Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 17 (2018) 571–578

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

28th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2018), June 11-14, 2018, Columbus, OH, USA

The Improvement of an APEX Machine involved in the Tire Manufacturing Process

R. F. L. Santos[a], F. J. G. Silva[a], R. M. Gouveia[a], R. D. S. G. Campilho[a], M. T. Pereira[a], L. P. Ferreira[a]

[a]*ISEP – School of Engineering, Polytechnic of Porto, Rua Dr. Antº Bernardino de Almeida, 431, 4200-072 Porto, PORTUGAL*

Abstract

Over the years, there has been a huge expansion in the automotive component industry and its consequent innovation, which has evolved along with automation and robotics. Therefore, in order to ensure component quality, as well as the quality of the entire production process, it is crucial to enhance competitiveness in the sector. Since quality is a key feature in this industry, all manufacturers and suppliers are scrutinized by systematic audits to ensure constant improvements. This work was developed at a multinational industry and focuses on tire production for the automotive sector. Tires present a complex production process, which covers a wide range of activities from mixing, preparation, construction and vulcanization to the inspection departments, all of which are greatly predisposed to process improvement. In one of these departments (Preparation - APEX machines, responsible for the tire bead production), one of the main problems detected was directly related to a large number of failures in the pneumatic systems. These were found to be difficult to control, both in terms of speed and positioning. Some of the failures in automation were generating delays in certain processes, leading to lengthy setup times and culminating in higher production costs. In order to achieve greater quality, reliability and accuracy, a higher level of automation was applied to these kinds of machines by resorting to 5S methodology. A safety upgrade of the equipment was also undertaken, which will allow for the improvement of workplace safety.The performance improvement of the APEX machines was reached by implementing the following strategies: the automation of conveyor and tray movements between the cutting and application subprocesses; the implementation of 5S methodology; the automation of the cutting process; the updating of safety devices; and the automated control of the separation subprocess. A strong decrease in the breakdown time was recorded (-62%) resulting of the project implementation. The APEXmachine performance was also improved in 9%.

Keywords: Automotive Industry; Lean Manufacturing; 5S Methodology; Automation.

2351-9789 © 2018 The Authors. Published by Elsevier B.V.
This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/)
Peer-review under responsibility of the scientific committee of the 28th Flexible Automation and Intelligent Manufacturing (FAIM2018) Conference.
10.1016/j.promfg.2018.10.098

1. Introduction

Meeting customer requirements constitutes an importante target in the automotive sector. To this end, companies must focus on the greater productivity and quality of their products [1,2]. In parallel with the growth of the automotive industry, one has always seen other pertinent developments in this sector, such as Lean Production strategies and management techniques [3]. Developed by the Toyota Production System (TPS), Lean Production constitutes a philosophy which aims to minimize waste, thus promoting quality and the improvement of products [4,5]. Due to this decrease in waste, costs are also inherently reduced and companies are thus able to become more competitive [6,7].

The work presented in this research article was undertaken at a company in the automotive industry which manufactures tires. The principal objective of the study was to focus on the automation of the APEX machines movements, which are responsible for the production of the tire bead, a section of the tire that seals the air between the tire and the wheel rim. Due to the substantial number of breakdowns on these machines, one decided that this study should focus on this problematic area. The purpose of the work was thus to achieve greater reliability and precision in machine movements, as well as to increase productivity and, consequently, reduce the running costs of the APEX machines by limiting the number of breakdowns. Thus, the goals initially set to make the project sufficiently attractive to the company was a 50% decrease in breakdown time and an improvement in machine performance by 6%.

This article is divided into five sections. Section 1 presents the introduction; section 2 deals with a review of the literature covering the Lean Manufacturing issues, such as TPS and 5S; Section 3 describes the methodology used to develop this study; Section 4 presents the practical work one developed subsequently in order to analyze and improve the process of APEX machines belonging to the automotive component industry in question. Finally, section 5 presents the conclusions of the work developed.

