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The Relationship between Lean and TPM

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Abstract:

Total Productive Maintenance(TPM) is mostly regarded as an integral part of Lean Manufacturing. Some authors considered TPM as a Lean tool but it always has been a matter of controversy.

The role of TPM in maintenance is similar and comparable to Total Quality Management (TQM) in Quality. TPM involves Autonomous and Planned Maintenance. Planned Maintenance consists of several maintenance strategies. Autonomous maintenance includes simple maintenance tasks done by the operators.

The aim of this thesis is to reach a prescription about the best attitude toward Lean and TPM implementation by reviewing Lean and TPM concepts as well as studying experiences of famous companies, their achievements, problems and difficulties to implement TPM

Two companies which had implemented TPM without considering Lean were investigated. Although these companies had implemented TPM before Lean, they now believe that a company should start with Lean and grow Lean thinking among the employees. In this way a company should start with recognizing the relationship and implementation sequence of Lean and TPM. In this thesis, Lean and TPM comparison supports this approach since it proves that Lean and TPM have some common tools and concepts. The comparison also supports the belief that Lean is a philosophy and TPM is a method.

Key words: TPM, Lean, Quality, Implementation, Maintenance

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1. Introduction

1.1 Background

It has been a controversial subject about how Lean and Total Productive maintenance (TPM) are related.

Some experts say that Lean is a complex of many tools, which one of them is TPM. They think that since the goal of TPM is increasing productivity and efficiency of equipments, this ultimately results in fewer losses and defects, which leads to less waste. Lowering wastage is the goal of Lean. Based on this idea Lean is a culture which paves the way to reach excellence namely in manufacturing, and TPM is a tool. (Lars Arrenäs, 2009)

Other experts believe that although Lean and TPM have something in common, but, due to wide extent of TPM and its focus on all levels of the organization from management to the workers, it could be regarded as a separated concept, but it will be more effective if it is implemented together with Lean.

TPM is structured based on 5S, which is one of the Lean tools and consists of several pillars requiring total employees participation culture with focus on operators. (Robert M. Williamson, 2006)

Therefore, the fundamental question to the companies has been; which one should they start with, Lean or TPM? In addition, what is the best prescription for TPM and Lean implementation and exploitation?

1.2 Research Question and project objective

The purpose of this work is:

Firstly, a thorough review of Lean and TPM concepts with regard to differences in definitions to reach a common view and perception about Lean and TPM, which could be accepted by the related experts

Secondly, finding what, Lean and TPM have to do with each other, similarities, differences, overlaps, weaknesses and their focus

Thirdly, providing companies who want to implement both Lean and TPM with a solution for better implementation to prevent re and over-doing and mistakes in adopting implementation sequences that can lead to wastage in organization resources and time

1.3 Methodology

Since Lean and TPM are mostly implemented in manufacturing companies, a part of the thesis will be conducted via site visits and interviews with experts in both Iranian and Swedish companies, which have implemented Lean and TPM. To get a better result, the companies will answer a questionnaire composed of questions about their experiences during Lean and TPM implementation. The purpose is to see how much the companies are successful in meeting Lean and TPM criteria, difficulties faced during Lean and TPM implementation and which Lean tools and TPM pillars are mostly under focus.

One chapter (2) is dedicated to the theoretical framework in which Lean and TPM are introduced in order to get a thorough overlook of them and search for critical concepts as well as points that may not be taken into consideration during implementation.

The chapter will help to point out pitfalls and drawbacks during the implementation processes of Lean and TPM. All the information in this chapter is gathered through literature reviews from books, websites and articles.

The other method of this research is regular meetings and discussion with the thesis supervisor.

Finally, Findings gained from the previous parts will be used for analysis and conclusion.

1.4 Delimitation

Major limitations for this work raised in the following formats:

Due to nature of the topic, it needs gathering of practical data through interviews, meetings and discussions with experts in order to exchange experiences in this way. It was hard to arrange some visits in organizations like SKF and there were some limitations for data transferring about improvements and results, which they regard them confidential. In addition, there is a lack of statistical and practical data about the results of TPM and Lean implementation, consequent improvements. Moreover, Different assumptions and theories for instance, controversies about the number of TPM pillars exist.

2. Theoretical Framework

It is an essential and fundamental fact that employees desire to eliminate waste. This fact has existed for a long time but nowadays this philosophy has a close relationship with Lean.

In this regard, we definitely need to consider the most valuable asset of the companies, the employees.

In order to take waste to the lowest possible point, companies need to develop and nurture employee skills. These skills include not only hands and operational skills but also team working, brain storming and problem solving that will affect processes and equipments' functions in form of raising the speed, precision and automation. By Lean thinking, waste could be eliminated in all its formats resulting in higher quality, shorter lead-time and ultimately customers' satisfaction and trust.

TPM is a tool for achieving the above-mentioned goal. Like Lean, it requires employees' involvement in all levels throughout the organization. Lean goals are not achievable without reliable machinery and processes, on the other hand, TPM is more effective in Lean driven enterprises. (Dennis McCarthy, Nick Rich, 2004)

In this chapter the focus shall be on the relationship between Lean and TPM, by comparing their goals and principles as well as how Lean and TPM can strengthen each other's results in order to reach sustainable growth of the organization.

2.1 Lean

Lean is a systematic approach and a combination of several techniques in order to identify and eliminate waste, which leads to continuous improvement and ultimately excellent performance.

Lean has a direct effect on a company's culture. Lean puts a big emphasis the role of employees. Without the help of employees, any change especially sustainable one seems to be out of reach. After a thorough implementation of Lean, improvements can be observed in the fields of how employees perform their job, the relationship between employees and management, team-working ability, reactions to changes, etc.

2.1.1 Lean results

Experiences in the companies that have implemented Lean have shown that Lean has a comprehensive influence on a company due to positive changes in:

- Encouraging the commitment of the whole company toward continuous improvement
- Focusing on customer requirements and expectations due to Pull point of view
- Morale of the Employees
- Value added activities ("Value added activities change the form, fit or function of a product or service. These are things for which the customer is willing to pay" (Kaye Krueger, 2004))
- Identifying and eliminating wastes namely those actions that customer is not willing to pay for
- Reducing lead times, costs and inventories
- Work force empowerment

- Quality of products and services
- Management and employees relationship
- Change over duration
- Effective teamwork and productivity
- Neatness and space usage (Word press.com, 2008), (MAMTC, 2009)

2.1.2 History of Lean manufacturing

After a short visit at Ford Company by Eiji Toyoda and getting more familiar with flow production, Taiichi Ohno founded Toyota Production System (TPS). In 1913, Henry Ford had invented Flow Production system, which is an integration of consistently interchangeable parts with moving conveyor belt and standard work. It was a real revolution from traditional shop practices to a new one. Ford lined up the machines within the process wherever possible and used check on points in order to have fitting parts forwarded to the line side. The problem with the Ford system was that it was unable to provide variety when the market begun to demand more models. Every machine in the line was customized to produce special parts and there were no changeovers to make the machines able to produce different parts.

In the 1930s and after the 2nd world war, Kiichiro Toyoda, Taiichi Ohno, and engineers at Toyota looked into the Ford way of thinking. They revised the Ford method and invented TPS. TPS is a combination of solutions resulting in flow of the product in the process using lined up the machines throughout the process with the ability to be changed over very fast, Quality controls and Pull system. In a pull system, each step will provide the next one with demanding materials only.

A thorough definition of Lean is in the book The Machine That Changed the World (1990) by James P. Womack, Daniel Roos, and Daniel T. Jones. In the subsequent book Lean Thinking (1996) by James P. Womack and Daniel T. Jones they developed Lean principles.

- Specify value: value should be defined for individual products and services while sticking to the customer desires

- Identify the value stream: Value stream is series of activities, operations and processes which constitute production process starting from order placement to product delivery to the customer and including both value-adding and non-value adding activities. Identifying the entire value stream of a product or service is a prerequisite to eliminate non-value adding activities

- Flow: After value stream mapping, the product should flow continuously through value-creating activities

- Pull system: Instead of forecasting and pushing unwanted products to the customer, the pull system responds to the customer's actual demands and needs. The result is lower waste in cases of handling, storing and getting the products to the customer.

- Continue perfection: the concept induces reduction in number of production steps and the amount of time & information while making the product closer to what the customer actually wants. (Lean enterprise institute, 2009), (Lean manufacturing concepts, 2008)

2.1.3 Why do companies implement Lean?

Experts of Manufacturing Extension Partnership (MEP) with NIST (National Institute of Standards and Technology in Wyoming, USA believe that reasons of Lean implementation are:

- Better quality achievement starting from identifying customer's expectations and designing processes, which meet customer requirements and expectations
- Waste Elimination: Waste is any activity that does not add value to the product or service
- Lead time Reduction which helps a Lean enterprise deliver the products to the customer in a shorter time
- Reducing total costs, both direct and indirect (manufacturing-works, 2008)

2.1.4 Types of waste

Waste is classified into eight categories:

- Defects: Instead of inspection, finding and repairing defects, they must be prevented from occurrence. Defects emerge from one or more of these items:

- Poor product design
- Misunderstanding of customer needs
- Lack of some skills and work instructions
- Unsatisfactory planned maintenance
- Low quality
- Shortages of process controls

- Waiting time: Down-stream (Next) activity is stopped and equipments are idle due to delay in delivery from an upstream (previous) activity. Causes of waiting time include:

- Lack of balance between processes namely engineering, workload, automation, scheduling, etc
- Long set up times
- Unplanned maintenance
- Lack of redundancy wherever possible
- Quality problems in upstream processes

- Over production (producing more, earlier or sooner than next workstation demand results in larger inventory and costs)

Causes of over production are:

- Just in case logic
- Lack of feedbacks from downstream processes
- Lack of balance between processes namely engineering, workload, automation, scheduling, etc

- Transportation: This word refers to transportation within Work-In-Process (WIP) and occurs because of reasons like weak plant layout and shortage of understanding of production or process flow. It should be lowered as much as possible or even be eliminated e.g. by means of Work Cells because it adds no value to the product.

A Work Cell can be defined as: “Physical or logical arrangement of all resources (employees, machines, material) associated with the performance of an activity, job, or task.” (Business dictionary.com)

- Inventory (Excess raw materials, finished products and WIP):

Although Inventory is a general term, but here it means type of inventory, which is not required to meet customer needs directly. In addition, more space and handling is needed. Inventory can be result of one of the following items:

- Poor communication

- Inadequate market forecasts

- Just in case logic

- Fluctuations in material procurement

- Poor scheduling

- Unused creativity (Failure in exploiting the knowledge and unique abilities of the employees):

Basis of unused creativity:

- Resistance to change

- Failure in employees’ involvement

- Low/no attention to training

- Over processing (Parts of processes that create no added-value to the product or service should be identified and eliminated)

This term may appear in forms of rework, excess inventory, reprocessing, etc. In other words, it is doing more than what the customer demands and is willing to pay for.

- Movement (Extra transportation due to wrong location of equipments and tools)

It can emerge due to one of the following causes:

- Low effectiveness of machines and employees

- Bad layout or unfavorable facilities

- Poor floor shop organization (EMS Consulting Group, 2003), (Wisc-online.com, 2004), (BERR, SWREA, 2007)

2.1.5 Lean benefits

Lean is a good solution to the following challenges:

- High cost of production
- Market share going down due to product cost and delivery time
- Missed order dates

Although the results are different from company to company, it has been shown that the following improvements are common (MAMTC, 2008):

- ***Decrease***:

- WIP 60%-80%

- Space needed for activities	5%-30%
- Manufacturing Lead time	50%-90%
- Rejected pieces	50%-100%

- ***Increase:***

- Product throughput	40%-80%
- Productivity	75%-125%

2.1.6 Lean tools and techniques

1. 5S

This method tries to make work environment well organized, clean and efficient in order to increase productivity and maintenance quality. 5S like other improvement techniques requires both employees' involvement and management commitment. 5S must be separately tailored to each department and needs to be implemented gradually to reach the best results. The most common pitfall in 5S implementation is that companies fail to teach 5S to the employees in the beginning. Top management and steering group members should have the practical knowledge of 5S implementation. A thorough review of 5S, the principles of 5S implementation, the team working concepts and the role of management are important subjects that should be presented. Practical exercises or some pilot projects must be included in the training program as well.

