Analysis of Time Measurement Strategies in the Automotive Components Industry Using Design Science Research

Erik Leonel Luciano[1], Jonas Henrique da Silva[2], Rosinei Batista Ribeiro[3], Eliane Antonio Simões[3], Alexandre Formigoni[3] & Eduardo Ferro dos Santos[4]

[1] State Center for Technological Education Paula Souza - CEETEPS - Postgraduate, Extension and Research Unit - São Paulo, SP, Brazil

[2] Teresa D`Ávila University Center - UNIFATEA - Lorena, SP, Brazil

[3] Postgraduate, Extension and Research Unit - Paula Souza State Technological Education Center – CEETEPS – São Paulo, Brazil

[4] Engineering School of Lorena, University of São Paulo-USP, Lorena, Brazil

Correspondence: Erik Leonel Luciano, State Center for Technological Education Paula Souza - CEETEPS - Postgraduate, Extension and Research Unit - São Paulo, SP, Brazil.

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Abstract

The digitization of production processes is an important factor when considering the development scenario of advanced manufacturing. For companies to start this development, their processes need to be digitalized, and this is a growing demand. In this sense, this work aims to analyze the digitalization of time measurement activity in industrial processes, which is also known as Time Study or Chronoanalysis. Thus, the purpose was to analyze the use of video technologies as a support for people who are responsible for carrying out time measurements in industrial activities. This analysis aimed at the automotive industry, in application to a manufacturer of structural components of automotive vehicles. The Design Science Research (DSR) method was applied to identify the most critical process of the company, and in this activity to carry out time measurements using a video reading software called Quick Time Player® from the company Apple®, with a proposal to analyze the micro automatic movements of the machine, helping to identify movements that could be eliminated or have reduced times, generating cycle time reduction and increased production capacity. Finally, it was identified that there were benefits in the proposed method when comparing the analysis of time measurements with the use of the software and the company's usual methods, resulting in greater precision of chronoanalysis and user satisfaction with the new method.

Keywords: digital chronoanalysis, design and innovation, ergonomics, applied production management

1. Introduction

Time measurements are basic activities in the industry and by means of them the production capacities of each process phase are determined. With this production capacity information it is possible to determine which operations restrict the entire manufacturing flow, that is, that activity which has the lowest level of production, for such operation it is called a bottleneck (ARAUJO, 2009). The activity of measuring and analyzing the times of each phase of a production flow is called Chronoanalysis or Time Studies.

The most common or traditional way of measuring times of an operation is using a stopwatch. In this method, the person responsible for time measurements, the chronoanalyst, carefully observes each movement of the operation, whether automatic or manual, and records the time for its execution in the chronometer, later calculating the average time required for that phase of process to be completed. carried out and its production capacity. Obtaining these time measures at all stages of a product's flow, the bottleneck operation can be identified.

However, new technologies can help chronoanalysts in the studies of measures of time, among them the analysis by means of filming. In this sense, video reading software is a means that allows the operation to be viewed and reviewed as many times as necessary.

This survey highlights Quick Time Player®. This application developed by Apple® allows the switching of video frames in hundredths of a second using the computer keyboard cursor. This functionality becomes essential when chronoanalysis requires a more detailed division of movements. Dividing the operation into micro movements facilitates the identification of unnecessary elements that can be eliminated from the operation.

The problem of this research was limited to analyzing the application of time measurement studies in a company that manufactures components for commercial vehicles, more specifically a manufacturer of wheels for commercial vehicles located in the Para ƀa valley and a reference in the area. In this analysis, the time measurements were made with a digital stopwatch and also with the use of footage with the Quick Time® software, in order to observe the gains when using this technology. Methodology for conducting the study was Design Science Research, adapting the model proposed by Santos (2018).

The general objective of the article was to carry out studies of time measurements with the use of footage and the analysis and division of the elements and to observe the potential gains in the use of this technology in the bottleneck operation of a company that manufactures wheels for commercial vehicles.

The work motivation goes through the traditional method in which chronoanalysis is cariied out by direct observation at the work place, measurement with analog or digital stopwatches and annotation on a record sheet (FULMANN, 1975), but with the availability of new resources such as filming , and video playback applications, there is a wider horizon that allows the realization of time analysis using digital technologies.

Thus, this research is justified in developing an innovative approach in the company, using digitalization in the chronoanalysis process, allowing a deeper understanding of the movements that add value or not during the performance of the task. Without the digital resource, the chronoanalysis usually carried out in the company does not allow the study to reach the same levels of precision and consequent understanding.

Relevance of innovation in this research is to digitize the chronoanalysis activity, opening space for detailed analysis of elements by means of the use of video frames, providing resources for the analysis of micro movements in operations, with details difficult to be observed without this technology.

2. Theoretical Reference

2.1 Design and Technology

Considering this current era innovations, it can be said that all aspects belonging to today's society are under domain of information and communication technologies, characterizing this society as informational (LIPOVETSKY; SERROY, 2011).

The International Council of Societies of Industrial Design defines design as a creative activity in which the goal is to determine multiform quality of products, services, processes and their systems throughout their entire lifecycle. Thus, design is the fundamental term of innovative humanization of technologies and the crucial factor of cultural and economic exchange (ICSID, 2021). Thus, design is at the meeting of culture of daily life, technology and economy. Operational aspect of material artifacts is the design focus, which does not explain function and functionality in terms of physical efficiency, like engineering, but explains behavior from a cultural and social dynamics and must integrate science and technology into life everyday life, focusing on intersection between the user and the product/information — the so-called “interface design” (BONSIEPE, 2012).

2.2 Design Science Research – DSR

According to Santos (2018), the process of conducting research in Design Science naturally has direct similarities with the design process, starting with the understanding of the problem, either partially or totally. Partial understandings are possible in Design Science, since the artifact itself can enable the refinement of the problem definition, enabling a new cycle of generating alternatives and developing the artifact.

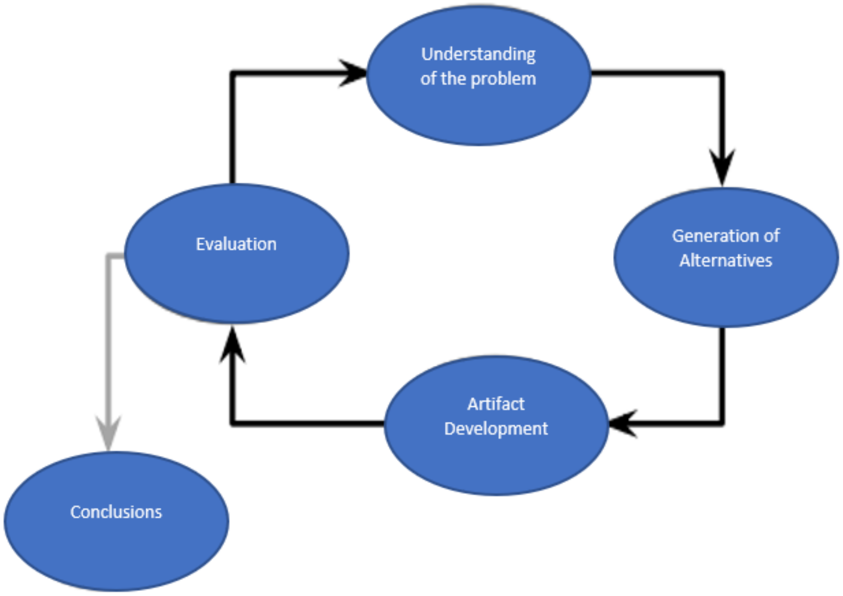


Figure 1. Stages of Design Science Research according to approach of researchers on the subject

Source: Santos (2018).

Myers and Venable (2014) explain that Design Science Research is a research method in which the efficiency and effectiveness of an artifact in solving a problem category are developed and evaluated. Its constructive and prospective characteristic seeks to establish how it should be, contrasting it with the analytical characteristic of other methods that aim to understand what the real world is like.