2. Literature review

Since stock management reduces or eliminates waste, this process enables improvements in productivity [3,6,7]. The growth of industries invariably drives mass production, so there is a need to produce great quantities of goods effectively in order to meet market demands and comply with quality criteria [8]. Increasing competition amongst companies has highlighted the need to use continuous improvement tools, which are dedicated to the elimination of waste, as well as to process improvements and enhanced productivity [9]. Based on the elimination of waste, The Toyota Production System (TPS) also addresses customer requirements, thus resulting in greater quality and flexibility [10-12]. The Lean Production concept ensues from the TPS, which seeks to eliminate all the activities which add no value to the product, and focuses on the following objectives [14-16]: elimination of waste, reduction of setup times, improvement of quality, reduction in manufacturing costs and product transportation, decreased lead times, inexistence of operations which are of no added value, less stock, absence of defects, involvement of people in the processes and production of necessary goods. Several studies have supported the use of these types of techniques and/or methodologies with a view to improving process performance. A study of a healthcare service operation system, where 1726 consultations were analyzed, implemented a lean project which resulted in a 27% increase in its service capacity to receive new patients, as well as a 12% reduction in the no-show rate [17]. Another study highlights how companies can enhance their inventory turnover performance through Lean practices [18]. The use of Lean techniques can also contribute to the improvement of the financial performance of companies [19]. The implementation of Lean techniques on an assembly line, producing steel cables for car windows, allowed for an improvement of 41 % in line productivity [20]. In the color industry, the use of Value Stream Mapping, one of the most significant Lean manufacturing techniques, contributed to the improved performance of a production line: Production Lead-time was reduced from 8.5 days to 6 days, and added-value time decreased from 68 minutes to 37 minutes [21]. Lean Manufacturing incorporates various tools, which include 5S methodology. When implemented properly and fully, these are able to contribute to improvements in the performance of the systems being analyzed [22,23]. In a study developed in laboratories belonging to a university institution, the implementation of 5S methodology was found to contribute to the work optimization at hand and to the safety conditions improvement. A reduction was also seen in the costs associated to learning activities, as well as in the control and maintenance of resources [24]. In another study, undertaken at a small industrial company located in India, the implementation of 5S methodology contributed to the improvement of the company's performance. It enabled better usage of the working area, enhanced the work environment, prevented the loss of tools and led to a reduction in accidents [25]. At a pressure vessel manufacturing company, the implementation of 5S methodology led to the reduction of operating cycle times, as well as to the enhancement of various aspects in the production process, such as work in progress, transportation and delays in delivery. It further contributed to the creation of a well organized working environment [26].

3. Methodology

This study adopted a methodology which was divided into five main stages. The first of these consisted of a literature review, during which one consulted scientific articles dealing with the processes analysis and improvement, as well as the philosophy of Lean Manufacturing. In the second stage, one analyzed all of the mechanisms which comprise the APEX machine under study, in order to gain a better understanding of its operation. The objective of the third stage was to identify the problems at hand, which consisted of numerous breakdowns due to problems related to the conveyor performance, cutting sub-process control and dependence on the operator to comply with the quality requirements imposed, which implied a loss of performance in the equipment operation. Inefficiencies related to lack of standardization and difficult access to tools were also detected. Also time measurements were made in order to quantify the average breakdown time per month, as well as their causes. In this case, an Ishikawa diagram was drawn based on two brainstorming meetings, taking into account the parties involved in the process. This diagram is not presented here due to space restrictions. In the fourth stage, one developed various proposals to eliminate the problems detected, namely a new drive for the main movement of the equipment (not dependent on compressed air), with higher accuracy and speed of action, new sensors and control, as well as safety devices, increasing worker protection. Finally, in the fifth stage, one carried out the implementation of the design previously developed, measuring during one month (due to time constraints) the breakdown time and the productivity rate. The results were compared allowing to observe the advantages of the implemented ideas.

4. Analysis and improvement of the APEX machine process

The different stages in the tire production process are divided into five departments: mixing, preparation, construction, vulcanization and final inspection. The APEX machine is allocated to the Preparation department, where tire materials are prepared for subsequent assembly in the Construction department. These machines execute an operation which applies a wedge to the tire bead.

4.1. Processes Mapping

The APEX machine process (see Figure 1) can be subdivided into four subprocesses: extrusion, separation, cutting and application. Due to the limitations observed in the APEX machine studied, as well as to the dexterity of its operator, the machine in question presented a production average of 4000 wedges per 8-hour shift. The average machine cycle time was 12,30 seconds.

Start	Subprocess 1	Subprocess 2	Subprocess 3	Subprocess 4	Expedition
Raw Material (Rubber and beads)	Extrusion	Separation	Cutting	Application	Wedged Bead

Fig. 1. Stages in the APEX machine's material production.

