LEAN MANUFACTURING METHODOLOGY FOR IMPROVING PRODUCTION FLOWS ON AN ASSEMBLY LINE

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Abstract

Purpose *– The article presents another stage of development of the methodology for improving production flows on an assembly line in the automotive industry.*

Approach *– The Lean Manufacturing methodology was developed to present in a logical chaining way the methods specific to this concept of production management, and as to allow efficient analysis and continuous increase of the performance of an assembly line. This chaining requires that, according to the results of each method application, specific paths/ methods will be followed/ applied.*

Findings *– This methodology was experimented and validated in the laboratory which integrates an experimental demonstrator (an assembly line of an experimental product), software (to analyse, improve or optimize different layouts of the workstations or line production and production flows) and specific concepts (learning, experimenting and research platforms) of the Lean Learning Factory. Along with the "Lean cubes" platforms, for each Lean method (5S, VSM, DOJO, Poka-Yoke etc.), flowcharts and tables specific to their application were made.*

Research limitations/implications *– The developed methodology allowed the increase, during the project/ research, of the TRL level (technological training level) of the experimental demonstrator from 2 to 4. The platforms specific to Lean methods can be used for other production systems, being able to be used successfully in any Lean learning factory, but the experimental demonstrator is intended only for assembly lines.*

Practical implications *– The lean manufacturing methodology presented in this paper can be used successfully in the "Lean learning factory" type laboratory for the education and training of students and employees of companies in the automotive industry.*

Originality/value *– The study is part of a research project of the authors, which has as aim the development of a methodology of improvement of production flows in the automotive industry, by integrating modern techniques and instruments of production management.*

Key words: *lean manufacturing, learning factory, assembly line*

Introduction

Around the 1950s, at the Toyota plants in Japan, the Toyota Production System (TPS) was created, with the aim of increasing production by using as few resources as possible, reducing physical effort, efficient use of equipment, time, movement and space and adding value to the final product. Starting from the TPS system, Womack first introduced the concept of Lean production (Womack et al., 1990). Thus, Lean Production or Lean Manufacturing are names currently adopted for TPS-based systems, and these are frequently found in the literature.

To achieve the main objectives of Lean manufacturing, several methods and techniques have been proposed, as highlighted by Ohno (Ohno, 1988) and Pascal (Pascal, 2007):

Objective:	Maximum Availability of Resources: TPM (Total Productive Maintenance) – OEE (Overall Equipment Effectiveness)
Objective:	Maximum Quality (Zero Defect): TQM (Total Quality Management)
Objective:	Minimum Productive Flow/Maximum Speed Cellular Manufacturing, SMED Systems and Error Proof (Poka-Yoke) Systems
Objective:	Minimum Inventory (Zero Inventory) JIT/Kanban Systems

Also, to support decision-making, several tools have been developed, such as: Value Stream Mapping (VSM - to evaluate the company and generate a map of all information flow processes), Kaizen (a continuous improvement program implemented within the company), 5S (tool intended to organize and clean the workplace), Visual Management (displaying the company's activities so that the whole team involved in the work has easy access) etc.

Throughout time, Lean methods and techniques have already proven their efficacy in various sectors, firstly in the automotive industry. Their use in the context of globalization of production and strong competition in the automotive industry, allows manufacturers to offer customers a wide range of good quality products at lower prices, by continuously improving the production system. This is possible by adapting production systems, especially assembly lines, to mass customization so that they can offer the variety demanded by customers, while limiting their costs and maintaining profitability (Limere, 2012).

On the other hand, to develop and transfer fundamental knowledge, e.g. about methods for process improvement (Lean manufacturing), to students or seminar participants from industry, a novel concept was developed: Learning Factory (Kreimeier et al., 2014). A Learning factory includes elements of learning or teaching, as well as a real manufacturing environment (Wagnera et al., 2012), which allow the analysis, simulation and optimization of various aspects of production systems and, thus, their easier and faster application in industry by the students or participants.

Research problem

This study is part of a research project of the authors that has as aim to develop new methodologies of improvement for the production flows of automotive industry, by integrating modern methods, techniques and tools of production management. The starting conceptual model is appreciated as having Technology Readiness Level 2 - TRL2 (DOE G 413.3-4, 2009) and was presented in (Gavriluta et al., 2018).

The proposed model has 3 interrelated investigations areas - layout design, modelling and simulation flows, Lean manufacturing – and, until now, the project team developed several studies in these areas: methodology for designing the layout for an assembly line to the automotive industry using the Lean concept (Gavriluta et al., 2018), methodology of learning to use simulation in the analysis of production system performances production system (Gavriluta et al., 2019), ergonomics study on an assembly line used in the automotive industry (Anghel et al., 2019), approach with genetic algorithms to improve the workstation space planning (Belu et al., 2019), SixSigma application (Belu, 2018) and implementation of Kanban using indoor location based on RFID (Belu et al., 2018). All these studies were integrated into general *Methodology for improving production flows on an assembly line*, fig. 1 (Nitu et al., 2020).

This paper presents another step of this methodology, *Lean manufacturing application*, which is applied in the exploitation stage of the assembly line. This methodology was experimented and validated in the laboratory which integrates an experimental demonstrator, software and specific concepts of the Lean Learning Factory (Nitu et al., 2019).

