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Application of the Six Sigma Method to Improve Vulcanization Times in Automotive Tires

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***Abstract**: The present paper considers the use of the results of the evaluations carried out by applying the "Six Sigma" statistical method to improve the vulcanization times of elastomeric composites on the external manufacturing cycle of several size types of car tires. This statistical approach aims to verify the distribution of the measured values of the external vulcanization times between the normal specification limits to optimize them and improve the performance, efficiency, and quality of the automotive tire vulcanization processes. Through the analysis carried out, the operations that caused delays and defects were identified, a program of corrective measures was carried out and after its execution, the fulfillment of the purpose was verified, namely the optimization of external vulcanization times and reducing the number of faulty tires. The new measured values of the vulcanization times were within the normal limits of the imposed specifications (LSS = 2.5). This situation corresponds to achieving a maximum level of performance and represents the successful completion of the quality improvement project.*

***Keywords:** Six Sigma, improvement, vulcanization time, external cycle, automotive tires*

1. Introduction

The ever-increasing demands on efficiency and quality pose new challenges for today's manufacturing companies around the world. Operational excellence combined with the ability to develop more efficient, effective, and innovative production processes within the value chain through procedural, organizational, technological, or cultural adaptations is gaining continuous importance at international level. Thus, industrial companies, in all sectors of the economy, implement several approaches to improve the quality, cost and productivity of production. Among such strategies is the current "Six Sigma" (6 σ) statistical approach, aiming to improve industrial manufacturing technological processes and to eliminate defects and variations through a readjustment/adjustment of processes within specification limits [1].

That is why the primary objectives of current scientific research regarding the improvement of the quality of some systemic entities (products, processes, services, resources, etc.), using the "Six Sigma" statistical approach, aim the achievement of three main results: increasing organizational satisfaction, reducing the number of defects, and improving the life cycle of entities [1].

In the specialized literature, there are numerous works and studies regarding the use of research and investigation methods on the line of quality improvement through the method offered by the "Six Sigma" concept [2 - 13].

Most papers in literature [14-16] are focused on minimizing and/or optimizing the curing process nominal cycle duration. The present approach is aiming to minimize external time of the process by analyzing each auxiliary step and thus increase the productivity and quality of the products.

Considering as a main direction of research the improvement of the quality of the manufacturing processes of car tires, by applying the current statistical approach "Six Sigma", this paper approaches in a new vision, the optimization of vulcanization times on the external cycle of their manufacture. For this purpose, it is aimed to fit the vulcanization times within the specification values and to introduce, as necessary, some corrective measures until the desired conformity is achieved.

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2. Materials and methods

2.1. Motivations and description

After monitoring the production of car tires from a high-capacity industrial technological facility, it was found that the decrease in production reported on the vulcanization technological section led also to the increase in the number of daily defects/rejects.

The vulcanization of an automotive tire consists of two main stages: the vulcanization time per nominal cycle (VTNC), which represents the length of time in which the tire is vulcanized, and which cannot be modified for a certain technology, and the vulcanization time per external cycle (VTEC), which is the time elapsed from the moment the mold opens to the moment it closes to vulcanize a new tire.

The external vulcanization cycle steps are:

- Evacuation
- Press opening
- Vacuum 1
- Lifting the cylinder and the ejector
- Vacuum 2
- Roller bed/unloader ingress
- Tire tipping / unloader lift
- Roller bed withdrawal / discharger exit
- Entering and lowering the loader
- Formation
- Lifting loader
- Closing the press

Thus, the intervention of the technical and technological management on the critical areas on the technological flow resulted in a decrease in the number of defects of the vulcanized products and, respectively, a reduction in the vulcanization time per external cycle.

It was found experimentally that VTEC has the greatest impact on tire productivity and quality, for the following reasons:

a. any delay of a few seconds for each tire generates total delays at the level of the production unit of more than one hour per day;

b. delays in closing the presses lead to a decrease in the temperature inside the cavity by up to 25 degrees and the appearance of condensation, which can generate an incomplete vulcanization of the tread or the appearance of spots on it, thus implicitly the appearance of surface defects;

c. delays in opening the press even by a few seconds lead to an over-vulcanization of the tires, a fact that negatively impacts their quality, performance and durability;

d. delayed or incomplete formation can lead to the deformation of the tires inside the press, leading to the impossibility of their evacuation at the end of vulcanization or to rejection;

e. all the delays generated by the other stages of the VTEC have a negative impact only on the general productivity of the vulcanization technological section.