The term Design Science Research (DSR) is a perspective that, when properly applied, results in effective scientific rigor in the case, for example, of management technologies and, in view of that, has been considered a method for conducting of technological research (LACERDA, 2013). Van Aken (2005), Van Aken, Berends and Van Der Bij (2007) argue that Design Science (DS) can be used in studies and analyzes in companies regarding management and demonstrate prescriptive character of DS.

2.3 Engineering of Times and Methods

The Study of Times and Methods is appropriate to help the maintenance and improvement of production system, because, for Barnes (1977), it is defined by the detailed observation of each constituent part of an operation and the timing of these cycles in order to determine instabilities, frequencies, rhythm and effort in each flow operation.

Taylor had as a principle the adoption of an observation technique in which movements of operation were subdivided in such a way that unnecessary or superfluous movements could be abolished from operation and fundamental movements would be standardized, studied and improved, as a result would have economy of elements in the task and reduced ergonomic effort (CHIAVENATO, 2004)

Maynard (1970) states the application of the study of times, motions and methods are techniques of a detailed diagnosis of each operation of a given task, with objective of eliminating any unnecessary element, defining the best and most efficient method to carry out them, however, it defines the chronoanalysis must aim at systematization of the method which is adapted to the needs of the manufacturing process, standardize the method, determine the time of activity of standard operator, and qualify other operators based on the established standardization.

2.4 Time Studies

Chronoanalysis technique is the efficient way to determine as precisely as possible, using a limited amount of observations, execution time of an operation, task or activity, by means of defined performance norms. Reconciling aspects of production with human being, the agent of activity, is one of the objectives of time studies. Therefore, detailed observation is necessary, correctly dividing elements (movements), determining frequencies, rhythm, instabilities, skill and efforts employed (BARNES, 1977).

The expected result of time study is the determination of standard working time, time required for production of a product, with this, the engineer will be able to define parameters of productivity, safety and quality in the operation (ANIS, 2011).

To arrive at definition of Standard Time, a few necessary steps are usually followed. According to Barnes (1977), they are as follows:

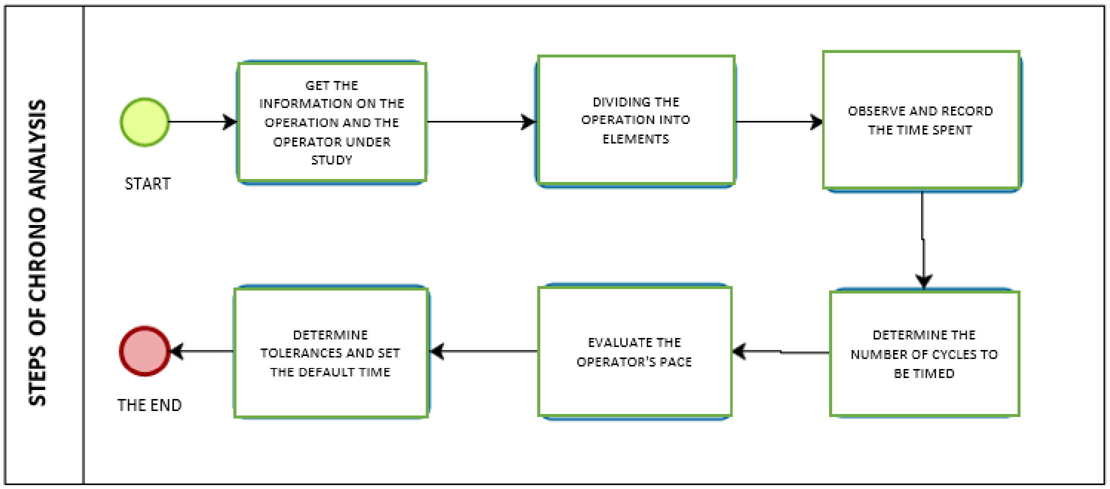


Figure 2. Chronoanalysis stages defined by Barnes

Source: Adapted from Barnes (1977).

2.5 Elements

The distinct parts which constitute an activity of a work operation are called elements. They can be movements of the operation performer or movements of machinery and equipment. It is emphasized that the element to be selected must always be subject to observation and observation timing (FULMANN, 1975).

The elements which constitute the activity must have a clear definition of beginning and end. These definitions can be determined by visual or auditory sense. Descriptions of the elements become more accurate when using some writing patterns that help in understanding the text, as explained in the table.

Table 1. Basic description of elements explained by Fullmann (1975)

Basic description of elements		
Manual elements	**Automatic elements**	**Methods**
Achieve	Mill	Right Hand (RH)
Take	Spin	Left Hand (LH)
Move	Stamp	Both Hands (BH)
Release	Roll	Right Foot (RF)
Join	Compress	Left Foot (LF)
Separate	Expand	Right Side (RS)
Operate	Move	Left Side (LS)
Etc	Etc	Etc

Discription: Table showing the description of elements from Fullmann (1975).

Source: Adapted from Fullmann (1975).

Elements are classified according to their characteristics, they can be repetitive, constant, variable, occasional and strange to the operation:

Table 2. Classification of elements in Fullmann's analysis (1975)

Elements classification	
Repetitive	Repeat for each activity cycle. Example: stamping a part.
Constant	Duration values are identical to each cycle or with low variation.
Variable	Duration values tend to vary with each cycle depending on characteristics of product or process itself.
Occasional	They are not identified at each cycle of operation, but found at regular intervals, for example, changing full parts buckets for an empty one.
Foreign to operation	These are identified elements that are not part of operation and that should be eliminated from activity.

Discription: Table showing the description of characteristics of the elements.

Source: Adapted from Fullmann, (1975).

2.6 Times Classification

Checking an operation in detail is to determine the times of each element so that they are easily found, such as, for example, supplying machines, activating commands, in order to organize time tables. Classification of times also consists of separating elements according to their nature, movement elements, manual elements and machine elements (PEINADO; GRAEML, 2007).

Manual elements are all actions carried out by operator during the task, for example, activating equipment command. Elements of movement or displacement are movements in operation in which the operator needs to move a certain distance. Automatic elements are all those carried out by equipment and machines (PEINADO; GRAEML, 2007).

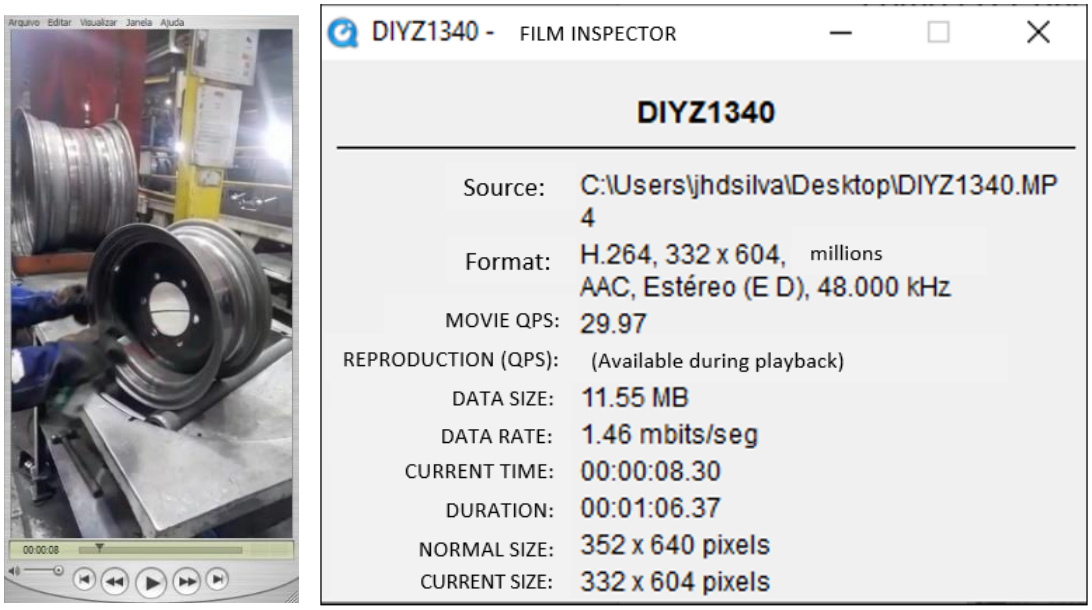
There are also acyclic elements, which are movements performed outside the part-by-part cycle, but in predetermined amounts, for example, changing a full parts container for an empty one, or performing the exchange of an equipment input. In all classifications of elements which have been described, simultaneity of elements can also occur and, in this case, they are classified as embedded elements (PEINADO; GRAEML, 2007).

