Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 13 (2017) 1104–1111

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

Manufacturing Engineering Society International Conference 2017, MESIC 2017, 28-30 June 2017, Vigo (Pontevedra), Spain

Improve the extrusion process in tire production using Six Sigma methodology

T. Costa, F.J.G. Silva*, L. Pinto Ferreira

ISEP – School of Engineering, Polytechnic of Porto, Rua Dr. António Bernardino de Almeida, 431, Porto 4200-072, Portugal

Abstract

Nowadays, market's constant changes require continuous flexibility and adaptation in the supply provided by organizations. In this context, the automotive industry represents one of the most demanding sectors due to the high levels of competition it is exposed to. Therefore, and so that these organizations are able to survive, it is crucial to seek operational excellence. This is undertaken through the constant processes improvement and continuous reduction of costs. This study was developed at a tire manufacturing company with the purpose of improving the rubber extrusion process of two tire semi-products: the tread and the sidewall. By adopting Six Sigma methodology and using the DMAIC cycle (Define-Measure-Analyze-Improve-Control), one was able to implement some improvement procedures whose resulted in a decrease of 0,89% on the indicator of work-off generated by the production system. This approach resulted in a significant financial impact (savings of over 165 000€ per annum) on the company's quality expenses.

Peer-review under responsibility of the scientific committee of the Manufacturing Engineering Society International Conference 2017.

Keywords: Tire production; Automotive industry; Increasing productivity; Six Sigma; DMAIC

1. Introduction

The permanent pursuit of excellence, in the competitive context of the automotive industry, is based on the existence of organisations commitment to deliver products or services close to perfection, promoting the philosophy

* Corresponding author. Tel.:+351 228 340 500; fax: +351 228 321 159.
E-mail address: fgs@isep.ipp.pt

2351-9789
Peer-review under responsibility of the scientific committee of the Manufacturing Engineering Society International Conference 2017.
10.1016/j.promfg.2017.09.171

of zero defects and first-time-right production [1]. Over the last years, the Six Sigma program has become increasingly popular and of a widespread use both in various organisations across the world as well as in several types of industries [2]. This methodology was initially adopted at the end of the 80s at the Motorola company, which used the term Six Sigma as a form of describing the approach used to measure defects and improvements in quality [2, 3]. However, there were also companies such as AlliedSignal, 3M and GE, pioneers in the use of the Six Sigma program, which reported savings of millions of dollars from the 90s onwards as a result of this implementation [4]. Initially, the Six Sigma methodology only targeted production processes; nevertheless, other types of sectors such as marketing, purchasing and customer support centres, amongst other services and functions, also currently have this methodology implemented with the aim of continuously improving their processes and ensuring customer satisfaction [5]. This methodology is widely acknowledged as an application of tools and statistical or non-statistical techniques to maximise the returns on investment made by organisations [6]. This is achieved through the optimisation and control of the organisation's processes, aiding management in the maximum enhancement of the value produced by using as few resources as possible [7,8]. The improvement cycle - Define, Measure, Analyse, Improve and Control (DMAIC) - constitutes one of the keys to the success of the Six Sigma program [9]. Through this approach, the improvement obtained in products and processes converges, in the sense that they become more efficient and effective [8].

The present study was developed in an industrial environment at Continental Mabor, a tire manufacturing company located in Famalicão, Portugal. The study's main objective was to improve the extrusion process, which is responsible for the production of two tire semi-products: the tread and the sidewall. One of the production system's performance indicators (KPI) is designated as a work-off generation (non-conforming material), which was found to be above the required target. This constituted the main reason for this study, which focus was to enable its reduction. The structure of this article is divided into five sections: the first one presents the introduction; section 2 consists of a bibliographical review concerning the approaches to continuous improvement in Six Sigma processes; section 3 deals with the methodology used in the development of this study; section 4 describes the work developed at the Continental Mabor company through the implementation of the DMAIC cycle and, finally, section 5 presents the final conclusions.