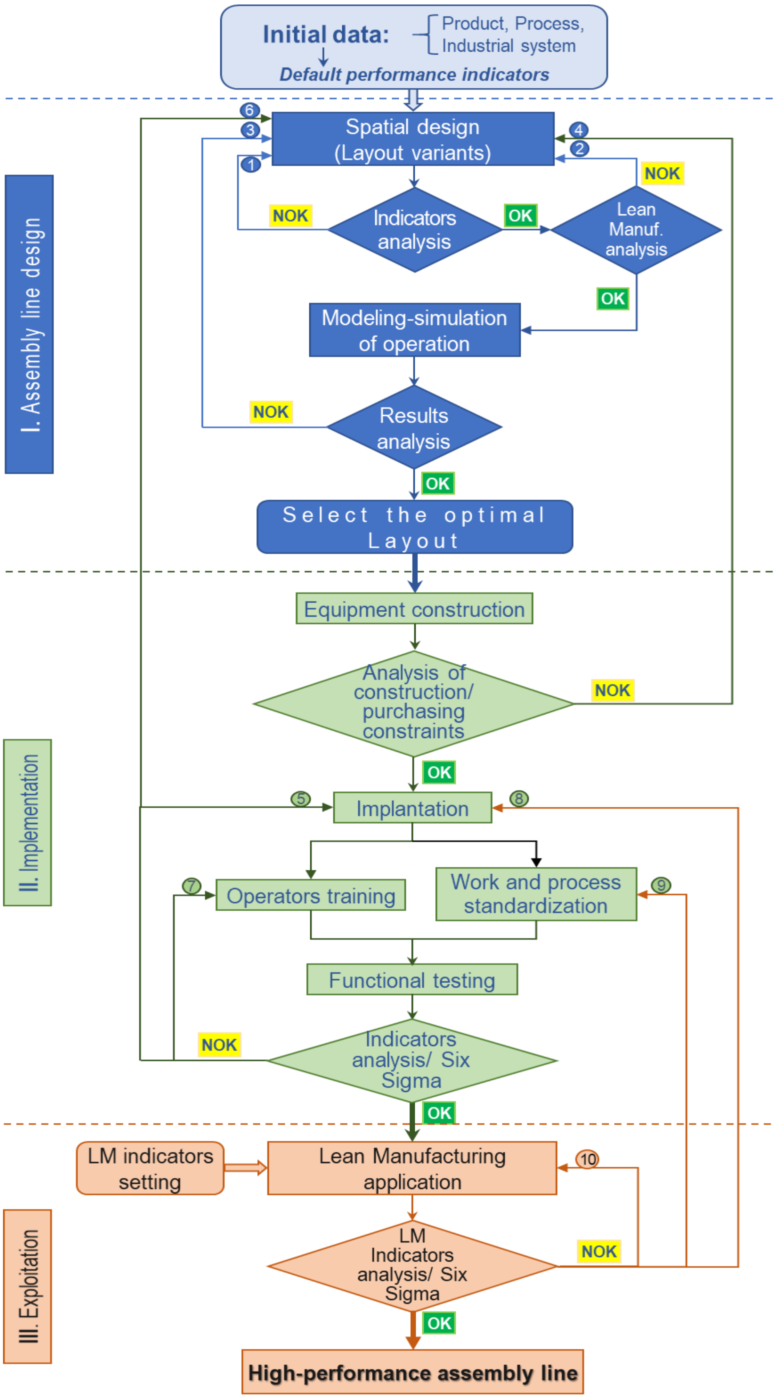


Fig.1 Methodology for improving production flows on an assembly line

Approach

The application methodology of Lean Manufacturing was developed in order to present in a logical chaining way the set of methods specific to this modern concept of production management, so as to allow efficient analysis and continuous increase of the performance of an assembly line. The performance of the assembly line is assessed by Lean indicators (whose value is to be achieved / increased), such as:

- Productivity – number of products assembled per hour;
- Quality – number of products without defects;
- Cost – cost per unit for the process of the assembly on the assembly line;

– Delivery time – the time between the moment of clients product demand and the moment when the product is available to the client;
– Safety and environment protection– possible situations of risk for the environment, with ways to prevent them, actions to collect and constant monitor the wastes (to surpass possible danger situations and to guaranty the safety conditions);
– Human capital – teamwork or the optimal use of the available human resources knowledge. The purpose is to increase the abilities of each team member (of teamwork, of team leading, of logical and clear thinking, of problem solving) and to increase the confidence of the team members in the own competences.

To obtain the LEAN performance indicators is needed to analyze and to do a successive evaluation of the stability and standardization of the process, its efficiency, "Just in Time" delivery of products, of the quality management system, of the working team, and followed with the use of specific methods that lead to improvements in the assembly lines functioning, fig. 2.

