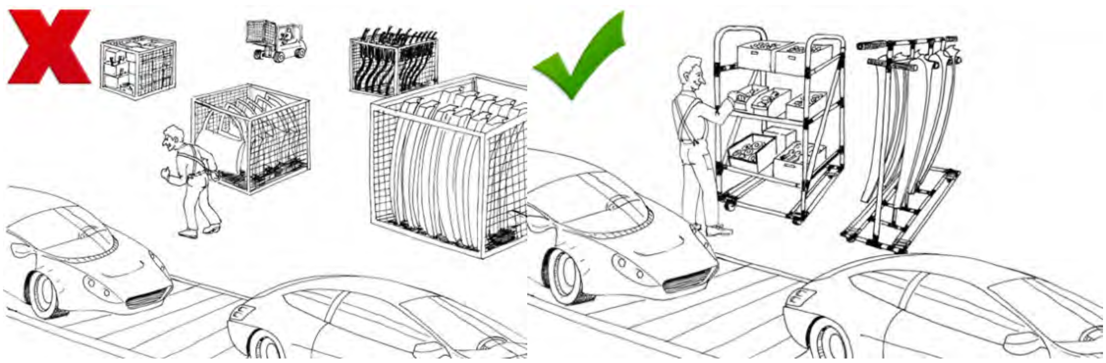


Figure 17 - Handling Operation

Defective products or rework loss

The loss for the manufacture of defective products (Figure 18) is the result of the generation of products with some characteristic out of the specified quality and which therefore does not meet the requirements of use. Produce defective products means waste materials, availability of labor, availability of equipment, materials handling defective storage of defective materials, products inspection, among others. Techniques to solve this waste are closely related to methods of quality control at the source of the cause of the problem (Köksal, Taşeli, Dolgun & Batmaz, 2004).

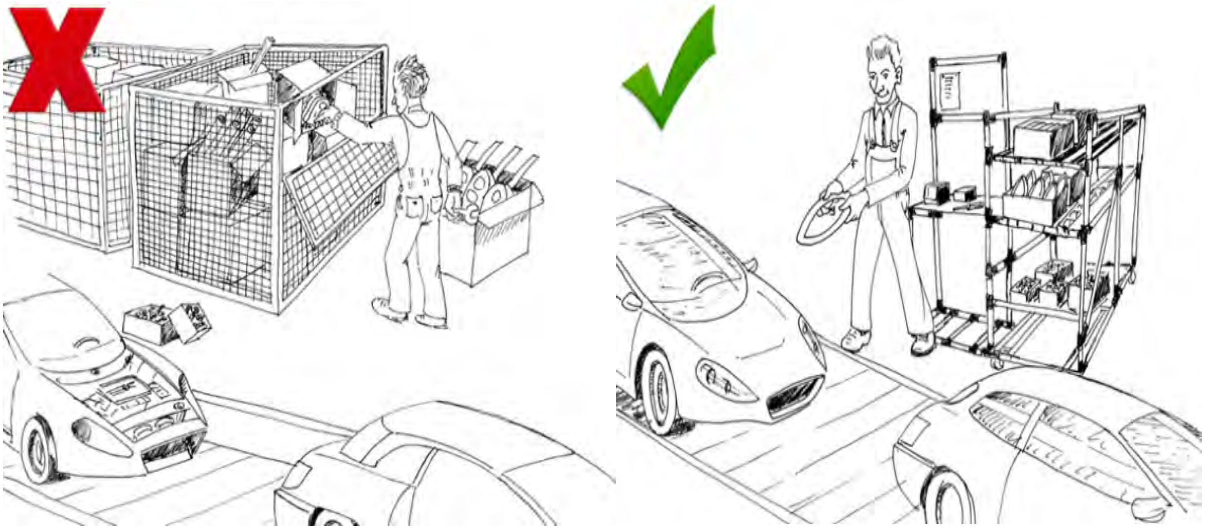


Figure 18 – Defective products or rework

Stock loss

It is the loss of stock in the form of raw materials and processing equipment in the finished product. It is the financial resource "trapped" in the productive system. Mean investment and waste space (Figure 19). The combat losses stock becomes a barrier from the moment it is considered an advantage when it comes to relieving the problems of synchronization between processes. Reducing waste inventory should be done by eliminating the causes that generate the need to maintain inventories. Eliminating all the other waste, reduce, consequently, waste inventory. This can be done by reducing setup times of machines and production lead times, synchronizing workflows, making them reliable machines and ensuring the quality of processes (Miodonski, 2010).

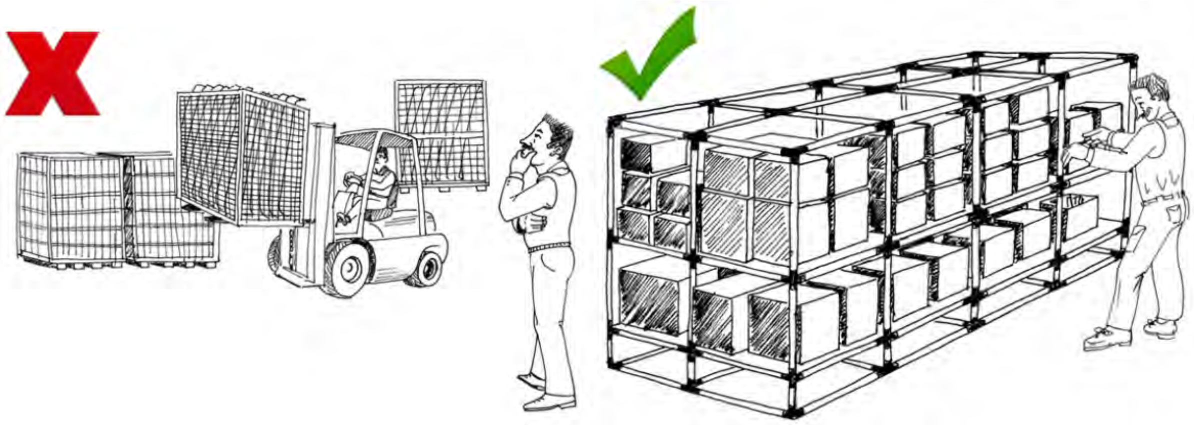


Figure 19 - Stock

Non-Utilized Talent

The 8th Waste of Lean, Non-Utilized Talent, is an ever-growing issue within businesses that needs to be resolved. Unlock the creativity and potential in the employees to achieve greater benefits to the company and to each individual. It's better to think of waste in terms of items, objects, or processes, but the waste of human potential is the greatest waste of all. Ignoring the creativity and ideas locked within each employee breeds an environment of apathy and discontent (Southworth, 2010). Once Hiroshi Okuda, Chairman of Toyota Motor Corp. said, "**Failure to change is a vice! I want everyone at Toyota to change and at least do not be an obstacle for someone else who wants to change.**" (Bodek, 2004).

According to Ohno (1997), Lean Production System focus in all matters which not adds value to the product, seen in the eyes of the customer is waste. All waste only adds cost and time. All waste is the symptom and not the cause of the problem.

2.2 The Five Principles

In Lean Production, five principles are defined as fundamental in elimination of losses, summarizing the entire Lean Thinking (Womack and Jones, 1996). These teachings are principles that guide companies wishing to adopt this philosophy, showing what must be done to achieve their goals. Before conceptualizing the five principles, it is necessary to have an understanding of the meaning of "Value Added", or simply "Value". The real value of a product, process or system is the degree of acceptability of a product by the customer, i.e., the final item is the economic value. The higher is the actual value of an item over another with the same purpose, the greater the probability of winning the competition. So what adds value to the product, is productive operation that is performed to meet the requirements of the customer or end user. The company should aim at providing products or services valued from the customer's perspective and not from the internal view of the organization, because the market is increasingly less willing to accept products that do not meet customer needs. Womack and Jones (1996) accurately defined five principles of Lean thinking to offer a valuable contribution to the management of processes.

2.2.1 Specification Value

It is needed in the beginning to define and investigate what value is the starting point for Lean thinking. The value of the product must be specified by end customer, not the company. And for that, this product must have requirements that meet customer needs, with a specific price and delivered in a timely manner to him. Any features or attributes of the product or service that does not meet the value perceptions of customers represent opportunities to rationalize. The company creates this important value which conceives, designs, produces, sells and delivers the product to the end customer (Ruffa, 2008).

2.2.2 Identification of the Value Chain

Chain or value stream is the set of all specific actions required to bring a product to pass through the three critical management tasks of any business:

- Task of troubleshooting: going from concept to product launch, through detailed design and the engineering process;
- Task of information management: will the receipt of order to delivery, following a detailed schedule.

Physical transformation task: going from raw material to finished product in the hands of the customer (Womack & Jones, 1996).

Identify and accurately map the value stream full product is fundamental to see the waste in each process and implement actions to eliminate them, thus creating a new flow optimized value (Rother & Shook, 1998).

Thus the identification of the value chain consists of mapping the set of all activities. At this stage it is important to separate the cases into three categories: those who actually create value, those that do not create value, but are important for the maintenance of processes and quality, and those that do not add value should be eliminated.

2.2.3 Value Stream Flow

Womack & Jones (1996), in "Lean Thinking", said, "since, for a given product value has been specified precisely, the value stream mapping, steps that do not add value eliminated, is fundamental value in the process flow, smoothly and continuously, within the three critical management tasks: problem solving, information management, and physical transformation.". Therefore, after identified the value according to the first principle, the mapped value chain product waste and disposed of according to the second principle, the next step is to make the Lean thinking stream with the optimized value flow in a harmonic until the arrival of the product to the end customer, redefining the functions and departments, allowing them to contribute to the creation of customer value (Lazalier, 2008).

2.2.4 Pull Production

Womack & Jones (1996), in "Lean Thinking" stressed not to manufacture any product, unless it is necessary, and in this case, manufacture the product quickly. This concept is to produce only what is needed when it is needed. Aims to prevent the accumulation of stocks of products through the production and supply what the customer wants, when the customer needs. The client "pulls" production, eliminating inventory, giving value to the product and bringing productivity gain (Bartholomew, 2012).

2.2.5 Search for perfection

Perfection should be the constant aim of all involved in the value stream. After the implementation of the four previous principles, specifying the value of the product from the customer, identifying the value chain as a whole, making the value stream flow and that customers pull the value of the company's business productivity consequently increases and the direct and indirect costs decrease. By intensifying the application of the four principles interactively come new waste and new obstacles to the flow of value, creating opportunities for improvement and allowing their elimination. It is a continuous process of increasing efficiency and effectiveness in pursuit of perfection. For this, the company can count on continuous improvement methodologies (Kaizen), as PDCA cycle, among others (Scott, 2005).

From the concept of the five principles outlined above, it is observed that the strength of Lean transformation initiative is the correct specification of the value to the end customer, eliminating the traditional form of each member of the value chain specify differently, the identification of all the actions that take a product from concept to launch, from order to delivery of raw material to the customer's hands. Furthermore, Lean thinking is focused on eliminating non-value added activities and stimulating actions that add value to occur in a continuous stream and pulled by the customers, and finally analyze the results and the creation of a new process (George, Rowlands & Kastle, 2004).

2.3 Some Tools of Lean Production

In order to LP can achieve the objectives, it is necessary to apply some tools that will assist in achieving the results. Tools are tools used to implement a Lean Production System, which dictate "how to" follow its principles. Some tools considered essential will be described below, according to research in the literature (Feld, 2001).

2.3.1 Value Stream Mapping

Value Stream Mapping is one of the essential tools of Lean Production, proposed by Rother & Shook (1998), which were based on a modeling technique of analysis of value line.

The VSM is the process of identifying all the specific activities occurring along the value stream for the product. It is understood by the entire value stream for all activities that occur from order placement to delivery to the final consumer. It is a process of observation and understanding of the current state and the drawing of a map of the processes that will become the basis for Lean Production, i.e., it is a visual representation of every process in the flow of material and information real recasting it a set of key issues and draw a future state map of how the production should flow (Jones & Womack, 2000).

Rother & Shook (1998), consider the Value Stream Mapping an essential tool as it assists in the visualization of the flow, rather than just individual processes and helps identify waste. The mapping helps identify the sources of waste, provides a common language for dealing with manufacturing processes, makes decisions about the flow apparent, so that you can discuss them, encompasses concepts and Lean techniques, which helps to avoid implementation some techniques alone forms the basis for an implementation plan and shows the relationship between the information flow and the flow of material. The goal is to achieve the Value Stream Analysis to obtain a continuous flow, driven by customer needs, from raw material to finished product. Below is the concept of Value Stream Map, defined by Rother and Shook:

"It is to follow the path of producing a product from the consumer to the supplier, and carefully draw a visual representation of every process in the flow of material and information. Then formulates a set of key issues and draw a future state map of how the process should flow. Doing this repeatedly is the simplest way so that you can see the value and especially the sources of waste." (Rother & Shook, 1998).

Next figure (Figure 20) illustrates an example of a process model using the technique of VSM. In this map we can see the entire flow of products and information from the parts supplier to the end consumer.

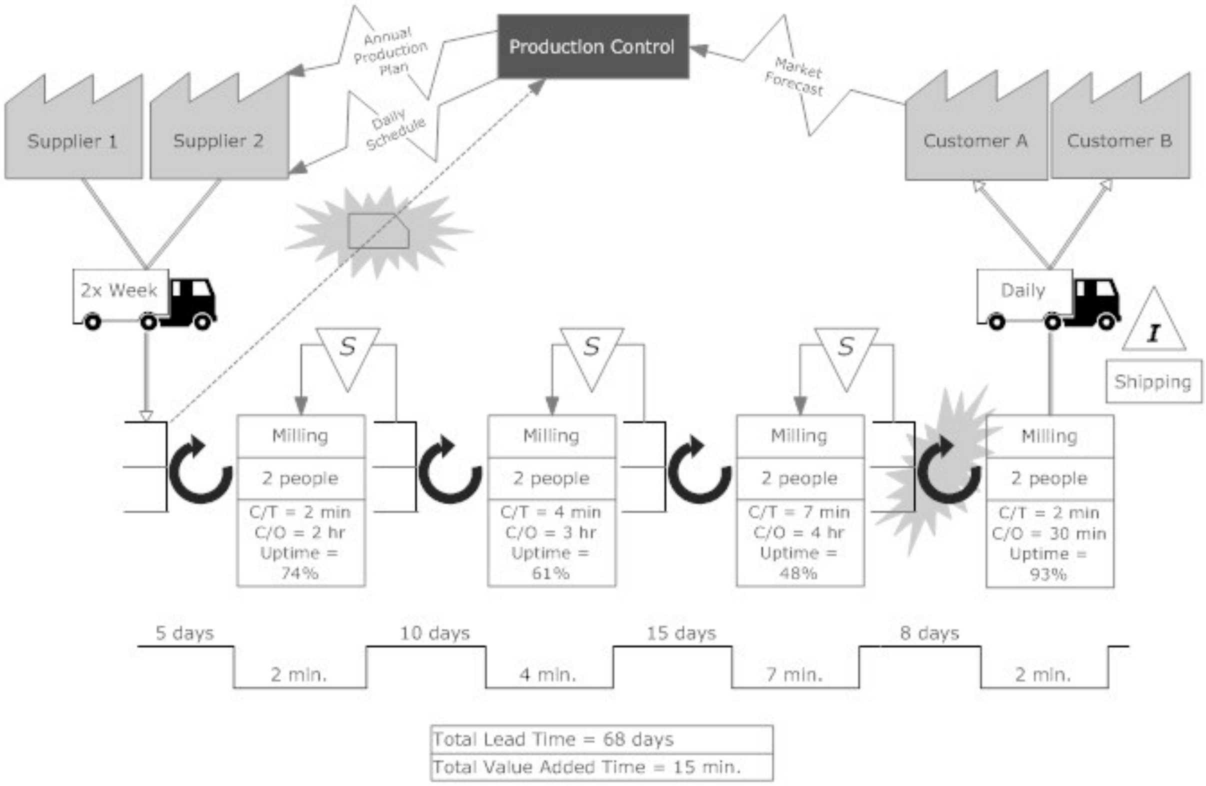


Figure 20 - Value Stream Map of the current situation

The visualization tool is always performed in reverse, namely from the client to the supplier in order to eliminate influences who in the process, ensuring that the flow is performed in favor of production. The great advantage of VSM is to significantly reduce and simply the complexity of the production system and still offer a set of guidelines for the analysis of possible improvements. In this sense, the technique of Value Stream Mapping helps in conceptual development of "future state" of the Lean Production System (Lasa, Laburu & Vila, 2008).

