Proceedings of the World Congress on Engineering 2015 Vol II
WCE 2015, July 1 - 3, 2015, London, U.K.

Implementation of a Lean Six Sigma Project in a Production Line

Valter R. Morais, Sérgio D. Sousa, *Member, IAENG* and Isabel Lopes

Abstract—**Companies from the motorcycles components branch are dealing with a dynamic environment, resulting from the introduction of new products and the increase of market demand. This dynamic environment requires frequent changes in production lines and requires flexibility in the processes, which can cause reductions in the level of quality and productivity. This paper presents a Lean Six Sigma improvement project performed in a production line of the company's machining sector, in order to eliminate losses that cause low productivity, affecting the fulfillment of the production plan and customer satisfaction. The use of Lean methodology following the DMAIC stages allowed analyzing the factors that influence the line productivity loss. The major problems and causes that contribute to a reduction on productivity and that were identified in this study are the lack of standardization in the setup activities and the excessive stoppages for adjustment of the processes that caused an increase of defects. Control charts, Pareto analysis and cause-and-effect diagrams were used to analyze the problem. On the improvement stage, the changes were based on the reconfiguration of the line layout as well as the modernization of the process. Overall, the project justified an investment in new equipment, the defective product units were reduced by 84% and an increase of 29% of line capacity was noticed.**

Index Terms— **Continuous Improvement, Industrial Projects, Lean Six Sigma**

I. Introduction

The Lean Six Sigma (LSS) method promotes, in organizations, the continuous improvement of products (and/or services) and processes that aligns with the business strategy to maximize the value of products [1]. The LSS can be defined as a work philosophy adopted by companies using methods and tools to reduce the variability of processes to eliminate waste and improve the quality perceived by the customer. This philosophy is aligned with the strategic planning of the company, providing greater opportunities in the market. It offers unique features combining multiple tools, serving to support the development of business strategies. It also assists in the breakdown of steps in improvement projects and in the achievement of planned results [2].

Manuscript received March 18th, 2015; revised April 1st, 2015. This work has been supported by FCT – Fundação para a Ciência e Tecnologia within the Project Scope: UID/CEC/00319/2013.

S. D. Sousa is with Centro Algoritmi, University of Minho, Campus de Gualtar, 4710-057, Braga, Portugal, phone: +351 253 604 762; e-mail: sds@dps.uminho.pt.

V. R. Morais is with Centro Algoritmi, University of Minho, Campus de Gualtar, 4710-057, Braga, Portugal, e-mail: megavalter@hotmail.com.

I. S. Lopes is with Centro Algoritmi, University of Minho, Campus de Gualtar, 4710-057, Braga, Portugal; e-mail: ilopes@dps.uminho.pt.

Strategic planning has an important role in running a business and allows foreseeing future implications of present decisions and prepare for the changes that occur in the political environment, economic, social and technological, seizing opportunities and meeting the unique threats of these environments [3]. Making organizations more efficient requires continuous planning and may require investments to adapt processes to the company's strategy. These actions may not bring immediate results, but differentiate them from competitors over time [4].

Standardization is an important factor to reduce variation and increase the efficiency of processes [5]. For Harrington [6], statistical process control is a source of information for the manager and assists in the continuous improvement of operations performance and processes in a sustainable manner. Organizations need to adapt to market needs and to identify opportunities in order to maximize three factors:

- Efficiency: producing with fewer resources;
- Effectiveness: achieving the desired results;
- Flexibility: Adapting to the market needs to meet customer expectations.

The Six Sigma methodology is the basis for the development of improvement project, starting by defining what the Defect is. The goal of the project will be the reduction of its occurrence, increasing the sigma level. The methodology has a set of steps, namely, Define, Measure, Improve and Control (DMAIC) and tools that contribute to the success of a project.

The justification to combine Lean and Six Sigma can be explained by its complementary advantages. According to Werkema [7], Lean philosophy does not have associated tools to carry out statistics analysis or a structured method to solve processes' variability problems. Six Sigma does not emphasize speed improvement of processes and the reduction of lead time. Therefore, using the best outcome of each methodology allows obtaining a method for process improvement by reducing variation and lead time while improving quality and speed of processes [8].