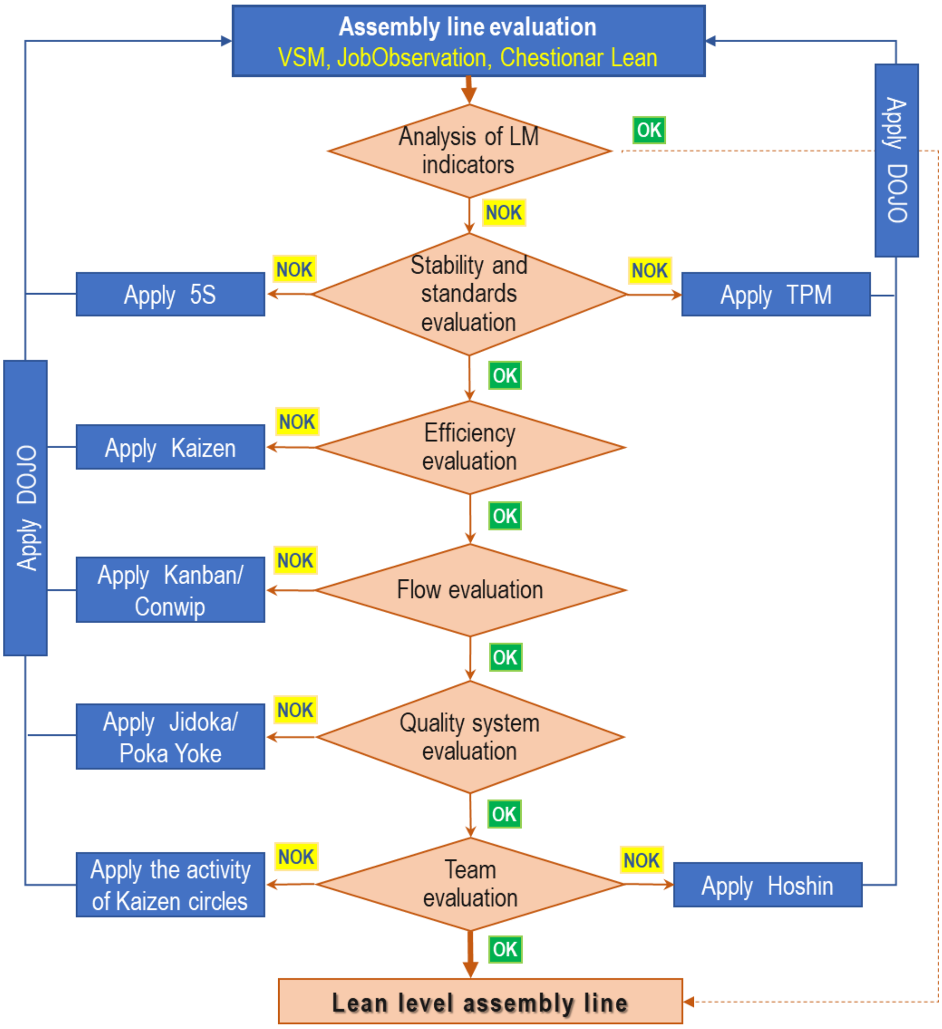


Fig. 2 Lean Manufacturing application methodology

"***Assembly line evaluation***" consists in the use of some methods to define, measure and analyze the flow of "things that are transformed", whether we talk about stocks, products or documents. These methods are: Value Stream Mapping – VSM, JobObservation and Lean Manufacturing Questionnaire. Value Stream Mapping – VSM is one of the most important methods of analysis of a production system, that helps to identify the current state and the improvement opportunities. JobObservation is a method of analysis of the activities that take place in a production system, with its help are confirmed the existence of standards and can be easily identified solutions of improvement. The method is based on the observation of the activities and on discussions with the operators. The Lean Questionnaire is a form that highlights the current status of the system by comparing it to the targeted Lean level. The evaluation focuses on:

- Philosophy – the long term thinking to an excellence vision;
- Process – stability, the consistent delivery of what the client wants, when he wants it;
- People – respected and guided to become process developers, to reach challenging objectives;
- Problem solving – with the help of Plan-Do-Check-Act model, using innovation to reach the excellence vision.

The results obtained after the implementation of these methods are analyzed in the step "***Analysis of LM indicators***". If the LM indicators resulted after the evaluation are in the range of established limits, is concluded that the assembly line has the needed performance, and the improvement of its performance implies the change of the Lean Manufacturing indicators. In the situation when the LM indicators resulted after the evaluation are not satisfactory, the team passes to the next stage, "***Stability and standards evaluation***", that consists in the analysis of stability and process standardization of the assembly line.

The most frequent causes of process instability in an assembly line are:

- The problems of quality of parts that are supplied from the external suppliers;
- The stocks of parts that are undersized in the workstations;
- Problems of equipment, tools, conveyers and other transport systems;
- The waiting time of the operators without activity;
- Safety issues caused by the design/ not ergonomic placing, sliding, tripping, falls of the operators.

A standard must give a clear image of the working way for the operator/ process in the targeted area, must be simple, clear and visible. With its help the abnormalities of the process are seen faster, making possible a quick implementation of the needed actions of improvement.

To evaluate the stability and the standardization of process in an assembly line can be used the following tools:

- Table/ chart of production capacity: documents the functioning time of machinery and operators and allows to quickly identify the bottlenecks in the system;
- The conjunct table of standardized work: highlights the steps to make the activities and their sequence, the duration of each activity, the working time for each operator and of each machinery and the interaction between operators or between operator and machinery;
- The analysis chart of standardized work: helps the rationalization of placing and training the workers. This includes the spatial organization of the workplace, the steps of the process and the durations for each activity, important articles for quality and safety, the standard work in process;
- Job Elements Sheet (JES), that contains: operations/ activities needed to make the product; the reason, motive to make the activities; images and photos that show the important key points; control records.

To increase the performances of a production line is absolutely necessary to stabilize and standardize the processes specific to the 4M:

- Man: team members;
- Machine: machinery, devices, conveyers and other transport devices, etc.;
- Methods: the used processes;
- Material: raw materials and the details given by the supplier.