If top management and steering group start 5S from their office, they will have the chance to get more familiar with the issues that should be addressed during implementation of 5S. Another benefit is that it will show commitment of the management toward a company-wide 5S program (EMS Consulting Group, 2003).

Consequently, the management must support 5S program by approving and setting dates for implementation.

The following S's constitute 5S:

- Sort (Seiri): Put everything right in order. Get rid of not needed things

The aim is organization. This process requires employees to remove all items, which are not needed for work. In the beginning, it seems very difficult for employees to get rid of such items .They get used to keep things for just in case purposes. Red tagging is one solution that helps employees find out the frequency of using items and their usefulness. Then employees can decide to return, store elsewhere, sell, give away or throw away the items. The optimum time for red tagging is one or two days.

Benefits of red tagging:

- Problems, disturbances and confusions are reduced
- Improves communication among the employees
- Product quality is increased
- Enhances productivity (EMS Consulting Group, 2003), (Siliconfareast.com, 2000), (Six Sigma community, 2000)

- Set in order (Seiton) - Proper Arrangement: Organize things in such a way that they are easily at your disposal

The goal is maximizing efficiency. The effect of the first two S's will be strengthened when they are implemented together. By putting everything in the right place and

labeling, everyone can find what he/she needs in the area, thus, the result is less human energy and time consumed to find things and less inventory. (EMS Consulting Group, 2003), (Siliconfareast.com, 2000)

- Shine (Seiso): Clean and polish things regularly in the workshop

If this work becomes a daily habit, tools could be kept in top condition and they will be ready for use at any time. The goal is having a bright place in which everyone enjoys working. Reviewing the previous S's and finding sources of dirt, litter and their elimination are other results. (EMS Consulting Group, 2003), (Siliconfareast.com, 2000)

- Standardize (Seiketsu): Standardize the way of maintaining cleanliness.

This part is a simultaneous work with the first 3 steps in order to check and plan continuous improvements. It consists of defining some procedures and daily check lists. The purpose of checklists is to monitor whether 5S requirements are daily met. Standardization integrates Sort, Set in order and Shine into a whole. (EMS Consulting Group, 2003), (Siliconfareast.com, 2000)

- Sustain (Shitsuke) – it also means commitment: Be enthusiastic about what you have done and maintain it. All employees in the organization should be motivated to follow the rules of 5S. This could be achieved by sharing values. Shared values are gained by coaching and employees participation. Achievements in 5S cannot be kept sustainable by any authoritarian activity and penalties imposed on the employees. (EMS Consulting Group, 2003), (Siliconfareast.com, 2000)

2. Error and mistake proofing (Poka-Yoke)

Do not let errors to get through the next operation. This error-free approach leads to scrap and rework reduction. Poka-Yoke tries to prevent defects before their occurrence by ensuring that good conditions exist before a process starts. If prevention is not possible, Poka-Yoke is performed through detective action to identify defects as soon as possible. (Lisa Somanchi, 2008)

"a poka-yoke can be electrical, mechanical, procedural, visual, human or any other form that prevents incorrect execution of a process step." (Lisa Somanchi, 2008)

3. Just In Time (JIT)

Producing the right part at the right time in the right place to meet the customer demand

In the JIT system, needed parts are pulled in small batches from other processes for final assembly. (Glovia International, Inc. Fujitsu, 2008)

The customer may be internal or end-user. JIT elements are, as follows. In the following parts, some of the elements will also be described as Lean tools.

- Eliminating waste
- Continuous improvement
- Good housekeeping - workplace must be well-organized and clean
- Set-up time reduction
- Productivity, flexibility and job satisfaction

- Leveled / mixed production
- Kanban
- Jidoka (Automation)
- Andon (trouble lights) (University Of Cambridge,2009)

4. Kaizen

The word is a combination of two Japanese words. 'Kai' means continuous and 'Zen' means improvement. It means improvement throughout the organization. Everyone should be involved i.e. managers and workers. Kaizen includes even small changes with the aim of improvement in any action but on a regular basis. In manufacturing companies, Kaizen consists of eliminating waste in machinery, workers and production methods. (Graphic Products, Inc., 2000)

5. One-piece flow

One-piece flow or continuous flow concept means moving a work-piece between operations within a work cell (One piece at a time). It has significant effect in terms of decreasing wastes like Inventory, waiting time, lead-time and defects moreover, by this method process gets stable, becomes more under control and problems will be visible. (LSS Academy, 2008), (Strategos)

Ten benefits of one-piece flow are listed in the below:

- Safety improvement
- Productivity Improvement
- Flexibility Improvement
- Scalability Improvement
- Inventory Reduction
- Decrease in Floor space usage
- Material replenishment is simplified
- Builds in Quality
- Help to Kaizen
- Morale improvement (LSS Academy, 2008)

6. Overall equipment effectiveness (OEE)

OEE is a measure of overall performance of equipments and is multiplication of three factors, which are stated in percent.

- Availability: the number of hours a machine runs (operating time) divided by the number of hours the machine was planned to work (Loading time).
- Performance rate: How quickly a machine runs compared to its nominal speed
- Quality rate: The amount of approved product compared to total produced.

The concept is based on the philosophy that all production losses on machines and processes could be quantified. (Oee, 2006)

7. Kanban

Kanban stands for Kan- card and Ban- signal. It is used to achieve JIT and is based on what an operation within production line exactly demands (pulls) in terms of right type and amount and in the right time. In other words, it controls flow of material in the assembly line

To reduce excess inventories, the warehouse or manufacturer should supply components only when they are needed . Work stations within the production line, only deliver parts when they receive a card together with an empty container which show more parts are needed. (Glovia International, Inc. Fujitsu, 2008)

Advantages of Kanban Processing

- Information generated is precise and quick
- No delay in response to every change
- Overproduction avoidance
- Wastage minimization
- Activities are under full control
- Higher responsibility of line workers (Glovia International, Inc. Fujitsu, 2008)

8. LPI

Standing for Lean Performance Indicator, LPI is a factor to evaluate Lean implementation effectiveness. Key factors are:

Lean Sustainment, Continuous Improvement Implementation, Real Time Performance, Profitability and Waste Elimination (Jim Warren, Sunset Manufacturing Company, 2007)

LPI represents a monthly figure or target number of 100, which is indicated as level C on the visual color-coded LPI chart. A 100 monthly goal equals to around 116% value added output performance (Level C).The LPI number defined when starting Lean implementation shows a set point for daily and yearly tracking historical improvement data. The higher LPI figure, the higher level of throughput per team member achieved by continuous improvements. (Jim Warren, Sunset Manufacturing Company, 2007)

Lean Performance Indicator Chart	
LPI Number	**Indicator**
0-59	Poor
60-79	Inefficient
80-89	Average
90-99	Efficient
100-124	Lean Level C
125-149	Lean Level B
150+	Lean Level A

Table1. LPI Chart (Jim Warren, 2007)

9. Set up reduction (S.M.D.E)

Single Minute Die Exchange is a tool used to accelerate machines' change over and shorten set up time. In other words, it reduces down time. Using the technique, the time to change the style in production will decrease from hours to less than 10 minutes consequently; the production line becomes more flexible. The focus in S.M.D.E is on doing more set-ups in a given amount of time instead of reducing total time spent on doing set-ups.

It is conducted in 3 steps: Segregation of activities, re categorizing and reducing or eliminating steps as they are done today.

In the first step, all set up steps should be identified and classified into two parts. First, is steps taken while the machine is down (Internal Set up), and the second is, the steps taken while the machine is running (External Set up).

Re-categorization tries to change Internal Set-ups into the External ones. This will lead to 50% decrease in changing over times. Finally, the last step is simplifying both Internal and External steps by standardization of set up process, making them consistent, repeatable and easy to learn be the employees (William M. Feld, 2001)

10. TPM

It is a maintenance program concept with the aim of emergency and unscheduled maintenance prevention. Results are less down time and more effective use of the equipment.

11. Value Stream Mapping (V.S.M)

It is a graphical tool to pace the flow of material and information from beginning to end, addresses added- value and non added-value activities and streamlines the work processes by using Lean tools. The goal is to identify and decrease the wastes. A Future State Map about how the value should flow will be drawn afterwards. (12 Manage, 2008), (Lean Enterprise Institute, 2009)

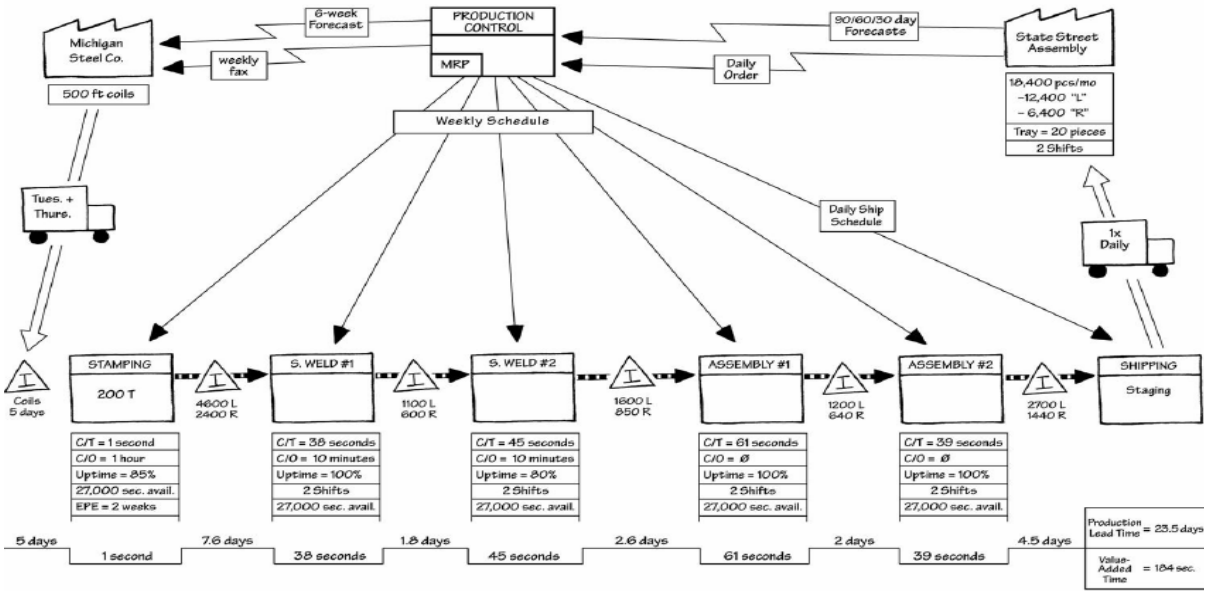

Figure 1. Current State Value Stream Map (Lean Enterprise Institute, 2009)