The work presented in this paper focuses on reducing problems that cause unscheduled downtimes in machining operations line. Three issues considered relevant were studied in its development:

1) The factors that influence the performance of operations on the production line;
2) How these different factors affect the performance (efficiency) of the production line;
3) How to define and implement a solution to improve line efficiency aligned with strategic planning, and considering existing restrictions.

ISBN: 978-988-14047-0-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

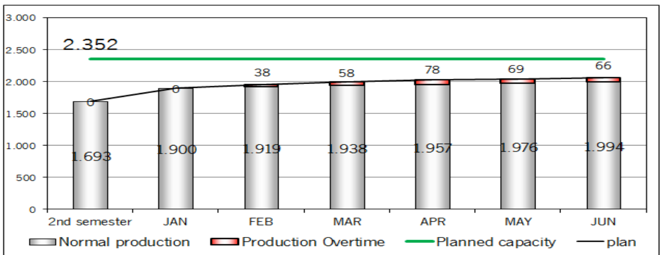
The paper is organized as follows. Section II presents the organization and the production line of the case study. In Section III, the different phases of the project are exposed and last section draws the conclusions

II. Problem Identification

The project focused a production line that manufactures in pairs (left and right) shock absorbers to two main customers: Moto Honda and Yamaha. The study aimed to characterize, following the DMAIC methodology, the operation of the production line and evaluate the root cause of the problem of lost productivity. To carry out the project, a team was constituted to address this problem over five months.

A SIPOC diagram was developed by the project team to characterize the manufacturing process of the production line.

To better understand the problem, data were collected about production in regular and overtime hours from the second half of 2013 to the first half of 2014, as shown in Figure 1.



Daily production in 2014 semenstre 1 (Parts)							
month	2nd semester	JAN	FEB	MAR	APR	MAY	JUN
plan	1.693	1.900	1.957	1.996	2.035	2.045	2.061
Normal production	1.693	1.900	1.919	1.938	1.957	1.976	1.994
Production Overtime	0	0	38	58	78	69	66
Planned capacity	2.352	2.352	2.352	2.352	2.352	2.352	2.352
Production Overtime daily	0	0	33	45	54	61	63

Fig. 1. Graph with the production plan and line production capacity

The line used overtime in the production schedule to meet deliveries, during the first half of 2014. Despite the line has used overtime to fulfill the production plan, its capacity would allow meeting the production plan in regular hours. The study aims to identify the root cause of this problem.

III. DMAIC Application

A. *Define*

The definition and quantification of the analyzed problem could be made by different metrics. However, in terms of the customers who require these parts (shock absorbers), the relevant information which is directly associated with the problem is “planned unit not produced”. Therefore, the team decided that this would be the defect definition for this project.

The production process of the machining lines is evaluated using performance indicators such as: Scrap (not usable material for the line), setup time and process efficiency. The latter is a time index established by the engineering sector.

To identify the root cause of the problem, the capacity of the production line was analyzed using the process efficiency calculation. This indicator measures the availability of the line and the production losses, resulting in an efficiency ratio.

The efficiency index is the relation between the time actually used to produce, which is the available time after subtracting planned and unplanned stoppages, and the available time. The unplanned stops are due to: equipment failures; settings; lack of material; quality issues; other (special meetings, lack of energy, etc.).

The collection of information for the determination of this indicator allows a detailed description of factors that cause production interruption.

B. *Measure*

After collecting data on the above performance indicators, the following information was obtained:

- Available time: 21 hours/day
- Efficiency index: 77.78%

Considering the efficiency index and a product cycle time of 25 seconds, the production line capacity is 2352 units/day, since the available time is 75600 seconds (21*60*60) and the time actually used to produce is 58802 seconds (75 600*0,7778).

Currently the daily production is approximately 2200 pieces. When comparing the 2200 units' production plan with the production capacity, it was found that it meets production needs, and the use of overtime to meet demand is not substantiated.