2. Literature review

Over the last years, companies have been confronted with huge competition in global economics. Many of the companies which adopted the Six Sigma approach have achieved success in their activities [10]. Six Sigma constitutes an innovative approach to the constant improvement of processes and is a methodology of Total Quality Management [11]. The Six Sigma concept was introduced in the 80s by Motorola and constitutes an essential feature of its own quality improvement program [12]. The term Six Sigma refers to a statistical performance target of operating with only 3,4 defects for every million opportunities [13]. As a result of the investment of 170 million dollars in Six Sigma training provided to its workers, Motorola reported savings of 2,2 billion dollars in expenses relating to poor quality [14]. This management strategy has gained popularity since it was adopted and explored by various organisations worldwide; General Electric (GE), Boeing, Kodak and Sony, amongst others, reporting great improvements in performance and savings of millions of dollars [15].

In the context of organisations' business dealings, Six Sigma is a strategy which is used both to improve profitability as well as ensure efficiency in all operations, with the purpose of meeting customers' demands and expectations [16]. It consists of a strict, focused and extremely efficient application of practices and quality concepts, and tends towards an approach of error-free performance in organisations [8]. Unlike other movements aimed at improving quality, which primarily focuses on the product or service provided to the final customer, Six Sigma methodology places emphasis on the quality of the organisation's global system [17]. Some of the benefits ensuing from the implementation of this system include cost reduction, improved productivity, growth in market share, customer loyalty, reduction in cycle times and defects, amongst others [13]. The strategy of this approach, as a problem-solving or process improvement methodology, resorts to a series of well-defined steps, which constitute the DMAIC cycle and are one of the keys to success in the implementation of the Six Sigma program [9]. The operation of this cycle is similar to other problem-solving procedures used in production systems, such as Deming's Plan-Do-Check-Act cycle and Juran and Gryna's Seven Step procedure [18]. This cycle consists of five stages, beginning with the definition of the problem and of all aspects which are relevant to the project (Define). During the second stage, one carries out a measurement of the problem; namely, all defects which result in its occurrence (Measure) [19]. The next stage consists of analysing the collected data, with the purpose of determining the problem's root causes (Analyze) [20]. The objective of the process improvement stage is to eliminate the previously identified causes (Improve). In the last stage, one must control and monitor the process to ensure that the problem does not remain (Control) [21]. The success in the implementation of the Six Sigma methodology, through the DMAIC approach, is not restricted to the automotive industry [5, 22]. Its use can be extended to many other sectors, such as the field of Healthcare [23, 24], the PCB (Printed Circuit Board) industry [25], as well as others related to energy [26] and food [27].

3. Methodology

In order to carry out this study, the methodology adopted began with a review of the literature. This was undertaken by means of published books and scientific articles dealing with the Six Sigma methodology, with the purpose of providing a basis for the study of the production system presented. The study was subsequently initiated through the application of the DMAIC cycle of Six Sigma methodology. In the first stage (the define phase), one established a problem definition by creating a Project Charter, which consisted of the high-level project planning using a Gantt graph, and plotting the process by means of a SIPOC diagram (Supplier, Inputs, Process, Outputs, Customer). The second stage (measure) was carried out by measuring process performance through a data collection plan. In the third stage (analysis), one used tools (Pareto, Ishikawa diagram) to determine the root causes of the problem. The fourth stage comprised the implementation of improvement actions aimed at eliminating the causes which had been identified previously. Lastly, during the control phase, the process was monitored and one proceeded with the quantification of the impact ensuing from the implemented actions.

4. Improving the extrusion process of tire semi-products

The production system consists of five sections; however, the Mixing, Preparation and Construction Departments are the most relevant in this work (see Fig. 1). The extrusion process is located in the Preparation Department and consists of seven extrusion lines (Extruder E01, E02, E03, E04, E05, E06 and E07). The Mixing Department receives the raw material and transforms it into compound sheets which will supply these extruders. There are two types of extrusion, tread and sidewall extrusion, which customer is the Construction Department. The non-conforming material generated during this process is called work-off, since it is later reused. The generation of work-off constitutes one of the indicators used by the factory to analyse the performance of the system and its evolution over the time. This quantitative indicator measures the percentage ratio between the amount of work-off generated and the amount of compound produced in the Mixing Department.