2.3.2 5'S

The calling "5'S" is another very useful tool in the process of implementation of Lean Production. It originated in Japan at the time was requested methods to help rebuild the country after the war. The main objectives of this tool are (Figure 21): to improve the quality of products/services, improve the working environment and user services, improve the quality of life of employees; educate for simplicity of acts and actions; maximize the use of available resources; reduce spending and waste, optimize space, reduce and prevent accidents, improve human relationships increase self-esteem of employees.

It is observed that these goals are very aligned with the concept of Lean Production (Flinchbaugh, 2006).

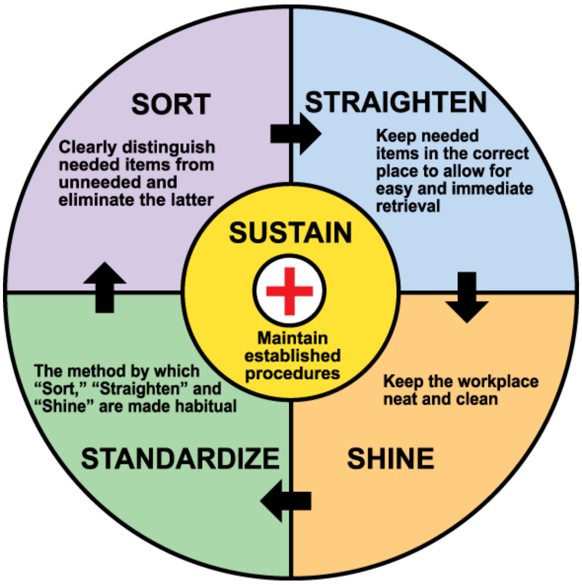


Figure 21 - 5'S cycle

The acronym 5S left five Japanese words that begin with the Letter S:

- __Seiri__ – Sense of Use: is deciding what is needed and eliminate what is not necessary. One should keep only the minimum equipment to support the day to day operations. There is what is useful and necessary and separate what is useless discarding what does not serve, or providing to another sector. This sense it is important to combat the human tendency to store things.
- __Seiton__ – Sense of Order: "A place for everything and everything in its place." This sense is to put everything in order and easily accessible. Must analyze where and how things are stored, setting criteria such as place and manner appropriate to arrange them. Keep everything in place after use. Standardization, as the creation of a visual recognition system and an inventory system that facilitates access to things is very important, thus reducing the time wasted looking for tools and materials and eliminating unnecessary movements.
- __Seisou__ – Sense of Cleaning: is to remove trash and dirt, making a spring cleaning, make problems easy to locate. Regular cleaning provides opportunities for preventive inspections. You should always regularly run the cleaning staff and maintenance, develop habits of cleanliness, for example, clean the objects before storing them.

- **Seiketsu** – Sense of Standardization: It is important to establish policies to eliminate all causes of clutter, how to establish a system of visual control; make the workplace easy maintenance, incorporating the first three S's; establish a system of visual control; improve environmental conditions of work; promote mutual respect, creating a harmonious work environment and take care always health and personal hygiene.
- **Shitsuke** – Sense of Self-Discipline: basically consists in regulating the practice of "S" above, keeping all the improvements made. For this it is important to make periodic inspections to establish guideline, change the culture to promote and maintain a permanent place of work clean and safe, share the goals established concepts and regularly disseminate information, fulfill routines with patience and persistence, incorporating the values of 5S in the lives of people and mechanisms of evaluation and motivation.

The senses of organization and cleaning are critical in Lean Production System, in respect of the reliability, visibility problems, reducing waste, controlling and improving the quality, condition, employee morale, etc (Carreira & Trudell, 2006), (Chiarini, 2013).

2.3.3 SMED – Single Minute Exchange of Die – Quick Change Tool

Reducing the time of tool change is of utmost importance in the success of Lean Production System, according Shingo (1996). Is the amount of time required to change a reference from the last produced part of a batch to the first part produced in the next production batch (Shingo, 1996).

The time reduction is important because it improves the effectiveness of all equipment, implement programs contributes to production level, helps to reduce the inventory of finished products, supports methodology "Production Flow", contributes to the elimination of waste, and add the machine capacity and improve quality (Shingo, 1985), (Sekine, 1992).

In today's manufacturing environment, assembly work is routinely characterized by short production cycles and constantly diminishing batch sizes, while the variety of product types and models continues to increase. Constant pressure to shorten lead times adds to these demands and makes the mix truly challenging, even for the most innovative manufacturers (Figure 22).

Figure 22 - F1 Team applying SMED technique

The ability to respond quickly to rapidly changing customer demands requires the use of manufacturing systems that can be re-configured and expanded at real time, and which can accommodate advances in assembly techniques without making any initial manufacturing investments obsolete (Nicholas, 1998).

Lean Production, an approach that depends greatly on flexibility and workplace organization, is an excellent starting point for companies wanting to take a fresh look at their current manufacturing methods. Lean techniques are also worthy of investigation because they eliminate large capital outlays for dedicated machinery until automation becomes absolutely necessary. Indeed, the concept of Lean Production represents a significant departure from the automated factory so popular in recent years. The "less is better" approach to manufacturing leads to a vastly simplified, remarkably uncluttered environment that is carefully tuned to the manufacturer's demands. Products are manufactured one at a time in response to the customer's requirements rather than batch manufactured for stock. The goal is to produce only the quantity required and no more. And since limited numbers of parts are produced, it may be necessary to change processes during the day–to accommodate different parts and to make maximum use of personnel, equipment and floor space (Ehrlich, 2002).

The flexibility inherent in manual assembly cells is therefore preferable to automated assembly. This requirement for maximum flexibility creates unique demands on the Lean workcell and the components that make up the Lean workcell. Granted, the Lean approach is not the solution for all production problems. But it does offer a uniquely flexible solution for assembling more complex products. Can be described 9 basic Lean Production principles that should help you evaluate Lean Production solutions for your own applications (Mudrikova, 2008).

The 9 principles are: Continuous Flow, Lean Machines/Simplicity, Workplace Organization, Parts Presentation, Reconfigurability, Product Quality, Maintainability, Ease of Access, and Ergonomics.

Just-In-Time

The term JIT (Just-In-Time) is from English origin and was adopted by the Japanese, which according Ohno, this concept originated at Toyota Motor Co.. Taiichi Ohno (1997) defines JIT:

> *"Just-in-time means that in a flow process, the correct parts required for assembly reaches the assembly line at the time that is required and only in quantities required. A company that sets this flow can reach the zero inventory. (...) To produce using just in time so that each process receives the exact item needed when it is needed, and the amount required, the conventional management methods do not work well".*

The JIT is a programming system to pull the flow of production and inventory control system (Figure 23). This means that each case must be supplied with the right items at the right time, in the right quantity and at the right place. The goal of JIT is to identify, locate and eliminate waste-related activities that do not add value, reduce inventory, ensuring a continuous flow production (Radovilsky, 1996).

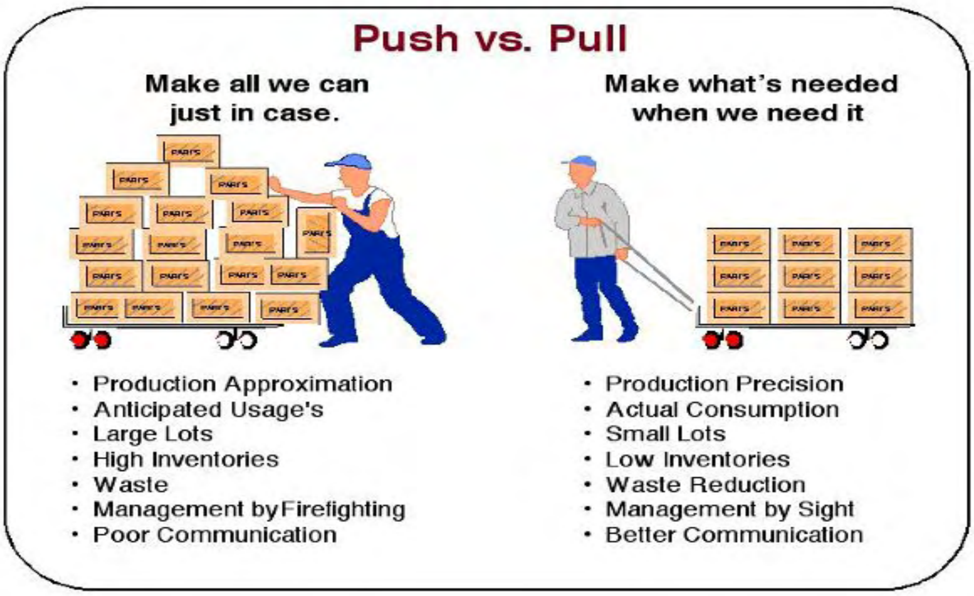


Figure 23 - Push Vs. Pull Production

This system is to manufacture only what is sold, preferably to sell yourself first, then manufacture and deliver posteriomente. JIT does not adapt easily to a diversified production, because in general this would require extreme flexibility of the production system in dimensions difficult to obtain in this system. However, this system tends to reduce operating costs, since it reduces the need for mobilization and maintenance of physical space, mainly in stocking raw material or merchandise to be sold (Hirano, 2009).

The JIT is a modern approach, that before this "fight" world in search of new markets, or maintain them wins distinct contours, where diversification is a weapon for the service consumer. JIT can not be considered as a tool for quick solution because can produce immediate results and long-term in all environments (Schonberger, 1987).

Thus, to eliminate loss systematically remove barriers to the flow of material and reduce safety stock. Until the ultimate goal of zero inventory and one-piece flow are achieved, the material flow can be created through the use of standard inventory, visual aids, and Kanban (Raia, 1989).

Kanban

Kanban, literally translated from Japanese as “signal“, is a signal system between customer and supplier, constituting a simple method of controlling visual processes. It aims to control and balance the production, eliminate waste, prioritize the production, control the flow of material. It allows the replenishment of inventory based on demand and supply information about the product and the process (Figure 24) (Lu, 1989).

Figure 24 - Kanban

Technically speaking, the kanban system is the communication tool of Just in Time. It is a way of ordering the work, defining what, how much, when, how to produce, how to move and where to deliver. The card, or signal functions as the trigger of the production, coordinating the production of all items according to demand and also can visually control the production schedule and production according to the system "pull" (Gross & McInnis, 2003).

By applying this technique, the work in process is limited and controlled by the number of cards in circulation, replacement needs are identified visually and bureaucracy is eliminated. These are some advantages of Kanban. Furthermore, the efficiency of the system can be measured as a reduction in the number of cards in circulation and also improves the quality of the production proces (Levy, Sneider & Gibney, 1983).

Kanban is a unique way to catalyze the application of Lean principles to product development, maintenance and operations. Kanban is a visual signal that something needs to be replenished and is a method for the implementation of changes; does not prescribe roles or practices. Instead, it offers a set of principles to optimize the flow and value generation delivery systems software. Kanban's focus on context and adaptability have become the method increasingly popular for teams that agile techniques do not apply directly, and agile teams seeking ways to optimize their development process so becomes one of the fundamental building blocks of a pull replenishment system.

Upon being introduced to the concepts of the method, however, many teams remain in doubt about how to start and what strategies or behaviors to adopt for a successful adoption of Kanban.

Simultaneously reducing setup times and lot sizes (Figure 25) is found to be the single most effective way to cut inventory levels and improve customer service. Shop factors of particular importance are productivity rates and worker flexibility. Grade of product standardization and the product structure are also high impact factors. Less crucial than earlier believed, at least over the factor settings simulated, are inventory record inaccuracy, equipment failures, and supplier reliability. Such results suggest that the selection of a production/inventory system can have less importance than the improvement of the manufacturing environment itself.

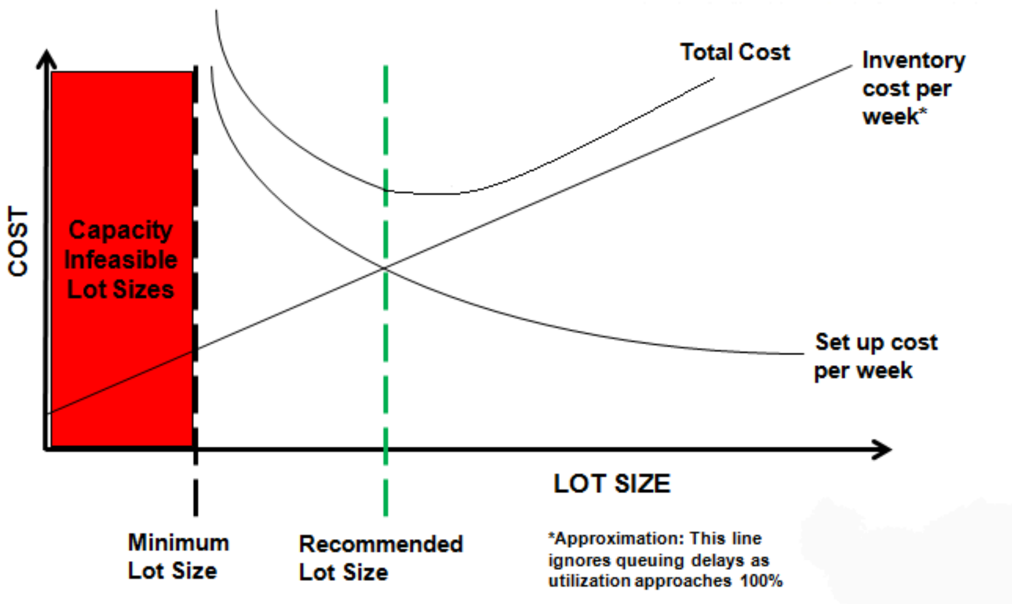


Figure 25 - Recommended Batch

Kanban works by pulling work though the development value chain which any workflow that involves a division of labor can be defined as a value stream, rather so that work-in-process (WIP) is minimized (Andersen, 2010).

The studies for scheduling methods and production control were developed and applied by the dual Taylor and Ford, highligthed the process of mass manufacturing, which the important factor was task division, and the determination by studies of movement time, and reduced standard manufacturing times. Men and machines should produce as much as possible in this system and shouldn't remain stopped, even if the destination of the products were the warehouses, then the marketing industry, including sales there, should take care to put these products to the consumer market. This process of mass production, also known as the process of pushing the production, works as follows: company direction solves by launching a new product, then communicate the decision to the product engineering that develops the idea and design and sends documentation for industrial engineering. Developing the process, the devices, etc, refers the orders for production sector that manufactures the new product. The production is transferred to the warehouse where the marketing industry strives to send it to the consumer.

Kanban aim efficiency; the fact of disorderly transport routes, overflowing finished goods stores, huge quantities of WIP (work-in-progress) and unscheduled stopping machines, often make the worth of this Lean Production functionality questionable. When there are also frequent complaints about delivery problems, the reality is quite distant from the theory. Poor implementation of kanban is quickly defeated in an e-kanban environment.