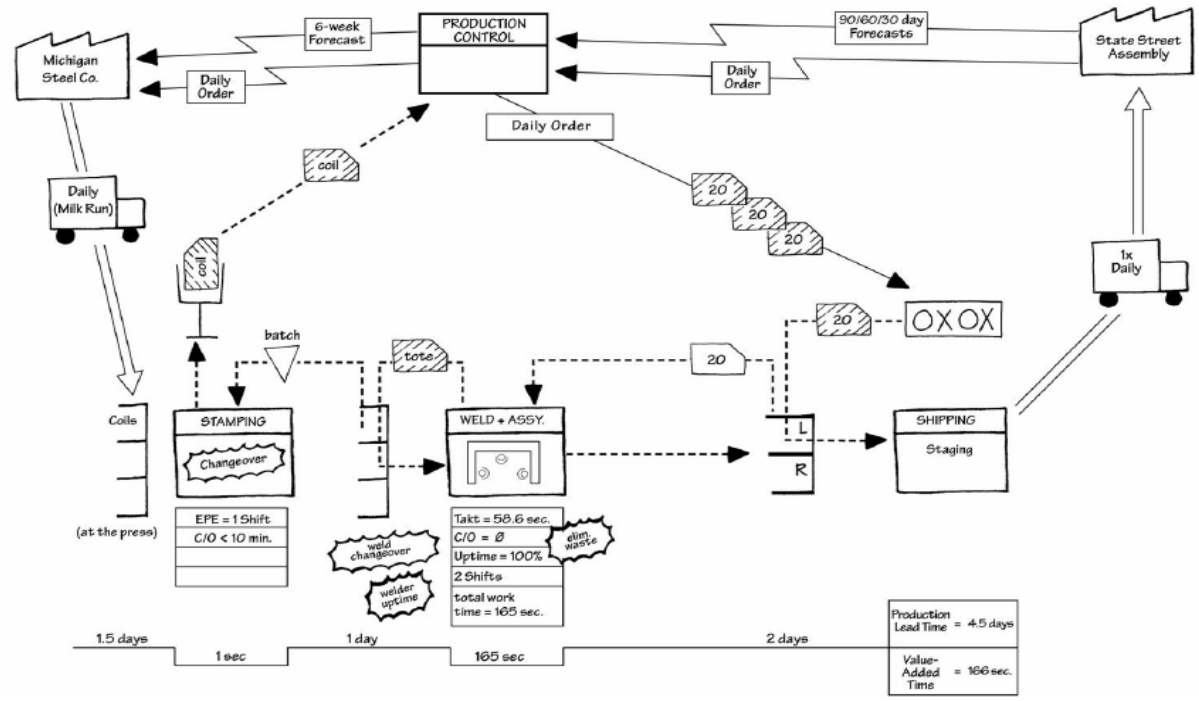

Figure 2. Future State Value Stream Map (Lean Enterprise Institute, 2009)

12. Heijunka

Also known as mixed/level –loaded production is a method for scheduling the production in a period of time and on the basis of volume and the product mix which will remain the same during the period. In fact, Heijunka changes uneven manufacturing process into even and predictable one. It is used with other key lean tools to stabilize value flow. Making manufacturing process stable, Heijunka causes less inventory and lead-time as well as producing variety of products as the customer demands. (Lean Enterprise Institute, 2009)

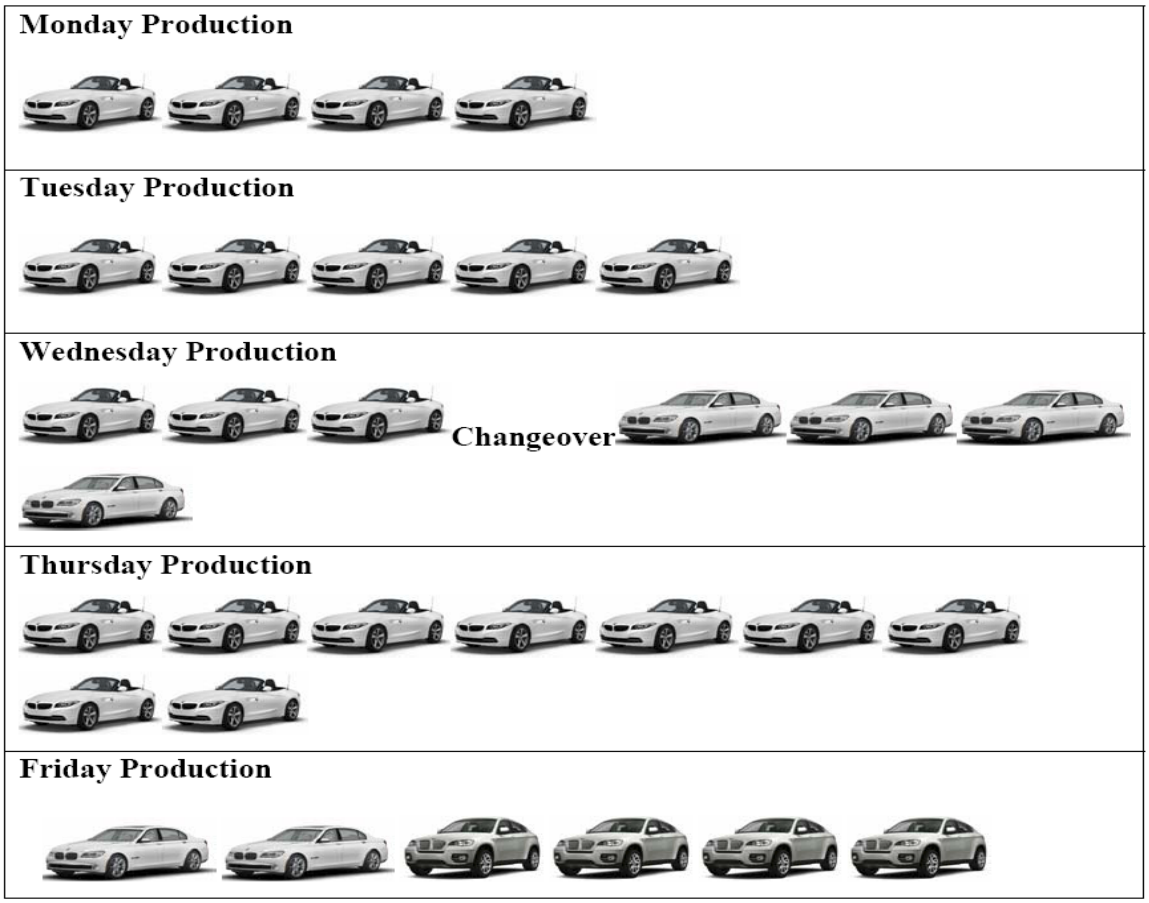

Figure3. Traditional (Un-even) Production (EMS Consulting Group, 2003)

Figure4. Leveled Production after adopting Heijunka (EMS Consulting Group, 2003)

13. 2-Bin Auto-Replenishment System

This is an effective way to eliminate downtime. It suggests two containers/bins of inventory. When the first bin becomes empty, order for replenishment should be made. The second bin will not be empty before having the first bin replenished. (TPS-ThroughPut Solutions, 2007)

14-Work cell layout

Work cell is a concept developed by JIT. Mainly 3-12 employees form a U shaped work-cell. The number of workers in each cell depends on the task they do. Many cells are engaged in product completion. Employees working in a cell are multi skilled. less movement, less over-production and less transportation are some of the work cell benefits. In addition, this concept increases flexibility in production because changing from one production to the other is very easy. Employees in a work cell should have a satisfactory communication with each other as well as motivation, which is necessary to team working. (TPS-ThroughPut Solutions, 2007)

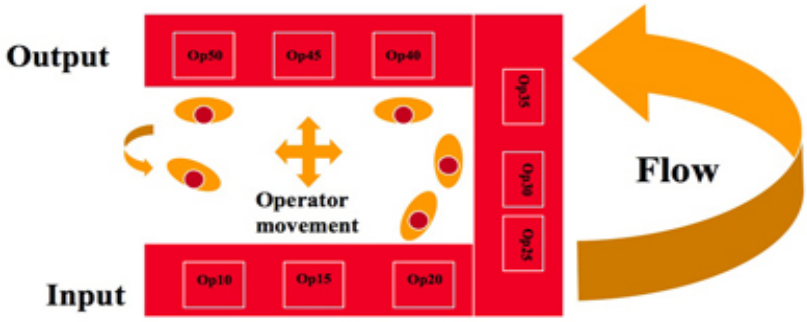

Figure 5. U-shaped work cell (C&H Distributors, 2009)

2.2 TPM

2.2.1 TPM Definition

Total Productive Maintenance is a method, which involves total participation on all levels and functions in an organization in order to raise overall effectiveness of equipment used in the production. TPM could be considered as result of PM and TQM combination because major elements of TPM are employees, processes and equipment. "*TPM capitalizes on proactive and progressive maintenance methodologies and calls upon the knowledge and cooperation of operators, equipment vendors, engineering, and support personnel to optimize machine performance. Results of this optimized performance include; elimination of breakdowns, reduction of unscheduled and scheduled downtime, improved utilization, higher throughput, and better product quality. Bottom-line results include; lower operating costs, longer equipment life, and lower overall maintenance costs."* (Jerry Kilpatrick, 2003)

In fact, TPM is a continuous improvement program. Considering Autonomous and Planned maintenance, which will be described later, the goal of TPM is to increase production and raise the morale of the employees as well as increasing their job satisfaction.

The concept induces that TPM plays a major role in production. Even more, down times which may occur due to maintenance, should be regarded as inseparable part of production scheduling. (J. Venkatesh , 2009)

2.2.2 Targets:

The most important goals of TPM are as follows:

- Higher productivity of equipment and plant
  - Obtaining Minimum 80% Overall Plant Effectiveness (OPE)
  - Obtaining Minimum 90% Overall Equipment Effectiveness (OEE)
- Maintaining product quality
- Zero equipment breakdowns by maintaining equipments at optimal level
- Zero product defects
- Produce a low batch quantity at the earliest time
- Input minimization

- Wastage avoidance
- Cost reduction
- Making workers multi-skilled and flexible (J. Venkatesh, Reliabilityweb.com, 2009), (J. Venkatesh, Plant Maintenance Resource Center, 2007)

2.2.3 History and origins:

Before the 1950s, maintenance was conducted on the basis of Breakdown Maintenance (BM), meaning, maintenance is fixing the machine when it gets faulty.

In the early 1950s, PM became dominant in Japan. Preventive maintenance is a concept that encourages following instructions for equipment operations and maintenance provided by manufacturers in order to prevent equipments from possible breakdowns. Japanese imported PM from America and developed it later. Although PM reduced downtime, it was not so good, because it requires periodical actions and shutdowns during which, some components should be changed even if they are still in a good condition. PM was used for 2 decades in Japan. During the 1960s, the focus was on productive maintenance, which considers reliability, maintenance and economic efficiency in plant design. In the 1970s, the emphasis was on taking the advantages of PM through total participation of the employees. This approach led them to add the word "Total" to PM and TPM was born. TPM consists of Predictive and Condition-based maintenance. These two concepts are solutions to the weakness of PM, which was mentioned before. The Japanese invented TPM to support TQM because they understood that companies cannot produce a quality product without well-maintained equipments. (Thomas R. Pomorski, 2004), (J. Venkatesh, Reliabilityweb.com, 2009)

2.2.4 Principles:

There are five major TPM principles:

- Improving OEE by identifying possible losses of facilities and equipment, and monitoring all of them in case of speed losses, defect losses and down-time losses.
- Making front-line asset care as a part of the job: Front-line asset care (Autonomous Maintenance) is carried out by the operator, with support from the maintenance department. The operator should be able to fulfill at least some maintenance tasks including simple repairs, preventive actions and improvements e.g. corrective actions and proposing ways to prevent drawbacks to recur.
- Having a systematic approach toward maintenance activities; This could be done by:

- Defining preventive maintenance for each piece of equipment (Time Based Maintenance- TBM)

- Creating standards for running Condition-Based Maintenance (CBM)

- Defining maintenance responsibilities for operators and maintenance staff

  - Operators' responsibilities: General care

  - Maintenance staff responsibilities: General breakdown activities, supporting operators by training them, problem diagnosis, devising and assessing maintenance practice, developing maintenance actions and continuous up grading of equipment

- In order to thoroughly fulfill their duties and perform all their tasks, the employees need to receive continuous and appropriate training to develop their abilities like hand and operational skills, team working and problem solving.

- Early equipment management: Zero maintenance is a concept inducing that failure causes and maintainability of the equipment should be considered during early stages of equipment life span like designing, manufacturing, installation and commissioning.

