PROPOSAL FOR THE DEVELOPMENT OF BURN-IN INLINE

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Abstract

Advanced manufacturing promises to significantly impact the economy in various branches and industrial segments, such as metallurgy and agribusiness. Therefore, the aim is to develop a new product implemented at the company Transire, an automated system for storage in a controlled temperature environment, testing and test monitoring in real-time of its final products. Thus, this article can be considered exploratory, applied, and qualitative under the aspects of bibliographical research and case studies. Data collection was through meetings with company professionals, technical visits, and research on the importance of the topic. The results showed that the main stages of development of the Burn-In Inline were validated and that studies of production capacity associated with these developments can generate factory modernization and greater competitiveness among companies in the field.

Keywords: Burn-In Inline, Modernization, Advanced Manufacturing.

1. Introduction

Industry 4.0 encompasses all aspects of the value chain and depends on Information Communication Technology to integrate manufacturing and business activities efficiently and seamlessly. At the current moment in the national industry, advanced manufacturing, also known as Industry 4.0, has played an essential role with the emerging need for new technology to optimize production processes [1][2][3]. It can accommodate the different mass production and customization requirements commonly encountered in the industry without excessive capital investment. Advanced manufacturing promises to significantly impact the economy in several areas and industrial segments, such as metallurgy and agribusiness [4][5].

The purpose of this article was to develop a new product implemented at the company Transire, being an automated system for storage in a controlled temperature environment, testing and test monitoring in real-time of its final products. IoT communication protocols, concepts, and tools emerging from Industry 4.0 will be used in this project. It was necessary to develop software that helped the functioning of the new equipment to implement the robotic system. [6][7]. A Burn-In test is a simulation subjecting an industrial product to the conditions it will face in the reality of its function forcing components affecting its reliability to fail to have them replaced or repaired by the manufacturer. It is common for companies to perform this test in an environment external to the production line employing several human operators to perform the function. [8][9][10].

From an institutional and scientific point of view, this project is justified by the interest in the innovation of implementing equipment capable of performing the Burn-In Inline, that is, in the same production space, with the application of Industry 4.0 characteristics, such as Internet of Things. The research was carried out through literature review and collecting data from the company whose activities support academic, scientific, and technological development projects, which can be introduced in any organization that identifies a need for this type of automation [11][12].

2. Literature Revision

2.1 General Aspects of Tests

The first plan for an accelerated life test emerged in the 1960s with Chernoff. This plan consisted of using exponential distribution, two accelerated variables, and censored data. In the 1970s, Wayne B. Nelson and his collaborators developed aging plans for lognormal Weibull distributions. Since then, several authors have studied new models and their applicability to different scenarios [13].

Stress testing basically follows the same principle of exposing a group of products to environmental stresses above normal operating conditions, causing latent reliability defects to accelerate into apparent failures in a much shorter period than would happen at normal stress levels [14].

In general, the tests are intended to promote reliability improvement, ensure designed reliability, and identify the reliability characteristics of the product. The first is concerned with increasing the product's safety margin by eliminating design deficiencies and thus acting on the product's maturity period. The second is related to eliminating defective components and process weaknesses before delivering the final product to the customer [15][16]. Such deficiencies cause the field reliability of the product to differ from reliability prediction. Eliminating these deficiencies minimizes the infant mortality period of the product. The third is the quantitative assessment of product life data [17].

Over time, the proposed use of Burn-in tests has attracted the attention of researchers such as [18], who, in order to perform more flexible tests with a variety of equipment validating alternating current (AC) power supplies including uninterruptible power supply, and the Burn-In test of an AC motor unit, has developed a method to improve the test flows included in the process. The result observed was that 80% of the energy needed for the tests was fed back, thus reducing the cost of electricity.

To perform Burn-In tests, one or more acceleration variables such as temperature, humidity, electrical tension, pressure, vibration, electromagnetic radiation, or the rate of use are altered. The data resulting from these tests are then extrapolated to normal conditions of use, using the most appropriate model [19][20].

2.2 Burn-In

Burn-in is a common term in the electronics industry. Burn-In Tests involve using a slightly elevated and constant temperature, applying an external DC (Direct Current) voltage, or both, on a device to establish its upper and lower operating limits. In other words, it is an operational test that takes the product to the limits of its specifications [21][22]. An electrical charge can be applied to accelerate the aging process. The test is usually designed to represent the first 90 days of operation of the product [23].

Accelerated Stress Testing can be defined simply as applying high-stress levels for a short period in an endurance test of the device, assuming it will exhibit the same failure mechanisms over a longer period at lower stress levels [24][25]. Burn-In tests generate significant production costs and should therefore be carefully designed, following norms and choosing non-destructive tests (END) whenever possible, which will have to be carried out – ideally taking advantage of the circumstances to identify and eliminate each new emerging root cause [26].

Testing on electronic products is usually carried out in chambers, ovens, or simply in a heating room when very high temperatures are not the case [27]. Importantly, regardless of the manner, structures must maintain products at a specified test temperature and provide access to electrical connections.

3. Materials and Methods

3.1 Experimental Methodology

Aiming to optimize the Burn-In process and modernize factories, there was a need to present a proposal for the development of Burn-In Inline in a factory in the Industrial Pole of Manaus, ensuring that the company's interests were met with regard to productive issues, maintenance, and modernization.

The present study can be considered exploratory as it provides greater knowledge on the subject, in an applied nature, establishing the practice of specific problems in the organization intending to solve them, and qualitatively seeking to understand its concepts under the aspect of bibliographical research to identify the authors' approaches through books, theses, articles, electronic sites, company documents and the aspect of case study to analyze the implementation of a pilot line applying Burn-In Inline in the company Transire being evaluated by professionals in the field.

For the prototype development, data collection was carried out through meetings, technical visits in a factory environment, analysis of process flowcharts, line layout, and researched bibliographical references to establish the theoretical foundation of new applications in industrial processes aimed at Industry 4.0.

Heating systems for electronic products are most often carried out off the production line. Therefore, a prepared and air-conditioned area is needed to receive these products, often far from the production line. Human resources are allocated to transport, monitor, and return products to lines making the process costly for the company. This project aims to develop a heating system on the production line itself, reducing transport time, the use of human resources, and possible transport damage. In addition to adapting the prototype to other automation projects under development at Transire, this project will eliminate the exposure of employees to a high-temperature environment.

3.2 Characterization of the Organization

Transire, a company located in the Industrial Pole of Manaus, since 2015, is a pioneer in the manufacture of highly secure POS terminals and PIN Pads, as well as contactless card readers (Contactless) and electronic products for financial transactions via card.