However, only planned stoppage and few losses were considered in the efficiency index. Therefore, the identification has focused on finding the losses that reduce the productive capacity. The planning of stratification on collecting data for evaluating the production line efficiency allowed the analysis of different categories of losses and its causes.

The collection of data was performed during 6 months. The Information was collected about: quality, adjustments, damage, material delays, others.

The project team developed the line efficiency chart, as shown in Figure 2.

With the characterization of the losses, the graph shows the difference between the planned production time and the actually production time. The problems/failures encountered are related to production unplanned stoppages, contributing to a situation that compromises the efficiency of processes, reducing the line capacity. The failures or unplanned stoppages are shown in red, totaling 2.69 hours/day.

Evaluation of operations with the greatest losses

After the evaluation of losses in the line operations, the team identified the operation that has the highest number of adjustments using a Pareto diagram to analyze the data, as shown in Figure 3.

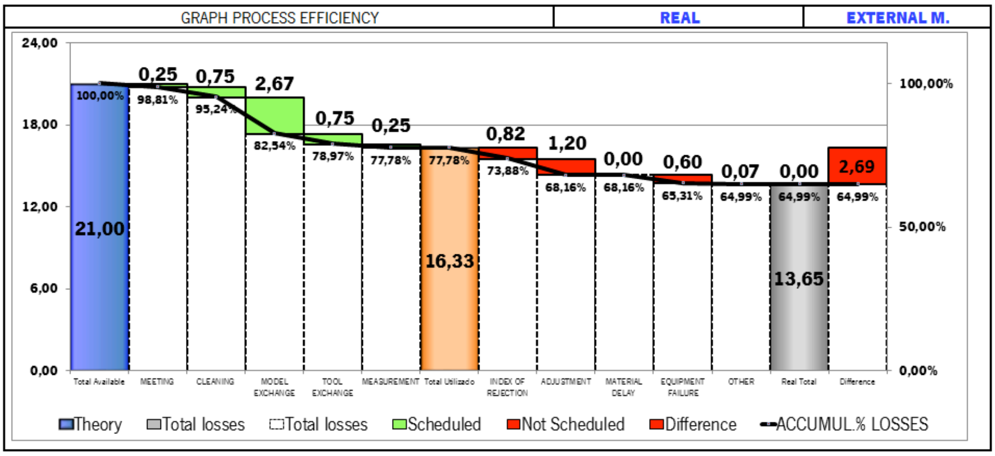
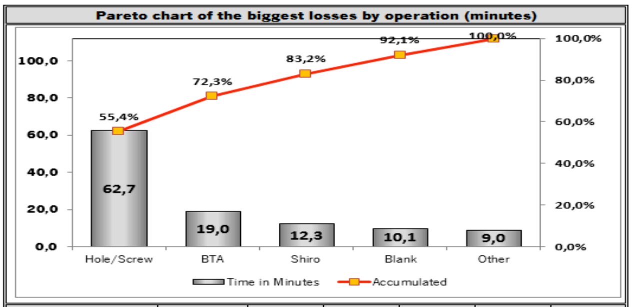


Fig. 2. Graph of the production line efficiency



Time in Minutes	62,7	19,0	12,3	10,1	9,0	113,1
ITEMS	Hole/Screw	BTA	Shiro	Blank	Other	
Accumulated	55,4%	72,3%	83,2%	92,1%	100,0%	

Fig. 3. Pareto chart of the biggest losses by operation

Based on the graph, it was concluded that the largest losses of productive capacity arose in the drilling and tapping operations.

After verification of the losses, the productive capacity was recalculated based on an efficiency index of 64.99%. Considering the efficiency index and a product cycle time of 25 seconds, the production capacity obtained was 1965 units/day. This production capacity justifies the need of overtime to fulfill the 2200 units/day plan.

To analyze how much of the production is "being lost" (units not produced), the initial planned daily capacity of 2352 units is compared with the actual daily production capacity (1965 units) giving a total of not produced units in the line of 387 units/day, representing approximately 16.44% of the total capacity. Considering the first half of 2014, the total number of units not produced was 54917.