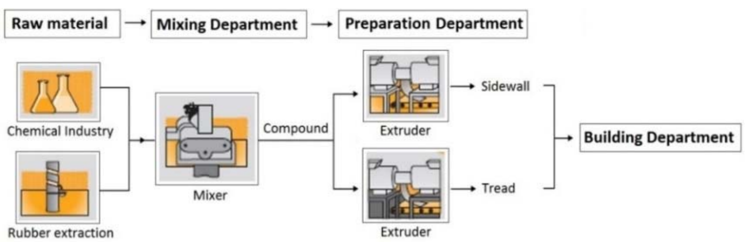

Fig. 1. Diagram of the production system (from the Mixing to Building Departments).

4.1. The define phase

This first stage of the DMAIC cycle is of crucial importance to the project's success and a complete definition of its elements must therefore be undertaken. To this end, a Project Charter was drawn up, which identified the problem and established the objectives to be reached, as well as the scope and teams involved. In order to assist planning, one set up a Gantt graph (see Fig. 2), which established the deadlines for the conclusion of the various project phases. The project began in May 2016 and extended over a time period of six months.

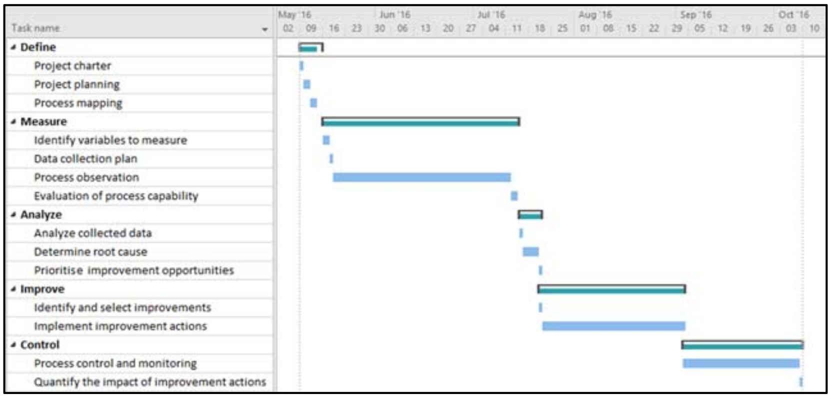

Fig. 2. Gantt chart for project planning.

A SIPOC diagram was drawn up with the purpose of plotting the extrusion process and delineating its context. On this diagram, one defined the suppliers and relevant entries for the process, as well as the sequence of activities, ensuring outputs and the customer's satisfaction. In this particular case, both the suppliers and customers were internal, as they constitute a part of the same production system. This tool allowed one to highlight information which was relevant to the project, thus focusing on critical activities in the process. The five main stages which occur during the extrusion process are described in Table 1.

Table 1. Main operations during the extrusion process.

Stage	Operation	Description
1	Preparation and compound feeding	The compound produced in the Mixing Department is transported to a zone near the extrusion line and stored in racks. The process begins with the displacement of the compound - by the operator - to the feed conveyor, according to production needs.
2	Extrusion	At this stage, the compound is heated and homogenised, thus acquiring a plastic state, and is transported to the die through the feed screws. In the extrusion head, the material is forced through the pre-die and die, which are responsible for defining the profile of the article to be produced.
3	Cooling and drying	The material is cooled through showers or by immersion in water tanks.
4	Cutting	In tread extrusion, this process consists of a loop and an automatic cutting machine. The loop is used to store material, whenever this area of the line must be stopped to make the cut. In sidewall extrusion, the cut is made without stopping, by means of a rotating blade.
5	Storage	Treads are automatically booked onto transport cars while sidewalls are rolled up at wind-up stations.

4.2. Measure Phase

During this phase of the DMAIC cycle, one collected data with the purpose of measuring process performance. A data collection plan was drawn up, which included monitoring the process on all of the extrusion lines. This data collection process included a record of rejected material during the occurrence of setups or disturbances in both types of extrusion. During the tread extrusion process, one took stock of the number of rejected tread pieces while, for the sidewall extrusion process, one recorded the number of metres rejected. During this measurement process, which took approximately 30 weeks, ten trials were carried out every week, each consisting of a three-hour time period. After measurements were undertaken, one established the state of the work-off generated. The current values are presented in Table 2. This presents, for each type of extrusion – sidewalls or treads – the percentage of non-conforming material (work-off) generated and ensuing from the occurrence of setups and disturbances.

Table 2. Percentage of WO (work-off) generated during production.