Among other purposes, the most important in the production management system using kanban, just as in any other system, is to increase productivity and reduce costs through the elimination of all kinds of unnecessary functions in the production process. This method is essencially to identify the non value-adding operations, investigate them individually, and through trial and error technique can reach a new operation, which present satisfactory results for that particular problem and specific company. This means that the kanban system is not a ready recipe that can be applied indiscriminately to any company. Even within a single company will be presented several solutions for each of the unnecessary functions studied (Hutchins, 1999).

2.4 TRIZ – Theory of Inventive Problem Solving

Known with the russian acronym TRIZ, Theory of Inventive Problem Solving was created by the soviet engineer Genrich Altshuller and his colleagues in former USSR at 1946.

The research of TRIZ started with the hypothesis that there are principles of invention which are a base and can be common and can also be used in different ways leading to improve new technology. That basis began to be collected, identified and codified for easier and faster research and also being teached to beginners and experienced people with predictable results (Figure 26).

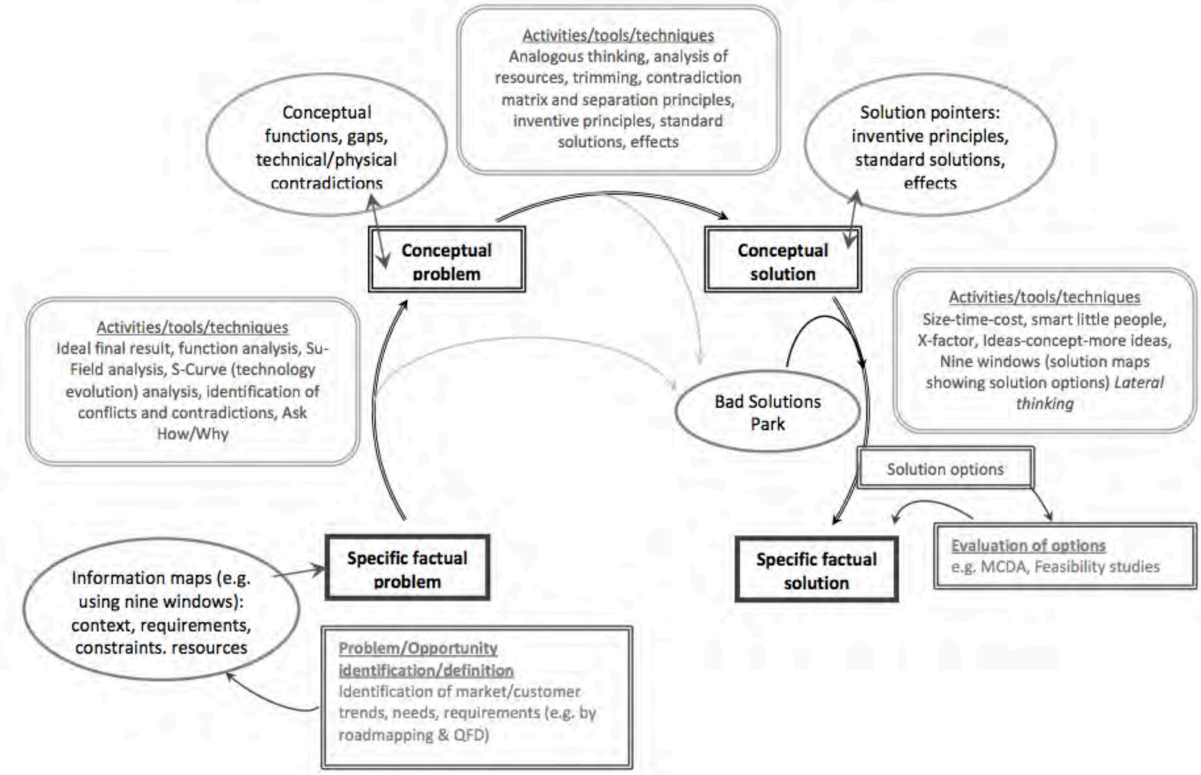


Figure 26 - The logic of TRIZ problem solving

Since TRIZ "born" were already over 2 million patents examined, classified by inventiveness level and analyzed.

The principal results of the research were:

- Problems and solutions were repeated across industries and sciences;
- Patterns of technical evolution were repeated across industries and sciences;
- Innovations used scientific effects outside the field where they were developed;
- Software products to accelerate the innovation proces;
- New analytical and knowledge-base tools and enhancements to Classical TRIZ tools.

These results can be applied to nearly any problem for which an inventive solution is desired to make and improve products, services or systems.

TRIZ methodology can be applied to nearly any problem for which an inventive solution is desired.

In the application of TRIZ all findings are applied to create and to improve products, services, and systems.

By analyzing the caracteristics of the patents problem-solving techniques it were splitted by 5 inventiveness levels:

Level 1 – Using well-known methods within a specialty or company to solve routine design problems accounted for about 32% of the solutions.

Level 2 – About 45% of the solutions were minor corrections to an existing system made by methods known within the industry.

Level 3 – Fundamental improvements that rely on methods from another industry to resolve a contradiction (mutually exclusive demands) in an existing system were characteristic of 19% of the solutions.

Level 4 – Only 4% of the solutions were classified as new generations of inventions using a new scientific (rather than technological) principle to perform a system's primary function.

Level 5 – Rare scientific discoveries or pioneering inventions of an essentially new system made up the final less than 1%.

The 5 levels represent an increase of the required knowledge of the inventor, the difficulty of the berriers and the profit it can make with the invention as it can be seen at Table 1.

Magnitude	Simple Improvement Inside Organization	Significant Improvement In Industry	Innovation Inside Paradigm	Innovation Outside Paradigm	Discovery
% of solutions	32%	45%	19%	4%	<1%
Level	1	2	3	4	5
Classification	Low Risk Organic Growth	Opportunity Innovation	Solving Contradictions	Disruptive New Technologies	Universal Breakthroughs
Description	Incremental improvement within trade/speciality	Innovation resolving a new "job to be done" using knowloedge from different areas in same industry	Innovation resolving a contradiction using knowledge from different industries	A new technology is applied/developed containing a breakthrough solution requiring knowledge of different fields of science	Discovery of a new phenomenon of universal value

Table 1 - Innovation Levels

Nowadays, TRIZ uses a systematic approach to guide to solutions to solve problems up to level 4 and with common engineering methods just provide solutions up to level 2.

Most problems will have an ideal solution plus many other good solutions. TRIZ offers several tools for finding these good solutions. Here is a list of the tools:

- Contradictions
- Eight Trends of Technical Evolution
- Forty Principles
- Functional Analysis
- Ideality
- Resources
- Seventy-six Standard Solutions
- Size-Time-Cost
- Smart Little People
- Thinking in Time and Space

2.4.1 Standard Solutions for Problem Solving

It exists 76 standard solutions categorized by five groups according to the nature of the engineering problems they solve. These classes are:

- Building and destruction of S-Field models.
    - There are 13 solutions to help in solve problems by building or destroying the S-Field model, if they are incomplete or have harmful functions. In the next figure (Figure 27) can be seen the difference between an useful action from an harmful action.

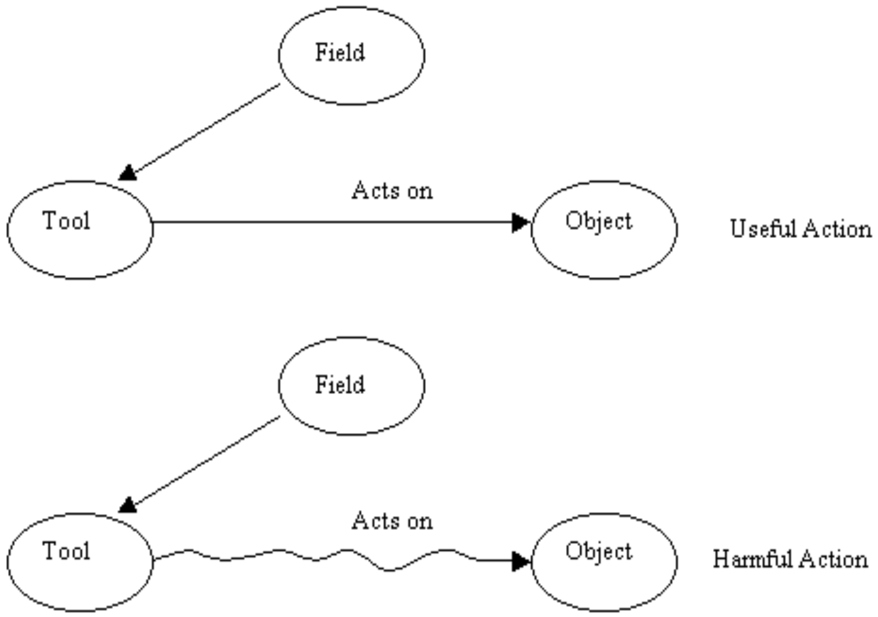


Figure 27 - S-Field model

- Development of S-Field models.
    - There are 23 solutions available for improving the efficiency of engineering systems by introducing minor modification. These solutions offer conceptual solutions of how to improve and evolve systems.
- System Transitions and Evolution.
    - 6 solutions are applied in solving problems by developing solutions at different levels in the system. In this class of solutions, the improvement of systems is mostly achieved by combining elements or combining with other systems.
- Detection and measuring.
    - There are 17 solutions for measuring or detection problems of engineering systems. Major recommendations of this class are:
        - to try to change the system so there is no need to measure/detect;
        - to measure a copy of the parameter of the system instead of the actual;
        - to introduce a substance that generates a field.

- Extra helpers
  - While the preceding 4 categories usually lead to solutions which increase complexity (since they introduce new features or objects into the systems to solve the problem), this category contains seventeen solutions that show how to get something extra without introducing anything new.

These solutions can also be grouped into three categories according to how they deal with functions:

- Harms – 24 ways of dealing with harmful functions.
- Insufficiency – 35 ways of dealing with insufficiency.
- Measurement – 17 ways of carrying out measurements or detections.

2.4.2 Thinking in Time and Space – Nine Windows

Another TRIZ concept is the System Operator or '9 Windows'. It's commonly depicted as nine squares arranged 3×3, horizontally representing time (past, present and future) and vertically representing size or hierarchy as seen in Figure 28. This allows us to regularize levels of hierarchy above and below almost any object being studied that can be in a different condition (growth, death, attainment of a goal and so on) before and after the time at which they are currently being considered.

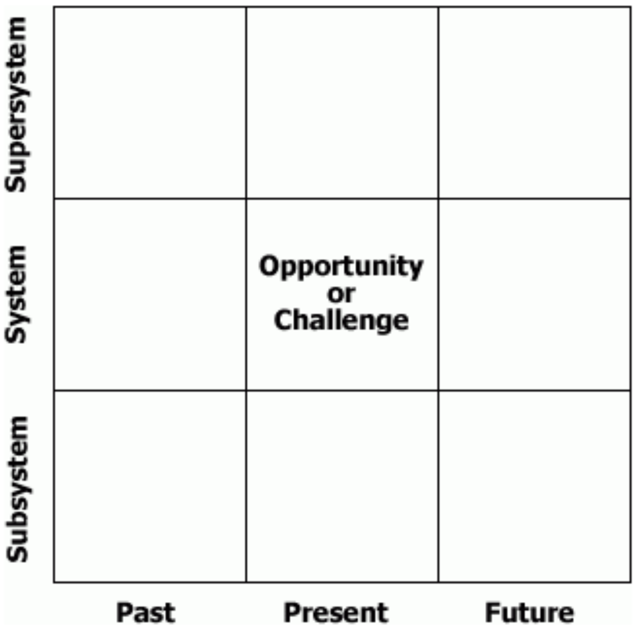


Figure 28 - Nine Windows

It gives you a set of tools that you can use to consider your opportunity by breaking it into smaller pieces as well as considering the larger context into which it fits. Here are the steps:

1. Prepare a nine windows grid;

2. Fill in the center box;
3. Identify the super-system and sub-system;
4. Determine the past and future;
5. Complete the grid;
6. Re-assess the opportunity.

2.4.3 System Modelling and Analysis – Function Analysis

The first step before the search for problems and their solutions is to understand interactions between all the components of a system. To help this first step it's used function analysis tool to draw out the difficulties to recognise issues in the problems. Function analysis of a system is closely tied with the understanding of the benefits delivered by it. This helps to clarify how well the benefits are being delivered and what harms are present. This understanding makes it easier to take appropriate steps in problem solving.

To perform a function analysis, a list of all components of a system is generated along with their interactions. This involves breaking down the system into simple units and laying them out in form of Subject-Action-Objects (SaOs). The SaO is the statement describing the action on an object by a subject. The subject is the active tool or initiator of the action or influence, while the object is the receiver of the action. In Figure 29 it can be seen the symbology of function mapping.

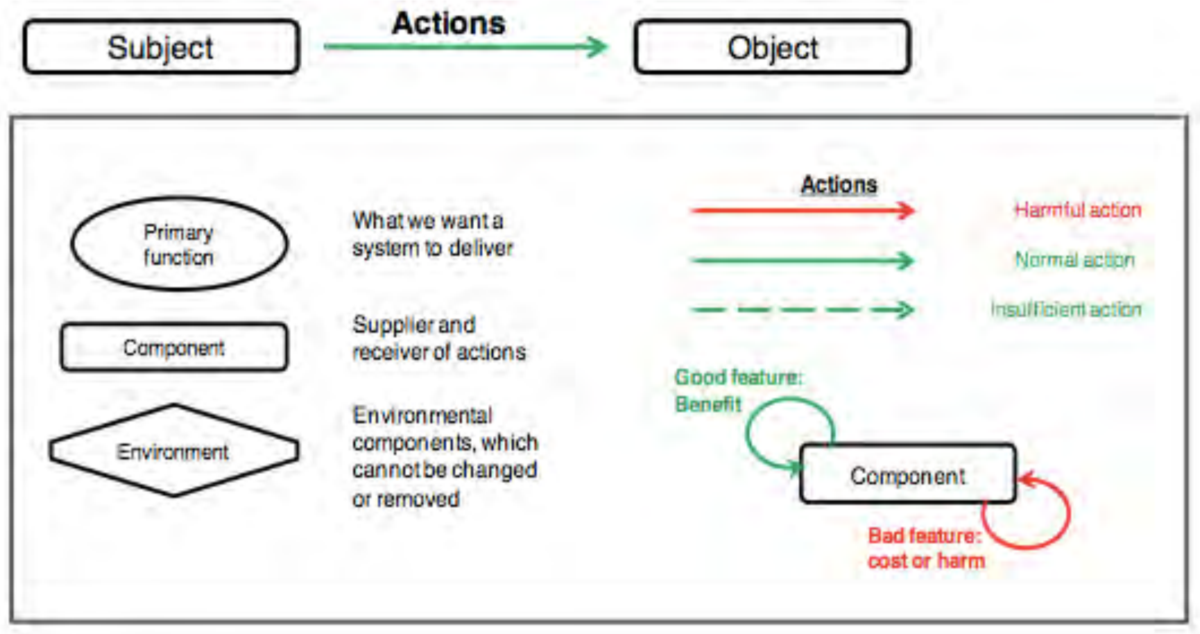


Figure 29 - Function Mapping Symbols

Trimming – Once the problems have been identified from the Function Analysis diagram we try to simplify the system using the Trimming Rules. Often, this step will eliminate problems but it also of course reduces the cost of the system and increases its ideality.

Solution map – After trimming we select one of the remaining problems to solve and identify where we can solve it (in time and space). The range of possibilities constitutes your solution map, and you choose which type of solution to try for according to what constraints you have.