Therefore, any problem can be tracked back and eliminated at the above-mentioned stages. (Thomas R. Pomorski, 2004), Imants BVBA, 2009)

2.2.5 Departments involved

TPM involves everyone in the organization from operators to senior management (in the improvement of equipments). TPM must be led by the manufacturing department and encompasses all other departments including Planning, Maintenance, Operations, Design Engineering, Project Engineering, Construction Engineering, Inventory and Stores, Purchasing, Accounting and Finance, Plant and Site Management and Administrative affairs

2.2.6 Foundation and Major Pillars of TPM:

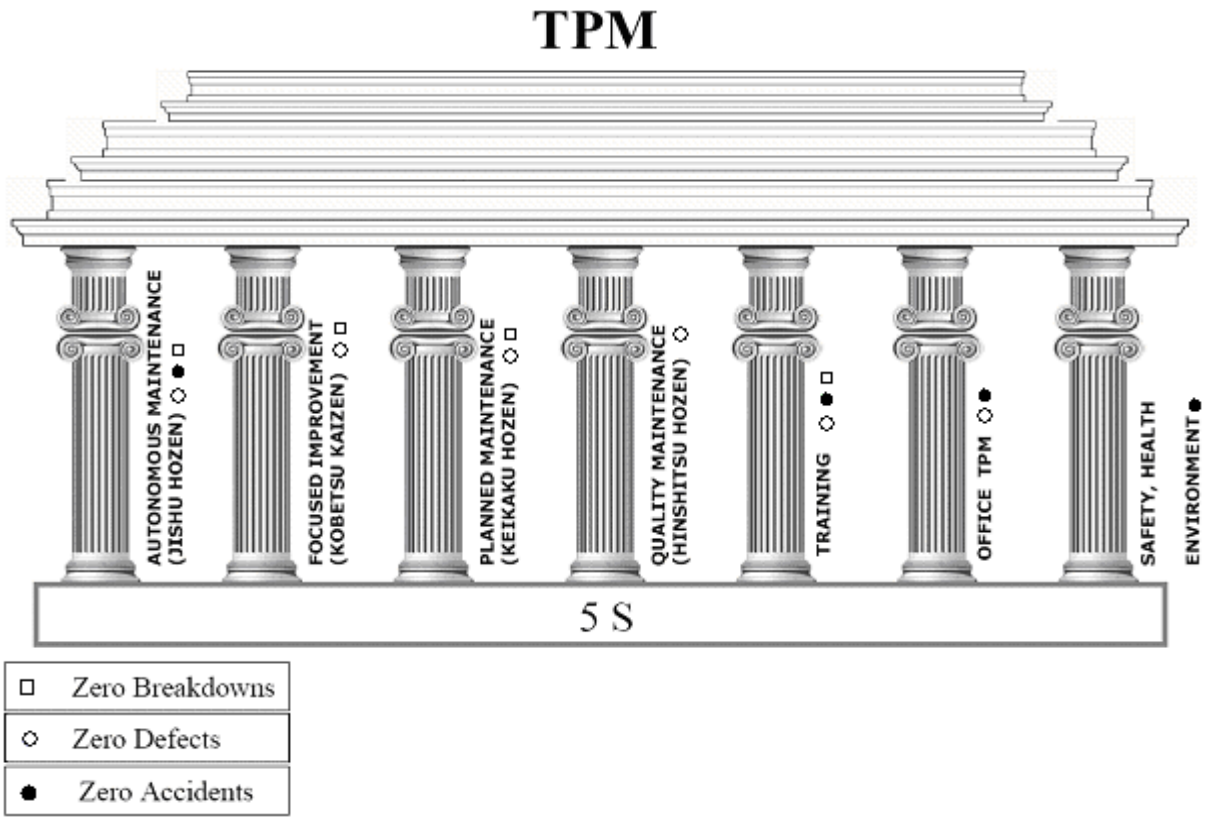

Figure 6. Pillars of TPM and their roles in Zero Break downs,

Zero Defects and Zero Accidents

(JIPM-Solutions co. Ltd., 2009)

• **5S:** It was discussed as a Lean tool (page 13)

• **AUTONOMOUS MAINTENANCE (JISHU HOZEN)**

This pillar stresses on performing simple maintenance tasks by the operators- Activities like lubrication, tightening of loosened bolts, visual inspection, cleaning- This will help more experienced maintenance staff to take care of more important maintenance tasks, which create more added values. The aim is keeping machines in good condition.

Benefits:

- Elimination of root causes of many defects

- Operators' flexibility to work and maintain other pieces of equipment

- Equipment's function with the least shot-downs

- Oil consumption reduction

- Process time reduction (J. Venkatesh, Reliabilityweb.com, 2009)

• **FOCUSED IMPROVEMENT (KOBETSU KAIZEN)**

This pillar states that small improvements are more effective than just one big improvement if they are continuous and encourage all employees to be involved. The pillar aims to reduce losses that can lower efficiency. Kaizen is applicable in both production and administrative areas.

Kaizen emphasis

- Finding the ways of achieving zero loss in all activities

- Elimination of losses by means of using results of PM analysis widely

- Commitment toward cost reduction for resources

- OEE and OPE improvements

Kaizen strives to make substantial improvements in productivity in forms of efficient equipment, operators and material in addition to energy utilization. Kaizen tries to eliminate six losses, which are described below:

- Equipment failure: Causes production downtime. By cooperation between the maintenance and production departments, equipment failures can be prevented by using, predictive and preventive maintenance, developing operation practices and design changes. Root Cause Failure Analysis (RCFA) is a technique that is used after a failure occurrence. RCFA aims to eliminate failures and mitigate their impact.

- Time for Setup and adjustments: It includes the time for the warming-up of a machine after its changing over.

- Small stops: These stops last between 5-10 minutes and include minor adjustments and cleaning.

- Speed losses: Several items may result in a machine working at a lower speed than what is determined before. These items can be no matching between machine and its application, inefficiency of the operator, unsuitable machine wear-parts and substandard materials.

- Losses during warming-up: This includes losses in a quality point of view for products produced during the time of warming-up. (J. Venkatesh, Reliabilityweb.com, 2009)

- **PLANNED MAINTENANCE (KEIKAKU HOZEN)**

In order to reach customer satisfaction, the products must be defect free. Defect free product requires machinery without trouble.

Planned maintenance focuses on reducing spares inventory, optimum maintenance cost, higher reliability and maintainability of machines, achieving and sustaining machine availability. The role of an information system is undeniable therefore; an information management system like Computerized Maintenance Management System (CMMS) should be established. The information system collects data relevant to time and parts of equipments for maintenance planning. (J. Venkatesh, Reliabilityweb.com, 2009)

Planned maintenance is comprised of four parts:

- Breakdown Maintenance: This type is based on the philosophy which says:" let it fail then fix it" and is applicable where failure does not impose any significant effect on production and any cost except the cost of repair.

- Preventive Maintenance: Maintenance actions like inspection, lubrication, cleaning, tightening to prevent machines from failures through periodic inspection and recognition of equipment condition. It is divided into two parts:

- Periodic Maintenance (Time Based Maintenance - TBM): Periodic inspection, servicing, cleaning, lubrication, adjustments and replacing worn out parts to prevent sudden failures

- Predictive Maintenance: (Condition Based Maintenance - CBM): After diagnosing the current condition of critical parts of equipment, optimum remaining of their lifetime should be determined .It uses condition monitoring through surveillance system. Some of the tests are: Vibration, oil analysis, Thermograph test, sound test, Ultrasonic test, performance test.

- Corrective Maintenance: To increase the reliability, productivity and improving maintainability, root causes of equipment failures should be removed. Root causes may originate from the design, manufacturing, installation or external factors.

- Maintenance Prevention: After checking current equipments and data gathering about their weaknesses, failure records and safety, new equipments are re-designed and installed. Easier maintenance, failure prevention, better safety, defects prevention and ease of manufacturing are some consequences. (J. Venkatesh , 2009), (J. Venkatesh, Reliabilityweb.com, 2009)

- **QUALITY MAINTENANCE (HINSHITSU HOZEN)**

Through defect-free manufacturing, higher quality and customer satisfaction are accessible respectively.

This pillar focuses on the equipment parts, which are critical for product quality. The trend of quality maintenance starts from elimination of current quality problems, which are reactive measures, and in form of Quality Control. The trend is continued with consideration of potential quality problems, which results in proactive measures and in form of Quality Assurance. Quality Maintenance focuses on prevention of defects at

source, in-line detection and segregation of defects, effective implementation of Operator Quality Assurance and Poka-yoke. (J. Venkatesh, Reliabilityweb.com, 2009)

- **TRAINING**

The aim of this pillar is making employees multi-skilled with high eagerness to come to work and fulfill their duties completely and independently. The knowledge and skills of the employees should be improved; also, the training environment must be in such a way that employees want to learn by themselves based on their felt needs as well as making work more enjoyable. It is not sufficient that knowledge of the employees is limited to "Know-How". They should also be aware of "Know-Why" to recognize the root causes of problems. All employees should gain knowledge and skills relevant to their duties. Basically employees are classified in 4 categories in skills point of view: Do not know, know the theory but cannot do, can do but cannot transfer their knowledge, can do and teach.

Steps of training are survey about the education and training status in company, determining policies and priorities and establishing a training system for operation and maintenance up grading, training the employees based on a scheduled program, evaluation of training and making decisions about future approach. (J. Venkatesh, Reliabilityweb.com, 2009)

- **OFFICE TPM**

Office TPM should be implemented in administrative and logistic parts in order to increase efficiency and productivity in addition to identification of losses and elimination. Logistics and support functions have significant impact on the production and manufacturing. The effectiveness and productivity of a production system can be increased by improving any activity that supports the production. Many administration losses are unmeasured and remain hidden.

Some important kinds of office losses:

- Administrative process losses
- Office equipment break-downs
- Communication channels' cut-offs
- Accuracy loss
- Idle loss
- Communication loss
- Customer complaints about logistics
- Expenses due to emergency dispatches and purchases
- Time spent on information retrieval
- Correct on-line stock status is not available (J. Venkatesh, Reliabilityweb.com, 2009)

Benefits of office TPM

- Better plant performance by involvement of the employees in supportive activities
- Clean and tidy work environment
- Reduced labor

- More creativity and productivity of personnel

- Less equipment breakdowns

- Reduction of administrative and overhead costs namely non-production and non-capital equipment

- Less inventory of documents and files

- Reduced repetitive work

- Higher efficiency through better utilization and organization of the office

- Reduced inventory in supply chain

- Reduction of customer complains about logistics (Thomas R. Pomorski, 2004), (J. Venkatesh, Plant Maintenance Resource Center, 2007)

- **SAFETY, HEALTH AND ENVIRONMENT**

This pillar plays an important role in all of the other pillars. TPM program is not meaningful without focusing on health and environmental issues because some policies of TPM are Equipment reliability, human error prevention, eliminating accidents and pollutions. The objectives of this pillar are:

- Zero accidents

- Zero injuries

- Zero environmental impact

Unreliable and faulty equipment is a threat to the operator and the environment.

Autonomous maintenance helps the operator get more familiar with the equipment, its potential hazards, and ways of safe and effective working. In addition, TPM will increase commitment of the operators towards health and environmental issues.

With using 5S techniques like cleaning and setting the work place (Seiton and Seiso), the risks of accidents will be reduced. (Thomas R. Pomorski, 2004), (J. Venkatesh, Plant Maintenance Resource Center, 2007)

2.2.7 TPM implementation

- Preparation: This phase is done through steps 1 to 5.

Step 1- Formal announcement regarding decision of top management for starting TPM through:

- Company newsletter

- Formal meeting

Requirement: Management commitment

Step 2- Introductory education and publicity campaign

- Training seminars for senior managers

- Presentations for other employees

Step 3- TPM Promotion

- Establishing a steering and committee of specialists

- TPM Promotion Office: including TPM coordinator, TPM facilitator-Including Supervisors- and TPM content expert

One of the TPM coordinator's duties is to communicate and sell TPM concepts throughout the organization.

Step 4- Establishment of basic TPM policies and goals

- Analyzing present conditions

- Setting goals and targets: Defining Initiative objectives, TPM policies, OEE and loss categories

Step 5- Prepare a master plan for implementation

- A master plan consists of the goals, actions to reach them and the time of achievement. A time line about starting to final activities must be prepared.

Each pillar shall have a detailed plan (Imants BVBA, 2009)

- Introduction: this phase is done through step 6

Step 6- Kick-off meeting:

- Hold a meeting with all employees attending. Top management will present TPM policies, goals and master plan. In order to involve all employees, their full support must be gained by ensuring Long-term commitment of the management team.