Production	Treads	Sidewalls
WO - Setups	5%	10%
WO - Disturbances	4%	10%
WO - Samples	1%	1%
WO - Returns	3%	5%
Acceptable pieces	87%	74%
Total	100%	100%

4.3 Analyse phase

The objective of this phase was to determine the defects root causes, as well as the sources of variation in the process. After analysing the data collected, an Ishikawa diagram was drawn up to establish cause-effect relations (see Fig. 3). This describes the possible root causes for the work-off generated. The analysis undertaken was divided into types of extrusion (treads and sidewalls) and events (setups and disturbances), given that they presented different features. During the measurement phase, one proceeded with data collection to enable setting up a Pareto chart to prioritise the analysis of disturbances (see Fig. 4 and Fig. 5) for each type of extrusion.

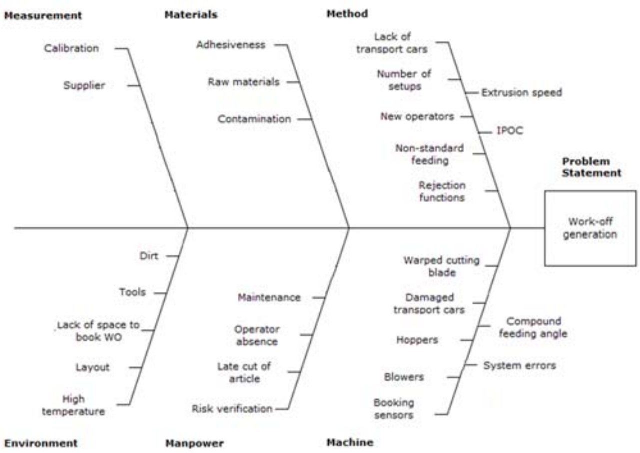

Fig. 3. Ishikawa diagram.

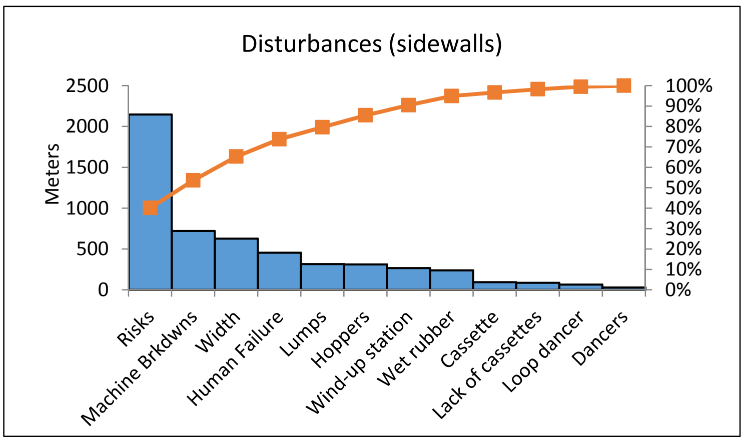

Fig. 4. Pareto´s charts for defects in sidewall extrusion.

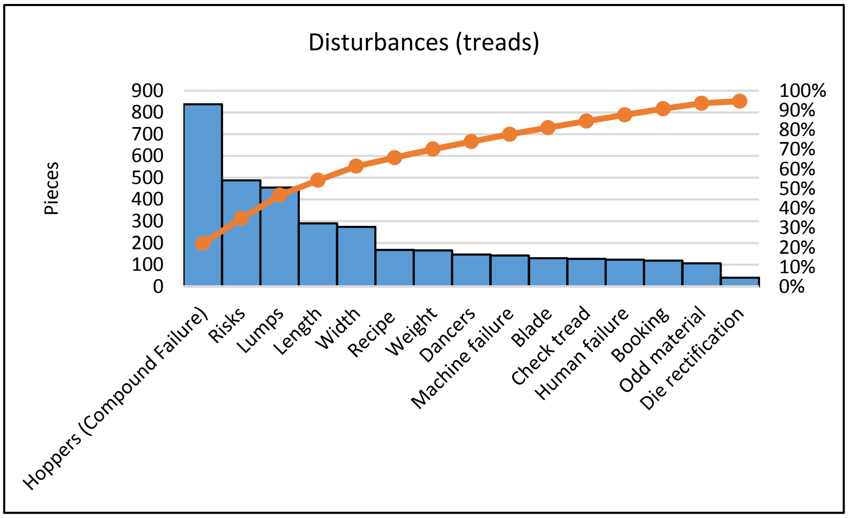

Fig. 5. Pareto's charts for defects in tread extrusion.