At the organizational level, were established the specification limits (optimization targets) for the vulcanization time on the external cycle [measured in centesimal minutes], in accordance with the internal procedural rules. For example, for the vulcanization of tires with a diameter of Ø14 and Ø15 [inch] on the technological lines of Guilin presses (Figure 1) [17], the time limit (standard) was set at the value of 2.5 min (2 min and 30 s), according to internal manufacturing standards.

Considering that in the vulcanization section, at the Guilin press lines, non-compliant results of the vulcanization time on the external cycle were observed, it was decided to start the timing of each stage of the VTEC, for each vulcanization press and then centralize and analyze them.

Thus, the following equipment and materials were used:

- Lenovo Ideapad 470 laptop, provided with Microsoft Office and vulcanizing press diagnostic software;

- digital stopwatch capable of measuring both seconds and centesimal minutes.

Figure 1. Guilin vulcanizing press [17]

2.2. Current performance level measurement and data acquisition

Since the vulcanizing presses had some extremely fast stages (5 - 10 centiminutes) initially each press was subjected to multiple sets of consecutive measurements to guarantee the accuracy of the results. The times for the VTEC component stages were measured continuously, using the SPLIT function of the stopwatch, after which they were recorded on the time sheet.

Thus, a sample consisting of 20 representative types of automotive tires (diameter Ø14 and Ø15 [inch]) was considered, for which vulcanization times were measured [min. centésimal] on the external manufacturing cycle. The results Xi (i = 1, 2, …, 20), are presented in a statistical string, as follows: 3.14; 2.76; 3.00; 2.78; 2.86; 2.95; 3.06; 2.80; 2.91; 3.12; 2.79; 2.89; 3.09; 3.02; 2.83; 2.98; 2.81; 2.85; 3.11; 2.77.

For the representation of the probability density graph in the case of a normal distribution (Gauss) of the measured results, it was necessary to go through the Six Sigma methodology [1, 18], for which the following main characteristics were determined:

- average value = 2.069;
- root mean squared error, σ

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(X_i-\bar{X})^2}{n-1}} = 0.89 \qquad (1)$$

Also, the Gaussian normal distribution function, f(X) [1] was used:

$$f(X) = \frac{1}{\sigma\cdot\sqrt{2\cdot\pi}} \cdot e^{-\frac{1}{2}\cdot\left(\frac{X-\bar{X}}{\sigma}\right)^2} \qquad (2)$$

and it was graphically represented (Figure 2):