The stability and standardization impose the use of specific methods and techniques of visual management/ 5S (the 5S method is the backbone of standardize work and Just In Time production) and Total Productive Maintenance (TPM, that is the way to stabilize and standardize the methods and machinery). Therefore, if after the evaluation of stability and standardization it is concluded that the assembly line does not meet the requirements, the next steps are organized "***Apply 5S***" and/or "***Apply TPM***", in parallel with the step "***Apply DOJO***". The use of these methods is restarted until the assembly line is completely stabilized and standardized, moment when the team can pass to the next steps.

After the stabilization and standardization of production process, the team can start the improvement activities. The production processes contain, in most cases, waste (muda). The stabilized and standardized work supply the initial information to improve the activities of the operators, by identifying the added value and the wastes in the process. The efficiency can be defined by:

Efficiency = Total achieved production/ Involved work force

Therefore, Lean Manufacturing highlights that one of the ways to increase the efficiency consists in decreasing the workforce involved in the process. In this context, in the next step "***Efficiency evaluation***" the purpose is to evaluate the efficiency of operators use in the assembly line. The tools used in this stage are:

- The chart of operators workload;
- The analysis of Cycle Time vs Takt Time;
- The combined table of standardized work;
- The analysis of operators movements;
- Ergonomic analysis of the workplace etc.

If, after the evaluation it is concluded that the assembly line is not efficient, the team passes to the next step "***Apply Kaizen***", in parallel with the step "***Apply DOJO***". The use of these methods is resumed until the assembly line reaches the needed efficiency level.

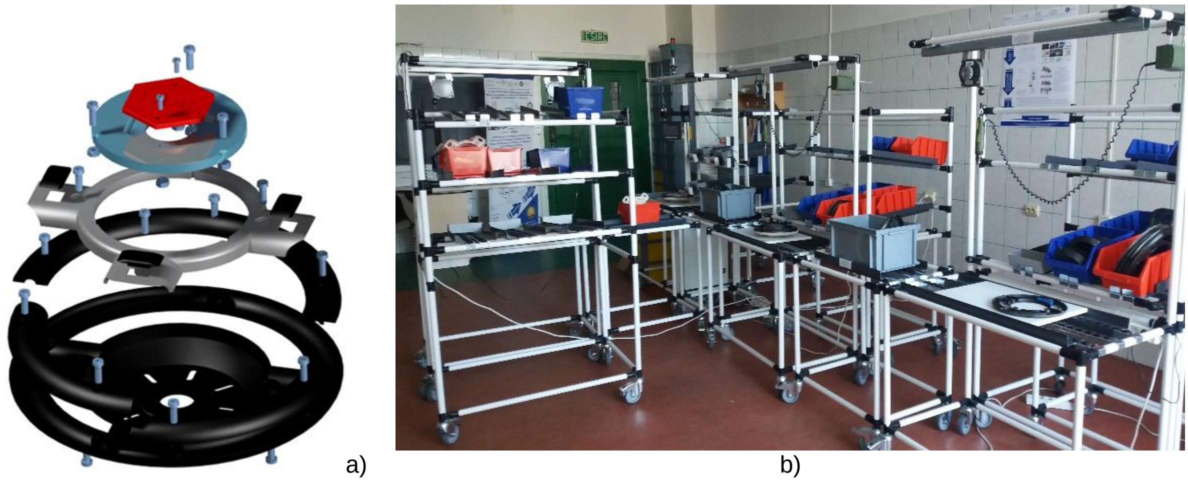
In the step "***Flow evaluation***" it is checked if the assembly line works in a pull flow, in a continuous way and in small production lots, preferable part by part (one-piece flow), characteristic of Just In Time production (JIT). If it is concluded that the line works in a push flow manner, the team will apply methods to reach pull flow by using Kanban or Conwip. This is done in the step "***Apply Kanban/ Conwip***". Kanban and Conwip are visual methods to manage the production, that synchronize and give information for the suppliers and the clients, intern and extern of the production system. This step is done in parallel with the step "***Apply DOJO***", until a pull flow is reached.

The implementation of Lean Manufacturing imposes also the implementation of a continuous improvement long term strategy. Therefore, in the step "***Quality System Evaluation***" it is evaluated the assembly line capacity to prevent, discover and reduce the errors that can lead to defects. If the obtained results are not satisfactory the team will pass to the step "***Apply JIDOKA/ POKA YOKE***" and, in parallel the step "***Apply DOJO***". The JIDOKA method consists in a fundamental rethinking of the quality management methods, different from the statistical methods, it leads to 100% inspections and use of POKA YOKE tools. A POKA YOKE is a simple and robust, inexpensive, device that allows 100% inspections of parts, identification of errors that can lead to defects and helps to find fast solutions to implement.

The involvement of team members is the heart of LEAN production. The involvement develops abilities for the team members and improves the long-term perspective, by eliminating wastes caused by the inefficient use of team members knowledge (that are, probably, the most obvious type of waste). Therefore, in the step "***Team Evaluation***" the management team evaluates the degree of involvement of the team members in solving problems and the capitalization of their knowledge. The activities of Kaizen circles (KCA) are, probably, the best way to encourage the involvement of the team members in the solving of identified problems. The involvement must be planned and controlled as good as the production and quality, and the most adequate method to do that is HOSHIN. If the answered obtained is unsatisfactory the team will pass to the steps "***Apply the activity of KAIZEN circles***" and "***Apply HOSHIN***".