2.7 Software Quick Time ®

Since 1991, a digital audio file can be played by an Apple Macintosh computer thanks to the Quick Time® software (also known as QT) which is a multimedia support structure, capable of handling digital video formats, media clips, sound, text, animation, music and several types of interactive panoramic images.

Quick Time® is a very important multimedia extension tool and includes an interactive environment which uses a software-based real-time image processing engine to navigate space in an authoring environment to create movies.

The software has the ability to change video frames by means of the keyboard's directional cursor in a very short time, depending on image quality, in up to hundredths of a second, which allows an analysis of microelements of each activity (AMOROSO, 2009).



DIYZ1340

Source: C:\Users\jhdsilva\Desktop\DIYZ1340.MP4
Format: H.264, 332 x 604, millions
AAC, Estéreo (E D), 48.000 kHz
MOVIE QPS: 29.97
REPRODUCTION (QPS): (Available during playback)
DATA SIZE: 11.55 MB
DATA RATE: 1.46 mbits/seg
CURRENT TIME: 00:00:08.30
DURATION: 00:01:06.37
NORMAL SIZE: 352 x 640 pixels
CURRENT SIZE: 332 x 604 pixels

Figure 3. Detail of human-machine interface of Quick Time® video player, using the window option, it is possible to open the Movie Inspector menu and visualize the current time associating it to the beginning and end of each element

Source: Authors, 2021.

3. Methodological Procedures

The method applied in this article has been Design Science Research, to understand the problem, solutions developed and validation of solutions with users in a productive environment (shop floor – *GEMBA*).

Based on the DSR operationalization model presented by Santos (2018), application of this model has been adapted to the study with characteristics and theories of time studies and methods, and the use of video footage, which stand out:

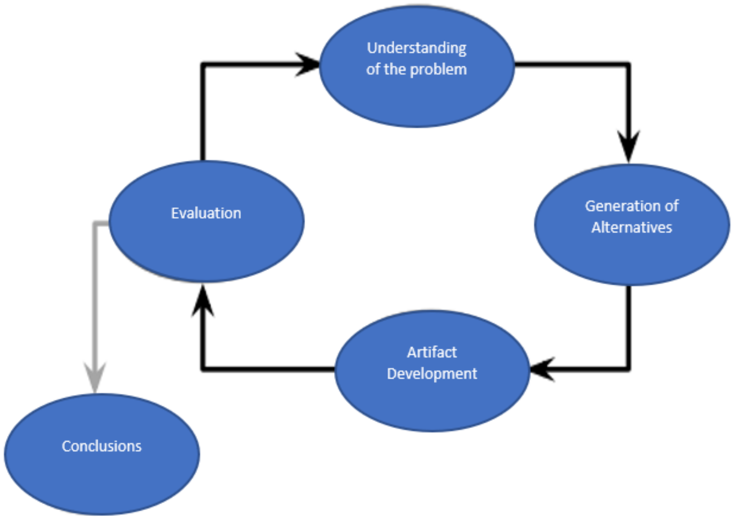


Figure 4. Operational model of research in DSR applied to productive environments of agricultural wheels in a company of the automotive sector

Source: Santos (2018).

Figure 5 demonstrates how the study was carried out based on DSR operationalization model, with adaptations for the Study of Time Measurements on factory floor – GEMBA.

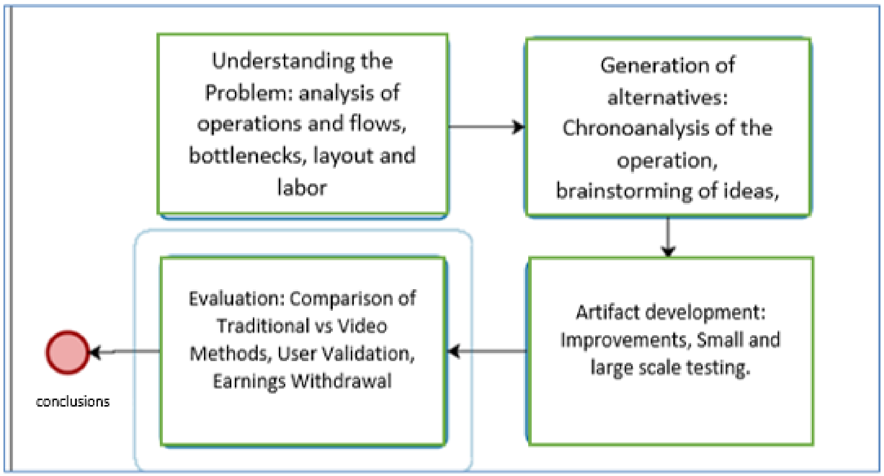


Figure 5. Flowchart of research steps adapted from Santos operationalization model (2018)

Source: Adapted from Santos (2018).

3.1 Methodology for Understanding the Problem

Company history information and developments in vehicle components industry, as well as website location and product portfolio information, are on the company's website.

In order to determine productive capacities until reaching the production bottleneck in which the study was applied, studies of previous times and methods of the organization were analyzed, with the obtaining of data in technical documentation of engineering area.

In order to understand production processes of all sectors of company, the production flowcharts and graphic presentation of operations and equipment were revised in order to make several aspects of each activity more illustrative.

3.2 Methodology for Generating Alternatives

After analyzing the productive capacities and all aspects of each operation and for a better understanding of the bottleneck operation, it was decided to observe the layout of the workstation, considering, in addition to the machinery, the work position of each employee, the flow of parts and the number of people involved.

Data and information were obtained in meetings with engineering area, in which technical profile of these is related to the study topic, time measures, people's experience was also considered, ranging from 1 to 4 years of expertise in engineering chronoanalysis, and consulting the previously prepared technical documentation.

The SIPOC tool was also applied to better understand the input and output process of parts in delimitation of the study site.

Finally, time studies were used in traditional method and with the Quick Time® software, with intention of evaluating which gains in interpretation and analysis of micro movements could be eliminated, reduced or combined to reduce operation cycle and increase production capacity.

3.3 Development Methodology and Solution Validation

Considering the concern of not causing side effects to the company's processes or damage to the equipment, even more because it is production bottleneck, changes were carried out on a small scale on a day when there was no production schedule and all movements of machine were carefully observed.

In DSR method, it is suggested solutions which require an evaluation by users, therefore, a questionnaire to validate the use of Quick Time® was applied so that the company's chronoanalysts could report their perception when using the application. The Google Forms® questionnaire platform was chosen for this purpose because it facilitates communication with users.

In order to validate changes implemented on a large scale in the machine and to verify production gains by reducing elements of operation and with the new cycle time, a new study of time measures was carried out also using Quick Time® as a tool.

4. Results and Discussion

4.1 Problem Understanding Results

The company in which the study was currently carried out is one of the largest manufacturers of wheels and structural components for commercial and light vehicles globally. According to the corporation's websites, the company's activities in Cruzeiro city, São Paulo State, began in the second half of the 1940s, first in railway sector and later adding manufacture of components for expanding road sector in Brazil in the early 1960s.

It stands out in the road sector in the 1990s, with the growing market demand, it decided to divide the business into two fronts: area of casting wheels for railway sector and the manufacture of wheels and components for road sector. The company's subdivision manufactures both tube and tubeless wheels. The current production volume is almost two million wheels per year, with the product "tubeless wheels" accounting for about 97% of the amount.