In Brazil's current industrial context, advanced manufacturing, also known as Industry 4.0, has significantly grown with an emerging need for new technologies that optimize production processes in electronics factories. Industry 4.0 can aggregate different mass production and customization requirements commonly encountered by the industry without excessive capital investments.

Several proposals for improvement in processes use Burn-In, to identify potential failures in products. However, the steps typically involve dedicated operators for this activity and a physical area within the factory outside the production environment. At Transire, the Burn-In process is performed on 100% of its products and occurs between the Pre and Post Burn-In, as shown in the flow chart below.

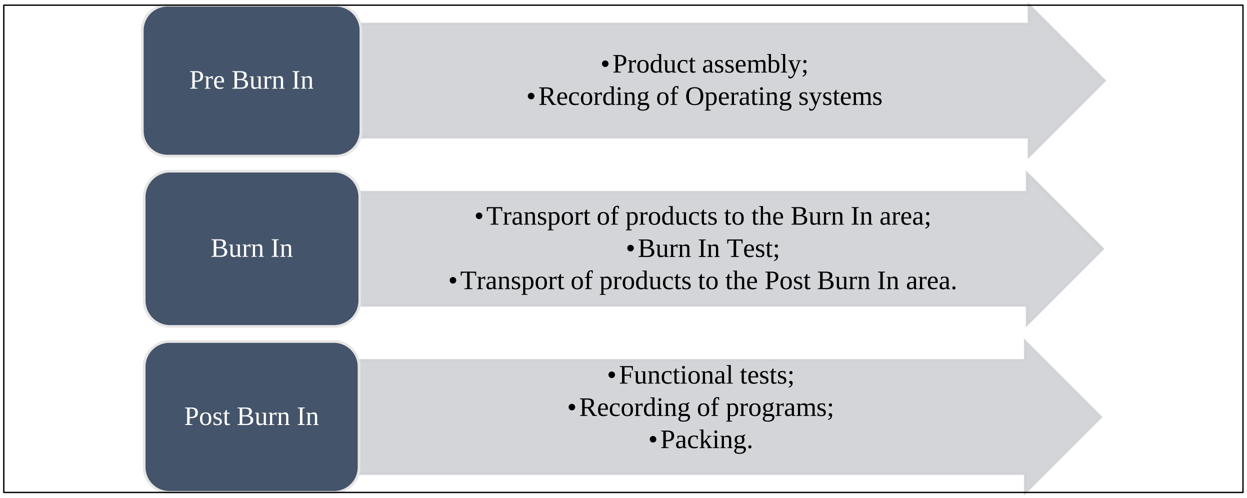


Figure 1. Process Flow.
Source: Authors, (2021).

Given the process flow in Figure 1, for the execution of the Burn-In, the procedure is shown below in figure 2.

Figure 2. Burn-In Process.
Source: Transire, (2021).

Figure 2a shows the operator taking the transport cart with the products to the Burn-In area. In the Burn room, the operator removes the marfinite products, puts them in the cart, and connects the power cables on all the products (Figure 2b. With the carts filled with approximately 160 products, as shown in Figure 2c, the operator takes them to the heated room to start the Burn-In test. Finally, in Figure 2d, the operator returns to the production line with the tested products.

The layout of the line was prepared according to the current arrangement of conveyor belts for a better understanding of the scenario and study. The current layout of the factory does not favor the optimization of this process, creating an opportunity to improve transport time, which in the current process was identified as a loss of 30 minutes every 3 hours of production.

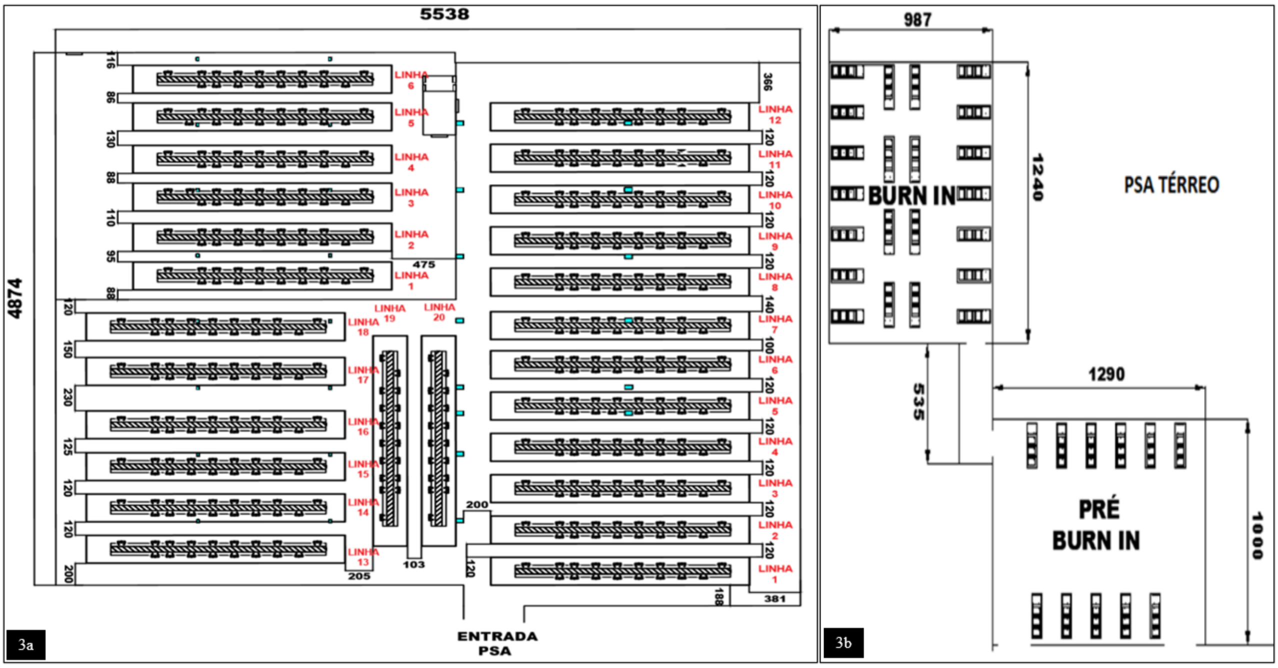


Figure 3. 3a - Layout of production lines and 3b Layout of the Burn-In area.
Source: Transire, (2021).