2.4.4 Patent Database

Patent information searches are done, if at all, as a part of the application drafting process before filing patent applications, or while planning and preparing for patent litigation. In the recent past, this traditional micro-level use of patent information has evolved into a much more strategic use of patent information, thanks to the development of customized computerized databases of patent information. It can be useful use this patents to the problems which appear.

2.4.5 Smart Resources to Find the Right Systems and Overcome Constraints

Identification of available resources around any problem is essential for finding good, cost effective, environmentally friendly solutions. Unlike any other problem solving technique the TRIZ definition of a resource is all-encompassing and focuses even on apparently negative or harmful resources. Organizational performance is dictated by constraints. These are restrictions that prevent an organization from maximizing its performance and reaching its goals. In Figure 30 can be seen the constraints involving people, supplies, information, equipment, or even policies, and can be internal or external to an organization (Goldratt, 2004).

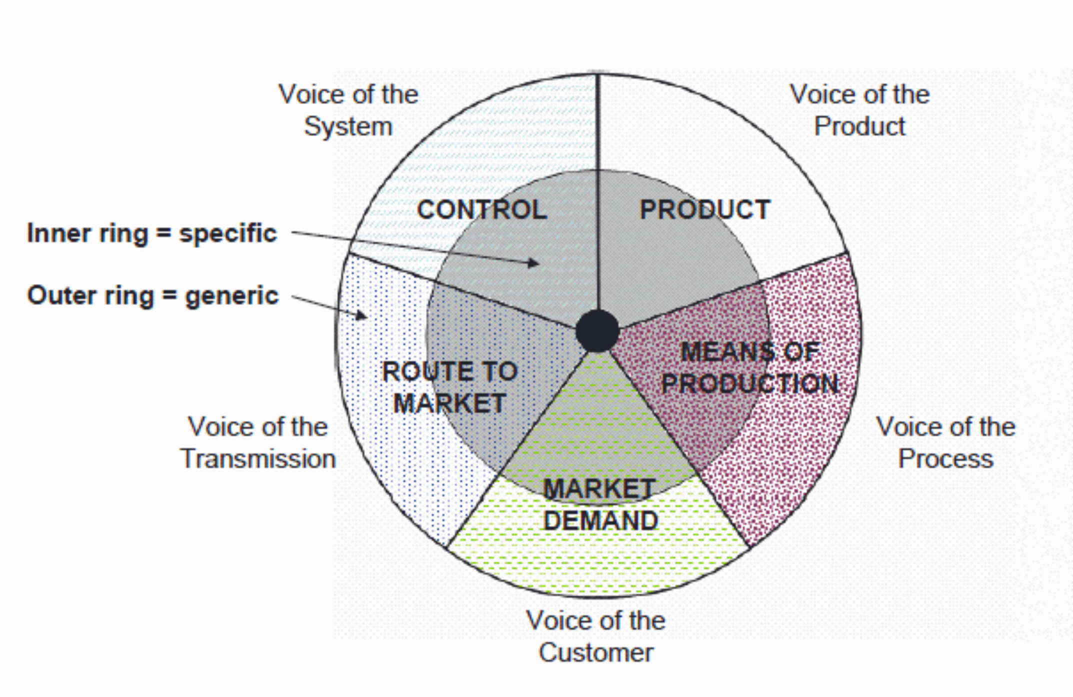


Figure 30 - TRIZ constraints

2.4.6 The 40 Inventive Principles

From Altshuller research (Altshuller, 1998) on over 40,000 most inventive patents, found that there are only "39 Features" which either improve or degrade. So, every problem could be described as a conflict between a pair of parameters (2-out-of-39 parameters). Many patents had, in the past, solved these individual conflicts in several different fields. The conflicts were solved over and over again, sometimes, these were spaced several years apart. The conclusion was that only "40 inventive principles" (Table 2) were used to fully resolve these contradictions and not as a trade-off or compromise.

Table 2 - 40 Inventive Principles

1. Segmentation (fragmentation)	2. Separation (or taking out)	3. Local quality	4. Asymmetry	5. Merging
6. Universality	7. Nested doll	8. Weight compensation	9. Prior counteraction	10. Prior action
11. Cushion in advance	12. Equipotentiality	13. The Other Way Around	14. Curvature increase	15. Dynamics
16. Partial or excessive actions	17. Another dimension	18. Mechanical vibration	19. Periodic action	20. Continuity of Useful Action
21. Rushing through	22. Blessing in Disguise	23. Feedback	24. Intermediary	25. Self-service
27. Copying	27. Cheap disposables	28. Replace Mechanical System	29. Pneumatics and hydraulics	30. Flexible membranes
31. Porous materials	32. Colour change	33. Homogeneity	34. Discarding and recovering	35. Parameter change
36. Phase transition	37. Thermal expansion	38. Accelerated oxidation	39. Inert atmosphere	40. Composite materials

Altshuller (Altshuller, 1998), therefore, set about to extract and to organize the frequently occurring contradictions and the principles of the resolution of these contradictions. He put it in the form of a matrix of 39-improving parameters and 39-worsening parameters (39 X 39 matrix – Annex I – TRIZ 39 Features – Improving & Worsing Features) with each cell entry giving the most often used (up to 4) inventive principles. Contradiction Matrix is the name which is known this matrix and remains to be the simplest and the most straightforward of TRIZ tools.

2.5 Combination of Lean & TRIZ – Critical Analysis

In this case of study were identified problems. In order to explain and solve them is was needed to plan a research methodology to guide to the solutions. Different types of data were collected and splited into primary and secondary data for an easier process of them. Due to involve the Lean Tool SMED with the TRIZ technique, which is what we want to combine in this case of study, it was needed to incorporate both strategy methods to try to eliminate the problems. The first step was search for articles/cases already done to know which tools/techniques/principles would be better to be the starting point to the case study as described in Table 3.

Table 3 - Combination of Lean and Triz already used tools/techniques/principles

Tools/Techniques/Principles	
Lean	**TRIZ**
5 S	Transition to the supersystem Trimming Standard Solutions Principle 20 - continuity of useful actions
Current State Map	9 window
Jidoka (Autonomation)	Principle 25 - Self-service
Kaizen	Searching for sources into subsystem or supersystem Trend "mono-bi-poly-mono" Principle 1 - Segmentation Principle 7 - Nested Doll Principle 10 - Preliminary action Principle 15 - Dynamics Principle 24 - Intermediary Principle 28 - Mechanics substitution Principle 32 - Color changes
Kanban	Inventive Principles Standard Solutions Trimming
Lean Sigma • Analysis of variations • No available resources or no process optimization • Optimization and disrupt techniques	Principle 23 - Feedback S-Curve Tools for solving contradictions
Leveled Production	Transition to the supersystem Trimming
Muda - Wastes	Trimming Principle 5 - Merging Principle 10 - Preliminary action Principle 16 - Partial or excessive action Principle 20 - Continuity of useful actions Principle 22 - Blessing in disguise
• Overproduction	Excessive functions
• Inventory	Corrective functions
• Extra Processing Steps	Providing & Corrective functions
• Motion	Providing & Corrective functions
• Defects	Insufficient, Excessive & Harmful functions
• Waiting	Insufficient functions

• Transportation	Providing functions
Product Family Matrix	Function Models of separated product lines
SMED	Standard Solutions Principle 1 - Segmentation Principle 2 - Taking Out Principle 3 - Local Quality Principle 5 - Merging Principle 10 - Preliminary action Principle 15 - Dynamics Principle 17 - Another dimension Principle 25 - Self-service
Standardized Work	Inventive Principles Standard Solutions
Takt Time	Rhythm coordination approach
VSM	Function Model of Process Trimming Cause-Effect Chain Analysis Function Model of Supersystem
Work Balancing	Function Model Function Re-allocation New function architecture

3. Problem identification

At this moment the changeover processo of the ATE takes 4 hours (240 minutes). That process is too long because it's not optimized and need to standardize some practice process to try to be less then 10 minutes reaching the goal of one digit.

3.1 Past/Present situation / Why to change? Why to improve?

The impulse to make the changeover process more efficient should be from economical order. The time takes costs so if it could reduce the time the costs will be less. A better utilization of the machines also need to be focus because some of its time is made of breaks or not at full usage of the machine and also to manufacture defected pieces.

Analyzing the historical data (secondary data) it can be deducted that in the utilization of the production system is about 70% and the target is 90% of utilization. This 20% of difference the biggest part, around 8.5% is due to changeover processes. A balanced line is a more efficient line in operation. Better line balance is achieved when both placement heads are operating in a fully optimized fashion, without idle time, and without wasted motion, which also absorbs time.

Because the changeover process were too complicated and long and also the market demand was too much uncertain, the time given for improving equipment and machinery was always tight. So it ended on an intransigent manufacturing so the time schedules of the production were never on time to reply the clients demand at the market.

If the utilization is not high and also you're not responding at the market, the costs will be higher too and to have profit the prices will need to be higher again so may not be attractive for costumers. So at least to respond to the market it is needed to buy more machinery so it will be a raised investiment and can be risky because the market demand change too much and the machines and products can be obsolete. This measure is a waste of money and should be applied Lean philosophys to maximize the utilization of what you already have, working at full capacity.

As an organization begins a Lean Production implementation, its ultimate goal is to produce according to customer demand (takt time) while utilizing "one piece flow". For this to happen, machines need to be set up more often, highlighting the need to reduce setup time. Reducing setup time results in increased production, better quality parts and a more flexible workplace leading to an improving of all system.

3.2 Detailed Review of the Case Study

The data collected exposed at the article used in this thesis case study was from a multinacional company of semiconductors located at Kulin High Tech Park from Malaysia called Intel Technology Sdn. Bhd.. This company is one of the best companies in the world producing microprocessors and chipset products being in the leadership due to their excellent technology which goes since the manufacture till the test process passing by the assembly phase which is an High Mix Low Volume (HMLV) platform factory.

The focus of the study will concern on the 2 principal products, based on company information, produced in this factory which are the chipset Nebula Peak and the chipset Nexus Peak. Both products are a new generation of chipset with I/O and integrated graphics function which supports the microprocessor device and even they are from the same family product technology. They have a different design segment for the market, so they are alike just in function because the architectual design of the product is different, so because of this difference both chipsets need also a different equipment configuration to make the assembly and testing phases.

The Nexus Peak and Nebula Peak to be produced pass by 20 manufacturing process to be finished and shipped for the clients. The goal of the project will pass for the testing operation where the chipsets are tested using an high technology equipment for testing called M4542D Dynamic Test Handler (Figure 31), the Extreme Test Handler, and it has combined an unit for test and an interface test which will execute a functional electrical testing to the semiconductor of the chipset devices under extreme temperatures. Due to the high duration of the changeover process of the Extreme Test Handler the focus of this work will be improve this process.

Figure 31 - Dynamic Test Handler

3.3 Current Situation of the changeover process

The changeover process of the ATE has 9 actions, 8 internal actions and 1 external action. The time each action takes by a trained technician worker make the changeover process is described in the graphic below (Figure 32).

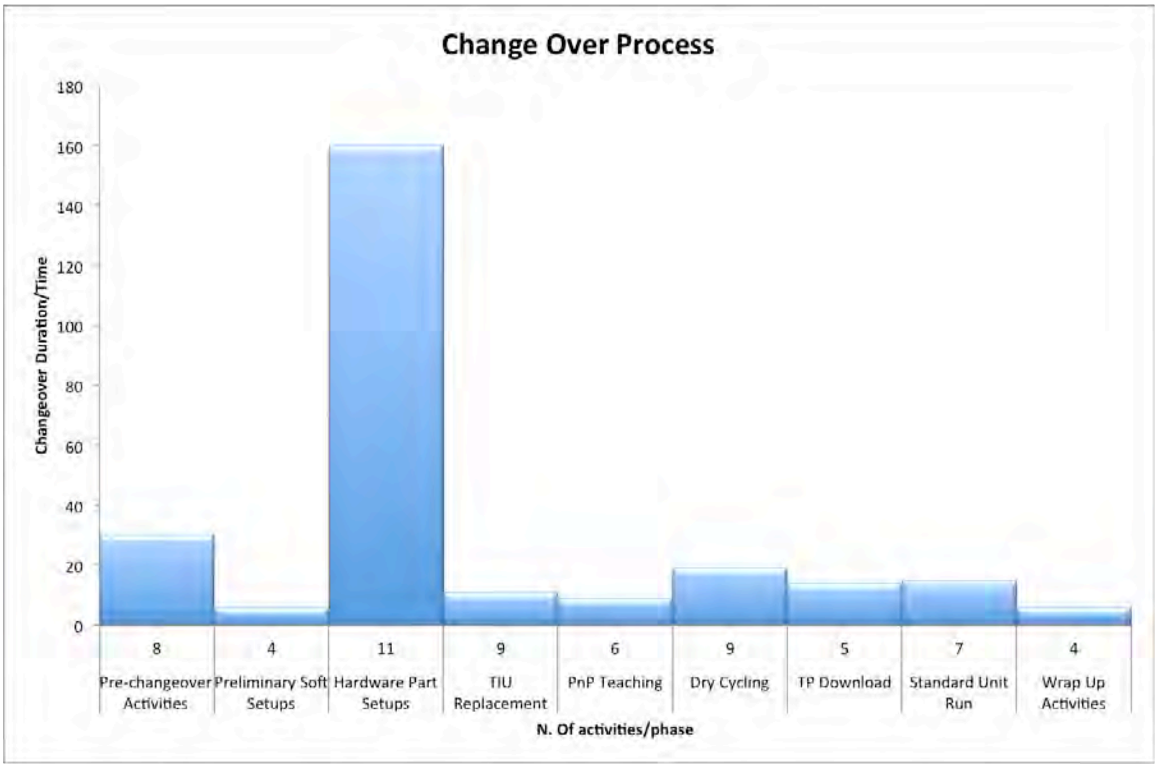


Figure 32 - Changeover Process

The hardware changeover takes 160 minutes to exchange 11 hardware pieces, it's the longest process so it is the bottleneck. The study will concern on making that process faster applying SMED and TRIZ methods.

That process of changeover has 3 phases, 2 of them are different validation steps and the 3rd one is the calibration step. It can also been counted the pre setup and post setup phases. All phases are identified in the next table (Table 4).

The improvement of the changeover process is being affected by some issues as non optimized processes non standardized practices and the activities that don't generate value for the productive process (NVA).

Table 4 - Detailed current time for each changeover step

Sequence No.	Activity & Milestone	Details	Average time (min.)
Pre Changeover Actvities		Supervisor communication and alignment with technician; End lot process for the last production run.	Not included in changeover time
1	Preliminary Soft Setup Activities	Official start of changeover process with the change in AEPT; Tagging of equipment i.e. sticky pad or barricading area; Preparation of change kit and toolsets.	6
2	Hardware Part Setups	11 major hardware part setups; Bottleneck of the overall changeover process.	160
3	TIU replacement	Interface unit that need to be replaced.	11
4	PnP Process	Required calibration process each time; hardware parts are replaced.	9
5	Dry Cycling with Mechanical Units	1st validation process on the hardware part setup; Using 5 trays of mechanical units 19; Ensure end of cycle, 100% pass with no mechanical defects.	19
6	TP download	Software coding to instruct tester to perform electrical testing.	14
7	Standard Unit Run	2nd validation performed using good production samples of 1 full tray; Validation under real production atmosphere Ensure all units pass with 100% yield.	15
8	Wrap Up Activities	Housekeeping and cleaning up work area; Official end of the changeover activity by 6 change in AEPT.	6
		Total	240

4. Countermeasure Proposals

Initially it was found the bottleneck activity, Hardware Part Setup, so it should be carefully observed the action more than once to figure it out the anomalies. After will be applied SMED and TRIZ techniques and methodologies to try eliminate the imperfections of the process, equipment and human errors of the system as described in Figure 33.