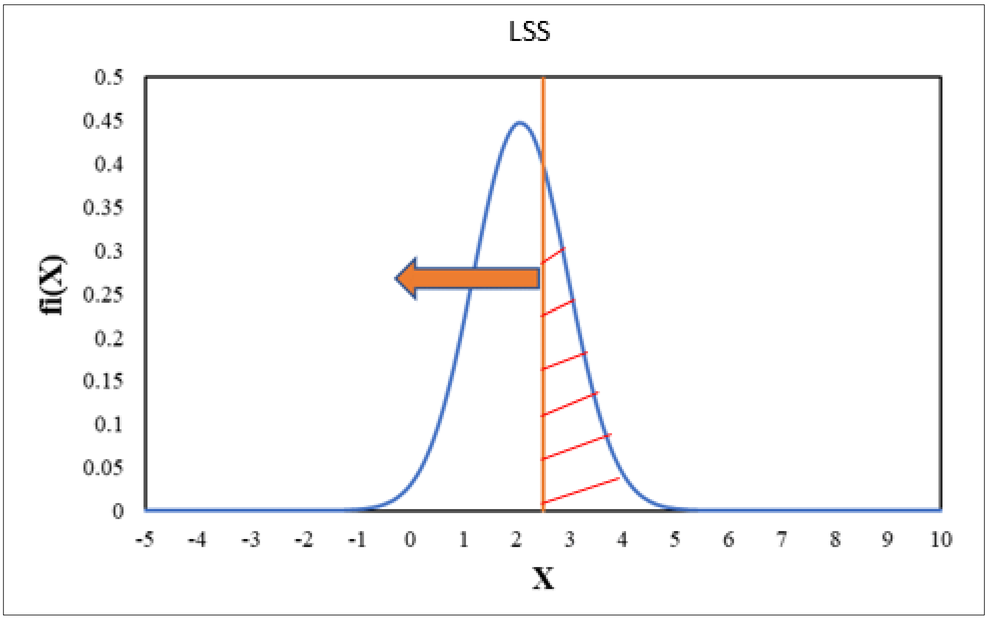

Figure 2. Gaussian normal distribution curve

The hatched area is out of specification and should be removed. The shape of the "Gaussian" distribution between the specification limits (lower limit, LIS* = - 0.6 and upper limit, LSS* = 4.74), must be shifted to the left of the upper (maximum) specification limit (LSS = 2.50), precisely to achieve a real level of maximum performance "6σ", equivalent to 3.4 defects per 1 million opportunities. In this situation, it is necessary to introduce firm measures to improve the quality and performance of vulcanization times on the external manufacturing cycle, by establishing a firm program of corrective measures and allocating adequate resources.

Therefore, the investigation of the possible causes of the recorded non-conformities led to the establishment of the main cause of non-productivity within the TVCF, as being the evacuation operation (with a weight of 89% of the affected presses), followed by the opening of the press and the entry of the roller bed (Table 1).

Table 1. Investigation of possible causes of registered non-conformities

Operation	**Cause**
Ejection	Defective vacuum pump Corroded installations Faulty sensors Clogged pipes
Press opening	Faulty hydraulic pump Defective hydraulic distributor Faulty hydraulic valves
Roller bed ingress	Clogged electric drive motor Defective / dirty sensors Radio interference Leaks in compressed air installation

Also, using the data obtained from the timing operations, an initial indicator was established highlighting the first 5 non-compliant operations found for the Guilin vulcanization technological line, composed of 13 vulcanization presses (Figure 3).

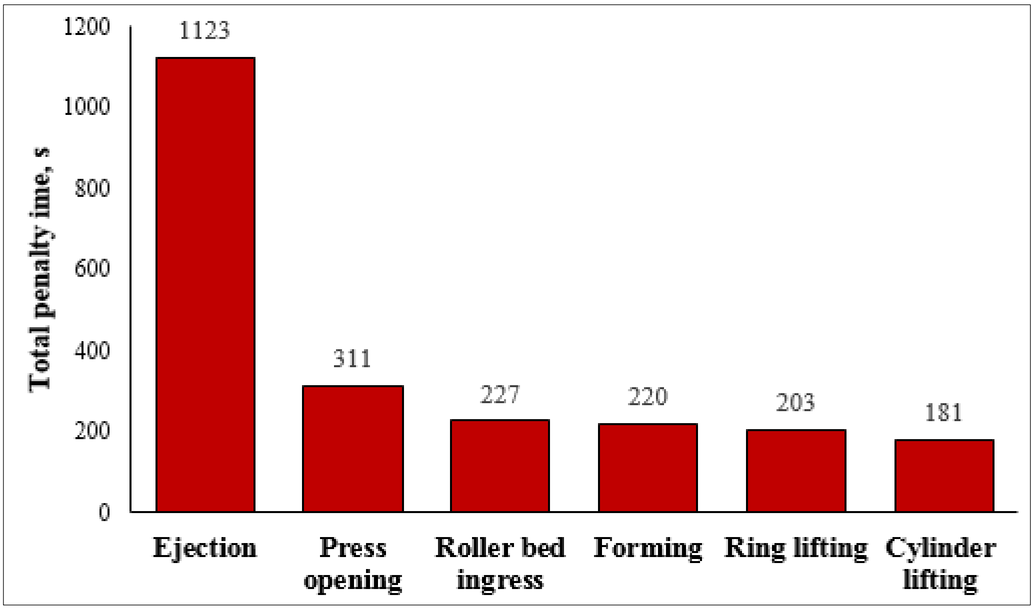

Figure 3. Chart of non-conforming stages for the analyzed vulcanization technological line (Guilin)

It turns out that the ejection operation is the most non-compliant stage, generating a total loss of 1123s for each vulcanized tire, followed by the opening of the press, with a total of 311 s.

Forming, ring lifting, and roller bed entry are close as delays, generating a combined waste of 650 s, while cylinder lift generated a waste of 181 s. A summary calculation shows that the first 5 global non-conforming stages add up to delays of approximately 38 min for each vulcanized tire.