Findings

In order to experiment and validate the developed methodologies, an experimental demonstrator (TRL4 level) – fig.3 was developed in the laboratory (Gavriluta et al., 2018). In fact, this experimental demonstrator is an assembly line of an experimental product (steering wheel) that can be made in several variants, through manual assembly activities. The assembly line was designed to integrate Lean principles: high flexibility for the workstations, one-piece flow, minimizing the activities with non-added value and, also, some concepts specific to Industry 4.0: a digital structure for one of the workstations.



a) b)

Figure 3. Experimental product (a) and experimental demonstrator (b) used in Lean Learning Factory laboratory.

Also, this laboratory integrates along with the experimental demonstrator, software and specific concepts of the Lean Learning Factory (Nitu et al., 2019). Software as IMPACT, TECNOMATIX (FactoryCad, FactoryFlow, Jack, Plant Simulation) and ARENA SIMULATION are used in order to analyse, improve or optimize different layouts of the workstations or line production and production flows.

To facilitate the understanding of the Lean manufacturing methodology on the assembly line (on the experimental demonstrator), its use and experimentation, a lot of methodologies and platforms specific to lean methods (5S, VSM, DOJO, Poka-Yoke etc.) were developed and tested in the laboratory. The platforms were made into “Lean cubes” from modular aluminium tubes, which are display systems that mix a white board with Lean display concept, providing a compact teaching solution, information display and visual management. Along with these platforms, for each Lean method, flowcharts and tables specific to their application were made, using the “Learning Factory” concept. Some of these methods and methodologies, together with their instruments are summarized below.

Value Stream Mapping – VSM is a method that allows the analysis with the help of a simple figure of the whole process of product making, from the moment when the client places the order to the moment when the products reach him. The VSM shows the flow of materials and the flow of information, as they go from a stage to another all along the process. The use of VSM to study the flow of production for a product consists in following the steps is presented in fig. 4. To apply this method in the analysis of an assembly line, using “Learning Factory” tools, was made a “VSM platform”, fig. 5.

The 5S method is a way to organize the workspace, that intends to make a clean, stable and efficient workspace. The use of 5S method to improve the workspace consists in following the steps shown in fig. 6. To apply this method on the assembly line, was made a “5S platform”, fig. 7, using a tool named “Lean Cube”, each side corresponding to a step (Wilson, 2010).

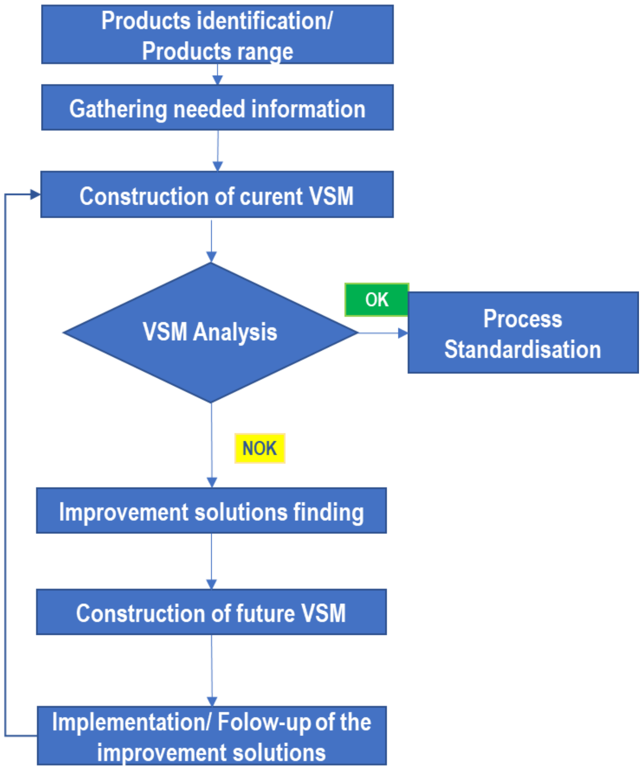


Figure 4. VSM application methodology

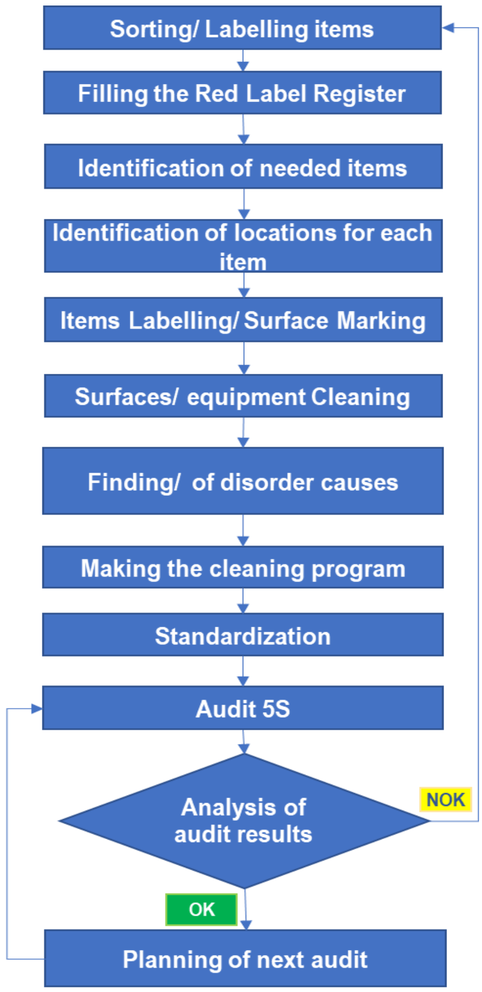


Figure 6. 5S application methodology

Figure 5. VSM Platform

Figure 7. 5S Platform

Kaizen is a method of continuous improvement, which is done step by step involving everyone, managers and workers alike (Imai, 1989). Kaizen is Japanese word composed of two terms: “Kai”, which means continuous and "Zen" which means improvement (Newitt, 1996). The stages and activities specific to the Kaizen methodology are based on the application of a PDCA (Plan–Do–Check–Act) cycle, which is also called the Deming cycle and are presented in fig. 8. In order to facilitate the use of this methodology, a lot of predefined tables and documents / instruments are proposed, fig. 9.