The first step will focus more in applying SMED techniques to distinguish all parts that can be studied to improve, so it will be done the separation of the internal from external activities, then it will be need to standardize external activities and to end first phase, convert internal into external activities.

The combination of SMED with TRIZ will be more related starting from next steps which will be more relevant where the process and hardware will suffer significant changes. This next step is to improve the internal activities and improve external activities, using specially the 40 principles methods of TRIZ on them.

The last steps are the ones to make all this changes stabilized so the activities will be mechanized and when this is done the process will be seen since the beginning to complete the elimination.

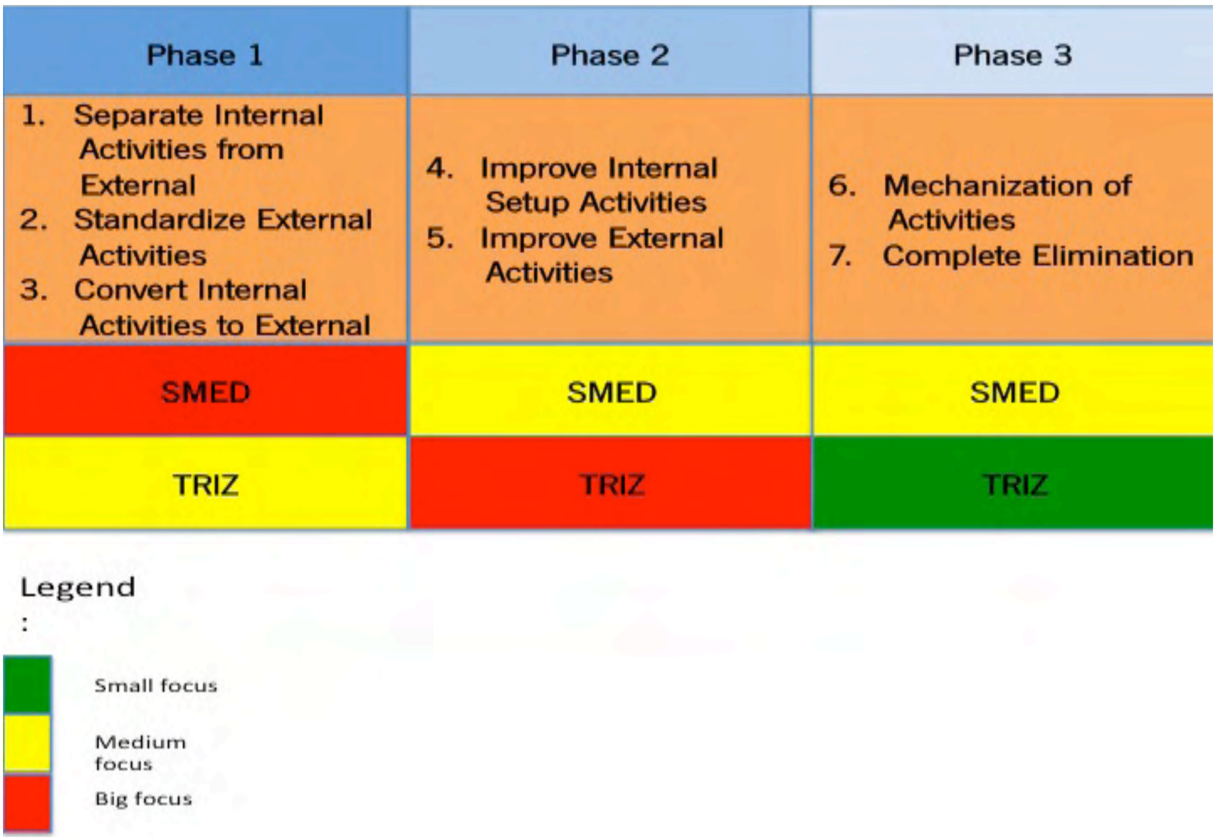


Figure 33 - Proposal Model

The process of the system will be the most affected by the changes which will be done where will be identified all the factors/members and then correctly separated to then try to delete the NVA activities. After, the activities left will be improved and flowing the others.

Hardware will also suffer changes either modifying or suffering a new concept creation to be easier and quicker make the inherent processes of the hardware setup.

The human dynamics will be observed to make them suitable and standardized to the process and also for the new changes. With these changes all process and hardware turn into most effortless and user-friendly but also passing thru economically attractive for acquirement.

In the end it's expected the changeover be improved like next figure (Figure 34).

Figure 34 - Changeover Goal System

5. Results and Discussion

Using the steps of the Proposal model (Figure 33) combining SMED and TRiZ techniques and methods improvements were made in process, as human part, as in hardware which was the one of the 3 parts most affected.

5.1 Hardware Setup Optimization

The hardware part was the one which had the most significant chance of the application of techniques. The contactor chuck/mandrel nest was the one who suffered the biggest improvement and most significant for the reducion of the changeover time. For that improvement it was used the 40 principle technique of TRIZ using the Dynamization (principle 15 of TRIZ) combined with the Functional Clamper technique of SMED.

Dynamics allow a system or object to change to achieve optimal operation under different conditions, split an object or system into parts capable of moving relative to each other. If an object or system is rigid or inflexible, make it movable or adaptable and it increases the amount of free motion.

Functional clamping involves securing objects with the least amount of effort. Often is used numerous turns of a screw to provide enough clamping resistance to secure a die or work piece. Yet, if the function required is clamping or holding, numerous turns are not required. We can reduce time and effort by minimizing motions to a single-turn, single-motion, or screwless (interlocking) fastening methods. The goal is to reduce the number of turns required for tightening operations to one at most.

Combining the techniques, it was designed a new model to improve the setup of 21 steps to 6 and a decrease of the setup time (just of the nest) from 120 minutes to 4 minutes. In Figure 35 are the old hardware compared with the new one which permits the improvement of the changeover because is flexible and adjustable (detailed in Figure 36) instead of the old one which was rigid and unchangeable.

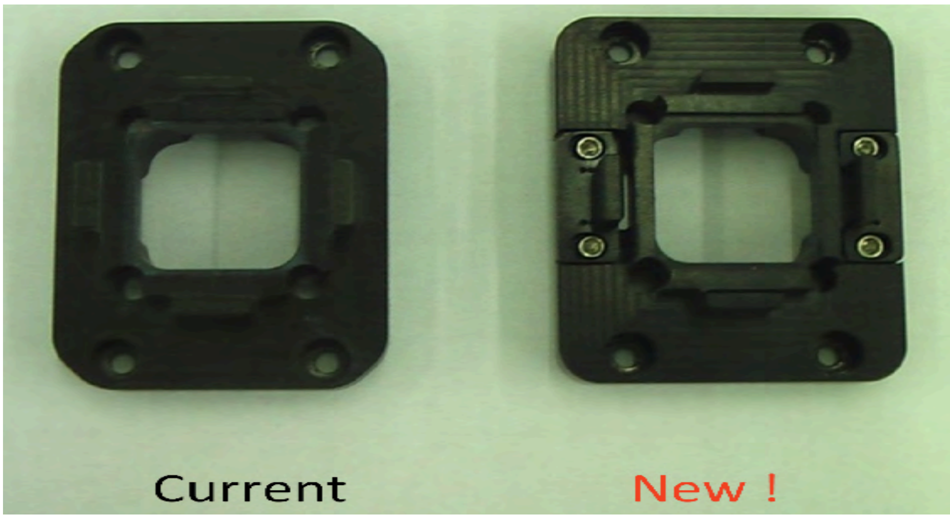


Figure 35 - Current nest Vs. New nest

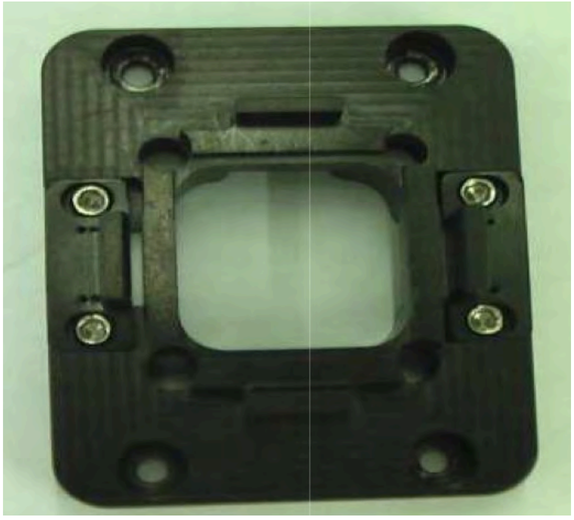


Figure 36 - Detailed new nest flexible and adjustable

Not just the nest was improved, also was inserted a screw with just one turn instead the last one with multiple screws which permits screwing with less effort and faster which don't had value and just take time to the process. With this new screw the NVA steps were reduced and with it now it takes just 1 minute make the screwing process instead of the old one which takes 4 minutes.

Last improvement was a reduced number of hardware parts from 12 to 7. This reduction was possible due to combination of Function Checks of SMED with Local Quality (principle 3 of TRIZ). A checklist is useful for determining whether all the parts are where they should be, but it does not tell whether they are in perfect working order if the work is standardized. Consequently, it is necessary to perform function checks also for external setup. Failure to do this will lead inevitably to delays in internal setup and inadequate repairs are sometimes discovered only after test runs have been completed. One frequent problem were repairs which are anticipated but take longer than expected. The operation begun before repairs being completed. When defective goods show up as a result, the die is hurriedly removed, and further repairs are made, interrupting production. It is always important to finish repairs before internal setup begun.

Local Quality (principle 3 of TRIZ) enounce that instead of uniform structure of the object it is needed to use non-uniform structure of the object, instead of uniform structure of environment, use non-uniform structure of the environment. If two functions are to be performed by the same object but this is not possible or result in negative effects, divide the object into two parts. Redesign the object and environment so that each part of the object must be in conditions proper for operation.

All the techniques together in the hardware setup improved the modification of the changeover which now it takes 11 minutes instead of the 160 minutes in the past.

5.2 Process Flow Optimization

The changeover process was improved and simplified with SMED techniques of Function Check, used also in hardware setup optimization, and Parallel Operations. To these techniques were also added 3 TRIZ techniques, Combining (principle 5 of TRIZ), Segmentation (principle 1 of TRIZ) and Taking Away (principle 2 of TRIZ).

Parallel functions entail having more than one worker involved in completing setup operations. Oftentimes, one person may waste time in movement from one side of the machine to another during changeover operations. Teamwork during such operations could reduce setup time. For instance, we can divide work on a large machine into work required to the front and to the rear of the machine. For safety, this requires clear signals and, sometimes, the use of safety switches where a worker can prevent the other from endangering him or her.

Visual aid charts can also provide a listing of detailed steps and signals to avoid confusion and safety problems. Parallel operations do not require additional personnel. Cross-training neighboring personnel or a floor supervisor to assist in parallel operations will relieve this problem, and the help is only needed durirg the short internal setup stage (the one that is supposed to be reduced to less than 10 minutes). The extra worker is usually justified in such cases.

With the combination of the technique it will be needed to merge (principle 5 of TRIZ) identical parts or components of the object in space or to merge in time. Segmentation (principle 1 of TRIZ) is known that we need to divide the object into independent parts, so some of its parts can be easily taken away to increase the degree of the object's fragmentation and the last one, Take Away (principle 2 of TRIZ), is used when a part of an object that interferes with other properties or influences on the object negatively. If some property of the object interferes with other properties, find what part of the object is a carrier of the property and separate it from the object.

The upfront setup has now just 1 external step which make the same effect of the 3 steps needed in old one reducing from 3 to 1 the NVA activities. Now using parallel activities at the same time internal and inactive time were also reduced. A group of functions of the same family are now together and standardized which now can be just one phase. If this phase don't add value it can be all together easily eliminated. New working ideas were introduced as the utilization of trolley and the utilization of magnifier which improve the process.

All the techniques together in the process flow improved the modification of the changeover which now it takes 30 minutes instead of the 80 minutes in the past.

5.3 Human Dynamic and Procurement Improvement

With the improvements of the changeover process this process suffered changes. On base of the changes all the workers which have functions on the process need to be re-trained to adapt to the new reality. With the changes, the training material and also documentation need to be updated and registered with the Best Known Methods (BKMs) to be able to share at the company and to the same company group, as also companies which have same equipments. First of all theoretical were given to the workers and then the practical part to test and guarantee the succesful of the process before put in practice at the normal process of the company manufacturing. When people be trained with the new processes the change will be well succeeded. Just when all the workers know the process and reach this level, it will be the time to know the exactly number of workers needed to complete the changeover process, just that time all of them are familiarized with it and be able to make the exactly number shifts of people.

5.4 Overall Optimized Changeover Process

The changeover duration it was 160 minutes of the hardware setup plus 80 minutes of the process flow which made a total of 240 minutes. Now the optimized changeover (Figure 37) takes 11 minutes of the hardware setup and 30 minutes of the process flow but as some steps can be made at the same time both combined the changeover process takes now 32 minutes to be completed which is a redution of 86,67% of the time (table 5).

Table 5 - Changeover Process - Splited and Together

	Hardware Setup (min)	Process Flow (min)	Hardware Setup + Process Flow (min)
Past	160	80	240
Optimized	11	30	32

Time reduced in 86,67%

In next figure (Figure 37) it can be seen with more detail the graphic with the activities of the optimized changeover with the time they take, the activities and when they occur.