To clarify the impact of these losses, the value associated with this waste was calculated. Considering 6 Euros the cost of not producing a planned unit, the total monetary losses relating to non-produced units in the first half of 2014 is 329499 Euros.

Calculation of the current sigma level and target

The sigma level is based on the ratio between the number of non-produced units (387 units) and the total production or number of opportunities (2352 units). The sigma level calculation, for continuous variables following a normal distribution, considers that the process mean can shift 1.5 standard deviations towards one specification limit. The sigma level is therefore 2.48.

A. Analyze

Identification of the problem Root Cause

In the previous phase, categories that impact the efficiency of processes were identified: quality, adjustments, failures and other stoppages. To identify the root causes of the problem, a brainstorming was performed with professionals whose functions are directly linked to the production line (operators, leaders and the sector head).

Description of the main problems encountered

The method used to list the causes was the cause-and-effect diagram, since it facilitates the ordering of categories, divided into six groups (Machine, Method, Measure, Environment, Materials and Manpower). Table I presents the problems observed on adjustments realization.

TABLE I
CAUSES OF ADJUSTMENTS PROBLEMS

Items	Adjustments Problems
Machine	Lack of flexibility High setup times Device fixation difficult to perform
Manpower	Low precision in regulating devices Fatigue (overtime)
Method	Adjustments method cause physical wear of operators Missing pattern in the set of activities
Materials	Many materials lost in parameter settings
Measure	Delay in the measurement of parts for machine settings

Table II presents the analysis of the causes of quality problems and Table III presents the causes of equipment failures.

After identifying the factors that influence the process, the team developed a Cause-and-effect matrix to characterize the potential impacts of improvement actions on the effects, which, in this case, is the excessive stoppages for adjustments. The critical points will be the focus of study in the next phase, the improvement phase. The matrix in Figure 4 was performed following the criteria:

- Items: The causes identified in the cause and effect diagram that are more likely to influence the process outcome;
- Rating variables: severity, need and benefits;
- Score: The score of each variable ranges from 0 to 5

(five is the most important). The total score is the product of the variables' scores.

TABLE II
CAUSES OF PRODUCT QUALITY PROBLEMS

Items	Adjustments Problems
Machine	Setup excess causes many losses in dimensional test Settings is performed using parts (technology characteristic) Heavy devices hinder accuracy in settings
Manpower	Adjustments incorrectly made Much effort of the operator on the device positioning Operator makes the device adjustments manually
Method	The accumulation of material causes finishing flaws Adjustments precision dependent of operators effort Transportation using metal carts
Materials	Handling exec causes failure on the parts Accumulation of material causes finishing flaws
Measure	Adjustments are low when they require three-dimensional measurement
Environment	Layout allows moving the product on carts

TABLE III
CAUSES OF EQUIPMENT FAILURE

Items	Equipment failure
Machine	Too many changes in the machine parameters Technology keeps values parameters Natural wear of the devices due to excessive adjustments
Manpower	Adjustments incorrectly made by operators Low motivation
Method	Failure to observe the changes in parameters before setup Adjustments on processes without verification of machine condition
Measure	Long time to stoppage registration
Environment	Long distance from maintenance to the line

B. Improve

Traditionally the improvement phase of DMAIC methodology relies on creativity of the project team to things better, cheaper or faster [9], evaluating the data collected in the process. It is not provided guidance on observing the performance of other opportunities outside the studied context such as new technological developments. In this case study the project team looked outside the studied process, to find potential solutions and by analysing their impact on the performance of operations and alignment with strategic planning.

Analysis of the characteristics of bottlenecks operations

As shown the data collected in the measurement phase, the main source of the problems encountered is related to the drilling and tapping operations. An analysis to understand the technical characteristics and working patterns of such equipment was performed. The relevant points associated with drilling and tapping operations and respective equipment are:

• Machines whose main function is to do holes, using a high-revving engine with one or more bits, removing the desired material;

• Equipment is used for various operations such as drilling, tapping and slotting, involving the replacement of tools;

• Performing the setups is difficult, requiring a variable time for adjusting the repositioning after exchanging some model.