From the obtained data, one decided to focus on the major five defects (disturbances) for each type of extrusion (see Table 3).

Table 3. Main disturbances and percentage of total defects in both types of extrusion.

Disturbances - Treads extrusion	Cumulative value of total defects (%)
1. Hoppers - feeding failure	22
2. Lumps	35
3. Risks	47
4. Length dimensions	54
5. Recipe parameters	61

Disturbances - Sidewalls extrusion	Cumulative value of total defects (%)
1. Risks	40
2. Machine breakdowns	54
3. Width dimensions	65
4. Human failure	74
5. Lumps	80

In order to analyse the setups, one compared all machines, as well as each kind of setup, for both types of extrusion. In the case of tread extrusion, no significant differences were recorded regarding material rejected by the extruder during setup. However, in the case of sidewall extrusion, the comparison between machine E07 and E01 revealed a considerable difference in the work-off generated during the die setup (see Table 4). Thus, since extruder E07 presented higher values for work-off produced during setup, it was subjected to an analysis in order to reduce these values.

Table 4. Amount of work-off per setup in sidewall extrusion.

Sidewall extrusion - Die setup	Setup phase (kg)		Total (kg)
	Cut	Adjust	
Extruder E01	5	16	21
Extruder E07	13	25	38

4.4 Improve phase

In this phase, one identified and selected the improvement measures to be carried out (see Table 5). Concerning the occurrence of disturbances and as was demonstrated in Table 3, one acted upon the main problem in tread extrusion, which was established as being a failure in extruder feeding. This problem was detected on all tread extruders in operation (Extruders - E03, E04, E05 and E06). Furthermore, during the observation of the process on extruder E04, one detected stoppages and jamming, so that one had to implement improvement action. With regard to the setups, the focus of intervention was directed at extruder E07 (see Table 4), used in sidewall extrusion, where one detected the problems described in Table 5 after a carried out analysis.

Table 5. Improvement actions.

Machine	Event	Cause	Improvement action
Extruder E04	Disturbances	Frequent machine stoppages due to height sensor activation	Increase pit depth to prevent treads from bending at the end of the article and activate height sensors
		Frequent material jamming in the air blower treadmill	Replacement of the air blower treadmill
Extruders - E03, E04, E05 e E06	Disturbances	Hoppers - compound feeding failure	Alarm sound installation on extruder E05 and replication for the other extruders
Extruder E07	Setups	Misfit cut of the article	Change in the material rejection function at the end of the article
		Late acceptance of conforming material at the beginning of the article	Change in the material acceptance condition at the start of article production
		Human failure – late cut by the operator	Beep sound installation before cutting the current article produced

4.5 Control phase

After the interventions were undertaken, one drew up a control plan to monitor the process, and carried out new measurements in order to validate the impact of the improvements implemented. Once concluded, and considering that 560 tonnes are produced daily in the Mixing Department, it was ascertained that the objective of decreasing the work-off produced had been achieved, with a reduction of 0,89%. This was the outcome of all interventions undertaken and represented a decrease of 5 tonnes of non-conforming material per day (see Table 6). After repayment instalments of equipment and labour costs had been calculated, the annual financial impact of these actions was translated in savings of over 165 thousand Euros per annum for the company.

Table 6. Savings related to implemented improvements.

Machine	Work-off reduction (%)	Work-off reduction (tonnes/day)	Financial savings (Euros/year)
Extruder E04	0,05	0,3	9 299
Extruders - E03, E04, E05 e E06	0,48	2,7	93 591
Extruder E07	0,36	2	62 304
∑	0,89	5	165 194

5. Discussion and conclusions

The development of this study was aimed at improving the extrusion process, with the purpose of reducing the non-conforming (work-off) material generated. This objective was reached through the use of Six Sigma methodology, as well as its associated tools, which allowed for the identification and efficient intervention in problems such as excessive rejected material during setup and feed failures on the extruders. The actions implemented contributed to a significant reduction in the non-conforming material generated, which was approximately five tonnes per day. The study thus culminated in a decrease of 0,89% on the indicator of work-off generated by the production system. Some of the direct consequences of this reduction in costs associated with poor quality are translated into greater efficiency of resources, as well as an increase in productivity and the elimination of rework. Another relevant aspect is that the improvement actions resulted in annual savings of over 165 thousand Euros. In this sense, the use of Six Sigma methodology played a decisive role in the achievement of the proposed goal, ensuring that there was a systematic and disciplined approach to the issues at hand through the DMAIC cycle. This provided the necessary support to the organisation, so that it was able to produce more quickly, more economically and with greater quality.