On the ground floor, Figure 3a, the company has 13 production lines. It is worth noting that to assemble a production line, two conveyor belts are used, they are arranged in approximately 270m², and 4 lines are arranged in a mezzanine. The mezzanine layout is arranged in 152m² and has 4 production lines, as in the lines on the ground floor, and eight conveyor belts are used.

Besides the 422m² of area for production, the plant needs to consider 251m² to implement the Burn-In test. Figure 3b shows the pre-Burn-In area, a space for the accommodation of products in carts and the connection of supplies, and the Burn-In space, which has a heated environment.

The physical space occupied by the Burn-In process has added value to Transire, as this area could be used to expand factory space. The area occupied by Burn-In is 59% of all production space.

It is possible to observe that, in addition to the cost of personnel employed for transport, there is still the time that the equipment is unavailable for the market. Thus, this paper proposes an integrated solution for stress testing, eliminating the need for an employee to transport the products to run the tests. It is estimated that, with the implementation of the proposed solution, the company will have a reduction of approximately

17% in product transportation time when compared to the current time. The following section presents the Burn-In proposal integrated into the production line, eliminating the need to transport the equipment for testing.

3.3 Proposed Model

For the proposed model, this article aims to present a proposal for a Burn-In Inline system design, i.e., a burn-in integrated into the production line, with temperature control, speed control belts, and product testing in the warm-up cycles, as illustrated in Figure 5 and described throughout this section.

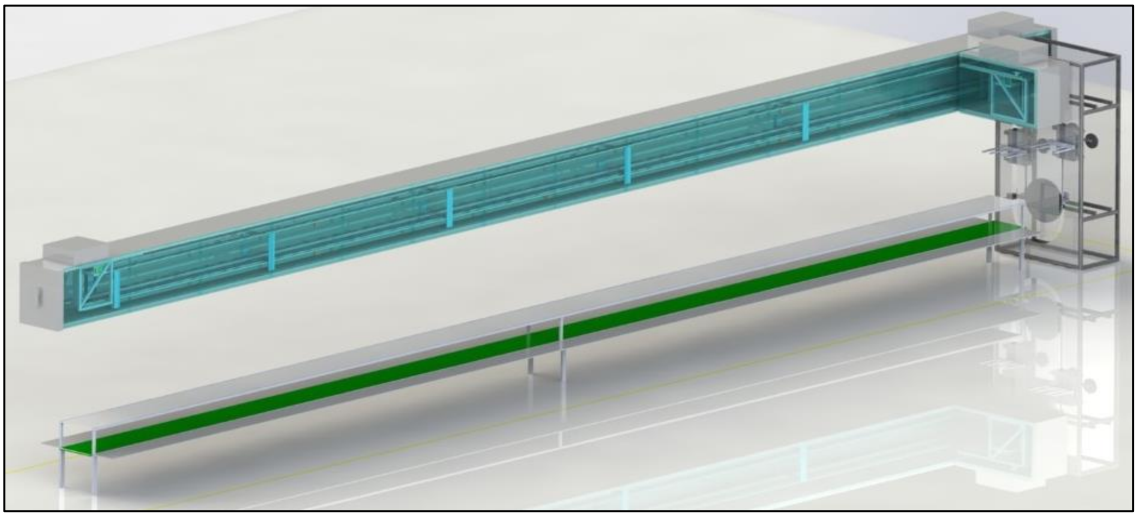


Figure 4. Burn-In Inline Proposal.
Source: Authors, (2021).

SolidWorks software was used for 3D modeling of the proposal, considering the characteristics of the process such as the available area for installation, length of the input conveyor belt, and process flow.

To install the equipment inline, it will be necessary to consider the assembly of a steel structure fixed to the columns existing in the production line. Burn-In will be positioned above the Pre Burn-In line, as shown in Figure 5.

The project has six main development subsets, namely:

1. Bottom and top conveyor belts;
2. Thermal insulation;
3. Cradles;
4. Elevators;
5. Software;
6. Productive Capacity.

4. Results and Discussions

4.1 Applying the Results

The study sought to propose a project for the Burn-In process to develop a new product implemented at the company Transire. After the presentation of the data, the project proved to be suitable for the company, as it ensured that the tests were carried out, eliminating the transport of products to another area, optimizing time, ergonomic aspects, and modernization of the factory.

For the analysis of the model of the entire project solution, several developments were carried out to provide the maximum vision of its financing.

The prototype has not yet been installed in the factory environment; tests were carried out in the development laboratory, proving it compatible with what was planned. Some records of the execution of the solution in the laboratory and partial tests are presented in this section.

4.1.1 Applying the Results

In the assembly of the conveyor belts for the Burn-In, the 30x50mm carbon steel tube was used, being approximately 2.65m long and 0.40m wide, 4 spur gears and a chain with flap were installed. To support the cradles, an aluminum angle with a spacing of 300mm was used. There is an overall view of the conveyor belt in the Figure below.

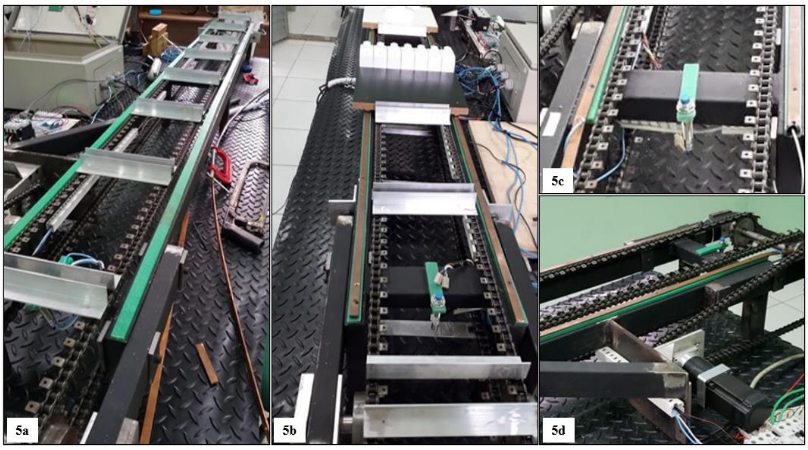


Figure 5. Conveyor belts.
Source: Authors, (2021).

Figure 5a shows an overview of the conveyor belt; the model was manufactured to store up to 10 cradles; note that only in 5b the copper bar is installed, responsible for energizing the products under test. In order to monitor the test time for each cradle, an inductive sensor was installed, Figure 5c; through software, the sensor informs the program of the passage time and starts timing up to the test time. Figure 5d shows a detail of the motor with a gear and chain system.