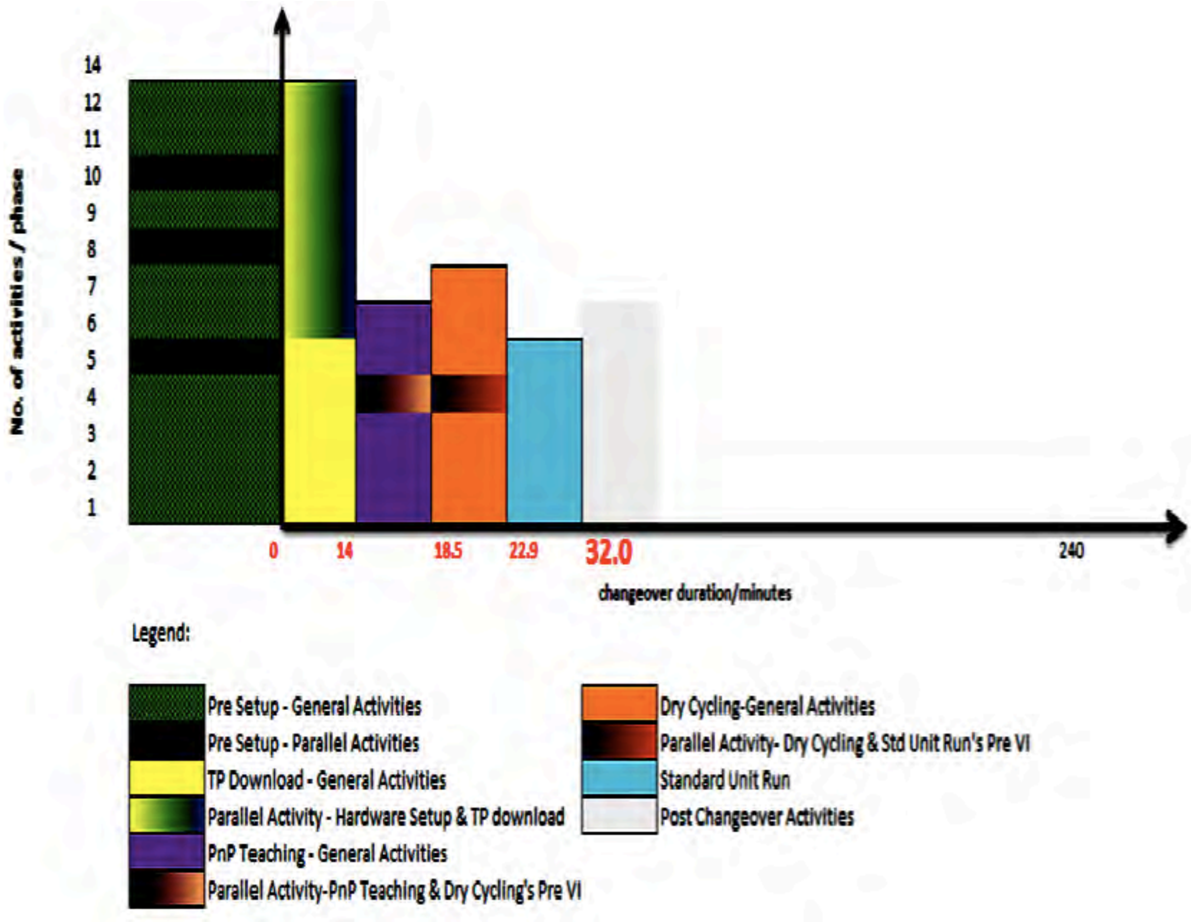


Figure 37 - Optimized Changeover Process

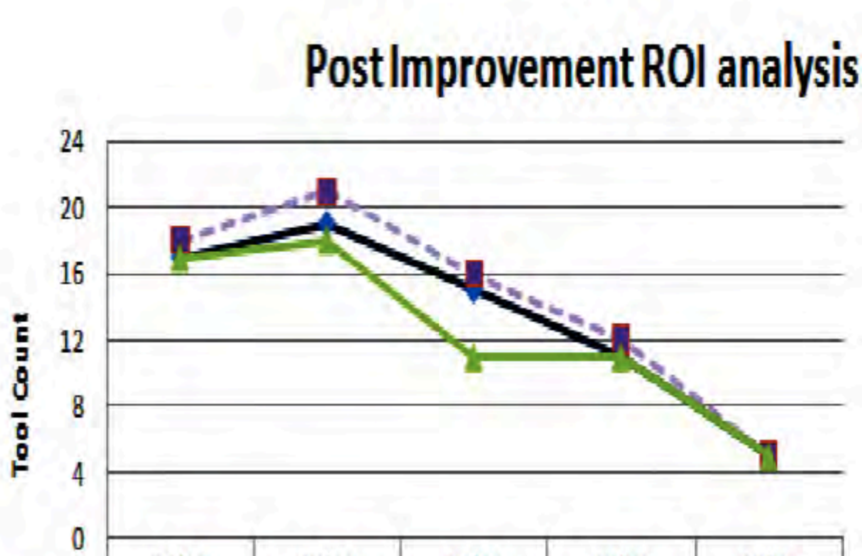
In Table 4 a synthesis of the new process was made with details of each activity and also the time they take. Now the time is reduced compared with the one presented in Table 6 because the activities suffer a new planification and some activities are together because of parallel operations or even because they were eliminated.

Table 6 - Detailed optimized time for each changeover step

Sequence No.	Activity & Milestone	Details	Average time (min.)
Pre Setup Phase		Integrates Pre Changeover and Preliminary Soft Setup phase; TIU replacement performed in parallel during end lot process; All other activities are prepared upfront.	Not included in changeover time
1	TP Download	3 steps are performed as 'Internal' task – Preform TP reset, SC initialization and ELI input; Actual download and TIU init are performed on the background.	14
	Hardware Part Setups	5 parts are exchangeable and not replaced; 5 parts are changeable and need to be replaced; 2 parts were re-engineered to minimize the setup time; The hardware setups are performed in parallel during TP download/TIU initialization.	
2	PnP Process	Improved process with reduced setup time; Pre VI for Dry Cycling units are perormed in parallel during actuall process.	4.5
3	Dry Cycling with Mechanical Units	Improved process with Dry Cycling performed with 1 tray of units; Reduced pre setup time and no temperature setup; Pre VI for Standard units are performed in parallel during actual process.	4.4
4	Standard Unit Run	Improved process with reduced setup time; AEPT state change is performed towards the end of the process.	9.1
Post Changeover Activities		All activities performed post AEPT state change; More all Wrap Up activities to this phase	Not included in changeover time
		Total	32

5.5 Economical Analysis

The optimized changeover process improved the equipment utilization which passed from 70% to 87%. Those modifications permit to produce more units for expedition and because it takes less time now the production system is more flexible and not so affected by the change of demand. For this, it can be made shorter batches and distribute the goods better without the risk of the products turn obsolete or the starting materials needed to be used in other part of the production. Also if the usage of the machinery is bigger and efficient the number of machines which need to be used can be less or, at least, won't be need to buy new ones to satisfy the market with the same demand (Figure 38).



	Q2'11	Q3'11	Q4'11	Q1'12	Q2'12
Available inventory	17	19	15	11	5
Additional inventory impact	18	21	16	12	5
Post Improvement inventory forecast	17	18	11	11	5

Figure 38 - The capital equipment purchase ROI

If the changeover is standardized will make improvements decreasing the waste time which workers had to make it. In the old process that waste time it was about 30 minutes which now was improved to just 1 minute. It results in a more simple process which is much more easier to train which leads to an efficient and quicker process and into a better headcount management (Figure 39).

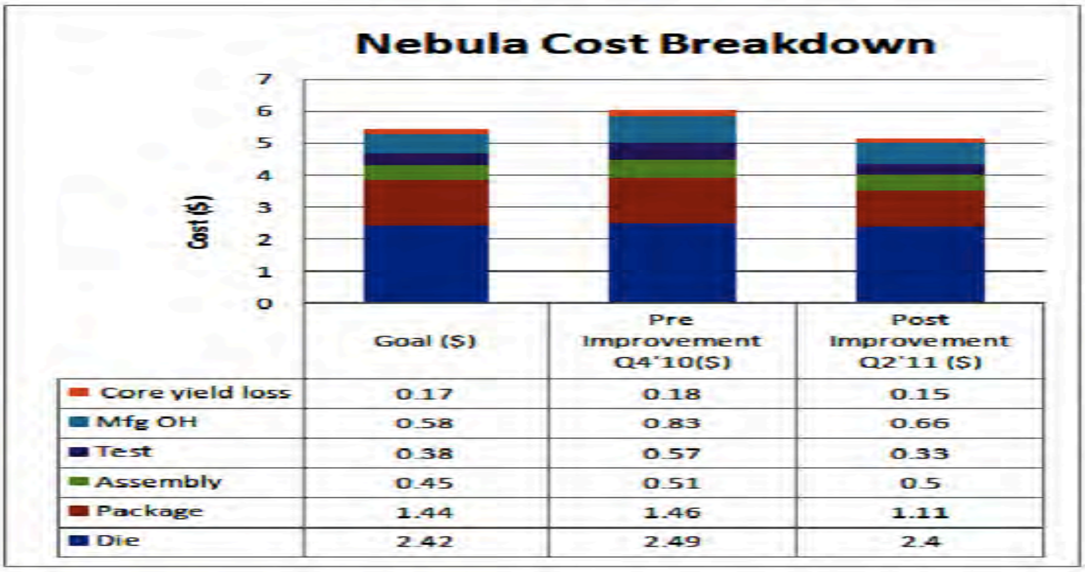


Figure 39 - Cost breakdown analysis

The changes made an improvement to the system and because made it efficient, less resources need to be purchased as machinery, people or primary material which permits have a better cost per unit so the company can be better in the market position even if it has to practice better prices atractive to costumers which permit the leading of the market of the semicondutor industry.

5.6 Critical Evaluation

This case study proved that combining TRIZ with SMED had much better results than use just one of the methods because using both improve the process with a major reduction of the changeover process.

The changeover process was about 240 minutos to make it completely and using just SMED methodologies we could just improve the process to 105 minutes for the changeover which was an optimization of just 56,25% of the time. Combining with the TRIZ techniques more aspects of the process were improved reducing by 86,67% of the beginning changeover time (Figure 40).

	Current	SMED	SMED + TRIZ
Time (min)	240	105	32
Reduction (%)	-	56,25	86,67

Figure 40 - Time & %Reduction of techniques

This TRIZ techniques were focused on the change of the hardware setup and segmenting the process flow and some activities at the same time SMED identified and improved the hardware parts and process activities.

The SMED goal is to reach a single digit of time on the exchange of the process (less than 10 minutes) to be considered an optimized process. This process was reduced around 87%, even that is not an optimized process because to make the complete changeover it takes 32 minutes so work still needed to do and has improvements which can be made.

The techniques of SMED and TRIZ focus mainly on the hardware and process but nowadays tools like software, IT or network computing are also a major aspect on the changeover because they are along all the system. The Test Program, a software part, couldn't be improved with these techniques so with the usage of informatic program improvement could be possible to improve it which could make a better performance to the changeover.

Many of the problems and improvement were easy to identify but with TRIZ and SMED is easy, better and in a discriminated manner of all the problems for later be easy to know which problem first to focus and the best solution identified.

SMED and TRIZ are not the best tool for human factor because they focus at the process and the product. Even that it was also improved but if we want a better improving of the human factor other Lean Production tools need to be applied together for the workers mantain focus and motivated in the future.

5.7 Suggestions to further studies

To get the SMED target which is make the changeover less then 10 minutes some improvements need to be done. These are some suggestions for further studies and attemps to try the improve goal of reducing the time of the changeover of the test handler machine:

- Eliminating the validation and calibration phases with more empirical data. To do it a good starting point could be the use of the Universality/Multi-functionality principle which is common used for measurement, inspection and test equipment calibration tasks which combne non contiguous operations of function. It says an object performs multiple functions thereby making other objects redundant and often can be helpful where space, time or interface complexity are an issue;
- Reducing the Test Program download phase. The TRIZ tools which possibly could make some improvement to the software would be ideality concept, contradictions and inventive principles. With this tools the software could get simplified which lead to be quicker to run;

- Improve the hardware setup focus on the non exchangeable parts by redesign or eliminate the NVA activities. It can also be made a Main Parameters of Value analysis to know what parameters are important of the product for the client because some NVA activities can be removed if won't have value or can be change for others with less impact;
- Apply the TRIZ principles and SMED techniques suggested in this case study for any other applicable semiconductor based equipment.

6. Conclusion

The case study was focus on the changeover process of the test equipment which took too much time to the complete changeover which gave us a starting point because of its duration. With this were collected data of the changeover process with detail of the quality of the step but also the quantity of the activities each step took to try to find improvement chances on them.

When the problem was well defined the techniques of SMED and TRIZ were outlined to upgrade the changeover to an advanced level and it started to combine functions and standardize the process, remove the NVA activities and also optimize the hardware setup with new design model.

The Japanese methodology integrated with the Russian methodology reduced the changeover process from 240 to 32 which was a gain of time around 87%.

Because of the success on this case study the methodology used on it can be used in similar studies, specially at the semiconductor industry.

Future Work

Future suggestions to new developers is using the last version of TRIZ called Innovation Discipline of TRIZ using the MPV analysis to focus on the most productive valuable for the client, make innovation roadmaps, business impact justification to be able to clearly state what this will provide the business, mechanical technology/trends of engineeting systems evolution to be a leader company and because nowadays products should be good for environment and there's lots of laws for it make the synergy index which could lead to a better knowledge of the environmental impact made by making the product/process.

Bibliographic References

Altshuller, Genrich, Lev Shulyak, Steven Rodman. *40 Principles: TRIZ Keys to Technical Innovation. TRIZ Tools Vol.1.* Technical Innovation Inc., 1998.

Anderson, David J.. *Kanban: Successful Evolutionary Change for Your Technology Business.* Books On Demand, 2010.

Anderson, Mark J. Whitcomb. *"Achieving six sigma objectives: for variability reduction in coating formulation and processing"*. Paint & Coatings Industry, November 1, 2001.

Barkan, Mark G., Nikolay Shpakovsky, Vassily Lenyshin. *TRIZ in a Bi-System with Lean Sigma.*

Bartholomew, Doug. *"Can lean and ERP work together? Searching for harmony between MRP's 'push' and lean's 'pull'. (Production Scheduling)(Enterprise resource planning)"*. Industry Week, May 23, 2012.

Besterfield, Dale H.. *Total quality management*. 3rd ed. Upper Saddle River, N.J.: Prentice Hall, 2003.

Bicheno, John. *The quality 50: a guide to 8 gurus, 7 tools, 7 wastes, 6 new tools, 20 techniques, 2 systems*. Victoria (Australia): Nestadt Consulting Pty. Ltd., 1994.

Black, John R., and David Miller. *The Toyota way to healthcare excellence increase efficiency and improve quality with Lean*. Chicago: Health Administration Press, 2008.

Blanchard, David. *"Leaning in the Right Direction"*. Material Handling Management, July 2010.

Bligh, Amanda. *The Overlap Between TRIZ and Lean.* 2006.

Bodek, Norman. *Kaikaku: The Power and Magic of Lean: A study in Knowledge Transfer*. PCS Inc., 2004.

Bosch worldwide. http://www.bosch.com/worldsite_startpage/en/default.aspx (accessed June 1, 2013).

Carreira, Bill, and Bill Trudell. *Lean Six Sigma that works a powerful action plan for dramatically improving quality, increasing speed, and reducing waste*. New York: American Management Association, 2006.

Chiarini, Andrea. *Lean organization from the tools of the Toyota Production System to lean office*. Milan: Springer, 2013.

Ehrlich, Betsi Harris. *Transactional Six Sigma and Lean Servicing: leveraging manufacturing concepts to achieve world-class service*. Boca Raton: St. Lucie Press, 2002.

Feld, William M.. *Lean manufacturing: tools, techniques, and how to use them*. Boca Raton, FL: St. Lucie Press; 2001.

Filmore, Paul. *A comparison of the problem solving and creativity potential of engineers between using TRIZ and Lean Six-Sigma.*

Flinchbaugh, Jamie. *"Planning 5S? First know why!"*. Assembly, June 1, 2006.

George, Michael L., Dave Rowlands, and Bill Kastle. *What is Lean Six Sigma?*. New York: McGraw-Hill, 2004.

Gilham, W. E. C.. *Case Study Research Methods*. Bloomsbury Publishing PLC, 2000.

Go Lean Six Sigma. http://www.goleansixsigma.com/ (accessed May 1, 2013).

Goldratt, Eliyahu, Jeff Cox. *The Goal – A Process of Ongoing Improvement*. Gower Publishing Ltd, 2004.

Gonçalves, Tiago José. *Elementos de fixação aplicados à troca rápida de ferramenta.*

Gross, John M., and Kenneth R. McInnis. *Kanban made simple demystifying and applying Toyota's legendary manufacturing process*. New York: AMACOM, 2003.

Gulati, Akhilesh. *Improving productivity by applying the concepts of self-service and multidimensionality.*

Harbert, Tam. *"Lean, Mean Six Sigma Machines.(lean six sigma)"*. Design News, December 11, 2006.

Harry, Mikel J. Crawford. *"Six sigma for the little guy: think you can't afford this business initiative? Recent changes have* *made it more affordable and accessible than ever"*. Mechanical Engineering-CIME, November 1, 2004.

Hirano, Hiroyuki. *JIT implementation manual: the complete guide to just-in-time manufacturing*. Boca Raton, Fla.: CRC Press, 2009.

Hoeft, Steve Davey. *"Proactively managing risk: the new "waste". (Risk Management)"*. Defense AT & L, May 1, 2007.

Huda, Fahmia, and David Preston. *"Kaizen: The Applicability Of Japanese Techniques To IT"*. Software Quality Journal 1, no. 1 (1992): 9-26.