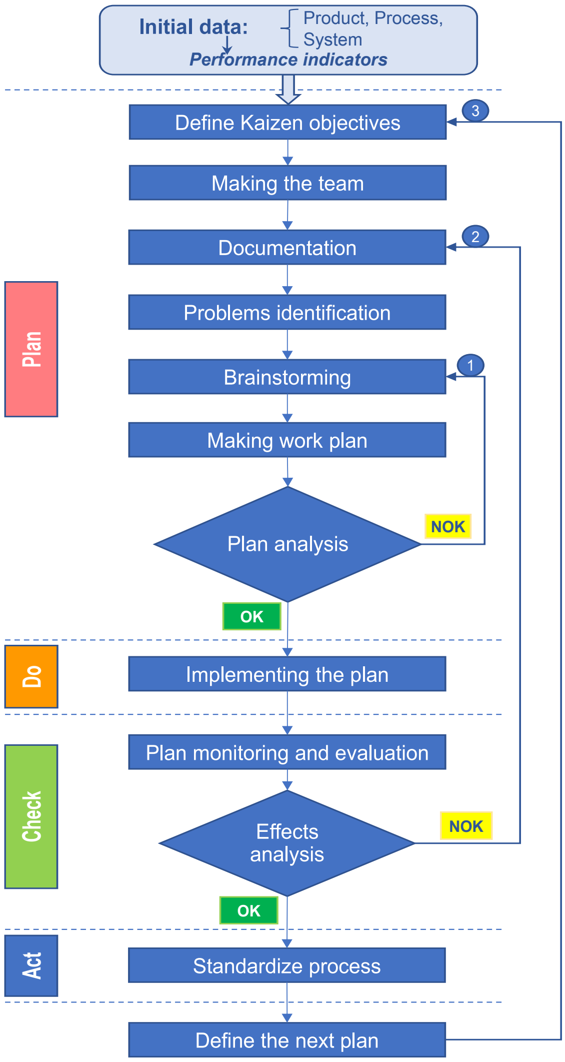


Figure 8. Kaizen application methodology

Date of completion:	KAIZEN ACTION PLAN			Ending date:
Task	Responsible	Due	Status	Remarks

Kaizen Report			
Location		Department	
Initial Condition (What was the problem?)		Solution Proposed (What was implemented, changed or improved?)	
Before (Include pictures, diagrams, etc.)		After (Include pictures, diagrams, etc.)	
Benefits Category		Benefits Description (results, cost benefit analysis, cost savings etc.)	
☐ Quality	☐ Safety / Health		
☐ Cost	☐ Environment / Energy		
☐ Delivery	☐ Customer responsiveness		
☐ Efficiency	☐ Morale		
☐ Waste	☐ Other		
Originated By	Validated By	Approved By	Contact Details
Team Members			
Implementation Date	Date of Completion	Remarks	

KAIZEN BOARD			
IDEAS	TO DO	DOING	DONE

Fig. 9 Tables specific to the application of the Kaizen method

Poka-Yoke is a quality tool invented and implemented by the Japanese engineer Shingo Shigeo (Shigeo and Dillon, 1989). By translating the two Japanese words "Poka" - mistake and "Yoke" - to escape, one arrives at the translation of the "Poka-Yoke" method (Shimbun, 1989). The purpose of this tool is to eliminate the defects of a product by preventing and correcting the errors as quickly as possible.

Poka-Yoke is a simple method of identifying defects, it is robust and easy to implement. Therefore, this method is also called „ZQC" (Zero Quality Control), „error proofing" or „mistake proofing", and its application stages are shown in the figure fig. 10. The fig. 11 shows a simple Poka-Yoke device used on an assembly line workstation.