The study of times, movements and methods of this research was developed in tubeless wheel manufacturing line. For the choice of this line, production capacities were analyzed in order to work on productive bottleneck, Figure 6.

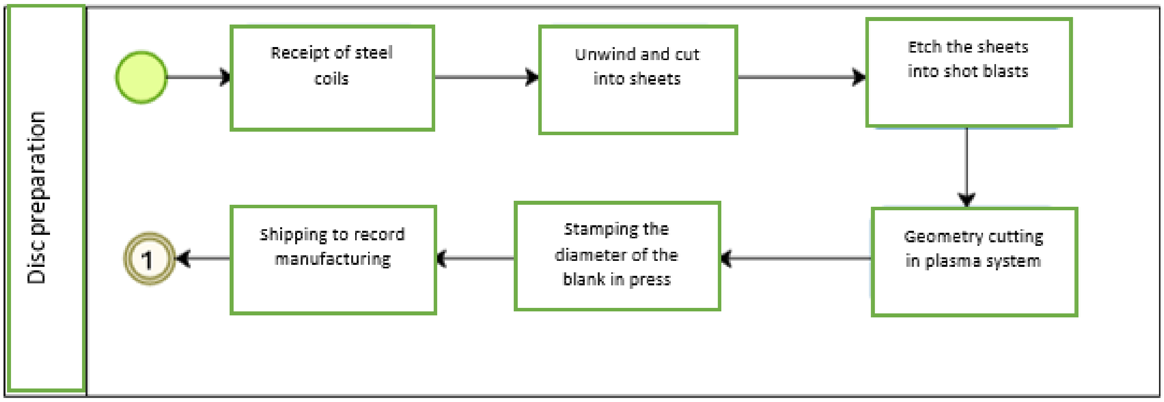


Figure 6. Flowchart explaining each step for processing raw material for manufacture of discs

Source: Authors, 2021.

Processing stages of disc manufacturing components start the entire manufacturing process, the receipt of raw material is conducted by rail to the care of supplier who makes available the steel coil wagons, which vary from 16 tons to 32 tons. Compositions are maneuvered to the company's yard by internal railway line and stored in a specific shed as an overhead crane movement, Figure 6.

The first activity of material preparation is carried out in a machine which unwinds, straightens, flattens and cuts the coils transversally to the appropriate length for process according to the disc blank dimension, which is internally called platinum.

Cut sheets are moved by roller conveyor to the next operation, where they receive surface cleaning by means of mechanical pickling. Purpose of this activity is to remove any type of dirt from the steel plant. Once pickled, plates are plasma cut into a geometry which reduces steel waste, so that, in the stamping process, burrs are as small as possible.

The last step of preparation is stamping plates in the diameter adapting to the process of manufacturing the disc.

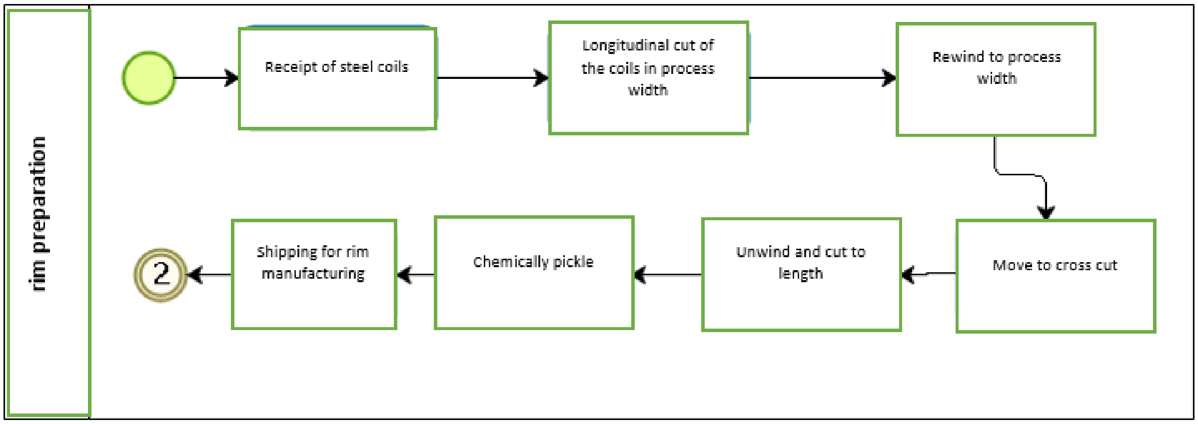


Figure 7. Flowchart of processing steps of rim manufacturing raw material

Source: Authors, 2021.

In stages of preparation of components for rims, the input of raw material for preparation of blanks of rims is similar to the preparation of discs and uses the same handling equipment. The first operation of this production line is the slitter cut, the coils arrive at the yard in widths greater than the width of the blank used for the manufacture of hoops, with this, this process consists of cutting the coil longitudinally, transforming it into smaller widths, Figure 7.

Smaller coils are transported to the blank cutting operation. In this step, the blank is cut to the ideal length and the product traceability identifications are engraved on the blank. Finally, blanks undergo a chemical pickling process to remove dirt and are sent to the rim manufacturing line.

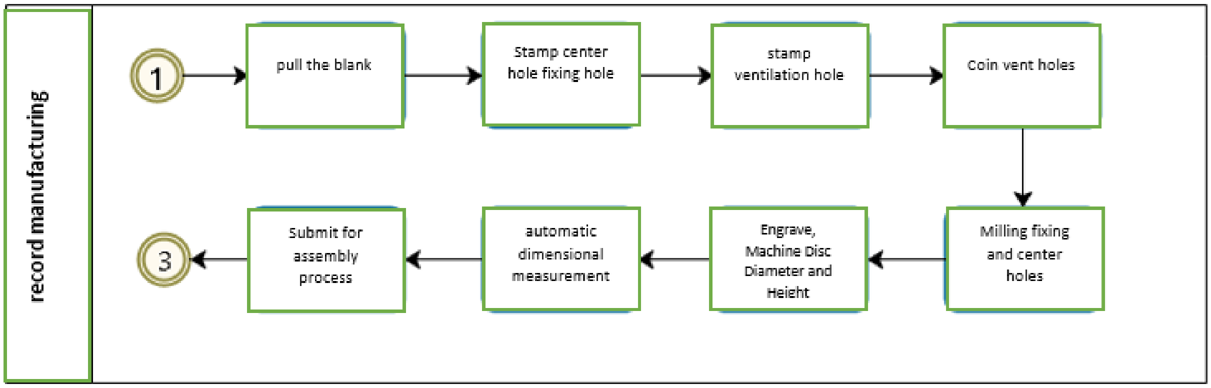


Figure 8. Flowchart explaining stages of manufacturing discs for commercial vehicle wheels

Source: Authors, 2021.

Disc manufacturing process, which is one of the most complex when it comes to the production of wheels, the plates sent by preparation area are supplied by a hoist on the inlet conveyor, from there the entire flow is automated, the drawing phase or stretching consists of transforming stage and leaving it in the geometry of disk profile. To this end, mechanical rollers push platinum material by means of computerized coordinates, so that the initial thickness becomes thinner as it advances through the disc shape, the flat face remains the same thickness as the base plate, Figure 8.

After stretching, the drilling steps in stamping presses begin, the discs have three holes and each of them has a need, the central hole corresponds to the diameter of the truck hub where the wheel is fitted for assembly, the fixing holes are where the bolts are attached to the hub and ventilation holes have two purposes: they help with wheel movement and assembly and, during the wheel turning in progress, they work as an air intake for cooling the braking system.

After performing the drilling operations, they go through milling finishing processes, and ventilation hole receives a coinage to break sharp corners, this prevents propagation of cracks during the useful life of the wheel. In addition, the disc is engraved on its flat face for manufacturing batch recording and other relevant information.

To finish manufacture, the product is turned in its diameter and end to guarantee adequate dimension for mounting on rim, and then it is sized in an automatic inspection machine, the storage and movement of disks is carried out by metallic buckets that hold 120 to 160 discs, depending on size.