Hutchins, David. *Just In Time.* Gower Publishing Ltd., 1999.

Ikovenko, Sergei. *TRIZ as a Lean Thinking Tool.* 2004

Imai, Masaaki. *Kaizen (Ky'zen), the key to Japan's competitive success*. New York: Random House Business Division, 1986.

Imai, Masaaki. *Gemba kaizen a commonsense low-cost approach to management*. New York: McGraw-Hill, 1997.

Ishikawa, Kaoru. *Introduction to Quality Control*. 3A Corporation, 1990.

Jones, Daniel T., and James P. Womack. *Seeing the whole: mapping the extended value stream*. Brookline, MA: Lean Enterprise Inst., 2000.

Kaplan, Stan. *An Introduction To Triz.* Ideation International Inc, 1996.

Kartik Sreedharaam Kumaresan & Muhamad Zameri Mat Saman. *Integration of SMED and TRIZ in Improving Productivity at Semiconductor Industry*.

Kirchner, Matt. *"The Kaizen event: how five weeks of focused planning can lead to a 40% increase in throughput and productivity"*. Products Finishing, July 1, 2010.

Kirchner, Matthew. *"Ensuring Your Next Kaizen Event Is a Colossal Failure: Because Sometimes "What Not to Do" Can Be an Important Lesson"*. Products Finishing, March 1, 2013.

Köksal, Gülser, Aysun Taşeli, Leman Esra Dolgun, and İnci Batmaz. *The Effects of Inspection Error and Rework on Quality Loss for a Nominal-the-best Type Quality Characteristic*. Turkey: EJIE, 2004.

Lasa, Ibon Serrano, Carlos Ochoa Laburu, and Rodolfo de Castro Vila. *"An Evaluation Of The Value Stream Mapping Tool."* Business Process Management Journal 14, no. 1 (2008): 39-52.

Lazalier, Mike. *"Transforming supply chain performance: creation of a lean extended value stream"*. Industrial Engineer, April 1, 2008.

Levinson, William A.. *Henry Ford's lean vision: enduring principles from the first Ford motor plant*. New York, NY: Productivity Press, 2002.

Levy, Dana, Lea Sneider, and Frank Gibney. *Kanban, shop signs of Japan*. New York: Weatherhill, 1983.

Liker, Jeffrey K. and Gary L. Convis. *The Toyota way to lean leadership: achieving and sustaining excellence through leadership development*. New York: McGraw-Hill, 2011.

Lu, David John. *Kanban just-in-time at Toyota: management begins at the workplace*. Rev. ed. Cambridge, Mass.: Productivity Press, 1989.

Maia, Laura Costa, Anabela Carvalho Alves, Celina Pinto Leão. *How could TRIZ tool help continuous improvement efforts of the companies?*. 2012.

Mašín, Ivan, Pavel Jirman. *Systematic creativity for process innovation*.

McIntosh, Richard I.. *Improving Changeover Performance: A Strategy for Becoming a Lean Responsive Manufacturer.* Butterworth-Heinemann, 2001.

Middleton, Peter, Philip S. Taylor, Amy Flaxel, and Ammon Cookson. *"Lean Principles And Techniques For Improving The*

Quality And Productivity Of Software Development Projects: A Case Study". International Journal of Productivity and Quality Management 2, no. 4 (2007): 387.

Miodonski, Bob. *"Lean thinking can reduce waste, costs for service contractors. (Around the Industry)"*. Plumbing & Mechanical, December 1, 2010.

Miyake, Dario Ikuo. *"The Shift from Belt Conveyor Line to Work-cell Based Assembly Systems to Cope with Increasing Demand Variation and Fluctuation in The Japanese Electronics Industries". 2006*.

Modarress, B., A. Ansari, and D. L. Lockwood. *"Kaizen Costing For Lean Manufacturing: A Case Study"*. International Journal of Production Research 43, no. 9 (2005): 1751-1760.

Morgan, John, and Martin Jones. *Lean Six Sigma For Dummies*. 2nd ed. Hoboken: John Wiley & Sons, 2012.

Mudrikova, Andrea Hruskova. *"Logistics of material flow in flexible manufacturing and assembly cell"*. Annals of DAAAM & Proceedings, January 1, 2008.

Ndahi, Hassan B.. *"Lean Manufacturing in a Global and Competitive Market: The Goal Was to Create a Manufacturing Environment That Is Driven by Demand, and That Holds Only a Small Amount of Inventory and Products at Any Given Time"*. The Technology Teacher, November 1, 2006.

Nicholas, John M.. *Competitive manufacturing management: continuous improvement, lean production, customer-focused quality*. Boston: Irwin/McGraw-Hill, 1998.

Ohno, Taiichi. O sistema Toyota de Produção: Além da produção em larga escala. Bookman, 1997.

Ortiz, Chris A.. *Kaizen and kaizen event implementation*. Upper Saddle River, NJ: Prentice Hall, 2009.

Pascal, Denis. *Lean Production Simplified: A Plain-Languague Guide to the World's most powerful Production System.* Taylor & Francis Inc., 2007.

Radovilsky, Zinovy Gotcher. *"JIT purchasing: analyzing survey results. (Just-in-Time purchasing systems)"*. Industrial Management, November 1, 1996.

Raia, Ernest. *"JIT in purchasing: a progress report. (Just-in-time systems)"*. Purchasing, September 14, 1989.

Reinertsen, Donald. *"Let it flow: how lean product development sparked a revolution"*. Industrial Engineer, June 1, 2005.

Rodriguez, Carlos. *"The Value of Lean Sigma in Driving Continuous Improvement: From Floor Space Utilization to Quality, There's Always Room for Improvement*". Printed Circuit Design & Fab, November 1, 2012.

Rother, Mike, and John Shook. *Learning to see: value stream mapping to create value and eliminate muda*. Version 1.1 ed. Brookline, MA: Lean Enterprise Institute, 1998.

Ruffa, Stephen A.. *Going lean how the best companies apply lean manufacturing principles to shatter uncertainty, drive innovation, and maximize profits*. New York: American Management Association, 2008.

Saunders, Mark, Adrian Thornhill, Philip Lewis. *Research Methods For Bussiness Students*. Pearson Higher Education, 2002.

Schonberger, Richard. *World class manufacturing casebook: implementing JIT and TQC*. New York: Free Press, 1987.

Scott, Arthur L.. *"Lean manufacturing in the mill room–improve efficiencies, decrease costs and improve quality (Tech Service)"*. Rubber World, March 1, 2005.

Sekine, Kenichi. *Kaizen for quick changeover: going beyond SMED*. Cambridge, Mass: Productivity Press, 1992.

Sheu, Daniel, Chun Ting Hou. *Innovative Problem Solving and Equipment Re-design through systematic component trimming*.

Shingo, Shigeo. *A revolution in manufacturing: the SMED system*. Stamford, Conn.: Productivity Press, 1985.

Shingo, Shigeo. *Quick changeover for operators: the SMED system*. Portland, Or.: The Press, 1996.

Shinohara, Isao. *NPS, New Production System: JIT crossing industry boundaries*. Cambridge, Mass.: Productivity Press, 1988.

Southworth, Tom. *"Muda, mura, muri"*. Label & Narrow Web, November 1, 2010.

Womack, James P., Daniel T. Jones, Daniel Roos. *The Machine that changed the world*. New York: Maxwell Macmillan International, 1990.

Womack, James P., and Daniel T. Jones. *Lean thinking: banish waste and create wealth in your corporation*. New York, NY: Simon & Schuster, 1996.

ANNEX I – TRIZ 39 FEATURES – IMPROVING & WORSING FEATURES

-Worsening Feature-

Improving Feature	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1: Weight of moving object	*	-	15 8 29 34	-	29 17 38 34	-	29 2 40 28	-	2 8 15 38	8 10 18 37	10 36 37 40	10 14 35 40	1 35 19 39	28 27 18 40	5 34 31 35	-	6 29 4 38	19 1 32	35 12 34 31	-
2: Weight of stationary	-	*	-	10 1 29 35	-	35 30 13 2	-	5 35 14 2	-	8 10 19 35	13 29 10 18	13 10 29 14	26 39 1 40	28 2 10 27	-	2 27 19 6	28 19 32 22	19 32 35	-	18 19 28 1
3: Length of moving object	8 15 29 34	-	*	-	15 17 4	-	7 17 4 35	-	13 4 8	17 10 4	1 8 35	1 8 10 29	1 8 15 34	8 35 29 34	19	-	10 15 19	32	8 35 24	-
4: Length of stationary	-	35 28 40 29	-	*	-	17 7 10 40	-	35 8 2 14	-	28 10	1 14 35	13 14 15 7	39 37 35	15 14 28 26	-	1 10 35	3 35 38 18	3 25	-	-
5: Area of moving object	2 17 29 4	-	14 15 18 4	-	*	-	7 14 17 4	-	29 30 4 34	19 30 35 2	10 15 36 28	5 34 29 4	11 2 13 39	3 15 40 14	6 3	-	2 15 16	15 32 19 13	19 32	-
6: Area of stationary	-	30 2 14 18	-	26 7 9 39	-	*	-	-	-	1 18 35 36	10 15 36 37	-	2 38	40	-	2 10 19 30	35 39 38	-	-	-
7: Volume of moving object	2 26 29 40	-	1 7 4 35	-	1 7 4 17	-	*	-	29 4 38 34	15 35 36 37	6 35 36 37	1 15 29 4	28 10 1 39	9 14 15 7	6 35 4	-	34 39 10 18	2 13 10	35	-
8: Volume of stationary	-	35 10 19 14	19 14	35 8 2 14	-	-	-	*	-	2 18 37	24 35	7 2 35	34 28 35 40	9 14 17 15	-	35 34 38	35 6 4	-	-	-
9: Speed	2 28 13 38	-	13 14 8	-	29 30 34	-	7 29 34	-	*	13 28 15 19	6 18 38 40	35 15 18 34	28 33 1 18	8 3 26 14	3 19 35 5	-	28 30 36 2	10 13 19	8 15 35 38	-
10: Force (Intensity)	8 1 37 18	18 13 1 28	17 19 9 36	28 10	19 10 15	1 18 36 37	15 9 12 37	2 36 18 37	13 28 15 12	*	18 21 11	10 35 40 34	35 10 21	35 10 14 27	19 2	-	35 10 21	-	19 17 10	1 16 36 37
11: Stress or pressure	10 36 37 40	13 29 10 18	35 10 36	35 1 14 16	10 15 36 28	10 15 36 37	6 35 10	35 24	6 35 36	36 35 21	*	35 4 15 10	35 33 2 40	9 18 3 40	19 3 27	-	35 39 19 2	-	14 24 10 37	-
12: Shape	8 10 29 40	15 10 26 3	29 34 5 4	13 14 10 7	5 34 4 10	-	14 4 15 22	7 2 35	35 15 34 18	35 10 37 40	34 15 10 14	*	33 1 18 4	30 14 10 40	14 26 9 25	-	22 14 19 32	13 15 32	2 6 34 14	-
13: Stability of the object	21 35 2 39	26 39 1 40	13 15 1 28	37	2 11 13	39	28 10 19 39	34 28 35 40	33 15 28 18	10 35 21 16	2 35 40	22 1 18 4	*	17 9 15	13 27 10 35	39 3 35 23	35 1 32	32 3 27 16	13 19	27 4 29 18
14: Strength	1 8 40 15	40 26 27 1	1 15 8 35	15 14 28 26	3 34 40 29	9 40 28	10 15 14 7	9 14 17 15	8 13 26 14	10 18 3 14	10 3 18 40	10 30 35 40	13 17 35	*	27 3 26	-	30 10 40	35 19	19 35 10	35
15: Durability of moving obj.	19 5 34 31	-	2 19 9	-	3 17 19	-	10 2 19 30	-	3 35 5	19 2 16	19 3 27	14 26 28 25	13 3 35	27 3 10	*	-	19 35 39	2 19 4 35	28 6 35 18	-
16: Durability of non moving obj.	-	6 27 19 16	-	1 40 35	-	-	-	35 34 38	-	-	-	-	39 3 35 23	-	-	*	19 18 36 40	-	-	-
17: Temperature	36 22 6 38	22 35 32	15 19 9	15 19 9	3 35 39 18	35 38	34 39 40 18	35 6 4	2 28 36 30	35 10 3 21	35 39 19 2	14 22 19 32	1 35 32	10 30 22 40	19 13 39	19 18 36 40	*	32 30 21 16	19 15 3 17	-
18: Illumination intensity	19 1 32	2 35 32	19 32 16	-	19 32 26	-	2 13 10	-	10 13 19	26 19 6	-	32 30	32 3 27	35 19	2 19 6	-	32 35 19	*	32 1 19	32 35 1 15
19: Use of energy by moving	12 18 28 31	-	12 28	-	15 19 25	-	35 13 18	-	8 35	16 26 21 2	23 14 25	12 2 29	19 13 17 24	5 19 9 35	28 35 6 18	-	19 24 3 14	2 15 19	*	-
20: Use of energy by stationary	-	19 9 6 27	-	-	-	-	-	-	-	36 37	-	-	27 4 29 18	35	-	-	-	19 2 35 32	-	*
21: Power	8 36 38 31	19 26 17 27	1 10 35 37	-	19 38	17 32 13 38	35 6 38	30 6 25	15 35 2	26 2 36 35	22 10 35	29 14 2 40	35 32 15 31	26 10 28	19 35 10 38	16	2 14 17 25	16 6 19	16 6 19 37	-
22: Loss of Energy	15 6 19 28	19 6 18 9	7 2 6 13	6 38 7	15 26 17 30	17 7 30 18	7 18 23	7	16 35 38	36 38	-	-	14 2 39 6	26	-	-	19 38 7	1 13 32 15	-	-
23: Loss of substance	35 6 23 40	35 6 22 32	14 29 10 39	10 28 24	35 2 10 31	10 18 39 31	1 29 30 36	3 39 18 31	10 13 28 38	14 15 18 40	3 36 37 10	29 35 3 5	2 14 30 40	35 28 31 40	28 27 3 18	27 16 18 38	21 36 39 31	1 6 13	35 18 24 5	28 27 12 31
24: Loss of Information	10 24 35	10 35 5	1 26	26	30 26	30 16	-	2 22	26 32	-	-	-	-	-	10	10	-	19	-	-
25: Loss of Time	10 20 37 35	10 20 26 5	15 2 29	30 24 14 5	26 4 5 16	10 35 17 4	2 5 34 10	35 16 32 18	-	10 37 36 5	37 36 4	4 10 34 17	35 3 22 5	29 3 28 18	20 10 28 18	28 20 10 16	35 29 21 18	1 19 26 17	35 38 19 18	1
26: Quantity of substance/the	35 6 18 31	27 26 18 35	29 14 35 18	-	15 14 29	2 18 40 4	15 20 29	-	35 29 34 28	35 14 3	10 36 14 3	35 14	15 2 17 40	14 35 34 10	3 35 10 40	3 35 31	3 17 39	-	34 29 16 18	3 35 31
27: Reliability	3 8 10 40	3 10 8 28	15 9 14 4	15 29 28 11	17 10 14 16	32 35 40 4	3 10 14 24	2 35 24	21 35 11 28	8 28 10 3	10 24 35 19	35 1 16 11	-	11 28	2 35 3 25	34 27 6 40	3 35 10	11 32 13	21 11 27 19	36 23
28: Measurement accuracy	32 35 26 28	28 35 25 26	28 26 5 16	32 28 3 16	26 28 32 3	26 28 32 3	32 13 6	-	28 13 32 24	32 2	6 28 32	6 28 32	32 35 13	28 6 32	28 6 32	10 26 24	6 19 28 24	6 1 32	3 6 32	-
29: Manufacturing precision	28 32 13 18	28 35 27 9	10 28 29 37	2 32 10	28 33 29 32	2 29 18 36	32 23 2	25 10 35	10 28 32	28 19 34 36	3 35	32 30 40	30 18	3 27	3 27 40	-	19 26	3 32	32 2	-
30: Object-affected harmful	22 21 27 39	2 22 13 24	17 1 39 4	1 18	22 1 33 28	27 2 39 35	22 23 37 35	34 39 19 27	21 22 35 28	13 35 39 18	22 2 37	22 1 3 35	35 24 30 18	18 35 37 1	22 15 33 28	17 1 40 33	22 33 35 2	1 19 32 13	1 24 6 27	10 2 22 37
31: Object-generated harmful	19 22 15 39	35 22 1 39	17 15 16 22	-	17 2 18 39	22 1 40	17 2 40	30 18 35 4	35 28 3 23	35 28 1 40	2 33 27 18	35 1	35 40 27 39	15 35 22 2	15 22 33 31	21 39 16 22	22 35 2 24	19 24 39 32	2 35 6	19 22 18
32: Ease of manufacture	28 29 15 16	1 27 36 13	1 29 13 17	15 17 27	13 1 26 12	16 40	13 29 1 40	35	35 13 8 1	35 12	35 19 1 37	1 28 13 27	11 13 1	1 3 10 32	27 1 4	35 16	27 26 18	28 24 27 1	28 26 27 1	1 4
33: Ease of operation	25 2 13 15	6 13 1 25	1 17 13 12	-	1 17 13 16	18 16 15 39	1 16 35 15	4 18 39 31	18 13 34	28 13 35	2 32 12	15 34 29 28	32 35 30	32 40 3 28	29 3 8 25	1 16 25	26 27 13	13 17 1 24	1 13 24	-
34: Ease of repair	2 27 35 11	2 27 35 11	1 28 10 25	3 18 31	15 13 32	16 25	25 2 35 11	1	34 9	1 11 10	13	1 13 2 4	2 35	11 1 2 9	11 29 28 27	1	4 10	15 1 13	15 1 28 16	-
35: Adaptability or versatility	1 6 15 8	19 15 29 16	35 1 29 2	1 35 16	35 30 29 7	15 16	15 35 29	-	35 10 14	15 17 20	35 16	15 37 1 8	35 30 14	35 3 32 6	13 1 35	2 16	27 2 3 35	6 22 26 1	19 35 29 13	-
36: Device complexity	26 30 34 36	2 26 35 39	1 19 26 24	26	14 1 13 16	6 36	34 26 6	1 16	34 10 28	26 16	19 1 35	29 13 28 15	2 22 17 19	2 13 28	10 4 28 15	-	2 17 13	24 17 13	27 2 29 28	-
37: Difficulty of detecting	27 26 28 13	6 13 28 1	16 17 26 24	26	2 13 18 17	2 39 30 16	29 1 4 16	2 18 26 31	3 4 16 35	30 28 40 19	35 36 37 32	27 13 1 39	11 22 39 30	27 3 15 28	19 29 39 25	25 34 6 35	3 27 35 16	2 24 26	35 38	19 35 16
38: Extent of automation	28 26 18 35	28 26 35 10	14 13 17 28	23	17 14 13	-	35 13 16	-	28 10	2 35	13 35	15 32 1 13	18 1	25 13	6 9	-	26 2 19	8 32 19	2 32 13	-
39: Productivity	35 26 24 37	28 27 15 3	18 4 28 38	30 7 14 26	10 26 34 31	10 35 17 7	2 6 34 10	35 37 10 2	-	28 15 10 36	10 37 14	14 10 34 40	35 3 22 39	29 28 10 18	35 10 2 18	20 10 16 38	35 21 28 10	26 17 19 1	35 10 38 19	1