The raw material required for the extrusion subprocess consists of a rubber compound. This subprocess enables the continuous extrusion of a double-wedged profile, which is previously defined by means of an appropriate die. In the separation subprocess, the profile is split into two halves. The cutting subprocess defines the required length for each type of wheel rim. The application subprocess consists of placing the two wedges (right and left) on a diaphragm. While the wedges are rolled on the diaphragm, the operator must apply two bead-cores and their respective separators onto a support mechanism. They are then pneumatically transported to the diaphragm. The diaphragm is then inflated and begins to rotate. Finally, the diaphragm returns to its initial position. As a result of this process, the bead is partially enveloped by the wedge due to the force exerted, and acquires the shape of a tire.

4.2. Identification of the problems and solutions proposed for the APEX machine

APEX machines often experience a great number of breakdowns (see Table 1). The most significant of these occur on the wedge applicator and on the programmable logic controller (PLC). These two types of breakdown were responsible for numerous interruptions in operation during the year 2015. On one of the twelve APEX machines on the production line studied, downtimes were registered at 1080 minutes for the wedge applicator and 1988 minutes for the PLC.

Table 1. Identification of breakdowns on an APEX machine for the year 2015.

Identification of breakdown	**Number of breakdowns**	**Downtime (minutes)**
Accumulator	7	149
General supply of electricity	22	476
Pneumatic electrical supply	19	225
Rubber feeder	8	133
Wedge applicator	50	1080
Bead cart	18	385
Temperature controllers	21	260
Extruder	20	298
Bead clamp	10	197
Continental basic data acquisition System	29	421
PLC	75	1988
Wedge cutting system	32	799
Safety systems	4	60
Slitter	29	474
Tray	34	589
Cooling drum	2	50
Forming drum	17	574
Transporter / conveyor belt	15	394
Total	412	8552

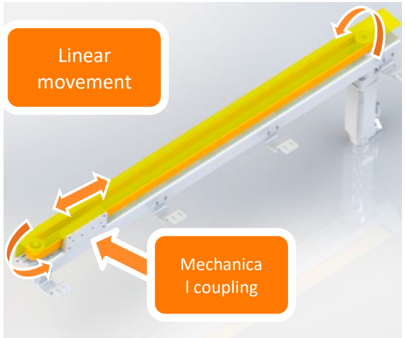
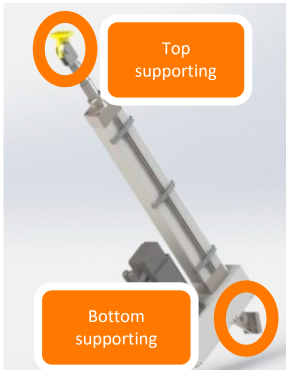
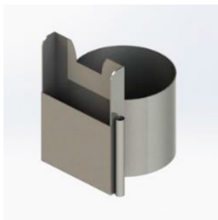
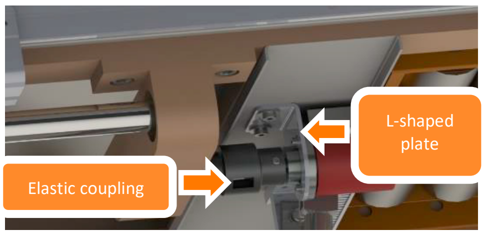
Table 2 presents the problems detected in the production process of the wedged beads by the APEX machine. The information pertaining to these was obtained through observation and dialogue with the workers operating the machine under study.

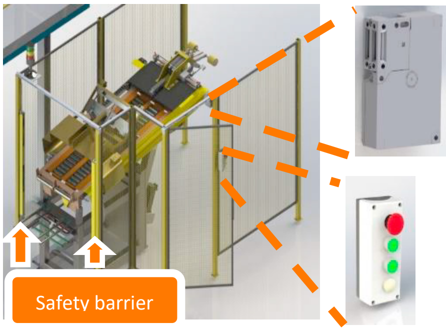
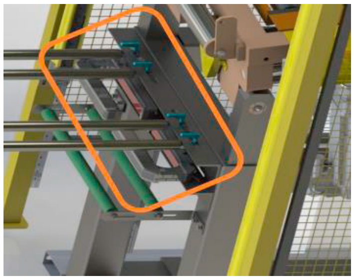
Table 2. Problems identified on the APEX machine.