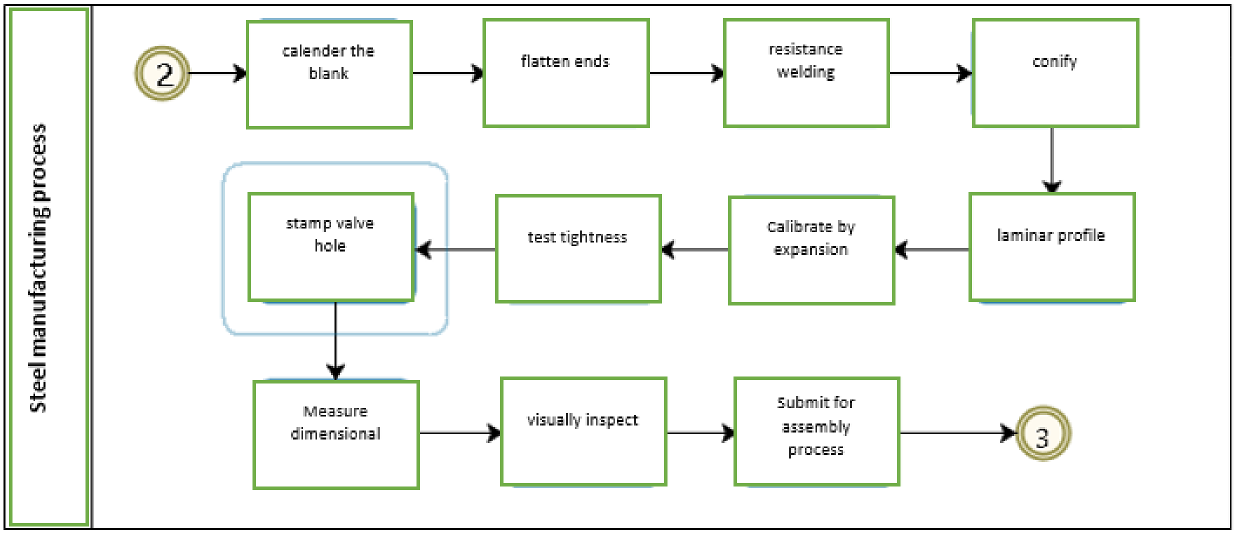


Figure 9. Flowchart of the steps to manufacture a commercial vehicle wheel rim

Source: Authors, 2021.

The rim fabrication and manufacturing flow requires blanks to have adequate length and dimensions because part of the material is consumed at the time of resistance welding, before welding the blanks are calendered and flattened at the ends so that resistance welding takes place with perfection, Figure 9.

This type of welding is performed by heating the material to the melting point, then the machine exerts force from one end to the other so that the material melts, after a time of holding the rolled and welded blank is deburred and proceeds to the next steps.

Taper aims to preform the rim for rolling process, the rim is deposited on rolling rolls that shape the profile of rim and form flap in three subsequent steps. Once rolled, rims are expanded to the correct diameter for mounting the disc.

The next steps are verification of leakage in the butt weld and valve drilling, finally, the rim is inspected in its dimension and visual aspect, being in appropriate standards, it goes to assembly line via conveyors, Figure 10.

Finally, Figure 11 shows the wheel assembly flow, among the wheel manufacturing processes, assembly tends to be the leanest process with fewer manufacturing steps, the complexity of this wheel manufacturing phase lies in welding operation, in which it is necessary to guarantee adequate quality of penetration and visual appearance so that components do not come loose in the field work and that there is also no propagation of cracks in wheels in welded region.

This critical process, however, begins in the assembly operation, in which the components, rim and disc, necessarily have to have diameters of assembly region in the correct measure so that there is the minimum interference necessary for them to fit together and not come off easily before soldering.

Assembly of disc on the rim is carried out by a hydraulic press with a minimum capacity of 80 tons. Then, wheels are manually dimensioned to certify that the assembly was carried out correctly, measuring the offset, which is the measurement from the center of the rim to the outer face of the disc and the deviation that relationship between rim fit on disc so that the wheel turns as little eccentric as possible in radial and lateral direction.

In the final stages of the line, the wheels pass through brushes which remove excess weld spatter and silica that form from the burning of wires. Afterwards, a team of inspectors checks the visual appearance of weld and, if flaws are found in the bead, they are sent for rework. After visual inspection, inspectors send the wheels to the machine, which checks all dimensions of the part, and sent to the painting area, Figure 12.

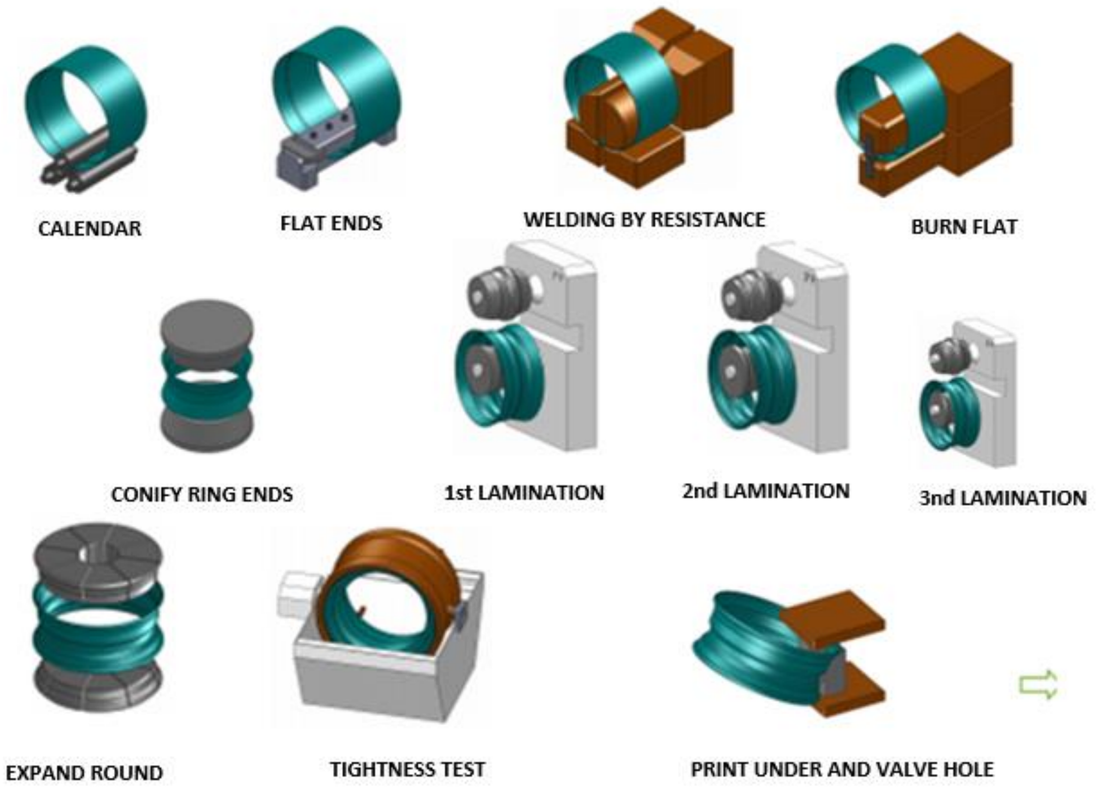


Figure 10. Schematic and step-by-step rim manufacturing operations

Source: Authors, 2021.