For the centralization of the data and their easy analysis, for each line of presses, two graphs were prepared: one showing the total number of non-compliant presses (Figure 4) and another showing the graph of the percentage of time for each stage (Figure 5).

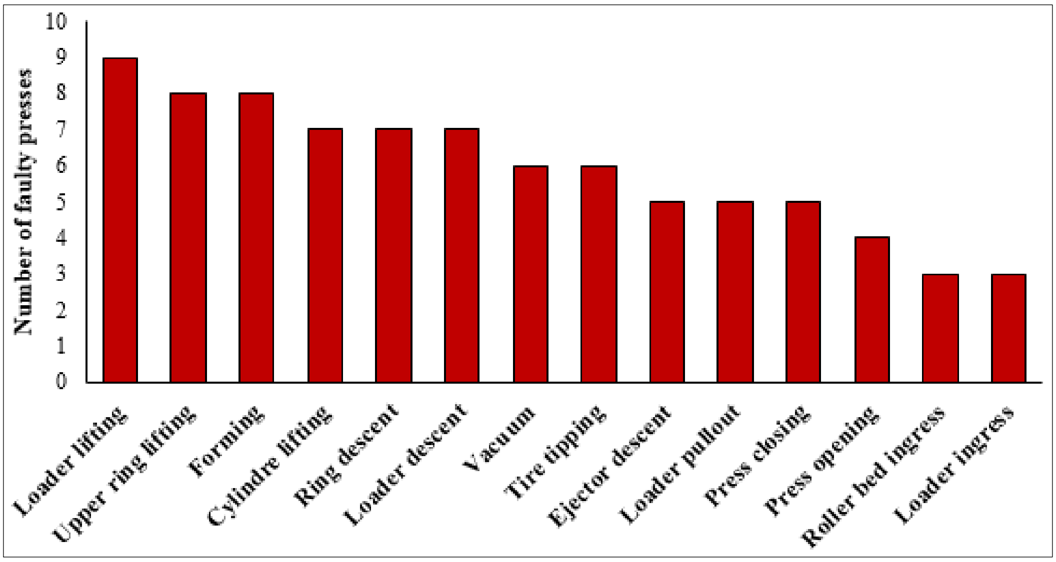

Figure 4. Total number of non-compliant presses for each stage

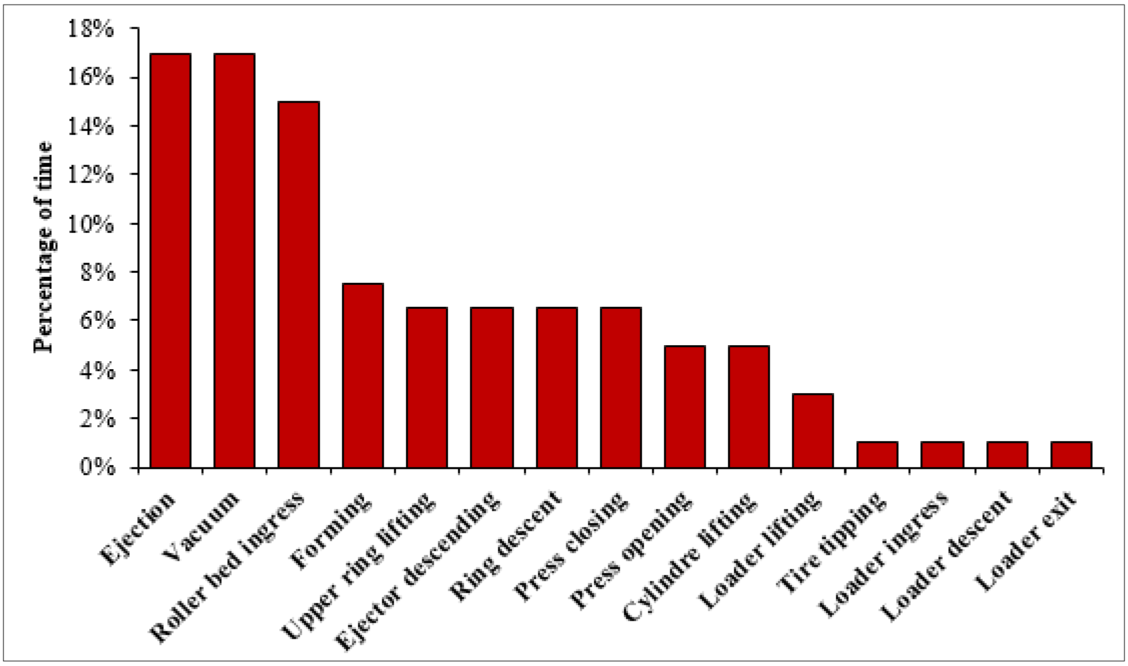

Figure 5. Graph of time percentage weights

From the analysis of the graphs in Figure 4 and Figure 5, it can be seen that the stages that generate the most delays on the external cycle time are: evacuation (17%), vacuum (17%) and roller bed ingress (15%), even if the number of non-compliant presses on these steps is lower than on the rest of the steps. Also, the same thing was shown by the Pareto analysis [19-21] (Figure 6), separating the vital or major nonconformities (evacuation; press opening; roller bed entry) from the minor ones (forming; ring lifting; cylinder lifting).