References

[1] A. Pugna, R. Negrea, and S. Miclea. Procedia-Social Behav Sci 221 (2016) 308-316.
[2] V. Arumugam, J. Antony, and K. Linderman. Eur J Oper Res 254 (1) (2016) 202-213.
[3] Y. Eslami, M. Mohaghegh, and A. Brun. Int J Eng Res Technol 3 (8) (2014).
[4] D.S.L. Marzagão, and M.M. Carvalho. Int J Proj Manag 34 (8) (2016) 1505-1518.
[5] J. Antony, E.V. Gijo, and S. J. Childe. Prod Plan Control 23 (8) (2012) 624-640.
[6] J. Antony, M. Kumar, and M.K. Tiwari. J Eng Manuf 219 (8) (2005) 633-646.
[7] A.K. Singh, and D. Khanduja. Procedia Mater Sci 5 (2014) 2645-2653.
[8] T. Pyzdek. The Six Sigma Handbook: The Complete Guide for Greenbelts, Blackbelts, and Managers at All Levels, Revised and Expanded Edition (2003).
[9] J. Antony, R. Banuelas. Meas Bus Excell 6 (4) (2002) 20-27.
[10] M. Ertürk, M. Tuerdi, and A. Wujiabudula. Procedia-Social Behav Sci 229 (2016) 444-452.
[11] T.N. Desai, and R.L. Shrivastava. Six Sigma–a new direction to quality and productivity management. In Proceedings of the World Congress on Engineering and Computer Science, San Francisco, CA. Elsevier (2008).
[12] H. Wang. In Wireless Communications, Networking and Mobile Computing, 2008. WiCOM'08. 4th International Conference on (pp. 1-4). IEEE.
[13] P.S. Pande, R.P. Neuman, and R. R. Cavanagh. The Six Sigma way. McGraw-Hill (2000).
[14] J. Antony. Bus Process Manag J 12 (2) (2006) 234-248.
[15] A. Ansari, D. Lockwood, E. Thies, B. Modarress, and J. Nino. J Case Res Bus Econ 3 (1) (2011).
[16] Y.H. Kwak, and F. T. Anbari. Technovation 26 (5) (2006) 708-715.
[17] K.Y.B. El-Haik, and K. Yang. Design for Six Sigma, A Roadmap for Product Development. RR Donnelly, SAD, str, 21 (2003).
[18] J. De Mast, and J. Lokkerbol. Int J Prod Econ 139 (2) (2012) 604-614.
[19] R.D. Snee. Int J Six Sigma Compet Advant 1 (1) (2004) 4-20.
[20] H. De Koning, and J. De Mast. Int J Qual Reliab Manag 23 (7) (2006) 766-787.
[21] H. Erbiyik, and M. Saru. Procedia-Social Behav Sci 195 (2015) 2556-2565.
[22] P. Kaushik, and S. Kumar. Manag Sci Lett 7 (3) (2017) 145-152.
[23] J. Van Den Heuvel, R.J. Does, and J.P. Verver. Int J Six Sigma Compet Advant 1 (4) (2005) 380-388.
[24] N.E. Eldridge, S.S. Woods, R.S. Bonello, K. Clutter, L. Ellingson, M.A. Harris, and R.L. Parlier. J Gen Intern Med 21 (2) 35-42.
[25] J.P.C. Tong, F. Tsung, and B.P.C. Yen. Int J Adv Manuf Technol 23 (7-8) (2004) 523-531.
[26] P. Kaushik, and D. Khanduja. DM make up water reduction in thermal power plants using Six Sigma DMAIC methodology (2008).
[27] H.C. Hung, and M.H. Scientific Research and Essays 6 (3) (2011) 580-591.