With Burn-In, the program for the motor has to accelerate smoothly until it reaches a certain speed, and then come to a complete stop immediately, so that the cradle stays idle momentarily while the operator puts the payment terminals on, then accelerates smoothly so that it doesn't drop or injure them, and finally stop when the next cradle is in front of the operator, so there are three main functions:

- Accelerate through the S-Curve;
- Maintain constant speed;
- Stop accurately.

A sketch of this isolated system was made by changing the frequency of a microcontroller Timer, in this way, at each period the Timer interrupts the process and calls the function responsible for sending a pulse to the motor, thus changing its speed. Therefore, decreasing this interval slowly through a specific calculation for the application of the S - Curve, an experimental acceleration curve was obtained, which was represented by MATLAB.

MATLAB is software that aims to perform matrix calculations; it can integrate numerical analysis, matrix calculation, signal processing, and the construction of graphics. In this project, MATLAB was used to optimize the time to analyze conveyor belt movement behavior, applying acceleration concepts through the S curve. A motor acceleration code was written, its performance simulated, and the graph of its course obtained, as shown in Figure 6.

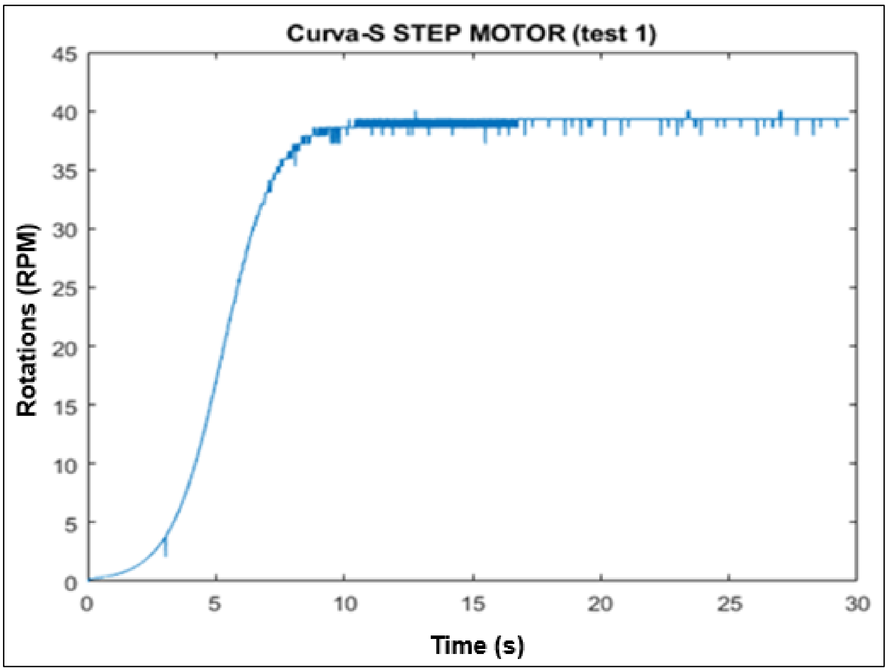


Figure 6. S-Curve Graph.
Source: Authors, (2021).

When starting the motor drive, the programming controls this action by gradually accelerating to the specified speed.

To validate the energization through the copper bar, a cradle was assembled with the installation of a lamp; this cradle covered the entire conveyor belt. The Figures below show this validation.

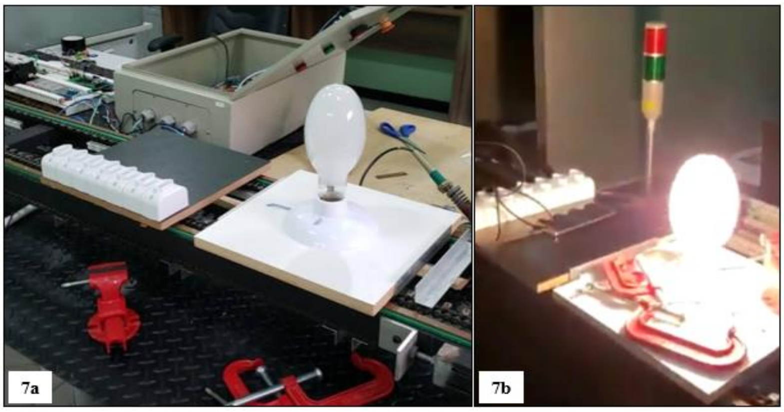


Figure 7. Validation of cradle energization.
Source: Authors, (2021).

To supply energy to the bar, a hole was made in each bar, and two 6mm cables were welded on, the end of the cables was connected to a plug and connected to a 220V electrical network. Figure 7A shows a white MDF base and the lamp installed with the cables connected to the copper bar of the cradle. When activating the motor, the conveyor belt rotates and makes the cradle move along the path with the lamp turned on, Figure 7b, validating the proposal to keep the products turned on during the Burn-In test.

4.1.2 Development of Thermal Insulation

The main purpose of thermal insulation was to keep the temperature controlled within specified standards and not change the climatic condition of the external environment. To validate the functionality of this set, it was manufactured in galvanized sheet 0.90mm thick; between this sheet, the insulating material, type PUR-D42, 50mm thick was pressed. The structure was manufactured in a type C format, closed by self-tapping screws, and front and rear doors were inserted (Figure 8a).

Figure 8. 8a - Thermal insulation module and 8b - Installation of thermal insulation elements.
Source: Authors, (2021).

According to Figure 8a, there is a thermal insulation module with a length of 1.22m, a width of 0.6m, and a height of 0.80m; following manufacturing requirements, the solution, in addition to ensuring thermal heating, also has inflammable characteristics.

After the manufacture of this module, 6 temperature sensors were installed (Located on the white MDF part on the left side), a 2,000W power resistor (Centralized), and a cooler (Black part located on the right side) for air circulation inside the duct, Figure 8b. With the fixation of these items, electrical connections were possible.

With the control of the conveyor belt's power supply by activating contactors suitable for the passage of high current, the electrical command module was developed, comprising heating resistance control and cooler control.

Finally, temperature sensors were added. For this, an isolated circuit was needed, which, for testing purposes, was mounted on a breadboard.

4.1.3 Cradle Development

To manufacture the cradle, 15mm thick MDF was used, machined on a CNC machine with measurements of 300mm x 300mm. To validate the energization stage, a lamp was installed in the cradles and sockets were installed in the other, and a source and cell were placed. This test aimed to verify the electrical conduction between the lamp and the cell with the copper bar installed on the conveyor belt.