External customers, associate and affiliated companies and sub-contractors should be invited and justified in a separate meeting (Imants BVBA, 2009)

- Implementation of Pillars: This phase is done through step 7 to 11

Step 7- This step includes implementation of the following pillars

- Training

- Checking present status of training and defining policies and priorities
- Developing knowledge of operation and maintenance skills by establishing and running the training system
- Employees knowledge and skills evaluation, identifying needs and gaps, preparing schedule and then holding relevant courses
- Training activities evaluation and planning for the future approach

- 5S: It is considered as a base for other pillars.

Training: Training procedure include several skills and items like team skills, problem solving, communication within the teams and to the management, TPM processes and details, OEE, Mid-project reviews (progress, problems, solutions), sharing success stories with others and management.

The training task starts with the management. Some topics are Review of 5S program, methods of implementation, team concept and management role. In addition, practical exercises and real pilot projects are done.

The next group for training is the implementation team, which consists of team leaders and supervisors. They should be trained as the same as management and need team leadership skills and practical training through pilot projects. The implementation group first perform a pilot project under the leadership of a 5S supervisor (a consultant

or internal specialist), and afterwards, perform a second project on their own. A committee including the plant manager and some area workers should take the responsibility of coordinating the projects.

5S implementation plans should be prepared and released. If the results are satisfactory, the program will be conducted in all departments.

There are eight recommended steps for successful 5S implementation:

- Form a program committee
- Make a plan for each S
- Program announcement
- Train the employees
- Set a day in which all employees clean up their work area
- Set a day in which all employees organize their work area
- Assess the 5S results
- Conduct self-control and take corrective actions (EMS Consulting Group, 2003)

- Autonomous maintenance:

Steps of Autonomous maintenance implementation:

- Preparation of employees by training them

Fields of training:

- TPM concepts and its advantages
- Autonomous maintenance and its advantages
- Abnormal conditions of equipment and relevant tasks
- Operators should be trained in order to get more familiar with systems like Pneumatics, electrical, hydraulics, lubricant and coolant, drives also bolts, nuts and safety to follow inspection manuals correctly.

- Initial cleanup of machines

Working together on a previously set date; operators and maintenance staff should clean the machines.

A suggestive methodology for cleaning is:

- It must be ensured that the equipment is clean and without any visually detectable minor defects
- Create inspection and cleaning instructions and standards to sustain the new situation
- Creation of visual controls to shortly find any deviation from the standard

Problems like oil leakage, loosened nuts and bolts, loose wires and worn out parts are some of the problems that should be addressed. Checklists about parts and their situation before and after controlling should be made.

- Counter Measures

Actions must be taken in order to:

-Make inaccessible parts easily accessible and observable e.g. using transparent lids and covers.

- Prevent parts from dust and dirt accumulation

- Precise scheduling

Strict scheduling for cleaning, inspection and lubrication of the equipment should be set and followed. It also consists of parts that should be considered, instructions and materials needed..

- Autonomous Inspection

Each operator will develop schedule for inspection based on the records of inspection in consultation with maintenance department. (Imants BVBA, 2009)

- Kaizen

- Kaizen Planning: Strives to define, measure and analyze the processes that will be under Kaizen focus. Three levels of kaizen planning exist:

- *High–level*: Specifies the processes, which need to be improved regarding the Lean strategy of the company and a timeline for improvement.

- *Mid-level*: Exploiting VSM, selects specific area of improvement that will be addressed through Kaizen

- *Event-level*: In order to make Kaizen successful, this level of planning uses standard documents and checklists to make sure that everything is in place

This level includes:

- Select members of Kaizen team

- Kaizen authorization

- Location preparation (Equipment, material, etc.)

- Needed data to be identified and prepared (IMEC, 2004)

- Kaizen Implementation:

It is actual improvement using probably needed measurement and analysis. Kaizen implementation steps are as follows:

- Providing Kaizen team members with training about Lean principles, which they will apply

- VSM reviews besides some necessary measurement and analysis.

- Brainstorming to come up with improvement options

- Performing improvements on separated parts of process and reassembling the process without waste.

- Preparing an action plan as well as activities needed for Kaizen process accomplishment.

- Matching the alignment of chosen improvements with the next version of VSM

- Identifying improvements, which are expected to be measured

- Getting feed backs from participants

- Informing champions about kaizen results (IMEC, 2004)

- Follow-up:

The improvement process should be complying with the time schedule. This process includes:

- Ensuring about successful completion of actions
- Cooperation with champions to remove obstacles
- Quantifying the actual results of Kaizen
- Checking sustainability of improvement through process control(IMEC, 2004)

- Evaluate:

Identified as learning organization Lean enterprises are engaged in:

Finding how Kaizen implementation process can be improved

Discovering any further possible improvements, by encouraging employees to do so

Periodical re-evaluation of VSM and commencing new Kaizen improvement project (IMEC, 2004)

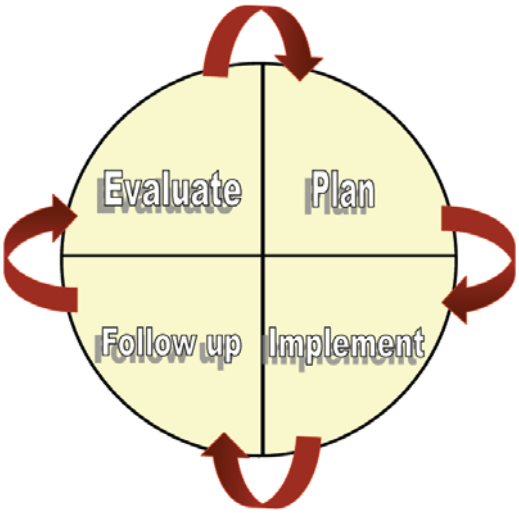

Figure7. Cycle of Kaizen steps

(IMEC, 2004)

Step 8- Planned maintenance

The aim is transforming the methods from reactive into proactive. The emphasis is on training operators by using trained maintenance staff.

- Policy

- Machines should be available all the time
- Optimization of maintenance costs
- Spare parts inventory reduction
- Machines reliability and maintainability must be improved

- Target:

- Zero equipment failures and break-downs
- Improving reliability and maintainability by 50%
- Maintenance cost reduction by 20%
- Availability of spare parts

- Phases

The phases of implementation are as follows:

- Evaluation of equipment and making records of its present status
- Equipment up-gradation and weakness removal
- Establishing an information management system like CMMS
- Making time-based information system and a plan regarding equipments, parts and maintenance staff
- Performing predictive maintenance by means of equipment diagnostic techniques
- Planned maintenance evaluation (Thomas R. Pomorski, 2004), (Imants BVBA, 2009)

Step 9- Quality maintenance

- Identifying major equipment and process conditions
- Maintaining major equipment and process conditions
- Identifying and elimination of deterioration and variation in equipment and process
- Creating new equipment and process without any defect
- Training the operators
- Practices and methodologies of effective production and maintenance should be established and sustained
- Providing requirements to support continuous improvement (Thomas R. Pomorski, 2004)

Step 10- Office (Administrative) TPM

Office TPM implementation is very similar to TPM used in the workshop. All Autonomous, Planned and Quality maintenance as well as maintenance prevention and training are used in office TPM. (Nihar Kanta Patra, 2005), (Thomas R. Pomorski, 2004)

- Office TPM implementation:

There are four steps of office implementation:

- 5S Implementation in order to get work place environment improved
- Abnormality identification
- More knowledge and skills through training the employees
- Creating a sense of ownership by Autonomous maintenance (Nihar Kanta Patra, 2005), (Thomas R. Pomorski, 2004)

Step 11- Safety, health and Environment

This pillar of TPM strives to detect and address dangerous conditions and activities, which are potential causes for accidents, dangers and unpredicted costs. Activities should be systematic and continuous. Actions should be taken to:

- Identify all potential hazards and harms for:
  - Safety purposes: Which process and equipment could pose threat/s to the employees?
  - Environmental purposes: Which process and equipment could be harmful to the environment?
- Defining and standardization of instructions for operations in fields of:
  - Material transportation
  - Using protective tools and measures e.g. special clothing, filters, etc.
  - Working methods with special equipment
- Train and make the employees involved
- Evaluate and record improvements, Achievements and short comings
- Use feedbacks in time of equipment's changeovers, renewals, purchasing and repairs. (Thomas R. Pomorski, 2004)

Step 12- Consolidation and stabilization

Sustain full TPM implementation and raise TPM levels by means of TPM process audits and Raising TPM team goals. (Thomas R. Pomorski, 2004), (Imants BVBA

2009)

2.2.8 Difficulties and pitfalls faced in TPM implementation

Several factors can be considered as barriers and pitfalls to TPM implementation:

- Sticking to a rigid schedule regardless of results

The first reason is that while TPM is a fairly long-term program but managers tend to look at the immediate results and are impatient. Scheduling might be unrealistic due to lack of experience. The second reason is that the schedule usually will not be immediately revised to a more realistic one, if needed.

- Lack of sufficient resources for a successful implementation

Many companies think that they can reduce the cost of TPM implementation by saving money through focusing on some critical equipments. In this way, they expect quick successes. This philosophy is derived from Theory of Constraints (T.O.C: The theory implies that a manageable system is limited to achieve more of its goals by few constraints. This theory helps organizations achieve their goals continuously by considering such constraints and restructuring the rest of organization around them. (Focused Performance, 2009))

- Resistance to change

Employees may show resistance to change in their roles because of inability to challenge the current situation

- Lack of understanding the benefits of TPM implementation

A majority of the employees see TPM as an one-sided benefit (only for the company). Operators must recognize that TPM will be a part of their work since TPM is helpful to them.

- TPM is sometimes regarded as a short-term program or project. Most of the times improvements take time to be achieved. In other words, the results of TPM implementation may not be visible immediately.
- It may be supposed that TPM implementation is a continuous duty of only a few persons within the organization whereas the TPM concept seeks continuous engagement and involvement of all employees.
- To satisfy business partners some companies like to show off that they are implementing TPM, rather than really focusing on TPM goals, which are Zero accidents, zero quality losses and zero failures.
- Lack of analysis capability (OEE, equipment performance, etc.)
- Potential waste minimization and pollution prevention is a matter that could be forgotten during equipment efficiency improvements (U.S. environmental Protection Agency, 2009), (Reliabilityweb.com, 2009)

2.2.9 TPM Benefits

- Maintaining equipments in a satisfactory way will result in fewer defects. This means that wastes by processes would be eliminated in three ways:

  - The fewer defects, the fewer products that must be scrapped

  - One consequence of less scrapping is that resources like raw materials, energy, person-hours and wastes consumed for defective products will be reduced.

  - Resources for fixing defective products will be decreased.

- TPM prolongs the life span of the equipments. It means that the intervals between the investments of the companies on new equipments get longer and therefore has an indirect effect on the usage of resources for new equipment manufacturing.
- TPM reduces the use of cleaning materials and hazardous chemicals, which are harmful to humans and the environment.
- Increases return on investment by increasing the productivity.
- TPM enhances job satisfaction by creating a pleasant work environment and a better employees' involvement (sharing knowledge and skills through team working as well as higher confidence level of the employees).
- Lowers maintenance costs
- Lowers production costs
- Reduces accidents
- It increases customer satisfaction by means of better quality, right quantity and reasonable lead-time. (U.S. environmental Protection Agency, 2009)

2.2.10 Measuring TPM Effectiveness

Overall Equipment Effectiveness (OEE) is an indicator, which shows the effectiveness and efficiency of the equipments. In other words, OEE shows how plants manage their assets. The higher OEE, the higher capacity of the equipment that a company uses

OEE indicates the efficiency during planned loading time. Planned down time is excluded from calculation hence, it does not affect OEE figures. (Thomas R. Pomorski, 2004), (Oee, 2006.)

$$\textbf{OEE} = \textbf{Availability} \times \textbf{Performance} \times \textbf{Quality yield}$$

Three factors are considered in OEE calculation.