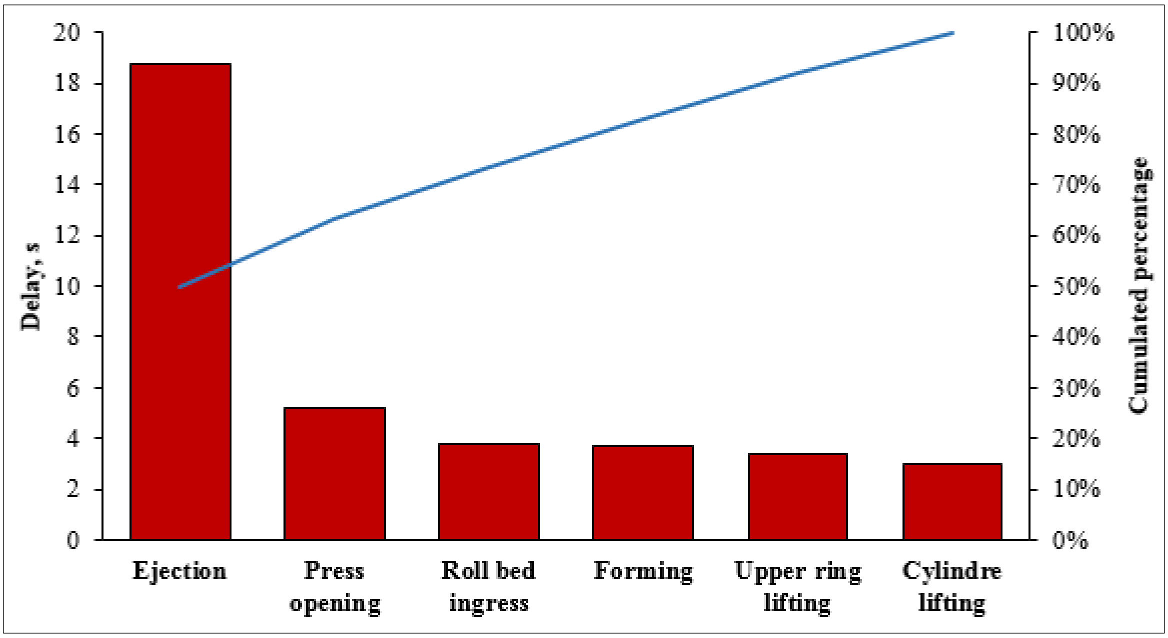

Figure 6. Pareto analysis

Thus, it was concluded that the 3 mentioned stages have the highest percentage of time, so the first action of the maintenance team was to optimize these stages (through measures intended to rehabilitate the vital non-conformities identified during operations described in Table 1), taking into account the existing conditions at the presses that are below the current time norm (2.5 min).

3. Results and discussions

After carrying out the program of corrective measures in conjunction with the specific maintenance operations, the measurement of the vulcanization time on the external cycle was repeated, for the Guilin press lines, on another sample of 20 representative types of car tires (with the diameter Ø14 and Ø15 inch), yielding the following statistical string X of measured values: 1.91; 1.92; 1.97; 1.98; 1.99; 2.00; 2.00; 2.01; 2.01; 2.02; 2.02; 2.03; 2.04; 2.04; 2.05; 2.07; 2.08; 2.08; 2.09; 2.10.