In Figure 9, the CNC is shown prototyping the cradles; the CAD designs are converted into machine language extensions and inserted into the CNC for use.

Figure 9. Manufacture of cradles.

Source: Authors, (2021).

Circled in red, the cradles are on two fixed copper bars and remained in contact with the bar that was fixed on the conveyor belt, as shown in Figure 10. It was through this contact that the products were energized throughout the conveyor belt.

Figure 10. Cradle prototype.
Source: Authors, (2021).

4.1.4 Development of the Elevator

The requirements mentioned during elevator design were met using an advanced vertical conveyor system that utilizes a drive chain for effective continuous operation. Two gears separated by the required distance (space between the production line and lower and upper Burn-In conveyor belts) were linked by a chain with meticulously placed bucket chain links to assemble the carts with the carrier fork as an integral part of it in order to transport the material. The rear fork mechanism is specifically designed to make sure the orientation of the fork carrying the material remains the same regardless of the cart's position.

Figure 11. Cradle support structure.
Source: Authors, (2021).

As a result of this development phase, a structure was obtained according to measurements available at the factory; the vertical elevator structure was made in 30x50 carbon steel, had the joints welded; the figure below shows its structure.

Figure 12. 12a - Elevator structure and 12b - Elevator assembly.
Source: Authors, (2021).

Assembly was followed according to the 3D modeling with two sprockets of the model 2-60-95 and 12.0 meters of chain of the type 60/2 wk-2 19x19 being installed. This solution had the purpose of rotating the fork and transporting the cradles of the Production Line/Burn-In/Production Line.

A motor with planetary gearbox was used to turn the gears, aided by electronic hardware and software. A support base for the motor was made, a gear installed in the gearbox shaft, and a chain positioned, and this was connected to another gear of the elevator shaft gears. It was necessary to use bearings to guide the shafts.

4.1.5 Software Development

The microcontroller used in the project is the 32-bit Arduino MEGA with 16Mhz crystal oscillator. This microcontroller is based on the ATmega2560. It has 54 digital Input/Output ports, and 16 analog ports and 4 UARTs (Serial hardware). The hardware implemented to control the motor of the elevator is shown in Figure 101. An interface with a 128x64 LCD was necessary to inform the user of the elevator state during runtime.

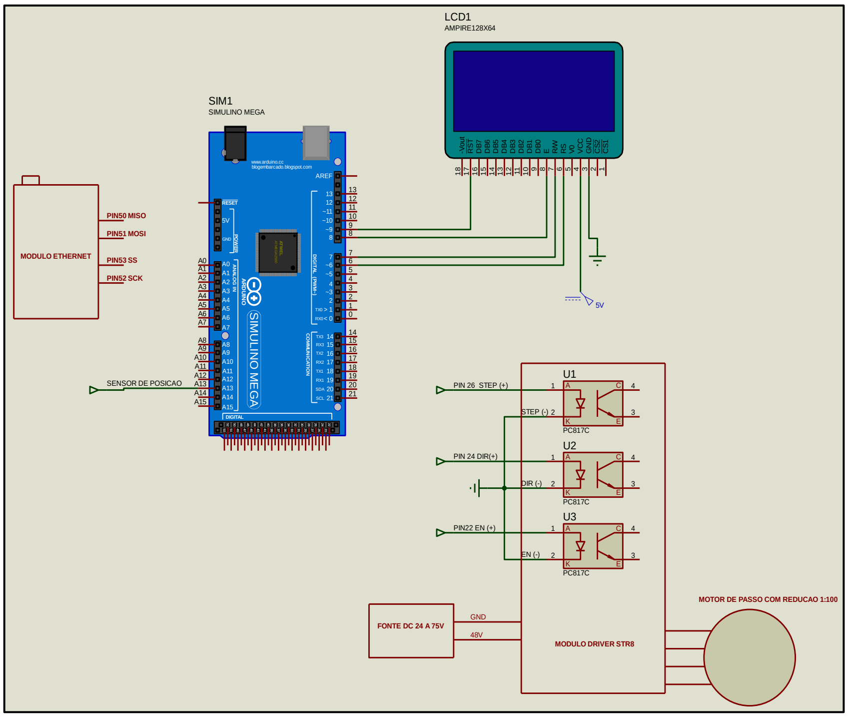


Figure 13. Elevator electronic diagram.
Source: Authors, (2021).

The IDE (Integrated Development Environment): Integrated Development Environment facilitates application development. This software combines common development tools into a single graphical user interface (GUI), improving application development. The IDE used wasVsCode PlatformIO.

- ***VScode Platform IO***

Visual Studio Code is based on Electron, a framework used to develop Node.js desktop applications running on the Blink layout motor. Despite using Electron as the framework, the software does not use Atom. Instead, it employs the same editor component (codenamed "Monaco") used in Visual Studio Team Services (previously called Visual Studio Online).

- ***Arduino Mega***

Power was supplied through the USB connector or the power connector (recommended voltage for the 7 to 12V input). The USB connector is protected via a 500-mA fuse. The board has a RESET button and an ICSP connector for writing firmware (optional). Current consumption through the USB port (5V power supply) is approximately 75 mA. Each Arduino Mega digital port can support up to 20 mA and be used as an input or an output. All Digital and Analog pins work with voltages from 0 to 5V.
The board also has an ICSP connector connected to the ATmega2560 SPI interface. This connector was used to burn the firmware (software) directly in the microcontroller.

- ***W5100 Ethernet Module***

The Shield W5100 Ethernet board was used for the standard Ethernet network interface. Its physical connection was made through an RJ45 cable. This board has an adapter for a direct interface with Arduino. Through this network shield, communication with the MySQL database was carried out.

The electronic circuit was assembled, as shown in the figure below. The STR8 driver was used in this electronic circuit, which has different configurations, allowing the motor speed to be increased or decreased by configuring its keys.

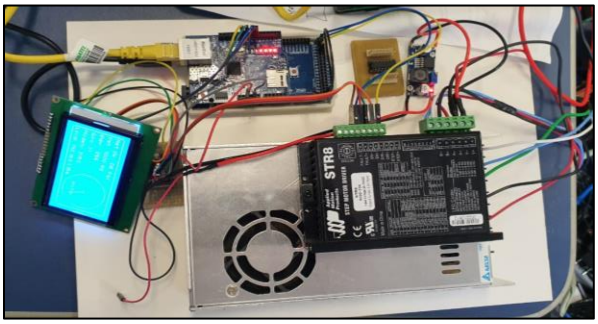


Figure 14. Assembly for testing the electrical circuit.
Source: Authors, (2021).