- **Availability:** Is the time during which the machine is actually running out of the time the machine should be available.

$$\textbf{Availability (\%)} = \frac{\textbf{Operating time}}{\textbf{Loading time}} \times 100\%$$

Loading time = Total possible time – scheduled non-production time

Operating time = Loading time – down time losses

Down time losses = Duration of "equipment failures + set up + adjustments"
(Thomas R. Pomorski, 2004), (Oee, 2006.)

- **Performance:** The effectiveness of operation in order to produce parts during the time the machine is actually available and able to produce.

$$\textbf{Performance (\%)} = \frac{\textbf{Theoretical cycle time} \times \textbf{Number of parts produced}}{\textbf{Operating time}} \times 100\%$$

(Thomas R. Pomorski, 2004), (Oee, 2006.)

- **Quality yield:** The effectiveness of operation in order to produce parts, which are complying with quality standards during the time the machine, is actually producing.

$$\textbf{Quality yield (\%)} = \frac{\textbf{Total number of parts produced} - \textbf{defective parts}}{\textbf{Total number of parts produced}} \times 100\%$$

(Thomas R. Pomorski, 2004), (Oee, 2006.)

3. Case study: TPM and Lean in practice

3.1 SKF company

3.1.1 Introduction

SKF is a global company producing a wide range of bearings used in cars, windmills, machinery, etc. SKF was founded in 1907. Until the early 1920s, they succeeded in establishing factories and sales offices in all continents. Now the company owns 130 offices and 100 manufacturing sites around the world (SKF Group Headquarters, 2009)

Manufacturing Development Center (MDC) is the name of an organization in SKF. They support SKF factories around the world by implementing methods for manufacturing excellence like Kaizen, zero defects and other tools.

Actually Lean manufacturing and TPS (Toyota Production System) are the same kinds of philosophies. They are not just methods. They are also ways of thinking and cultures in the organization. On their journey to manufacturing excellence, SKF was very much inspired by Scania in which a common language, currently being used by all the employees, was created.

Lean manufacturing and its origin, TPS, are thinking models. They deal the question: ” How do you look at your organization?”

There are two different types of organizations in the management point of view:

- **Result-driven Management**

Lean thinkers like production managers and technicians create methods for processes improvements. They plan and dictate how a work should be done. Even worse as it is in some organizations, head quarters do so and communicate plans and decisions throughout the organization.

One drawback is that the employees, who actually do the work, are not involved in developing their own jobs.

Another drawback is that the result-driven method requires strict control in the organization. Sometimes a sudden rise in production capacity is very important. When top managers decide to increase the production capacity, working pressure on the employees rises. Employees should work more to take the production capacity to a new point. Sometimes the matter may get reverse to decrease the capacity. The ultimate result of this approach is confusion and less job satisfaction among the employees.

In result-driven companies, managers very often put too much focus on results, parameters, efficiency and their levels and targets but these are different from reality because the tools are just used without working on Lean thinking (Martin Hjelte, 2009).

Figure8. Management by result-driven (Martin Hjelte, 2009)

- **Means-driven Management**

Induces the concept of supporting organization; everything here is done to meet the customer demands. This task is very difficult because sometimes customer demand goes up or down and variable interests exist. Due to this fact, organizations need to increase creativity and competence of the employees. This will result in enhanced working methods, which leads to better results.

Since employees create value for customers, their role in the Value Creating Chain (VCC) is very crucial. In VCC, employees create value and middle managers like production managers support them by providing the best conditions to perform their tasks (Martin Hjelte, 2009).

Figure9. Management by means-driven (Martin Hjelte, 2009)

In order to reach manufacturing excellence, SKF tries to move from the Management by result-driven type to the other one. In this way, they need a common language and a way of thinking which is Lean culture.

The organization types in question are the extremes. The best choice is a mixture of them but with more emphasis on the second type.

Benchmarking Scania, SKF tries to send a common message within the organization. The message is “Meeting customer demands”. The customer demands are right amount, right quality, on time delivery and reasonable cost.

Establishing a common language within the organization is a difficult procedure. It can be done by defining principles. SKF defined five principles as bases for the bridge (Processes) between the supplier and the customer.

The principles are not methods. They do not tell us how to do things and how to reach the goals. They talk about what is important and show the direction. The principles represent a way of thinking.

Based on the principles, SKF tries to be more demand-driven while considering right quality in every step of the process by means of TPM, Poka Yoke, etc. (Martin Hjelte, 2009).

3.1.2. SKF Principles

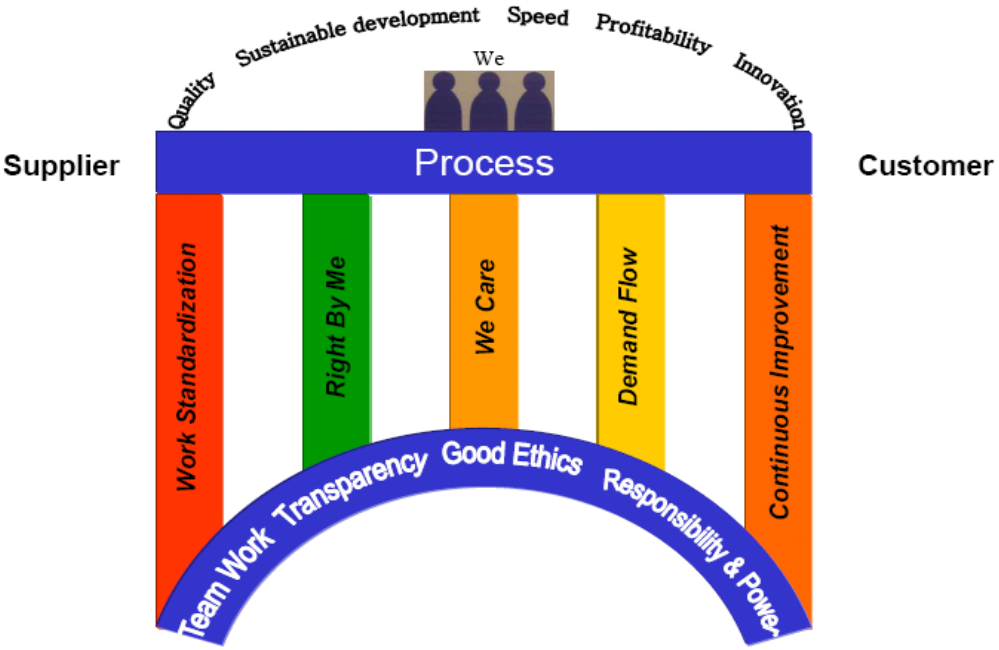

Figure 10. SKF Model of Principles (Martin Hjelte, 2009)

- Work standardization:

Standardize work and improve it continuously through employees' participation.

Work standardization implies that certain ways of operations must be identified and applied until a better is discovered.

- Right by me: It means right quality in every step of the process. Defects should not be allowed to flow through the process.

- We care: This SKF principle concerns inner and outer environment of the company. When it comes to internal environment, everyone should be ensured about health and safety through making work place, safe and ergonomic.

Employees should have the possibility to gain more competence and grow in their career as well.

The other part is caring outer environment .SKF tries to be sustainable. They try to use right kind of energy in an efficient way, which also creates value for the customer.

- Demand Flow: It is a pull system concept (versus push type). It is not only applicable in the field of customer demand but also within the company including all processes and the employees. Pull system indicates that no operation should produce more than what, the next operation needs. It also strives for a continuous flow, which requires reliable equipment, and it is achievable by TPM.

- Continuous improvement

3.1.3 Manufacturing excellence

Manufacturing excellence is about creating a thinking organization.

When employees understand what the SKF model of principles is about and why they are important, the organization can start utilizing the employees for instance if employees

know why demand flow is important, they will cooperate in developing methods to make the company more demand-driven. To utilize all employees' creativity and competence, SKF needs to have a common language. This language consists of principles. In SKF, they discussed the principles and methods with the employees in Bridge Meetings. The aim of these meetings is creating common thinking and perception of the principles and finally moving towards the second type of organization.

Consequently, by creating a thinking organization, all employees as well as the management can use a common language by using the same words and will have the same understanding but everyone will use the words based on his/her task and perspective. As an example, Demand Flow represents different meanings for different levels of organization .For an operator, demand flow is between two machines in a process and for a CEO it means the whole supply chain from suppliers to the customers. By sharing common understanding of principles, employees will be involved more and will apply the principles in reality and the principles become more sustainable. Therefore, the employees will contribute because the operators, for instance, know better than the management how the machines work.

Encouraging employees to use a common language by understanding the principles takes a long time but when it comes to taking actions and use of methods, the process will be much quicker and sustainable. The important factor in gaining a common language is mutual trust. A company should trust the employees to do trial and error works under controlled conditions. Employees need to understand the principles, believe in them and have the opportunity to experience by themselves. In this way, the company should let them fail in some cases, unless when it has a negative effect on the customer. This method will empower the employees and guarantees continuous improvement because they will look for better ways of doing (Learning by Doing). Ultimately, the employees will be more self-confident and will trust managers more.

3.1.4 SKF thinking model

Lean is culture and TPM is a method. The philosophy behind each method is very important. For example, General Motors benchmarked Andon Cord from Toyota but failed in Andon use because they thought that the less pulling the cord to stop the production line, the better results it will represent. They missed the philosophy behind Andon, which is prevention of the defects to flow throughout the process by immediate stops after observation of each defect (Today Andon is an electronic device in form of a visual display). (Elsmar Cove, 2009) The philosophy is very important to be understood. After identifying and defining the principles, companies need to develop methods like 5S, Poka Yoke, Kaizen, TPM, Kanban cord, etc. to fulfill the principles better.

In this model, methods are used to fulfill the principles. Then SKF will follow up the results of using the methods. If results are not satisfactory, they will change or revise the methods (Martin Hjelte, 2009).

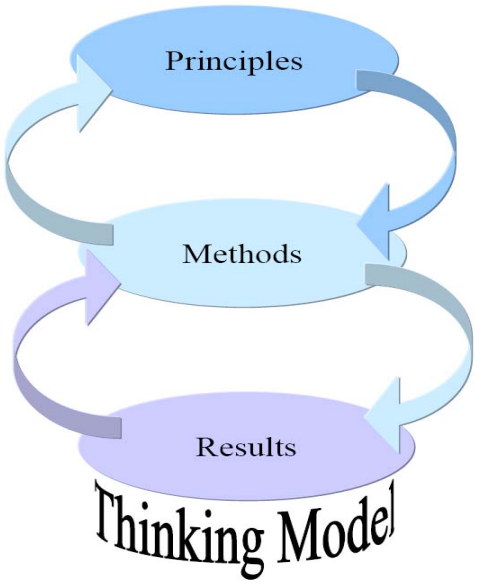

Figure11. SKF Thinking Model

(Martin Hjelte, 2009)

3.1.5 TPM in SKF

In SKF, they put a large emphasis on 5S, Kaizen, Autonomous Maintenance, Planned Maintenance and training & education. They formed a team consisting of a mechanic, an electrician and a maintenance engineer for maintaining each machine to support operators. Generally, when it comes to practice, managers do not push methods to the processes; instead, they listen to each process problem and then recommend solutions.

The Manufacturing Excellence Office (ME Office) supports the factory with thinking, methods and tools. The office consists of six persons working as facilitators. Their duty is selling thinking and, suggesting methods and tools. The office also consists of 2 resetting (Methods and tools preparation) departments with 26 employees. They focus on resetting losses.

At SKF, they believe that Autonomous Maintenance and planned maintenance are very strong together. Everything is in the hands of the operators and they should feel ownership of the equipments and take the responsibility. The Maintenance department is responsible for Planned Maintenance. Human Resource (HR) department is responsible for training and education. They cooperate with the maintenance department to raise the ability of the operators. All TPM pillars focus on the operators to make them feel the ownership of the equipments, obtain the skills and take actions to take care of the equipments.

As for Environmental, health and safety pillar, actions must be taken to reduce losses and problems of the machines, which may have impacts on the environment, but in SKF, this pillar is not under much focus because outside the ME Office, others are working in this field. The company has appointed an environmental coordinator as well. He is responsible for taking care of the environmental issues.