Next, the same procedural steps specific to the Six Sigma methodology were applied to represent the probability density graph of the measured values, as follows [1,18]:

- average value = 2.02;
- mean squared error σ = 0.217;
- LSS target value = 6σ = 2.50.

Then, the Gaussian normal distribution curve was represented (before, fi(X) and after the maintenance operations, f(X)), according to Figure 7:

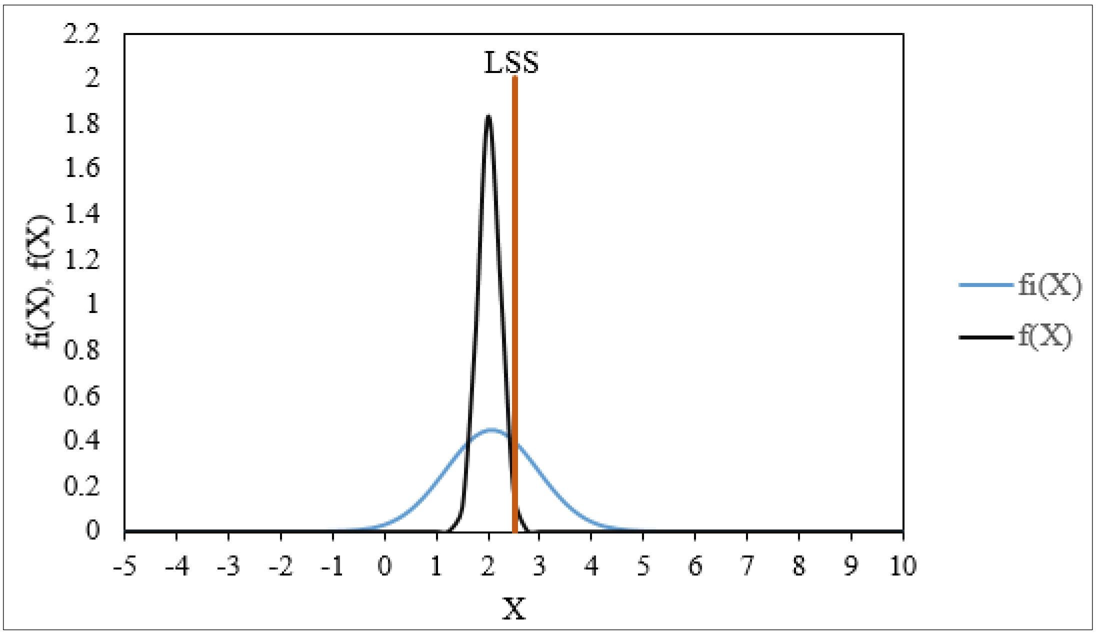

Figure 7. Gaussian normal distribution curve before and after the implementation of corrective measures

According to the graphic representation of the f(x) function in Figure 7, the shape of the "Gaussian" type distribution is included between the calculated specification limits (LIS* = 1.37 and LSS* = 2.67). Such a distribution characterizes a real level of maximum performance "6σ", equivalent to 3.4 defects per 1 million opportunities, which proves that by carrying out the maintenance operations the goal function was achieved, namely the optimization of the external vulcanization times on the car tire manufacturing cycle by fitting the distribution of the measured values of the vulcanization times between the normal limits of the mentioned specifications.

4. Conclusions

From this paper it follows that the basic requirement of the measured values for the optimization of the external vulcanization times on the manufacturing cycle of car tires in the automotive industry is met by framing the distribution of the measured values of the vulcanization times between the normal specification limits imposed (LSS = 2.5). This situation corresponds to achieving a real maximum performance level of 6σ, equivalent to achieving an efficiency of 99.9997% and synonymous with the successful completion of the quality improvement project.

The implementation of the optimization project of the above-mentioned indicator can be an example worth following for other vulcanization technological lines.

Through this work, it is possible to respond to the objective function defined by the improvement of the quality characteristic related to the optimization of vulcanization times on the manufacturing cycle of car tires. Although it is a method based on mathematical statistics, "Six Sigma" does not offer a tool that is difficult to use and thus represents a guaranteed success for organizations whose goal is to obtain outstanding results and ensure superior performance levels. That is why the "Six Sigma" statistical method is equally addressed to all industrial companies for improving the performance, efficiency and quality of technological manufacturing processes, of the products made, as well as for reducing non-conformities within the specified limits, by ensuring a stability and maximum effectiveness.

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