On the graphic display located on the elevator panel, information relevant to the elevator operation is displayed. Information such as: Checking if the network is connected or if there is an active physical network medium to communicate with the database, or checking if the database is active. Network communication is often active without there being any communication with the database due to some database maintenance. Information about the model that was tested in the Burn-In process is also informed on the display. A GIF of the motor was spinning on the screen informing that the Burn-In motor is in perfect working order, Figure below.

Figure 15. Display.
Source: Authors, (2021).

4.1.5.1 Software Development

For remote control of the prototype, a monitoring application was modeled responsible for making the connection between the system operator and the "Burn-In" commands, so it directly accesses the idealized database and then chooses the product model that will be tested. With this, the application searches within the database all the parameters necessary to meet that test, such as:

- Burn-In Time;
- Motor speed;
- Test temperature.

As shown in Figure 16, in addition to the parameters sent when selecting a model, the application also has the function of allowing these values to be changed in real time for possible adjustments, finally, it aims to show on the monitor a graph indicating the temperatures in progress of the time in each of the temperature sensors installed inside the stove, this through a constant search in the database, where Burn-In sends the registered temperatures.

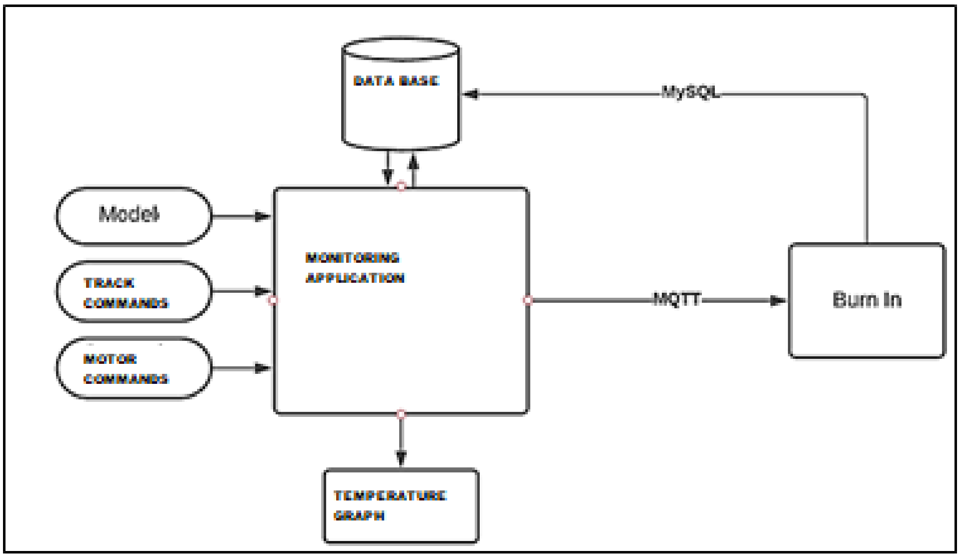


Figure 16. Monitoring application flowchart.
Source: Authors, (2021).

- **Application**

To apply this concept, we used the programming language called Lazarus 2.0, which is a program responsible for assembling graphical interfaces; for this it uses Pascal language, but the range of resources that can be connected is quite large, for example, the tool itself has direct access to databases created in MySQL, simplifying the query of its tables. Another important factor is the ease of executing Raspberry Pi's command terminal lines, which allows easy use of MQTT protocol commands.

- **MQTT Protocol**

The MQTT protocol has the function of connecting two or more devices through the Internet, as in the case of this project, communicating information from the Arduino to the Raspberry, and thus sending the Burn-In temperature information to the monitor, or sending the monitor commands for the microcontroller, but before that, it was necessary to establish and test the communication through the protocol that makes the IoT possible.

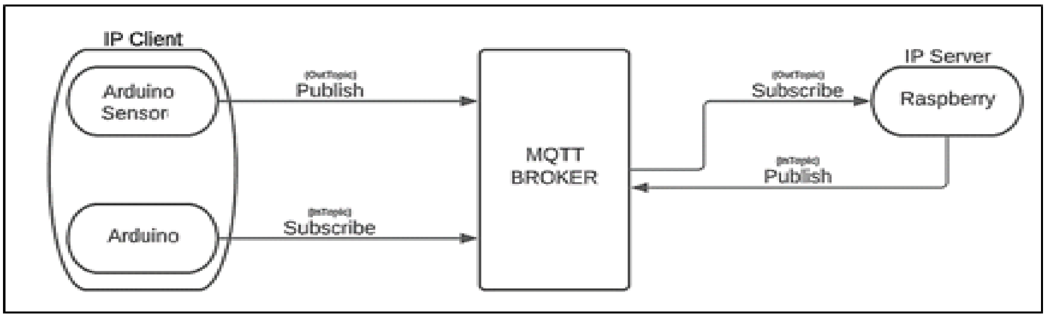


Figure 17. MQTT Communication Map.
Source: Authors, (2021).

As shown in Figure 17, MQTT receives all data from microcontrollers; through it, Arduino and Raspberry communicate and make decisions according to the readings received from each other.

- **Shield Ethernet 5100**

To communicate information with the Arduino, either sending or receiving, the Shield Ethernet W5100 was used, as there is only one way to connect to the Arduino, its electrical scheme is dispensed with, replacing it with a schematic diagram, Figure 18.

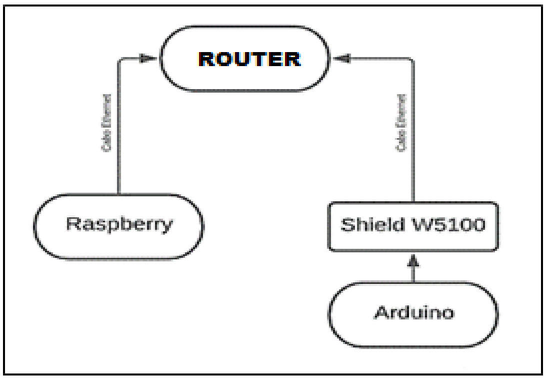


Figure 18. MQTT connection.
Source: Authors, (2021).

As per the diagram shown in Figure 18, the Raspberry and Arduino communicate with the router, but the Shield Ethernet W5100 was used to place the Arduino in this hardware.

- **MySQL Database on Raspberry**

To store the temperature and speed values, in addition to the setup of the automated system's SETUP, a database was used through MySQL to store it on a server in Raspberry, and for that, a library was installed to send Arduino information to the bank, through the Shield Ethernet W5100.