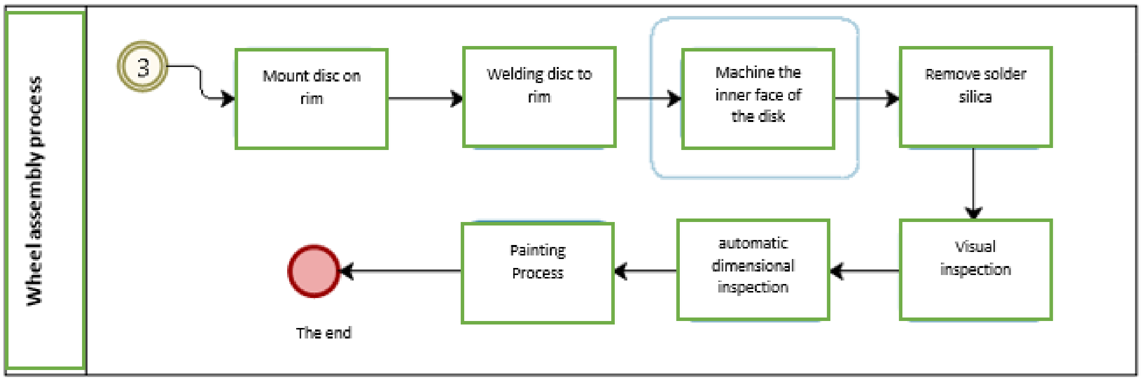


Figure 11. Flowchart of wheel assembly operations

Source: Authors, 2021.

Figure 12. Schematic and step by step of wheel assembly operations

Source: Authors, 2021.

After assembly, wheels are welded in the rim and disc fitting region. Welding process is MIG/MAG, carried out by deposition of copper wire with protection of a gas composition of 92% Argon and 8% CO2. After welding, the wheels go through machining step of the inner face of the disc to ensure proper flatness and roughness in order to avoid vibrations in wheels mounted on vehicles.

After all operations described in production flow, the wheel has the characterized geometry, Figure 13.

Figure 13. Final product – tubeless wheel for commercial vehicles, applied to trucks, trailers and buses

Source: Portal Maxion (2021).

It was used studies of times which the company already had a history, in such a way that, among all the manufacturing processes, the one that would potentially bring the greatest benefit to the business, if it were improved, was chosen, Table 3.

Table 3. Productive capacities of company's sectors with cycle time measures, identifying bottleneck in wheel assembly lines

Area	Cycle time (seconds)	Parts/hour	Parts/day
Disc preparation	6.85	525	12600
Rim preparation	6.92	520	12480
Disc manufacturing	6.92	520	12480
Rim manufacturing	6.42	560	13440
Wheel assembly	***7.11***	***506***	***12144***
Wheel paint	5.07	709	17016

Discription: The table 3 shows the production time per hour and per day separated by area.

Source: Authors, 2021.

The capacities above consider the OEE at the theoretical maximum of capacity, that is, at 100%. As previously mentioned, the company has two lines for manufacture of tubeless wheels. The Table indicates the production bottleneck is in the wheel assemblies, however, before identifying the bottleneck operation, it was necessary to analyze the two assembly lines the company has, Table 4.

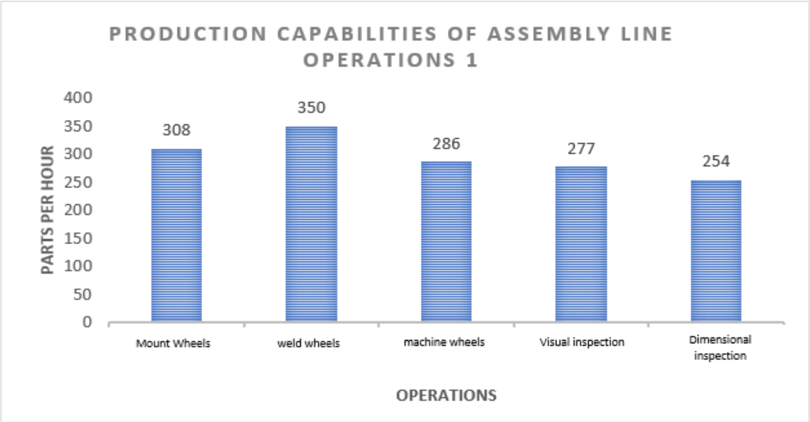
Table 4. Production capacity with cycle times of the two tubeless wheels assembly lines, demonstrating the bottleneck in assembly line 1

Line	Cycle time (seconds)	Parts/hour	Parts/day
Assembly 1	***1.,80***	***243***	***5832***
Assembly 2	13.68	263	6312
Total	7.11	506	12144

Discription: Table 4 demonstrates the production bottleneck based on two production lines.

Source: Authors, 2021.

Result of analysis shows that, of the two lines, the one with the lowest production capacity is assembly line 1. With this, further deepening in analysis and based on history of studies of times and methods of assembly sector of tubeless wheels and demonstrates in which operation the production volume restriction is, Graph 1.



Graph 1. Production capacity in parts per hour of each assembly line operation 1

Source: Authors, 2021.

In the data, it was identified the production bottleneck is in the dimensional inspection operation which is performed by a machine automatically. Study of the entire production flow of the company, with the respective production capacities, has delimited the study for this operation. Therefore, it justifies a more detailed study of time measures.

4.2 Diagnosis in Generation of Alternatives

In contextualization and problematization, the dimensional inspection operation of line 1 of tubeless wheel assembly sector is the productive bottleneck of wheel factory, so that the method analyzes are justified, Table 5.

Table 5. Previous situation with elements of bottleneck operation, average cycle time and elements combination graph

Sequence	Classification	Element description	Time (s)
1	Automatic time	Robots descend simultaneously, fix the wheels and move them to the inspection mandrel and exit conveyor	6.98
2	Automatic time	Disc measuring car approaches the outer face	2.22
3	Automatic time	Robots return to initial position (home)	1.71
4	Built-in auto time	Rim measuring car approaches it	1.01
5	Automatic time	Machine inspects the wheel	3.23
7	Automatic time	Disc measuring carriage returns to home position	2.37
8	Built-in auto time	Identify and segregate disapproved wheels or signet approved wheels	5.12
9	Time to check	Perform equipment safety checklist	300
End cycle time			14.80

Discription: Table 5 shows the operations that are carried out in production separated by elements and steps.

Source: Authors, 2021.

The time measurements of each element of operation are presented, these measurements were taken by direct observation in operation, using a digital stopwatch and noting measurements on a record sheet, characterizes tolerances applied according to the nature of the operation, Table 6.

Table 6. Application of tolerances, elements and result of cycle times and standard time

Application of Tolerances/Elements		Time Analysis	
Physical effort	0%	Manual work time	0s
Mental effort	0%	Automatic time	14.80 s
Fatigue recovery	0	Walking time	0s
Monotony	0%	Time to check	0.16s
Noises	0%	Cycle time	14.80s
Temperature	0%	Maximum parts hours - parts/h	243 part/h
Rest	5%	Standard time	15.70s
Time to check	1.06%	Standard hours parts	229 part/h
% of tolerances	5%		

Discription: Table 6 shows the application of tolerances according to the time and movement analysis methodology.

Source: Authors, 2021.

Using direct observation method, the study was divided into seven elements, with one element classified as acyclic, which are those activities carried out with equipment stopped at certain frequencies. The total cycle time of operation is 14.80 seconds and, applying the tolerances to operators, it adds a 5% increase in the cycle time due to fatigue recovery time, in addition, there is an acyclic element to carrying out a checklist of equipment safety points at the beginning of each shift, resulting in another 1.06% increase in cycle time. With these additions mentioned, the standard operating time is 15.70 seconds, corresponding to a capacity of 229 pieces per hour. Every element must be subject to observation and timing, thus, the ability to observe and time record the movements of operation, on site, allowed the chronoanalyst to divide elements with a minimum time of 1.01 seconds recorded in element number 4, Table 7, so that variation of person performing chronoanalysis does not exaggeratedly influence the cycle time.