Improvements in sustainability point of view:

- Shutting machines down when they are not actually producing

- Electricity consumption: As an example, if the lighting switches are located in the right places, no light will remain on after working hours.

Economic crisis and SKF:

Focusing on fewer things but the right ones instead of taking something away is what they prescribe during the current economic crisis (Reducing the number of shifts, less working hours, training of employees to use the resources more efficiently, etc. are some of the actions they have taken.) (Lars Arrenäs, SKF Company, 2009).

3.2 Khavar Spring Manufacturing (KSM)

3.2.1 Introduction

KSM was founded in 1977 with the aim of manufacturing car springs. It‘s located in Kaveh industrial zone near Saveh city in Iran. The company is one of main suppliers to the biggest Middle East car manufacturer, Iran Khodro, and National Railway Company. The company was certified to ISO 9002 in 1998, ISO 9001 in 1999 and QS 9000 in 2001 by TUV, Germany also it was certified to ISO TS 16949:2002 by DQS in 2004, which was extended in 2007 for 3 years.

Khavar Company implemented TPM in 2003 and Lean afterwards.

Reasons for TPM implementation in Khavar Company:

- A large number of unpredicted stops (Breakdown maintenance)
- Long down times of the equipment
- Low equipment efficiency and productivity
- High number of Wastage, “redo’s” and rejects due to poor quality
- Extensive imposed overhead expenses
- Inconvenient purchases in qualitative, quantitative and on time point of view
- Lack of proper communication between the warehouse, Maintenance and Purchasing departments
- The maintenance staff performed primary maintenance actions because the operators had not been trained
- Lack of Multi-skilled and flexible staff
- Problems due to different products that were produced in low amount
- Lack of listening to the voice of customers and stakeholders
- Lack of job satisfaction
- Improper equipment care by the operators
- Nothing was defined as preventive maintenance
- Lack of standards for equipment setups
- Critical parts of equipments, which have direct effect on the quality of product, were not identified.
- Lack of total culture for productive maintenance within the organization

Due to the above mentioned reasons, TPM was implemented through Benchmarking and Outsourcing. (KSM, 2009)

3.2.2 Time table for TPM implementation in KSM

No.	Action	Person in charge	Duration
1	**Preparation**		
1-1	Public announcement and giving seminars	Top management	1 month
1-2	TPM teams establishment	Management representative	1.5 month
1-3	Defining TPM targets and strategies	TPM team	2.5 month
1-4	Master plan preparation for each pillar	TPM team	2 month
1-5	Holding internal and external meetings for program justification and goal achievements	Management representative	15 days
2	**Training**		
2-1	Training policies' determination and needs' identification	H.R.	10 days
2-2	Training performance	H.R.	35 days
2-3	Training evaluation and continuous improvement	H.R.	Continuous
3	**Implementation**		
3-1	5S implementation	5S Team	95 days
3-2	Review of equipment manual and maintenance instructions	TPM team	1 month
3-3	Preparing list of risks and environmental impacts as well as MFMEA analysis	TPM team	2 month
3-4	Preparing program for Autonomous maintenance	TPM team	1 month *
3-5	Review of Planned maintenance program	TPM team	1 month *
3-6	Relevant technical and systemic documents up gradation	TPM team	10 month
3-7	Taking actions	TPM team	4 month
3-8	Actions' effectiveness analysis and, review and improvement if needed	Management	1 month

* Steps 3-4 and 3-5 were simultaneous

Table2. Schedule for TPM implementation in KSM (KSM, 2009)

KSM Principles: Similar to SKF, there are some principles arranged in KSM to reach excellence via changing attitudes and understanding organizational values in all levels of the company.

- Emphasis on human recourse, and its development
- Respect, faith and transparency
- Continuous improvement

- Respect to stakeholder satisfaction in all levels of organization
- Innovation and new technologies exploitation
- Individual and public learning as well as employees' involvement
- Be open to and analyze change
- Commitment to optimal use of recourses and energy (KSM, 2009)

3.2.3 Lean implementation in KSM

Although, TPM was implemented, the following problems existed. Therefore, KSM decided to implement Lean as response to these difficulties:

- No decrease in Lead time
- No thorough waste elimination especially as of "redo's"
- Lack of suitable and specific internal and external communication channels in case of incidents and emergences
- Lack of listening to voice of customers and stakeholders
- No decrease in number of employees
- Improper lay-out of the equipments and its consequences like non value adding motions and transportation as well as energy over-use.
- No inventory reduction
- Insufficient job satisfaction and enthusiasm among the employees
- Unused creativities
- Over production and using Push system instead of pull one
- Increase in number of competitors and their progress in quality and quantity of products
- Increasing costs of raw materials, equipments in addition to rising wages
- High overhead expenses
- Losses and wastage
- No dramatic decrease in number of incidents, injuries and damages
- Commitment toward changing the organization into a learning type
- Forming" Lean is a culture and TPM is a tool" as a popular belief (KSM, 2009)

3.2.4 Lean tools used and achievements

On the way to implement Lean, these tools were used: 5S, Andon, JIT, One piece flow, OEE, Heijunka, 8 wastes

Achievements through Lean:

No.	Targets	Year 2005	Year 2008
1	Increase in margin	0	+ %6 *
2	Increase in sales	9440	11200
3	Customer satisfaction	80 %	84%

4	Employees' satisfaction	74%	77%
5	OEE	68%	75%
6	Wastage	0.35%	0.04%
7	Suppliers' improvement	10%	30%
8	Per capita production	30 Ton	36 Ton
9	Inventories	23%	7%
10	PPM	7943	1137
11	On time delivery	75%	85%
12	Production amount	8365	11200
13	Number of employees	340	300
14	Decrease in transportation wastes(WIP) and relevant costs	5% improvement compared to the year 2004	20% improvement compared to the year 2005
15	Lead time	35 Working days	25 Working days
16	Work incidents	70	45
17	Waste in raw materials	300 Ton	200 Ton
18	Environmental impacts	------	20% decrease compared to the year 2005
19	"Re-do's"	4%	0.13%

* Compared to 2005

Table3. Achievements through Lean (KSM, 2009)

4. Lean and TPM comparison

In this part, similarities and differences between Lean and TPM are discussed in order to understand which of the theories about the relationship between Lean and TPM is closer to reality. Therefore, the two concepts are compared in the fields of Origin, Theory, Process view, Approach, Methodology, Tools, Primary effects, Secondary effects, Criticism.

- **Origin and Theory:** Lean concept came into existence at Toyota Company during the 1930s and mainly after the Second World War. Toyota managers and engineers had benchmarked the Flow Production concept from Ford. After understanding and using the concept, they started to develop and improve it and defined Toyota Production System which focuses on elimination of wastes like waste in time as well as resources. TPS is the base of what is known as Lean now. TPM also originated at Toyota but was introduced during the 1970s. Toyota developed the American concept, PM, with focus on Total Employees Participation. That is how Total was added to PM and formed TPM. Production loss is in contrast with right quality, reasonable cost and right time. In this way, Reliable equipment is needed.

- **Process view and approach:** Lean is a discipline that focuses on process speed and efficiency, or the flow, in order to increase the customer value.

In Lean, manufacturing improvements are mainly in the form of projects, which are performed by project groups. TPM can also be considered as an improvement project with the aim of decreasing process delays, involving operators and maintenance teams (teamwork).

- **Methodology:** Principles of Lean and TPM show the way to reach their objectives. Lean principles are Understanding customer value, value stream, analysis, flow, pull, perfection. TPM principles are OEE improvement, Front line asset care as part of the job, Systematic approach toward maintenance, Continuous & appropriate training, Early equipment management.

If TPM is regarded as a tool for Lean, its principles should support and help Lean principles. In this way, OEE is a part of Lean analysis; also, OEE improvement has a positive effect on Flow and Perfection. Front line asset care affects Flow and Perfection. Systematic approach toward maintenance serves Lean principles like Flow and Perfection. Continuous and appropriate training helps in understanding customer value by providing external or internal customers with fewer defective products and positively affects Flow and Perfection. Finally, early equipment management facilitates Flow and Perfection.

- **Tools:** Unlike Six Sigma (6σ), whose tools are statistical in order to eliminate source of variation, Lean tools are of analytical type. They help reduce and eliminate waste. TPM doesn't have tools like those of Lean but it has some pillars that work in a variety of fields like autonomous maintenance, planned maintenance, Kaizen, Quality maintenance, Office TPM, Training and Health, safety &Environment. Some measuring factors like OEE exist in order to see how much TPM implementation is successful.

- **Effects:** Lead time reduction is the main objective of Lean which ultimately results in customer satisfaction as a secondary effect. After Lean implementation, we can also see other secondary effects and changes like a productivity increase and a reduction in inventory. The primary effect of TPM is a decrease in loading time, which is "Total possible time – Scheduled non-production time". This effect positively influences the Availability factor for machines and OEE respectively. More Reliability and efficiency

of the equipments as well as a Productivity increase, could be achieved as secondary effect.

- **Criticism:** the main criticism against Lean is the lack of flexibility the concept offers, (Dove, 1999). In addition, the concept actually can lead to delays for the customers (Cusumano, 1994). It is a question among the theorists whether Lean, which was developed for manufacturing and distribution situations, is applicable in all industries. (Mast, 2004) TPM needs a long time to be fully implemented. This time includes times for introduction, training, making TPM groups and implementation.

TPM tries to increase the margin of companies by increasing the productivity. It only makes the operators and staff maintain equipments without considering the working on their attitudes and trying to encourage them to take responsibility and feel the ownership of equipments.

Concepts*	**Lean***	**TPM**
Origin	Quality evaluation, Toyota , 1940s	Toyota , 1970
Theory	Removes waste	Remove production losses
Objective	Reliable processes	Zero breakdowns & continuous improvement in equipment optimization
Process view	Improve flow in processes	Decrease process delays
Approach	Project management	Team working and employees involvement
Methodology	Understanding customer value, value stream , analysis, flow, pull, perfection	OEE improvement, Front line asset care as part of the job, Systematic approach toward maintenance, Continuous & appropriate training, Early equipment management
Tools(Methods)	Analytical tools	Pillars including methods like TBM, CBM, RCM, etc.
Primary effects	Reduces lead time	Decreases loading time in process
Secondary effects	Reduces inventory, increases productivity and customer satisfaction	Increases reliability and efficiency of equipment as well as total productivity
Criticism	Reduces flexibility, causes congestion in the supply chain ,Lean culture takes a long time to be totally accepted	-TPM implementation is a long term process -TPM mostly focuses on company margins

* (Roy Andersson, 2007)

Table4. Lean and TPM comparison

5. Conclusion

In order to reach manufacturing excellence in a company, the first step is creating Lean thinking.

Lean is a culture and is a philosophy for quality improvement. It starts with revolutionizing the minds of employees. TPM is a method. Many organizations implement TPM before establishing a Lean thinking. Companies use TPM to increase their productivity and equipment efficiency without trying to motivate the operators to take part in the program actively and voluntarily.

The employees regard TPM as just another improvement program, which merely serves targets and strategies of the company. A company should raise employees' responsibility and enthusiasm toward their job. This can be achieved by transferring the message through trainings and meetings, stating that everyone has his/her share in success of the company and all the roles are important. Furthermore, all employees should obtain a common view by understanding targets and goals of the company. When this goal is achieved, following steps should be taken:

- Defining the principles of organization
- Public announcement of principles and training for more clarification: This action leads to a common language by which, all levels of employees will use the same words but to different extents and applications based on their status.
- Forming a thinking organization: This means that all employees should feel free to suggest improvements, make decisions and be productive but only to an extent that poses no threat to the values and reputation of the organization.
- Employees will discover work shortcomings and ask for techniques for improvements. In addition, the company management may decide to push some new techniques for improvement therefore, the employees should gain enough flexibility to welcome, understand and apply new techniques.
- Lean tools like 5S, JIT, Kanban, TPM, etc., will be deployed with employees participation
- The results will be periodically evaluated
- Reviews, modifications or further methods' implementation shall take place.

The success of Lean and TPM implementation is highly dependent on the training. Mistake-proofing and problem solving are two competences that are under focus in Lean and TPM and must be highlighted during the training program.