4.1.5.2 Database

- **Table of Models of Products**

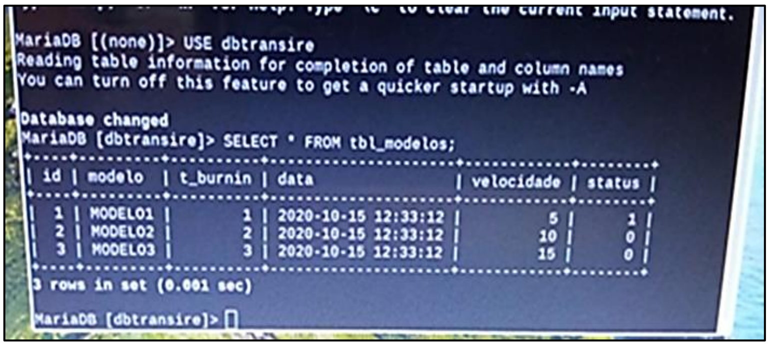
The "tbl_modelos" table is responsible for commanding and synchronizing all the project's microcontrollers, as it will have different product models, which have undergone Burn-In, and each one has a different treatment requiring the sending of this information to the microcontrollers.

Table 1. Table of models.

ID	MODELO	T BURN-IN	DATA	VELOCIDADE	STATUS

Source: Authors, (2021).

- ID: assigns a unique numbering to each model;
- MODELO: specifies the product name;
- T Burn-In: specifies the time this model should take in the process;
- DATE: assigns the moment when the process of that model started.
- VELOCIDADE: specifies the speed the motor must have to meet the time;
- STATUS: this column specifies which model is in process; when it becomes 1, all microcontrollers receive this information and already read all the information referring to this model.


MariaDB [(none)]> USE dbtransire
Reading table information for completion of table and column names
You can turn off this feature to get a quicker startup with -A

Database changed
MariaDB [dbtransire]> SELECT * FROM tbl_modelos;

id	modelo	t_burnin	data	velocidade	status
1	MODELO1	1	2020-10-15 12:33:12	5	1
2	MODELO2	2	2020-10-15 12:33:12	10	0
3	MODELO3	3	2020-10-15 12:33:12	15	0

3 rows in set (0.001 sec)

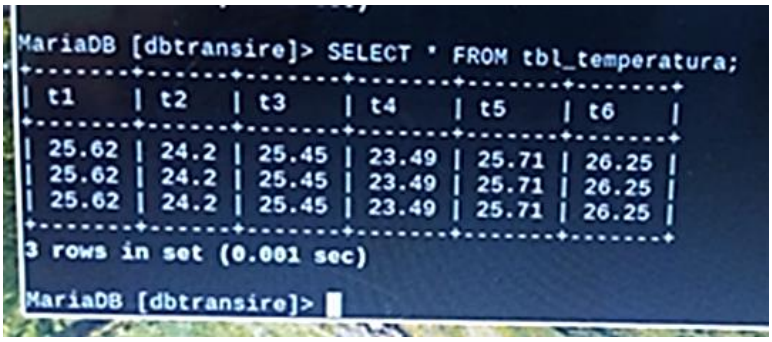
MariaDB [dbtransire]>

Figure 19. Product model table.

Source: Authors, (2021).

- **Temperature Table**

The "tbl_temperature" table stores the current temperature measured by each sensor and is updated every second, and then it is read by the monitor, which shows the operator the temperature along the line, that is, each column referenced as t1, t2, t3, t4, t5 and t6.


MariaDB [dbtransire]> SELECT * FROM tbl_temperatura;

t1	t2	t3	t4	t5	t6
25.62	24.2	25.45	23.49	25.71	26.25
25.62	24.2	25.45	23.49	25.71	26.25
25.62	24.2	25.45	23.49	25.71	26.25

3 rows in set (0.001 sec)

MariaDB [dbtransire]>

Figure 20. Temperature table.

Source: Authors, (2021).

- **Table of Cradles**

A solution to the processing bottleneck found in the functions of sending to the database, and to ensure that a failure in reading the cradles interferes with the entire process, each RFID sensor was isolated, which reads the unique cards of each cradle, to the Arduino UNO, and these are linked directly to the database. In other words, each time the sensor reads the swipe of a card associated with a cradle, it will send to the database the time at which a cradle passed, as shown in Figure 21.

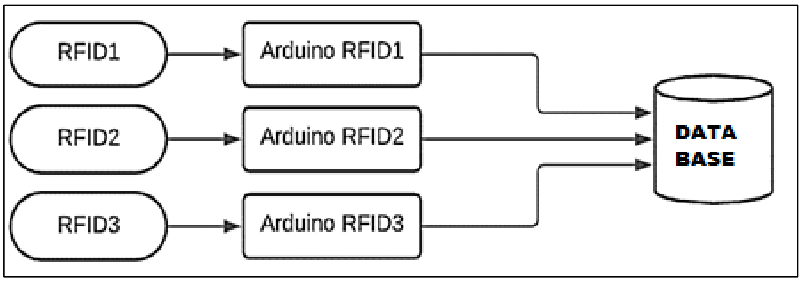


Figure 21. Flowchart of CRADLES.
Source: Authors, (2021).

The "tbl_bercos" table is responsible for recording each of the cradles' entry and exit times, and for that, it reads which card ID is read and immediately sends the current time to the bank through the server.

Table 2. Cribs table.

ID	N_BERÇO	DATA_IN	DATA_OUT	TEMPERATURA	CARD_ID

Source: Authors, (2021).

- ID: assigns a unique number to each cradle;
- N_BERÇO: specifies the name of the cradle;
- DATA_IN: specifies the time this cradle has passed the start of the conveyor belt;
- DATA_OUT: specifies the time this cradle passed the end of the conveyor belt;
- TEMPERATURA: registers the average temperature that this cradle was subjected to;
- CARD_ID: it has registered the id in hexadecimal of each of the cards, being a specific value for each of the cards inside each cradle.