Table 7. Division of elements of dimensional inspection operation using the Quick Time® video player

Sequence	Classification	Element description	Time (s)
1	Automatic time	Robots descend simultaneously	1.36
2	Automatic time	Close robot 1 jaws until it touches the wheel	0.95
3	Built-in automatic time	Close robot 1 jaws until it touches the wheel	0.95
4	Automatic time	Raise, advance and deposit wheel on chuck and conveyor	2.86
5	Automatic time	Open robot claw 1	0.51
6	Built-in automatic time	Open robot claw 2	0.51
7	Automatic time	Raise robots 1 and 2	1.20
8	Built-in automatic time	Lock the chuck	0.26
9	Automatic time	Approach measuring carriage to disk face	2.57
10	Built-in automatic time	Bring the measuring car closer to the rim	0.49
11	Automatic time	Rotate chuck and measure wheel	2.57
12	Automatic time	Retreat disc meter car	2.78
13	Built-in automatic time	Retreat rim meter car	0.8
14	Built-in automatic time	Rotate the wheel to position at the least mass point	0.96
15	Built-in automatic time	Unlock the chuck	0.49
16	Built-in automatic time	Identify and segregate disapproved wheels or signet approved ones	5.12
17	Time to check	To do equipment safety checklist	300
End cycle time			14.80

Discription: Table 7 demonstrates the timing of each operation using the Quick Time® video player.

Source: Authors, 2021.

It was noted the element with the longest time is number 1, which table describes as the robot movement time to supply the machine in which they perform cyclical operations. It is verified there are opportunities for gain in this element, however, by method of timer and observation on site, identification of micro elements was not identified. To this end, solution analysis has used time engineering techniques and methods by means of video, using the Quick Time® software, so that micro movements could be obtained by functionality of changing the frames, during filming, Table 7.

On the other hand, applying the chronoanalysis method with the Quick Time® application, where the chronoanalyst went to the operation and filmed it and, on the computer, evaluated the elements, using advance of frames with in-depth details, Table 7. By application of Quick Time®, divisions of the elements were created which could be expanded from 7 (seven) to 17 (seventeen) movements, with ability to observe and clock times of up to 0.26 seconds, according to element number 8, above all, the elements that lasted longer were divided into smaller fractions, allowing observation of possible points of improvement in the operation.

Figures 14 to 27 were captured from application screens to indicate each considering only elements that add up to the cycle time.

Figure 14. Element 1, descent of robots close to wheels on the inlet conveyor and the chuck, average movement time of 1.36 seconds

Source: Authors, 2021.

Figure 15. Element 2, closing the robot grips on wheel flaps, fixing them, average time of 0.95 seconds

Source: Authors, 2021.

Figure 16. Element 4, wheel deposit on chuck and on machine's output conveyor, average time of 2.86 seconds. Source: Authors, 2021.

Figure 17. Element 5, opening of robot claws, average time of 0.51 seconds
Source: Authors, 2021.

Figure 18. Element 7, retreat of supply robots, average time of 1.2 seconds

Source: Authors, 2021.

Figure 19. Element 9, approach of rim and disc measuring cars, average time 2.57 seconds

Source: Authors, 2021.

Figure 20. Element 11, chuck turning, in study recorded with a duration time of 2.57 seconds

Source: Authors, 2021.

Figure 21. Element 12, measuring cars recoil of disc and rim, included in the chronoanalysis with 2.78 seconds of duration

Source: Authors, 2021.

After taking time measurements of current situation and analyzing each element, it was identified by the chronoanalysts some opportunities for changes which could result in capacity improvements. We highlight below those which were considered most relevant and were considered viable according to the experience of the company chronoanalysts:

- Reduce the forward and backward time of moving robots;
- Reduce the advance time of disc measuring carriages.

4.3 Implementation of Improvements in Operations in the Production Environment

Results of improvements implemented in dimensional inspection operation, identified as a productive bottleneck in manufacture of tubeless tire wheels for commercial vehicles, based on suggestions of people involved in the operations (operators, chronoanalysts, maintenance and engineering staff), tests were carried out small-scale changes in the dimensional inspection machine.

It started with test to reduce elements of handling robots that, when checking the electronic program of the machine, it was noticed there was a single parameterization for all models of wheels regarding the transport height of wheels, that is, the minimum height the robot must raise after fixing the wheel on the input conveyor and moving to the chuck.

One started from the premise of using the widest wheel and doing the movement manually, identifying what would be the minimum height at which the equipment could be parameterized. The parameter previously recorded was 900 millimeters, as shown on the interface screen, in the manual test with the widest wheel, a height of 700 millimeters was reached. The specification was changed to 700 millimeters and saved in the electronic program, Figure 22.

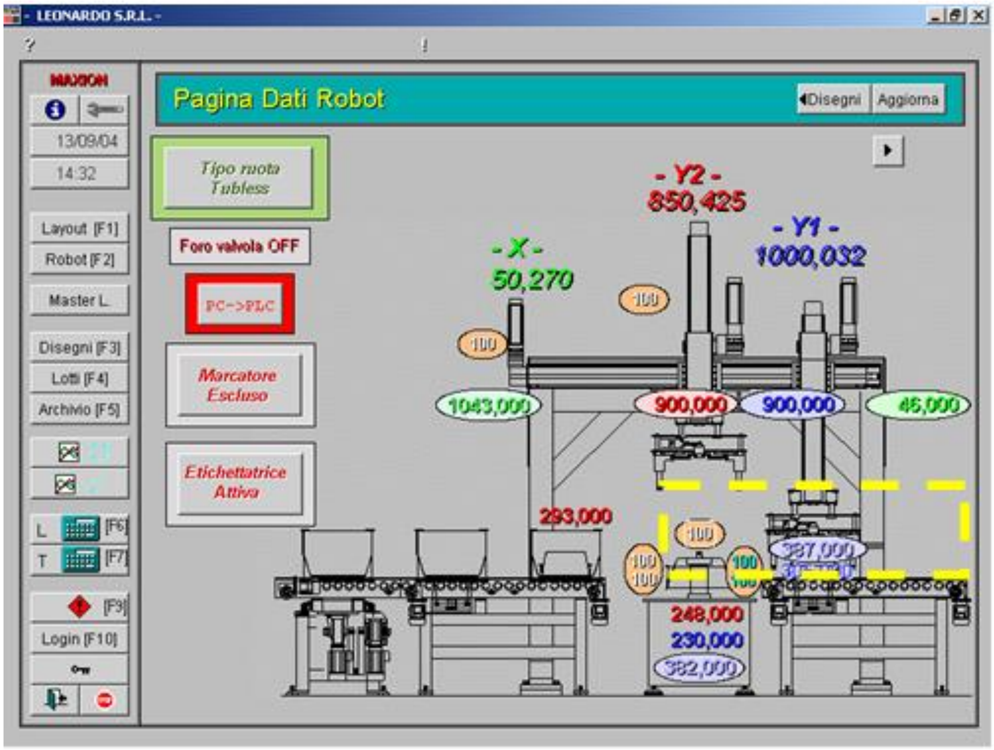


Figure 22. Interface screen for changing robot movement, with indication of robot movement height axis parameters

Source: Authors, 2021.

After the change, machine was put into automatic mode, but with reduced speed for safety reasons, there were no significant complications during this test, so the speed was put at 100% of capacity and production was observed for a period of one hour. With appropriate result, without any complications that affect the safety of operation, effectiveness of the idea was considered and the change was definitively made and technically documented with equipment specifications for this condition.

Result for this change was a reduction from 2.56 seconds to 2.27 seconds in the two elements that were impacted by the improvement and a reduction of 0.29 seconds in the total cycle (Table 8).

The second suggestion, mentioned by the cross-functional team, was to reduce the disc measurement car approach cycle time. Observation made by video and later on the machine itself was that this movement could be reduced, so the fixing structure of this car was investigated to define what change could be made.

From the experience of collaborators, it was suggested that distance between the measuring car and the face of the disk was quite far, Figure 23.

Figure 23. Detail of the disc measuring carriage, there is an opportunity to change its fixation in the holes in machine structure, as indicated by the arrow

Source: Authors, 2021.

When observing the equipment structure, it was possible to notice there was a mirrored hole in the structure that would allow the descent of entire carriage, so that the movements to approach the measuring rollers on the disk would be reduced.