Improving Feature	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
1: Weight of moving object	12 36 18 31	6 2 34 19	5 35 3 31	10 24 35	10 35 20 28	3 26 18 31	1 3 11 27	28 27 35 26	28 35 26 18	22 21 18 27	22 35 31 39	27 28 1 36	35 3 2 24	2 27 28 11	29 5 15 8	26 30 36 34	28 29 26 32	26 35 18 19	35 3 24 37
2: Weight of stationary	15 19 18 22	18 19 28 15	5 8 13 30	10 15 35	10 20 35 26	19 6 18 26	10 28 8 3	18 26 28	10 1 35 17	2 19 22 37	35 22 1 39	28 1 9	6 13 1 32	2 27 28 11	19 15 29	1 10 26 39	25 28 17 15	2 26 35	1 28 15 35
3: Length of moving object	1 35	7 2 35 39	4 29 23 10	1 24	15 2 29	29 35	10 14 29 40	28 32 4	10 28 29 37	1 15 17 24	17 15	1 29 17	15 29 35 4	1 28 10	14 15 1 16	1 19 26 24	35 1 26 24	17 24 26 16	14 4 28 29
4: Length of stationary	12 8	6 28	10 28 24 35	24 26	30 29 14	-	15 29 28	32 28 3	2 32 10	1 18	-	15 17 27	2 25	3	1 35	1 26	26	-	30 14 7 26
5: Area of moving object	19 10 32 18	15 17 30 26	10 35 2 39	30 26	26 4	29 30 6 13	29 9	26 28 32 3	2 32	22 33 28 1	17 2 18 39	13 1 26 24	15 17 13 16	15 13 10 1	15 30	14 1 13	2 36 26 18	14 30 28 23	10 26 34 2
6: Area of stationary	17 32	17 7 30	10 14 18 39	30 16	10 35 4 18	2 18 40 4	32 35 40 4	26 28 32 3	2 29 18 36	27 2 39 35	22 1 40	40 16	16 4	16	15 16	1 18 36	2 35 30 18	23	10 15 17 7
7: Volume of moving object	35 6 13 18	7 15 13 16	36 39 34 10	2 22	2 6 34 10	29 30 7	14 1 40 11	25 26 28	25 28 2 16	22 21 27 35	17 2 40 1	29 1 40	15 13 30 12	10	15 29	26 1	29 26 4	35 34 16 24	10 6 2 34
8: Volume of stationary	30 6	-	10 39 35 34	-	35 16 32 18	35 3	2 35 16	-	35 10 25	34 39 19 27	30 18 35 4	35	-	1	-	1 31	2 17 26	-	35 37 10 2
9: Speed	19 35 38 2	14 20 19 35	10 13 28 38	13 26	-	10 19 29 38	11 35 27 28	28 32 1 24	10 28 32 25	1 28 35 23	2 24 35 21	35 13 8 1	32 28 13 12	34 2 28 27	15 10 26	10 28 4 34	3 34 27 16	10 18	-
10: Force (Intensity)	19 35 18 37	14 15	8 35 40 5	-	10 37 36	14 29 18 36	3 35 13 21	35 10 23 24	28 29 37 36	1 35 40 18	13 3 36 24	15 37 18 1	1 28 3 25	15 1 11	15 17 18 20	26 35 10 18	36 37 10 19	2 35	3 28 35 37
11: Stress or pressure	10 35 14	2 36 25	10 36 3 37	-	37 36 4	10 14 36	10 13 19 35	6 28 25	3 35	22 2 37	2 33 27 18	1 35 16	11	2	35	19 1 35	2 36 37	35 24	10 14 35 37
12: Shape	4 6 2	14	35 29 3 5	-	14 10 34 17	36 22	10 40 16	28 32 1	32 30 40	22 1 2 35	35 1	1 32 17 28	32 15 26	2 13 1	1 15 29	16 29 1 28	15 13 39	15 1 32	17 26 34 10
13: Stability of the object	32 35 27 31	14 2 39 6	2 14 30 40	-	35 27	15 32 35	-	13	18	35 24 30 18	35 40 27 39	35 19	32 35 30	2 35 10 16	35 30 34 2	2 35 22 26	35 22 39 23	1 8 35	23 35 40 3
14: Strength	10 26 35 28	35	35 28 31 40	-	29 3 28 10	29 10 27	11 3	3 27 16	3 27	18 35 37 1	15 35 22 2	11 3 10 32	32 40 25 2	27 11 3	15 3 32	2 13 25 28	27 3 15 40	15	29 35 10 14
15: Durability of moving obj.	19 10 35 38	-	28 27 3 18	10	20 10 28 18	3 35 10 40	11 2 13	3	3 27 16 40	22 15 33 28	21 39 16 22	27 1 4	12 27	29 10 27	1 35 13	10 4 29 15	19 29 39 35	6 10	35 17 14 19
16: Durability of non moving obj.	16	-	27 16 18 38	10	28 20 10 16	3 35 31	34 27 6 40	10 26 24	-	17 1 40 33	22	35 10	1	1	2	-	25 34 6 35	1	20 10 16 38
17: Temperature	2 14 17 25	21 17 35 38	21 36 29 31	-	35 28 21 18	3 17 30 39	19 35 3 10	32 19 24	24	22 33 35 2	22 35 2 24	26 27	26 27	4 10 16	2 18 27	2 17 16	3 27 35 31	26 2 19 16	15 28 35
18: Illumination intensity	32	13 16 1 6	13 1	1 6	19 1 26 17	1 19	-	11 15 32	3 32	15 19	35 19 32 39	19 35 28 26	28 26 19	15 17 13 16	15 1 19	6 32 13	32 15	2 26 10	2 25 16
19: Use of energy by moving	6 19 37 18	12 22 15 24	35 24 18 5	-	35 38 19 18	34 23 16 18	19 21 11 27	3 1 32	-	1 35 6 27	2 35 6	28 26 30	19 35	1 15 17 28	15 17 13 16	2 29 27 28	35 38	32 2	12 28 35
20: Use of energy by stationary	-	-	28 27 18 31	-	-	3 35 31	10 36 23	-	-	10 2 22 37	19 22 18	1 4	-	-	-	-	19 35 16 25	-	1 6
21: Power	*	10 35 38	28 27 18 38	10 19	35 20 10 6	4 34 19	19 24 26 31	32 15 2	32 2	19 22 31 2	2 35 18	26 10 34	26 35 10	35 2 10 34	19 17 34	20 19 30 34	19 35 16	28 2 17	28 35 34
22: Loss of Energy	3 38	*	35 27 2 37	19 10	10 18 32 7	7 18 25	11 10 35	32	-	21 22 35 2	21 35 2 22	-	35 32 1	2 19	-	7 23	35 3 15 23	2	28 10 29 35
23: Loss of substance	28 27 18 38	35 27 2 31	*	-	15 18 35 10	6 3 10 24	10 29 39 35	16 34 31 28	35 10 24 31	33 22 30 40	10 1 34 29	15 34 33	32 28 2 24	2 35 34 27	15 10 2	35 10 28 24	35 18 10 13	35 10 18	28 35 10 23
24: Loss of Information	10 19	19 10	-	*	24 26 28 32	24 28 35	10 28 23	-	-	22 10 1	10 21 22	32	27 22	-	-	-	35 33	35	13 23 15
25: Loss of Time	35 20 10 6	10 5 18 32	35 18 10 39	24 26 28 32	*	35 38 18 16	10 30 4	24 34 28 32	24 26 28 18	35 18 34	35 22 18 39	35 28 34 4	4 28 10 34	32 1 10	35 28	6 29	18 28 32 10	24 28 35 30	-
26: Quantity of substance/the	35	7 18 25	6 3 10 24	24 28 35	35 38 18 16	*	18 3 28 40	13 2 28	33 30	35 33 29 31	3 35 40 39	29 1 35 27	35 29 25 10	2 32 10 25	15 3 29	3 13 27 10	3 27 29 18	8 35	13 29 3 27
27: Reliability	21 11 26 31	10 11 35	10 35 29 39	10 28	10 30 4	21 28 40 3	*	32 3 11 23	11 32 1	27 35 2 40	35 2 40 26	-	27 17 40	1 11	13 35 8 24	13 35 1	27 40 28	11 13 27	1 35 29 38
28: Measurement accuracy	3 6 32	26 32 27	10 16 31 28	-	24 34 28 32	2 6 32	5 11 1 23	*	-	28 24 22 26	3 33 39 10	6 35 25 18	1 13 17 34	1 32 13 11	13 35 2	27 35 10 34	26 24 32 28	28 2 10 34	10 34 28 32
29: Manufacturing precision	32 2	13 32 2	35 31 10 24	-	32 26 28 18	32 30	11 32 1	-	*	26 28 10 36	4 17 34 26	-	1 32 35 23	25 10	-	26 2 18	-	26 28 18 23	10 18 32 39
30: Object-affected harmful	19 22 31 2	21 22 35 2	33 22 19 40	22 10 2	35 18 34	35 33 29 31	27 24 2 40	28 33 23 26	26 28 10 18	*	-	24 35 2	2 25 28 39	35 10 2	35 11 22 31	22 19 29 40	22 19 29 40	33 3 34	22 35 13 24
31: Object-generated harmful	2 35 18	21 35 2 22	10 1 34	10 21 29	1 22	3 24 39 1	24 2 40 39	3 33 26	4 17 34 26	-	*	-	-	-	-	19 1 31	2 21 27 1	2	22 35 18 39
32: Ease of manufacture	27 1 12 24	19 35	15 34 33	32 24 18 16	35 28 34 4	35 23 1 24	-	1 35 12 18	-	24 2	-	*	2 5 13 16	35 1 11 9	2 13 15	27 26 1	6 28 11 1	8 28 1	35 1 10 28
33: Ease of operation	35 34 2 10	2 19 13	28 32 2 24	4 10 27 22	4 28 10 34	12 35	17 27 8 40	25 13 2 34	1 32 35 23	2 25 28 39	-	2 5 12	*	12 26 1 32	15 34 1 16	32 26 12 17	-	1 34 12 3	15 1 28
34: Ease of repair	15 10 32 2	15 1 32 19	2 35 34 27	-	32 1 10 25	2 28 10 25	11 10 1 16	10 2 13	25 10	35 10 2 16	-	1 35 11 10	1 12 26 15	*	7 1 4 16	35 1 13 11	-	34 35 7 13	1 32 10
35: Adaptability or versatility	19 1 29	18 15 1	15 10 2 13	-	35 28	3 35 15	35 13 8 24	35 5 1 10	-	35 11 32 31	-	1 13 31	15 34 1 16	1 16 7 4	*	15 29 37 28	1	27 34 35	35 28 6 37
36: Device complexity	20 19 30 34	10 35 13 2	35 10 28 29	-	6 29	13 3 27 10	13 35 1	2 26 10 34	26 24 32	22 19 29 40	19 1	27 26 1 13	27 9 26 24	1 13	29 15 28 37	*	15 10 37 28	15 1 24	12 17 28
37: Difficulty of detecting	18 1 16 10	35 3 15 19	1 18 10 24	35 33 27 22	18 28 32 9	3 27 29 18	27 40 28 8	26 24 32 28	-	22 19 29 28	2 21	5 28 11 29	2 5	12 26	1 15	15 10 37 28	*	34 21	35 18
38: Extent of automation	28 2 27	23 28	35 10 18 5	35 33	24 28 35 30	35 13	11 27 32	28 26 10 34	28 26 18 23	2 33	2	1 26 13	1 12 34 3	1 35 13	27 4 1 35	15 24 10	34 27 25	*	5 12 35 26
39: Productivity	35 20 10	28 10 29 35	28 10 35 23	13 15 23	-	35 38	1 35 10 38	1 10 34 28	18 10 32 1	22 35 13 24	35 22 18 39	35 28 2 24	1 28 7 10	1 32 10 25	1 35 28 37	12 17 28 24	35 18 27 2	5 12 35 26	*

Figure 41 - Improving & Worsing Features

Site 1 - http://www.triz40.com/aff_Matrix.htm