Problems	**Description**
Manual adjustments	No standardization in the machine tuning process
High number of breakdowns	The inconsistency of adjustments leads to the premature wear and tear of the mechanical components
Air leaks/ High consumption of compressed air	High number of pneumatic components
Disorganization of the workbench	Inefficient organization of the workbench
Delays in the adjustment of the cutting subprocess during machine setup	No automation of the cutting subprocess
Outdated safety devices	Poor safety may expose machine operators to risks
Manual adjustment undertaken in the separation subprocess	Manual adjustment may result in the production of material which is unsuitable for the required specifications

With the purpose of eliminating the problems identified and presented above in Table 2, one drew up Table 3 to present the various solutions which will increase the productivity and quality of the products manufactured by the APEX machines.

Table 3. Solutions proposed to improve the performance of the APEX machine.

Problems	Proposed solutions	Representation
Manual adjustments High number of breakdowns	Automation of the transporter movement between the cutting and application subprocesses – Implementation of a motorized servosystem with a belt drive, since speed and accuracy are essential to this process (see Figure 2). This solution requires installing two pulleys which are connected by a belt. These are driven by a servomotor to control the equipment.	 Fig. 2. Automation device for transporter movement.
Air leaks/ High consumption of compressed air	Automation of tray movement between the subprocesses of cutting and application - Implementation of a motorized servomechanism which is similar to a pneumatic cylinder and uses the connection components on both the top and bottom supporting devices (see Figure 3). The proposed solution thus consists of a compact module equipped with an electrical linear actuator.	 Fig. 3. Automation device for tray movement.
Disorganization of the workbench	Implementation of 5S methodology – Provision of a device to support utensils and the operator's task files (see Figure 4).	 Fig. 4. Device to support tools and task files.
Delays in the adjustment of the cutting subprocess during machine setup	Automation of the cutting subprocess – An encoder was placed on the end of the electrical linear actuator which produces the movement for the cutting subprocess (see Figure 5). The purpose of this device is to determine where the cutting subprocess occurs by observing the electrical linear actuator rotation. The movement is executed by means of a direct current drive which is already in place on the other end of the electrical linear actuator.	 Fig. 5. The drive system for the cutting subprocess.

Outdated safety devices	Updating of the safety devices – The height of the protection railings was increased to 2 metres; a control panel was installed outside the railing to carry out cutting operations in manual mode; a safety barrier was placed at the back of the cutting subprocess section and a safety lock was placed on the access door (see Figure 6).	 Fig. 6. Updating of the safety devices.
Manual adjustment undertaken in the separation subprocess	Automated control of the separation subprocess – The two band sensors placed in this section permanently control wedge width and comply with the requirements which were initially proposed, ranging from resolution to maximum reading width (see Figure 7).	 Fig. 7. Band sensors.

4.3 Analysis of expected results

Through the implementation of the proposals for improvement presented in Table 3, it is expected that the performance of the APEX machine will improve greatly. Table 4 presents the expected results in accordance with the suggested solutions.

Table 4 –Results expected from the implementation of the proposed solutions

Item	Solutions	Results
1	Automation of the conveyor and tray movements between the cutting and application sub-processes	Fewer breakdowns and lower energy costs due to the elimination of air leaks and less consumption of compressed air; the pneumatic components were replaced with electromechanical ones (electrical linear actuator).
2	Implementation of 5S methodology	The tools needed to setup were standardized and became conveniently organized, allowing easier and faster access, reducing preparation times, allowing increased productivity.
3	Automation of the cutting sub-process	Decrease in APEX machine setup times due to the elimination of manual adjustments and to the control of speed carried out by the servomotor, which is responsible for movement in the cutting subprocess.
4	Updating of the safety devices	Greater safety for the workers operating the APEX machines.
5	Automated control of the separation sub-process	Better overall quality in the tires manufactured.