Cause-and-effect matrix						
	ranges from 0 to 5	Y1	Y2	Y3	Total	Prioritization
Item	X's	Severity	Need	Benefits		
X1	Lack of Flexibility	4	5	5	100	1º
X2	High Setup Times	4	4	5	80	2º
X3	Faults and Breaks Equipment	4	4	4	64	3º
X4	Accuracy in trade models operator dependent	4	3	4	48	4º
X5	Excessive wear devices	3	3	5	45	5º
X6	Layout provides movement between posts	3	3	5	45	6º
X7	Space for storing WIP	3	2	4	24	7º
X8	Setup method that causes physical wear the operator	3	2	3	18	8º
X9	Inadequate method of fixing devices	3	2	3	18	9º
X10	Lack of standardization in the setup activities	3	2	3	18	10º

Fig. 4. Cause-effect matrix

Due to the recent increase in the number of the line models, there is an increased in time spent on these activities, reducing the availability of the work machines and dependency on the human factor and on its accuracy. Therefore, the process needs to be more flexible to perform frequent model changes.

Comparison of improvement opportunities

Two improvements were proposed and compared:

• The application of single minute exchange of die (SMED) methodology - SMED is used to reduce setup times, working in machine preparation activities, before turning off the machine, reducing the total time. However, it is limited since it only reduces a percentage of the time and does not act in machinery start-up waste;

• Exchange of technology - the model exchange is performed only by exchanging software programs. The new computer controlled machine performs the tasks with greater productivity and lower setup times.

Results

As a result from assessment of the two alternatives (Table IV), the new technology is the one that best meets the project requirements, since it not only allows reducing the time used in the setup, but reduces also other activities that the customer does not pay, such as adjustments, failure to execute operations and movements.

The main impacts of the proposal on the system are: the exchange of faster models, better working environment, elimination of the physical efforts of operators in the regulations of the devices, greater precision in machining operations, reduction of quality defects and grouping operations, reduction of the number of devices on the line.

Planning the implementation of the selected improvements

The project team sought not only to use the new technology, but also standardize the activities of processes. The implementation was carried out according to the following sequence:

1) Grouping operations: Design a new layout for the machining process.
2) Redo the line balancing and provide training to employees.
3) Assess the new line capacity and performance.

ISBN: 978-988-14047-0-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

TABLE IV
COMPARISON OF IMPROVEMENT OPPORTUNITIES

Items	SMED	CNC technology
Advantages	Reduce setup times Standardizes activities No investment	Reduce setup times Reduces the rejection indices Reduces the duration of processes Offers greater operating range Allows grouping processes
Disadvantages	Only act on setup Devices changeover conditions not changed Condition of the other lines problems not changed	High investment Hand labor training is required

Grouping of operations

Without the need to group processes by families, it became possible to group processes by operations. Thus, the operations defined for equipment were hole and screw. Grouping is made to assure that all holes and screws are made in new equipment, as shown in Figure 5.

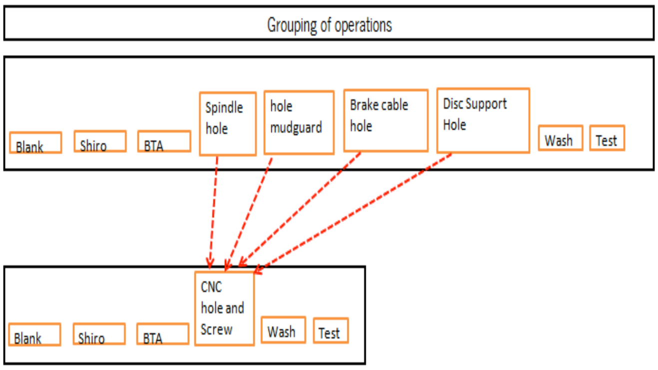


Fig. 5. Grouping of operations at CNC

Line balancing and new job positions

The minimum number of equipment that ensures productivity consists of three pieces of equipment. However, if four equipment is used, it enables to expand the capacity of these operations and form two production lines, significantly increasing productivity. Figure 6 illustrates the new distribution line.