6. References

Amy Reyner, Kweku Fleming, Internal Lean Consultant, Honeywell, 2004. *Heijunka Product & Production Leveling* [Online]
Available at: http://ocw.mit.edu/NR/rdonlyres/Engineering-Systems-Division/ESD-60Summer-2004/924D69DB-ADA4-402A-8CEB-3508FFA53724/0/9_3product_level.pdf [Accessed 9 June 2009].

BERR, SWREA, 2007. *7 Wastes* [Online] (Updated: August 29, 2003)
Available at:http://www.swmas.co.uk/info/index.php/7-Wastes [Accessed 04 05 2009].

Business dictionary .com. *Work cell* [Online]
Available at: http://www.businessdictionary.com/definition/work-cell.html [Accessed 7 June 2009].

Conny Leinstedt, 2008. *Project so what* [Online]
Available at: https://pingpong.hb.se/courseId/10115/content.do?id=5292579 [Accessed 2 June 2009].

Cusumano, M. A. (1994). "*The limits of Lean*", Sloan Management review, Vol 35 No 4, pp. 27-32.

C&H Distributors, 2009. *Lean Manufacturing* [Online]
Available at: http://www.chdist.com/info/leanmanufacturing.do [Accessed 9 June 2009].

Dennis McCarthy, Nick Rich, 2004, *Lean TPM; A blue print for change*, foreword [e-book] Google books
Available at:
http://books.google.co.uk/books?id=2uXWZbDHlpMC&pg=PA36&lpg=PA36&dq=%2Blean%2Btpm&source=bl&ots=g1n3AobSMJ&sig=dVARyx8Efbva1PNvr3eLKAXIoi8&hl=en&ei=N_1BStysOpGi_AbThonDCA&sa=X&oi=book_result&ct=result&resnum=11 [Accessed 22 04 2009].

Dove, R, (1999) "Knowledge management. Response ability and the agile enterprise", *Journal of knowledge Management,* Vol 3 No 1,pp18-35

Elsmar Cove, 2000. *Andon – Definition* [Online]
Available at: http://elsmar.com/Forums/showthread.php?t=12821
[Accessed 22 06 2009].

EMS Consulting Group, 2003. *Heijunka: Leveling the Load* [Online] (Updated 1,9, 2004)
Available at: http://www.emsstrategies.com/dm090804article.html [Accessed 2009 04 25].

EMS Consulting Group, 2003 . *The 7 Manufacturing Wastes* [Online] (Updated: August 29, 2003)
Available at: http://www.emsstrategies.com/dm090203article2.html [Accessed 04 05 2009].

EMS Consulting Group, 2003 . *5S implementation* [Online] (Updated: May 22, 2009)
Available at: http://www.emsstrategies.com/dm103103article.html [Accessed 04 05 2009].

Focused Performance, *TOC and Six Sigma -- Better Together* [Online]
Available at: http://www.focusedperformance.com/articles/tocsigma.html
[Accessed 22 06 2009].

Glovia International, Inc. Fujitsu, 2008. *Kanban* [Online] (Updated 22,10, 2008)
Available at: http://www.glovia.com/pdf/datasheets/GloviaKanban.pdf
[Accessed 7 June 2009].

Graphic Products, Inc.,2000. Kaizen is... [Online]
Available at: http://www.graphicproducts.com/tutorials/kaizen/index.php

[Accessed 04 05 2009].
Graphic Products, Inc.,2000. *What is Five S?* [Online]
Available at: http://www.graphicproducts.com/tutorials/five-s/index.php
[Accessed 04 05 2009].
Imants BVBA, info@managementsupport.com, 2009. *The Total Productive Maintenance Guide*. [Email]. Message to Mohammadreza Enaghani (enghani2002@yahoo.com). Sent 16 April 2009, 9:24.
IMEC, 2004.*Kaizen Process* [Online]
Available at: http://www.imec.org/imec.nsf/All/Kaizen_Process?OpenDocument
[Accessed 05 May 2009].
James P. Womack, 2009, *The machine that changed the world*. [e-book] Massachusetts, Scribner
Available at: http://gigapedia.com/items/302728/the-machine-that-changed-the-world---based-on-the-massachusetts-institute-of-technology-5-million-dollar-5-year-study-on-the-future-of-the-automobile [Accessed 21 04 2009].
Jeffrey K. Liker, 2004, *The Toyota way*. [e-book] Concordville, Pennsylvania: Soundview Executive Book Summaries
Available at: http://gigapedia.info/1/the%20toyota%20way [Accessed 09 05 2009].
Jerry Kilpatrick, Manufacturing extention partnership, 2003. *Lean Principles* [Online]
Available at: http://supplychain.tamu.edu/academics/444/LeanPrinciples.pdf
[Accessed 25 05 2009].
Jim Warren, Sunset Manufacturing Company, 2007. *Designing Throughput Accountability* [Online]
Available at:
http://www.shopwerkssoftware.com/docs/Designing%20Throughput%20Case%20Study%209-07.ppt [Accessed 9 June 2009].
JIPM-Solutions co. Ltd. *What is TPM* [Online]
Available at: http://www.tpm.jipms.jp/tpm/index.html [Accessed 30 April 2009].
J. Venkatesh, Reliabilityweb.com, 2009. *Total Productive Maintenance* [Online]
Available at:
http://reliabilityweb.com/index.php/articles/total_productive_maintenance/
[Accessed 15 March 2009].
J. Venkatesh, Plant Maintenance Resource Center, 2007. *An Introduction to Total Productive Maintenance (TPM)* [Online]
Available at: http://www.plant-maintenance.com/articles/tpm_intro.pdf
[Accessed 22 04 2009].
Kaye Krueger, 2004. *Value-Added vs. Non-Value-Added Activities* [Online]
Available at: http://www.wisc-online.com/objects/index_tj.asp?objID=ENG11104
[Accessed 1 June 2009].
KSM Company, 2009. *Report of Lean and TPM implementation results*. [Word document- translation]. May 2009
Lars Arrenäs, SKF Company, 2009. *TPM in SKF* [Interview] (Personal communication, May 2000).
Leading Edge Group, 2007. *Lean Tools and Techniques* [Online]
Available at: http://www.Leanscm.com/Leanthinking1.htm
[Accessed 22 04 2009].
Lean enterprise institute. *A brief history of Lean* [Online]
Available at: http://www.Lean.org/WhatsLean/History.cfm
[Accessed 21 04 2009].
Lean Enterprise Institute. *Value stream mapping and management* [Online]

Available at: http://www.lean.org/Community/Resources/Presentations/new_APICS1202.pdf
[Accessed 9 June 2009].

Lean manufacturing concepts, 2008. History of lean manufacturing [Online]
Available at: http://www.leanmanufacturingconcepts.com/HistoryOfLeanManufacturing.htm
[Accessed 22 04 2009].

Lisa Somanchi, 2007. *Poka Yoke or Mistake Proofing :: Overview* [Online] (Updated 5 May 2008)
Available at: http://thequalityportal.com/pokayoke.htm
[Accessed 25 04 2009].

LSS Academy. *One Piece Flow versus Mass Production* [Online] (Updated: 18, 02, 2008)
Available at: http://lssacademy.com/2008/02/18/one-piece-flow-versus-mass-production/
[Accessed 04 05 2009].

LSS Academy. *10 Benefits of One Piece Flow* [Online](Updated: 27, 03, 2008)
Available at: http://lssacademy.com/2008/03/27/10-benefits-of-one-piece-flow/
[Accessed 04 05 2009].

MAMTC . *Benefits of Lean* [Online]
Available at: http://www.mamtc.com/Lean/intro_benefits.asp
[Accessed 18 04 2009].

Manufacturing-Works. *Goals of a Lean Enterprise* [Online]
Available at: http://www.manufacturing-works.com/lean/lean_enterprise.php
[Accessed 18 04 2009].

Martin Hjelte, SKF Company, 2009. *Lean thinking* [Interview] (Personal communication, May 2000).

Mast, J. (2004). "A methodological comparison of three strategies for quality improvement", *International Journal of Quality & Reliability Management*, Vol 21 No 2, pp. 198-213.

National institute of standards and technology (NIST) *Lean - Pull Systems/Kanban* [Online]
Available at: http://www.mep.nist.gov/manufacturers/services/Lean/pull-system.htm[Accessed 21 04 2009].

Nihar Kanta Patra, Jayanta Kumar Tripathy, Dr. Choudhary, B. K., 2005. Implementing the office total productive maintenance (''office TPM'') program: a library case study. *Emerald Group Publishing Limited*, [Online]. 54(7)
Available at: http://www.emeraldinsight.com/Insight/ViewContentServlet;jsessionid=4B69FE91233F31A515B9A0E2FF342060?Filename=Published/EmeraldFullTextArticle/Pdf/0350540704.pd-f [Accessed 09 05 2009].

Oee, 2006. What we do [Online]
Available at: http://www.oeeuk.com/what/manufacturing_measure.html#basics
[Accessed 04 05 2009].

Robert M. Williamson, Strategic Work Systems, Inc., 2006. *Total Productive Maintenance: What It Is and What It Is Not* [Online]
Available at: http://www.swspitcrew.com/articles/TPM%20What%20Is%20It%200606.pdf
[Accessed 22 04 2009].

Roy Andersson, 2007. *Quality-driven logistics*. Thesis for the degree of licentiate of Engineering, Report 68, paper 1, pp. 6-8. Göteborg: Chalmers University of technology

Siliconfareast.com, *The 5 'S' Process: Seiri, Seiton, Seiso, Seiketsu, Shitsuke* (Page 1 of 2), 2000. [Online]
Available at: http://www.siliconfareast.com/5S.htm [Accessed 04 05 2009].

Six Sigma community, 2000. *5 S* [Online] (27, 08, 2003)
Available at: http://www.isixsigma.com/dictionary/5S-486.htm [Accessed 04 05 2009].

SKF Group Headquarters, *This is SKF* [Online]
Available at:
http://www.skf.com/portal/skf/home/about?contentId=000493&lang=en
[Accessed 10 05 2009].

Strategos, One Piece Flow - Magic or Myth? [Online]
Available at: http://www.strategosinc.com/onepieceflow.htm
[Accessed 04 05 2009].

Thomas R. Pomorski, 2004. Brooks Automation, Inc. *Total Productive Maintenance (TPM) Concepts and Literature Review*
Available at: http://www3.brooks.com/tmp/2110.pdf
[Accessed 15 March 2009].

TPS-ThroughPut Solutions, 2007. *2-Bin Auto-Replenishment System* [Online]
Available at: http://www.tpsLean.com/2bin.htm [Accessed 2009 04 25].

University Of Cambridge, Institute For Manufacturing (IFM). *JIT Just-in-Time manufacturing* [Online]
Available at: http://www.ifm.eng.cam.ac.uk/dstools/process/jit.html [Accessed 04 05 2009].

U.S. environmental Protection Agency. *Total Productive Maintenance (TPM)* [Online] (Updated 03 April 2009)
Available at: http://www.epa.gov/Lean/thinking/tpm.htm [Accessed 05 May 2009].

William M. Feld, 2001, *Lean Manufacturing Tools, Techniques, and How To Use Them*. [e-book]. Washington, D.C.: The St. Luise press, Alexandria, Virginia: APICS
Available at: http://xinio.info/?http://ifile.it/ce1gud5/157444297X.zip
[Accessed 22 04 2009].

Wisc-online.com, 2004. *The Eight Wastes of Lean* [Online]
Available at: http://www.wisc-online.com/objects/index_tj.asp?objID=ENG10603
[Accessed 04 05 2009].

Word press.com, 2008. *The Advantages of Lean Manufacturing* [Online] (Updated 31 Jan. 2008)
Available at: http://learnsigma.wordpress.com/2008/01/31/the-advantages-of-lean-manufacturing/ [Accessed 25 04 2009].

12 Manage.*Value stream mapping* [Online] (Updated: 30, 11, 2008)
Available at: http://www.12manage.com/methods_value_stream_mapping.html
[Accessed 2009 04 25].