5. Results and Discussion

The objective of this study, which pertains to a production line manufacturing components for vehicles, lies in presenting several different proposals to enable the improved performance of the APEX machines in use and implement them, measuring the real gains achieved through the new ideas. These constitute an important aspect of the production process at the company in question. In order to achieve these results, one identified the main problems which contribute to APEX machine downtimes and sought to analyze various solutions. The solutions pointed out in Table 4 were implemented, providing the following feedback:

- Item 1: The number of breakdowns was drastically reduced due to the reliability of the new conveyor actuation. The energy consumed in the process was decreased and the accuracy of the movements was improved because these are features commonly presented by electromechanical actuators. The initial cost is higher, but the operation and maintenance costs are significantly lower.
- Item 2: An average decrease in the setup time between different tire bead types was measured of 22%. This value was achieved regarding the use of less tool (the same tool is now able to tighten and unscrew different settings. The tools are better tidied up and identified, becoming faster the adjustement tasks.
- Item 3: The automation applied to the cutting sub-process through a servomotor able to adjust the exact position of the blade improved drastically the setup time (44%) and greatly reduced the risk of error in the operation.
- Item 4: Due to the introduction of new protection devices, the worker safety was dramatically improved, despite no severe work accidents have been registered in the past.
- Item 5: The improvement of the separation sub-process allowed for a better uniformity and quality in the final product, due to an integrated control with the cutting sub-process.

6. Conclusions

It was thus concluded that the improved performance of the APEX machines can be reached by implementing the following strategies: the automation of conveyor and tray movements between the cutting and application subprocesses; the implementation of 5S methodology; the automation of the cutting process; the updating of safety devices; and the automated control of the separation subprocess. The implementation of servomotor systems (electromechanical actuator) to replace the former pneumatic systems will allow for a greater control of movements. This will also eliminate the need for pneumatic supply and the resulting leakage of compressed air, which will in turn ultimately lead to a great reduction in the number of breakdowns on these mechanisms (the wedge applicator). All of these problems were responsible for a downtime of 1080 minutes just in one APEX machine for the year 2015 (see Table 1). In addition, the automation of the cutting subprocess will contribute to a decrease in the setup time required for APEX machines, while the implementation of 5S methodology will allow for faster setups. Furthermore, the updating of the safety devices will ensure greater safety for the workers operating the machine, and the quality of the final product will also be enhanced by means of the automated control of the separation subprocess. All of these solutions will lead to a reduction of 38% in the maintenance costs of the Apex machines, which are chiefly caused by the excessive number of breakdowns. Moreover, the breakdown time was reduced in 62%. The APEX machine performance was also improved in 9%. In this regard, the use of Lean tools supported by a rigorous mechanical design and updated control, played a key role in the development of this study.

Acknowledgements

Teresa Pereira thanks the financial support of CIDEM, R&D unit funded by the FCT – Portuguese Foundation for the Development of Science and Technology, Ministry of Science, Technology and Higher Education, under the Project UID/EMS/0615/2016. The Authors also thank the cooperation and financial support provided by LAETA/CETRIB/INEGI Research Center, as well as FLAD – Fundação Luso-Americana para o Desenvolvimento (Proj. 116/2018).

References

[1] R. Rodríguez-Méndez, D. Sánchez-Partida, J. L. Martínez-Flores, E. Arvizu-Barrón, “A case study: SMED & JIT methodologies to develop

continuous flow of stamped parts into AC disconnect assembly line in Schneider Electric Tlaxcala Plant.", IFAC Proc. Vol., vol. 48, pp. 1399-1404, 2015.

[2] J. Choomlucksana, M. Ongsaranakorn, P. Suksabai, "Improving the productivity of sheet metal stamping subassembly area using the application of lean manufacturing principles", Procedia Manufacturing, vol. 2, pp. 102-107, 2015.

[3] S. J. Hu, "Evolving paradigms of Manufacturing: from mass production to mass customization and personalization", Procedia CIRP, vol. 7, pp.3-8, 2013.

[4] A. C. Moreira, G. C. S. Pais, "Single minute exchange of die. A case study implementation", Journal of Technology Management & Innovation, vol. 6, issue 1, pp. 129–146, 2011.

[5] V. Kumar, A. Bajaj, "The implementation of single minute exchange of die with 5 ' S in machining processes for reduction of setup time", International Journal on Recent Technologies in Mechanical and Electrical Engineering, vol. 2, issue 2, pp. 32–39, 2015.

[6] C. Eroglu, C. Hofer, "Lean, leaner, too lean? The inventory-performance link revisited" ,J. Oper. Manag., vol. 29, pp. 356-369, 2011.