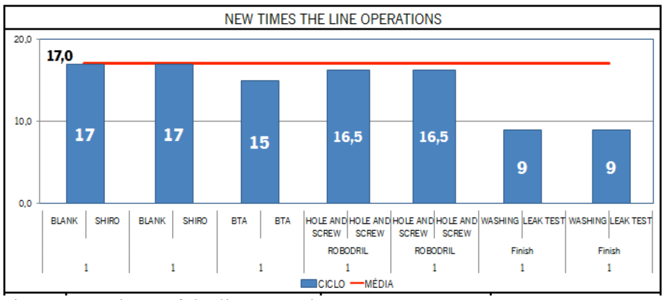


Fig. 6. New times of the line operations

The new times redefined the productive capacity, for now the line presents another bottleneck. The Blank and Shiro are the largest operating time with 34 seconds on the job. However, two lines are now realizing production. With the new balance, the cycle time of the line decreases from 25 to 17 seconds.

Performance after improvement

A reduction in the settings from 72 minutes to 12 minutes was achieved. The rejection decreases from 3,9% to 1.9%. Figure 7 shows the new values of process efficiency.

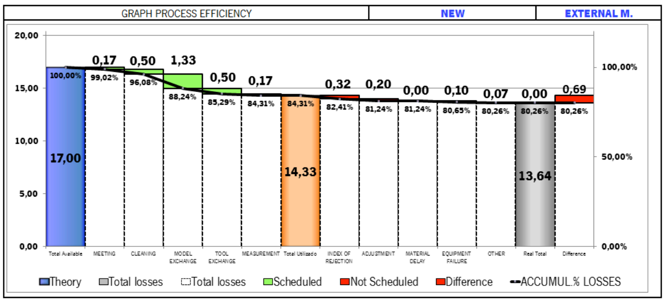


Fig. 7. New line efficiency

There is a significant reduction in losses due to unscheduled stops with increased availability of operation and consequently an increase in the line efficiency, allowing the sector to comply with delivery deadlines. With the new balancing of 17 seconds and 84.31% efficiency, the new production capacity is 3035 units/day.

With the new capacity of 3035 units/day, in two shifts, the demand of 2200 units was fulfilled. This has eliminated the need of the third shift, also reducing the total number of employees in the line from 21 to 16. Although the capacity is higher than current needs, the company's strategic plan had the goal of increasing production volume, to meet an increase in demand of approximately 9% every year for the last four years.

Other positive results were also achieved, as shown in Table V.

TABLE V
OTHER PERFORMANCE INDICATORS

Item	Initial	New	Unit
WIP	190	84	Parts
Hand Labor	21	16	Operator
Capacity	2 352	3 035	Parts/day
Productivity	112	190	Parts/operator
Lead time	418,5	226,5	Seconds

C. Control

3.5.1 Impact and effectiveness of improvements

The implementation phase ended in June 2014. The number of non-produced parts reduced from 387 175 in 2352 opportunities to 78 in 3035 opportunities. This corresponds to a new sigma level of 3.45.

This represents a reduction on DPMO from 164429 to 25581 representing a reduction on defects (units not produced) of 84.4% (from its original value). This was achieved together with an increase in line capacity of 29%, from 2352 units/day to 3035 units/day and a reduction in the number of defective products from 3.9% to 1.9%.

Process monitoring

For the monitoring of the new times of operations and confirmation of stabilization, graphs were established. A registration system for faults and errors of procedures performed by operators was also implemented.

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Return on investment

To demonstrate the monetary results achieved with improvements, it is necessary to measure the cost savings, increased productivity and improved performance. This study will be based on three factors: hand labour, number of devices used and reduction of stoppages. Table VI shows the cost savings of € 365904/year.

The team calculated the potential payback of the investment in new equipment. Table VII shows the return time of the investment (ROI).

TABLE VI
TOTAL ACHIEVED WITH IMPROVEMENTS

Description	Values
Loss reduction	€ 325 259
Hand Labor reduction	€ 40 645
Reduction in devices maintenance	€ 0
Total	€ 365 904

TABLE VII
RETURN ON INVESTMENT

Description	Values
Investment	€ 419 355
Return	€ 365 904
Return time (year)	1,15

The ROI is 1.15 years or about 14 months. The project proved to be viable, with significant gains to the company.