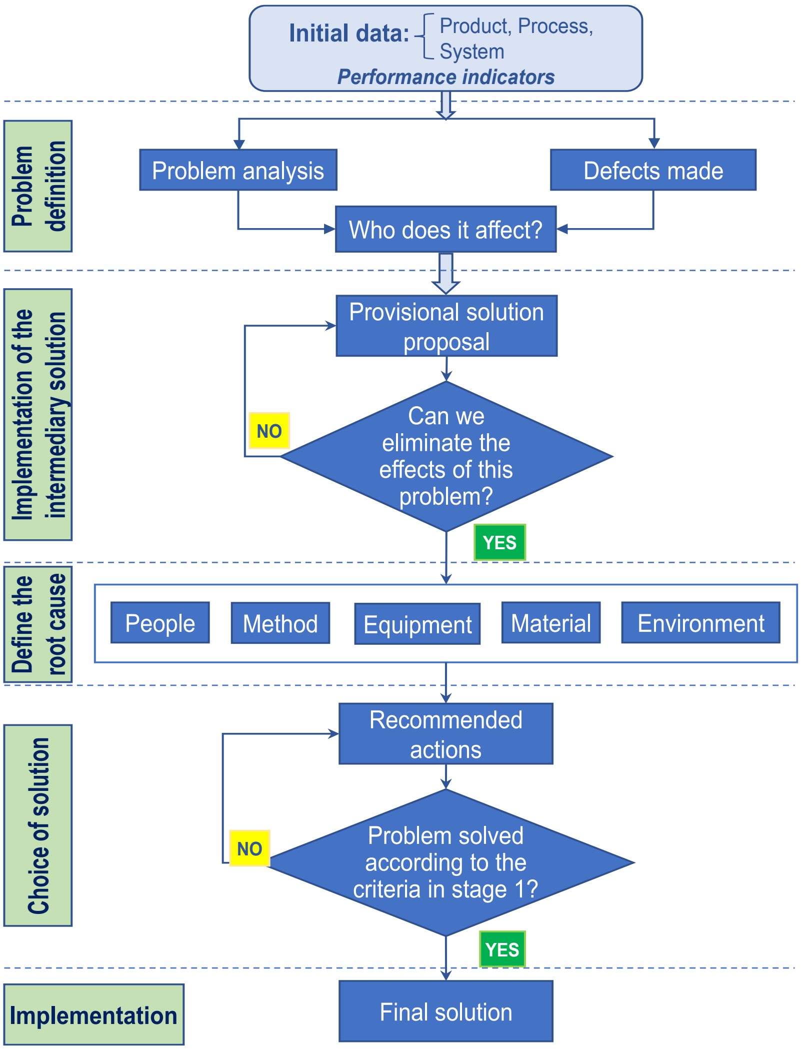


Figure 10. Poka-Yoke methodology

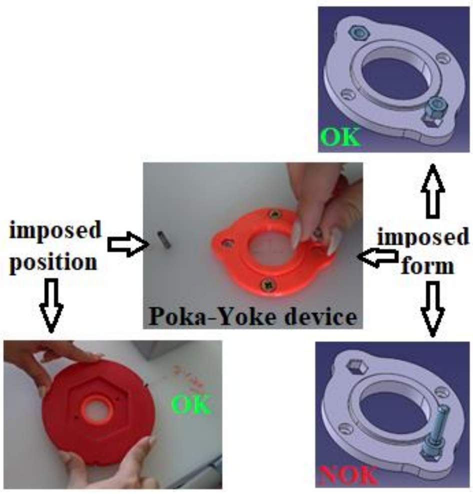


Figure 11. Poka-Yoke device used on an assembly line workstation

The **Hoshin Kanri** method is a tool for effective strategic that makes it easy to identify critical targets, evaluate restrictions, establish performance measurements, develop implementation plans and conduct to periodic review meetings used to carry out the alignment (Lagarda-Leyva et al., 2014). This is a technique that helps organizations to focus their efforts and analyse their activities and results. It translates the vision and mission of an institution in an understandable arrangement of tactical objectives, which defined performance indicators and transforms them into a framework of project-based work (Jimenez, P. et al., 2016). The proposed steps for applying this method are shown in the fig. 12. The most popular way of implementing this method is applying the Hoshin Kanri matrix that includes goals, strategies, strategic projects (initiatives) and owners, fig.13.

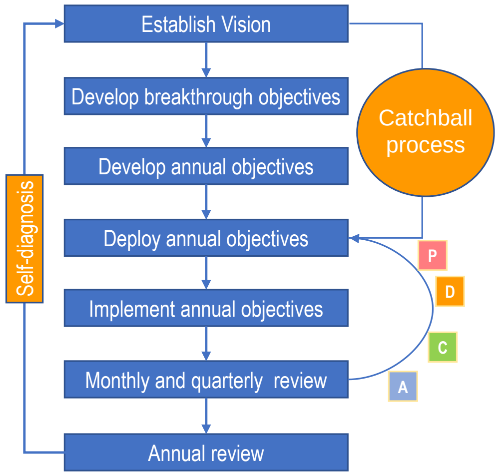


Figure 12. Hoshin Kanri methodology

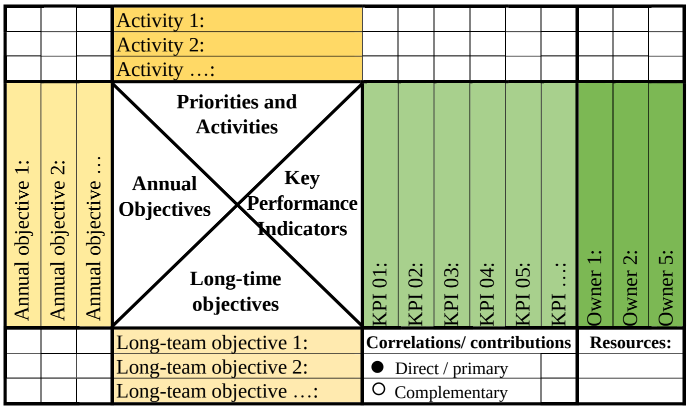


Figure 13. Hoshin Kanri Planning matrix

Kaizen circles encourage employees to improve service activities through their own proposals in order to increase productivity. These are held consistently on a regular basis comprising six to eight employees usually led by a team leader and circle consultant instigated to resolve work related issues, typically chronic quality or productivity issues (Damrath, 2012). Structural problem-solving algorithms, fig. 14, are conducted through these meetings ending up with a delivery in form of a report, as shown in the fig. 15.