However, before making any changes, question arose among the participants as to why the equipment supplier had not considered this distance in the equipment design. To obtain the answer, the technicians of supplier company were consulted by e-mail. In response, it was discovered there were some models of wheels that were manufactured on this production line and required that measurement carriage positioning.

With this statement, one more consultation was necessary, this time with the planning department, considering whether there would be future demands for this model on production line, the answer to this question was negative. In view of the described picture, it was possible to carry out a small-scale test, modifying the position of carriage and changing the parameterization of equipment. Thus, as done in the improvement of robot movements, the first test was in manual mode and the second one with the machine at reduced speed, Figure 24.

However, after measuring some parts, the machine was brought to 100% of its capacity, thus validating the improvement. After a few hours and, measuring other wheels of other dimensions, the machine remained with the carriage position changed for a large-scale test of two weeks with the two changes carried out.

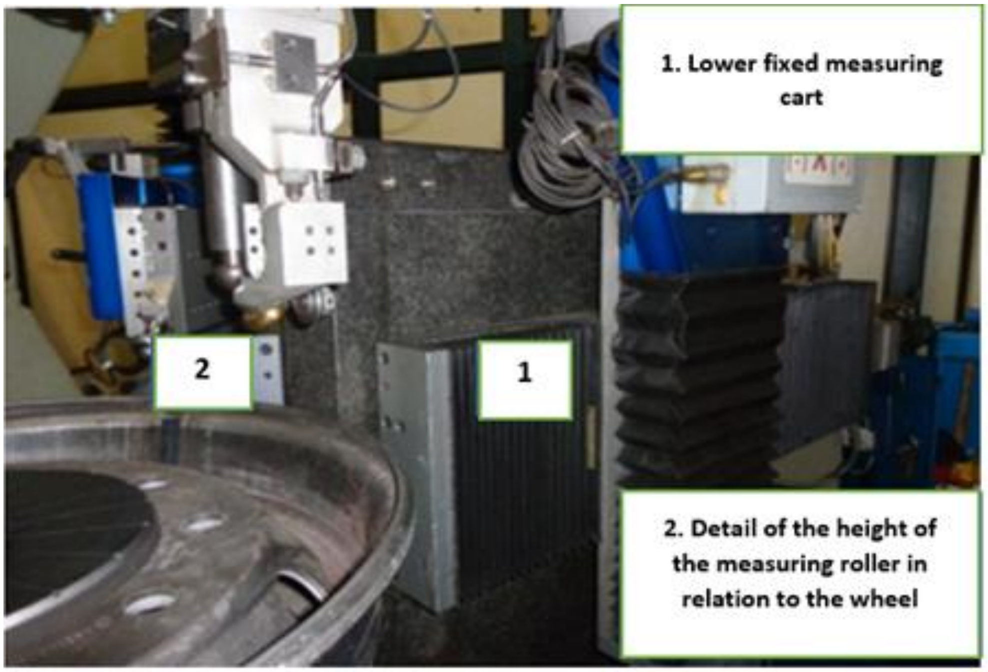


Figure 24. Changing the disc measuring carriage, the entire measuring carriage has been positioned about 200 millimeters lower than the previous position

Source: Authors, 2021.

For this second improvement the gains were as follows: Element times before change 5.15 seconds. Times of elements impacted by the change 4.85 seconds, representing a reduction of 0.3 seconds.

4.4 Study Validations

After implementing changes in the equipment, to validate the time gains, the chronoanalysis was carried out once again using the Quick Time® application. Table 8 presents values of reduction in element times and the new cycle time and Table 9, the applied tolerances.

Impacts on cycle time were significant, the cycle time of operation was reduced from 14.80 seconds to 13.83 seconds, in terms of wheels, the maximum capacity of the equipment jumped from 243 wheels per hour to 260 wheels per hour, a 7% increase in production per hour, validating the improvements proposed by the cross-functional team. Considering 23 hours of production per day and 23 working days in the month, the monthly production capacity was increased from 128,547 wheels/month to 137,540 wheels/month, 8,993 more wheels, which corresponds to almost a day and a half of production capacity previous.

To validate the functionality of the Quick Time® application as a tool for chronoanalysis, the questionnaire on Google Forms® platform was answered by eight professionals from the company, and experience of these people with time studies ranged from one to five years, the answers collected results.

As for validation of application by users in relation the micro movements and data scaling, application's effectiveness in measuring micro movements times, 75% of people completely agree, confirming the application's ability regarding its functionality to change frames in hundredths seconds, increasing observation and timing of elements. Regarding the fact the software is a strong ally in division of elements of operations, 87% agree with the benefits of Quick Time®, there are opportunities to be explored regarding this process of chronoanalysis and the use in relation to chronometer seeks accuracy and details in movements with significant reduction of time/productivity.

Table 8. Detailing elements of dimensional inspection operation after large-scale implementation of machine improvements

Sequence	Classification	Element description	Time (s)
1	Automatic time	Robôs descem simultaneamente	1.07
2	Automatic time	Fechar as garras do robô 1 até encostar na roda	0.95
3	Built-in auto time	Fechar as garras do robô 1 até encostar na roda	0.95
4	Automatic time	Raise, advance and deposit wheel on chuck and conveyor	2.86
5	Automatic time	Open robot claw 1	0.51
6	Built-in auto time	Open robot claw 2	0.51
7	Automatic time	Raise robots 1 and 2	1.02
8	Built-in auto time	Lock the chuck	0.26
9	Automatic time	Approach the measuring carriage to the face of the disk	2.07
10	Built-in auto time	Approach the measuring carriage closer to the rim	0.49
11	Automatic time	Rotate chuck and measure wheel	2.57
12	Automatic time	Retreat disc meter carriage	2.78
13	Built-in auto time	Retreat rim gauge carriage	0.80
14	Built-in auto time	Rotate wheel to position at the point of least mass	0.96
15	Built-in auto time	Unlock the chuck	0.49
16	Built-in auto time	Identify and segregate disapproved wheels or signet approved wheels	5.12
17	Time to check	To do equipment safety checklist	300
		End cycle time	**13.83**

Discription: Table 8 demonstrates the required operation times for the dimensional inspection.
Source: Authors, 2021.

Table 9. Detailing of times of automatic dimensional inspection operation with improvements presented by collaborators after the study of times and methods

APPLICATION OF TOLERANCES		TIME ANALYSIS	
Physical effort	0%	Manual work time	0s
Mental effort	0%	Automatic time	13.83s
Fatigue recovery	0	Walking time	0s
Monotony	0%	Time to check	0.15s
Noises	0%	Cycle time	13.83s
Temperature	0%	Maximum hours parts	260 part/h
Rest	5%	Standard time	14.68s
Time to check	1.06%	Standard hours parts	245 part/h
% of tolerances	5%		

Discription: Table 9 demonstrates the application of time and motion methodology tolerances in the operations necessary for the dimensional inspection.
Source: Authors, 2021.

5. Conclusion

In view of the proposal of this research to innovate in studies of time measurements in industry and to analyze the use of footage and analysis and division of elements with the Quick Time® software, results were satisfactory, from both the point of view of improvements for the sector where studies were applied and users who validated the software responding to the survey with high percentages of satisfaction.

The Application demonstrated by means of results achieved that Quick Time® video reading is an excellent tool for chronoanalysis due to its functionality of changing video frames in fractions of hundredths of a second, which significantly increases the observation capacity and timing of elements, reducing them to micro movement.

The DSR method has guided the researcher to analyze all the complexity of company's production flow and to delimit the study in operation which restricts this flow, applying measures of time in activity that brought the greatest impact to wheel factory, and improvements applied in operation were all suggested and validated by the users, in addition, satisfaction of chronoanalysts with the use of the software was also a differential in research.

Finally, compared to the chronoanalysis method with a stopwatch, this research demonstrated the video software is superior for chronoanalysis activity and, digitizing the operation to measure the times, provides benefits for both the users and the company.

As a future work, it is interesting to redo the chrono analysis from time to time in order to identify new adjustment points, using the same tool, making it possible to introduce the thought of continuous improvement of the processes.

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