IV. CONCLUSION

A LSS project was done to improve the performance of a machining line that produces shock absorbers for motorcycles. The Defect definition was "units planned but not produced". The defect definition is not related to a defective part but as a negative process outcome. Other works [10, 11] have reported similar definitions, not relating directly to product quality or product defect.

Some relevant performance indicators were defined to analyse the problem. The analysis revealed excessive stops for adjustments in operations, reducing the efficiency of processes and compromising the delivery. The improvement actions were carried out in order to correct these problems, standardizing the setup of activities, increasing the availability of equipment and improving the productivity of the line.

The changes implemented in the production line, resulted in a reconfiguration of the production system, modernizing operations that cause major losses of productivity. To perform the actions the project team developed a new layout, improving the provision of equipment and facilitating the flow of materials.

The implementation of actions brought positive impacts: the reduction of settings stops from 72 for 12 minutes, the reduction of defective units by approximately 50% (from 3.9% to 1.9%). The new working conditions led to a reduction in the number of operators from 21 in three shifts to 16 in two commercial shifts, also contributing to the increase in production capacity of 2352 to 3035 units/day and the system productivity increased from 98 to 152 units/operator by day. Overall the sigma level increased from 2.48 to 3.45. The investment on new equipment was also studied. The ROI is 14 months despite its contribution to other company's strategic objectives.

It can be concluded that the development of the project contributed to the achievement of sector goals and improved the company's competitiveness in the market.

This work reports a Six Sigma project carried out to justify investment in new technology. That was achieved by the acquisition of a new technology instead of implementing improvements in the use of existing equipment.

Future works could test, through different cases, the impact of using Six Sigma projects to justify investment in new equipment.

REFERENCES

[1] George, M. L. (2002). Lean Six Sigma - Combining Six Sigma Quality with Lean Speed. USA: McGraw-Hill Professional.
[2] George, M. L. (2005). The Lean Six Sigma Pocket Toolbook: A Quick Reference Guide to Nearly 100 Tools for Improving Process Quality, Speed, and Complexity. USA: McGraw-Hill Professional.
[3] Drucker, P. F. (1992). Administrando para o futuro. São Paulo: Pioneira, 4ed.
[4] Porter, M. E. (1996). What is strategy?. Harvard Business Review, Boston, v.74, n.6, p.61-78.
[5] Hopp, W. J. & Spearman, M. L. (2004). To Pull or Not to Pull: What Is the Question? M&SOM Manufacturing & Service Operations Management, Vol. 6, No. 2, Spring, pp.133–148.
[6] Harrington, H. J. (1997). Business process improvement workbook: documentation, analysis, design and management of business process improvement. New York: McGraw-Hill.
[7] Werkema, M. C. (2008). Integração Lean & Seis Sigma: muito barulho por nada? Banas Qualidade. São Paulo, ano XVII, n 192, p.48-54.
[8] Ferguson, D. (2007). Lean and six sigma: The same or different?. Management Services: Journal of the Institute of Management Services, United Kingdon, p. 12-13. 01 out.
[9] Pyzdek, Thomas (2003), The Six Sigma Handbook – revised and expanded, McGraw-Hill, New York.
[10] Abreu, Patrícia; Sousa, S. D. and Lopes, Isabel, "Using Six Sigma to improve complaints handling", Lecture Notes in Engineering and Computer Science: Proceedings of the World Congress on Engineering 2012, WCE 2012, London, UK 4-6 July, 2012, pp. 1363-1368.
[11] Sousa , S. D., Nunes, E. P. and Antunes, D. (2014) Lean Six Sigma in internal logistics: A case study, IAENG Transactions on Engineering Sciences Special Issue of the International MultiConference of Engineers and Computer Scientists 2013 and World Congress on Engineering 2013, Edited by Sio-Iong Ao Alan Hoi-Shou Chan Hideki Katagiri Li Xu, CRC Press pp. 161–170.

ISBN: 978-988-14047-0-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)