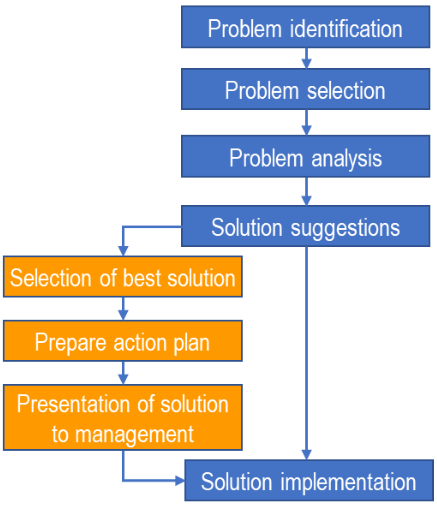


Figure 14. Kaizen circles methodology

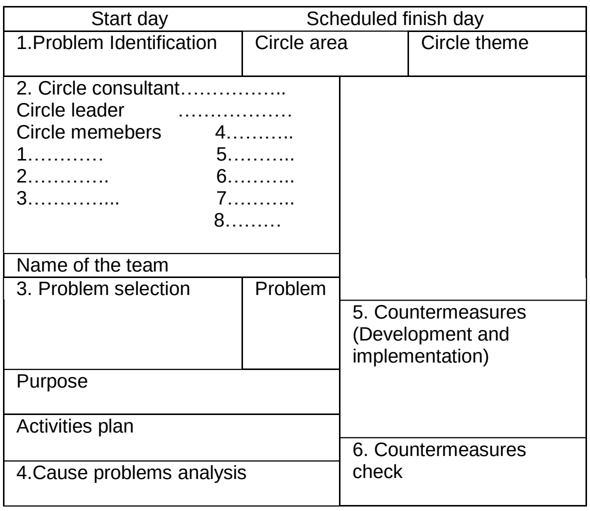


Figure 15. Kaizen circles reporting form

Dojo is a management method which allows the managing and continuous improvement of a grand diversity of problems by training to achieve the best performances in the workstations. In a Lean environment, a Dojo is a place and method for structured knowledge sharing by employees through other employees, encouraging their multi-skill capabilities, with the idea of "what our best resources know, can benefit the rest" (Damrath, 2012). The main idea of the concept is sharing of best practices how to execute tasks. The proposed steps for applying this method are shown in the fig. 16. A DOJO workstation used for wiring assembly was developed in our laboratory, fig. 17.

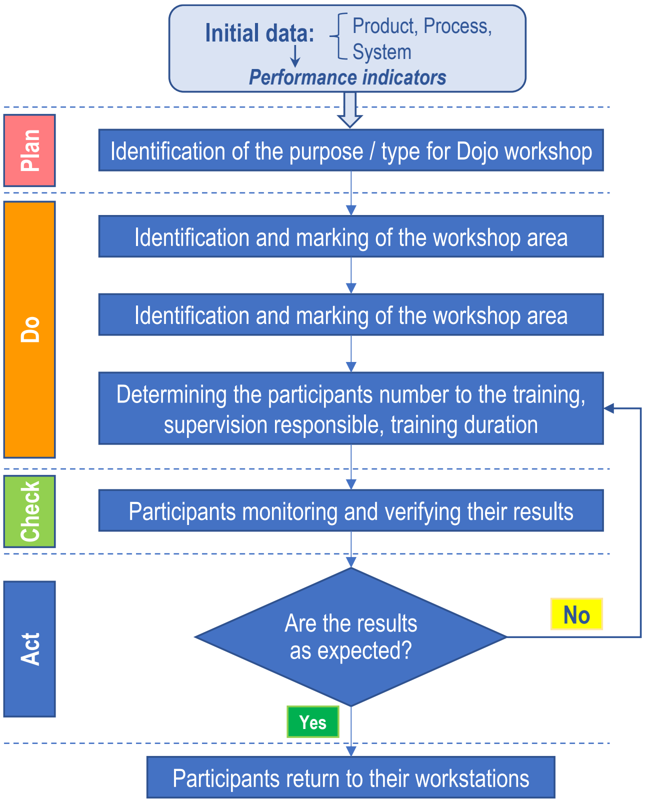


Figure 16. DOJO methodology

Figure 17. DOJO workstation for wiring assembly

Conclusions

In this paper is presented a methodology to use Lean manufacturing methods and techniques in order to improve an assembly line performance. The Lean Manufacturing methodology was developed as a logical chaining way the methods specific to this concept of production management, and according to the results of each method application, specific paths / techniques be followed / applied. This methodology was experimented and validated in a "Lean Learning Factory" type laboratory and, along with the “Lean cubes” platforms, for each Lean method (VSM, 5S, DOJO, Poka-Yoke etc.), flowcharts and tables specific to their application were made

The Lean manufacturing methodology allowed the increase, during the project/ research, of the TRL level (technological training level) of the experimental demonstrator from 2 to 4. The platforms specific to Lean methods can be used for other production systems, being able to be used successfully in any Lean learning factory, but the experimental demonstrator is intended only for assembly lines.

The Lean manufacturing methodology can be used successfully in the "Lean learning factory" type laboratory for the education and training of students and employees of companies in the automotive industry. Future work will focus on developing and integrating Lean - Industry 4.0 platforms and integrating the developed methodologies into the generally methodology for improving production flows on an assembly line.

Acknowledgments

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