[7] M. Scherrer-Rathje, T. A. Boyle, P. Deflorin, "Lean, take two! Reflections from the second attempt at lean implementation," Bus. Horiz., vol. 52, issue 1, pp. 79-88, 2009.

[8] M. G. Yang, P. Hong, S. B. Modi, "Impact of lean manufacturing and environmental management on business performance: An empirical study of manufacturing firms," Int. J. Prod. Econ., vol. 129, pp. 251-261, 2011.

[9] I. Antoniolli, P. Guariente, T. Pereira, L. P. Ferreira, F. J. G. Silva, "Standardization and optimization of an automotive components production line" Procedia Manufacturing, vol. 13, pp. 1120–1127, 2017.

[10]. B. M. D. N. Moreira, R.M. Gouveia, F.J.G. Silva, R.D.S.G. Campilho. A Novel Concept Of Production And Assembly Processes Integration. Procedia Manufacturing 2017;11:1385-1395.

[11]. R. J. S. Costa, F.J.G. Silva, R.D.S.G. Campilho. "A novel concept of agile assembly machine for sets applied in the automotive industry". The International Journal of Advanced Manufacturing Technology , vol. 91, pp. 4043-4054, 2017.

[12] M. J. R. Costa, R.M. Gouveia, F.J.G. Silva, R.D.S.G. Campilho. "How to solve quality problems by advanced fully-automated manufacturing systems". The International Journal of Advanced Manufacturing Technology 2018. In press. DOI 10.1007/s00170-017-0158-8.

[13] Melton, T. "The benefits of lean manufacturing: what lean thinking has to offer the process industries", Institution of Chemical Engineers Trans IChemE, Part A, 2005.

[14] E. Costa, R. Sousa, S. Bragança, A. Alves, "An industrial application of the SMED methodology and other lean production tools," 4th International Conference on Integrity, Reliability and Failure, 2013.

[15] C. Rosa, F. J. G. Silva, L. P. Ferreira, R. Campilho, "SMED methodology: the reduction of setup times for Steel Wire-Rope assembly lines in the automotive industry", Procedia Manufacturing, vol. 13, pp. 1034–1042, 2017.

[16] Womack, J.P., Jones, D.T., Roos, D., "The machine that changed the world", 1990.

[17] L. R. LaGanga, "Lean service operations: reflections and new directions for capacity expansion in outpatient clinics", Journal of Operations Management, vol. 29, pp. 422-433, 2011.

[18] K. Demeter, Z. Matyusz, "The impact of lean practices on inventory turnover", Int. J. Production Economics, vol. 133, pp. 154-163, 2011.

[19] C. Hofer, C. Eroglu, A. R. Hofer, "The effect of lean production on financial performance: the mediating role of inventory leanness", Int. J. Production Econimics, vol. 138, pp. 242-253, 2012.

[20] C. Rosa, F. J. G. Silva, L. P. Ferreira, "Improving the quality and productivity of steel wire-rope assembly lines for the automotive industry", Procedia Manuf., vol. 11, pp. 1035–1042, 2017.

[21] J. M. Rohani, S. M. Zahraee, "Production line analysis via value stream mapping: a lean manufacturing process of color industry", Procedia Manufacturing, vol. 2, pp. 6 – 10, 2015.

[22] O. Omogbai, K. Salonitis, "The implementation of 5S lean tool using system dynamics approach", Procedia CIRP vol. 60, pp. 380 – 385, 2017.

[23] M. Alefari, K. Salonitis, Y. Xu, "The role of leadership in implementing lean manufacturing", Procedia CIRP, Vol. 63, pp. 756 – 761, 2017.

[24] M. Jiménez, L. Romero, M. Domínguez, M. del M. Espinosa, "5S methodology implementation in the laboratories of an industrial engineering university school", Safety Science, vol. 78, pp. 163-172, 2015.

[25] P. M. Rojasra, M. N. Qureshi, "Performance improvement through 5S in small scale industry: a case study", International Journal of Modern Engineering Research (IJMER), Vol. 3, Issue. 3, pp. 1654-1660, 2013.

[26] R. B. Ruben, S. A. P. Narendran, S. Abuthakeer, A. S. Prasanth, P. V. Mohanram," Implementation study on applying lean manufacturing principles in the manufacturing of pressure vessels in an Indian Company", International Conference on Machine Learning, Electrical and Mechanical Engineering, Dubai, 2014.