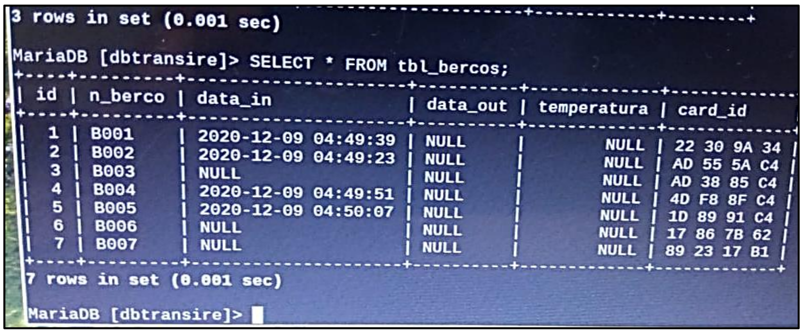


Figure 22. Table of cradles.
Source: Authors, (2021).

4.1.6 Productive Capacity

For the analysis of productive capacity, the data was evaluated according to the MOST® study, the objects of study were the products A930 and D150. The study was divided into two stages, calculation of production capacity and calculation of operational capacity of cradles in the Burn-In..

The proposed calculation memory methodology related all the process variables ensuring the balance of the lines, reducing unproductive times and losses due to inventory of products in process.

This line of thought allows the Transire company to deal day-to-day with decision-making problems within strategic, tactical, and operational scopes. At the strategic level, there are decisions related to the company's mission and its long-term goals, such as the location of industrial plants, acquisition of new resources, and introduction of new technologies and products. Tactical-level decisions fall within a narrower planning horizon that ranges from weeks to months and generally serve as input to longer-range decisions. They relate to the type of manufacturing system (mass or batch production), the model of the product to be manufactured, and the volume to be produced. Finally, operational level decisions are made in the shop floor environment, are short-term ones that may vary from hours to days and are usually related to the allocation of recoverable resources (machines) for the transformation of unrecoverable resources (raw materials and components) into finished products.

Resource allocation problems involve production batch sequencing activities, which compete for scarce resources also commonly called finite capacity resources.

4.1.6.1 Analysis of the Capacity of Operational Cradles

The calculation of the Burn-In capacity to receive the cradles was necessary to identify the number of products that could be tested simultaneously. During development, a dimension of 430x300mm was obtained, which was considered ideal for positioning the products.

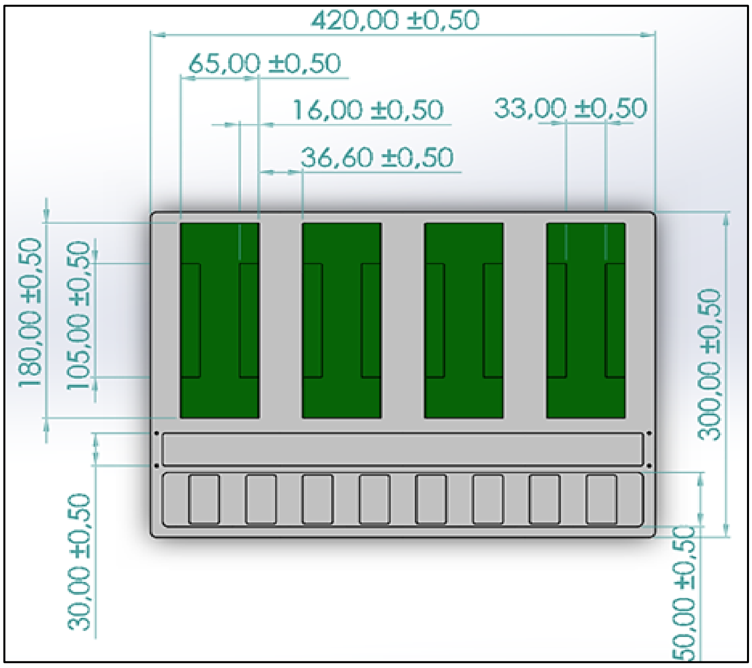


Figure 23. Dimensions of the cradle.

Source: Authors, (2021).

The size of the 30,000mm mats was considered, the spacing between the chain pushers is 342.9mm. Dividing the total lengths of the conveyor belts by the spacing of the pushers provided a result of 87.49 with this finding was considered the ability of 85 operational cradles.

4.1.6.2 Production Capacity Analysis

The A930 and D150 products and their respective production capacity were gathered; Transire considers Units Per Hour – UPH to measure the production data. The figure with this data is shown below.

Table 3. Productive Capacity.

Product	**Image**	**Production Hour - UPH**
D150		310
A930		90

Fonte: Transire, adapted by authors, (2021).

According to Table 3, model D150 has a production of up to 310 products per hour and model A930, a production of up to 90 pieces. Studies on the development of the cradles led to the result that the same base would have the capacity to receive 8 D150 products and 4 A930 products. To obtain the capacity of each product in Burn-In, the number of cradles was multiplied by the capacity of products in each cradle. The table below shows the result.

Table 4. Productive capacity by model.

Product	**Qty of cradles**	**Qty of product per cradle**	**Qty of product in Burn-In**
D150	85	8	680
A930		4	340

Source: Authors, (2021).

To assess the actual capacity of products in Burn-In, it is necessary to multiply the production capacity, Table 3, by the number of hours of Burn-In, as shown in the Table below:

Table 5. Required Capacity X Designed Capacity.

Product	UPH	Burn-In Time (Hours)	Capacity required for Burn-In	Designed Capacity for Burn-In
D150	310	2	620	680
A930	90	3	210	340

Source: Authors, (2021).

As shown in Table 5, it is noted that Burn-In has the physical capacity to receive the products for testing without the need to create a buffer, optimizing the flow of the production line.

4.1.6.3 Time Analysis

The MOST® method classifies any type of movement in general, controlled, or combined movement of both. The use of hand tools is analyzed through a sequence of tool events in the task execution, which can be described as a combination of both general and controlled movements. The models described in MOST® are represented by a sequence of activities during object movement using specific parameters. Each parameter is associated with an index equal to or a multiple of 10, representing a resistance to be overcome or a degree of difficulty to perform a certain action.

In general movement, the sequence of activities consists respectively of obtaining the object, moving the object to place it at its destination, and returning to the origin. The sequence of MOST® parameters that describe this activity is: [ABGABPA], where parameter A represents a horizontal distance action to be overcome to gain control of the object, B concerns the vertical movement of body members that demonstrate hesitation or pause when picking up an object, G identifies various ways to obtain control of the object (simultaneous or not, pickup, pickup, etc.) and the parameter P that is related to the object's disposition at the destination location (leave of side, place with care, precision, etc.). The final A parameter describes the object's return to its original position. The sum of the sequence indices defines the unit that the MOST® method uses to quantify the time spent in the execution of the activity, which is called TMU (Time Measurement Unit). Therefore, 1 TMU = 0.00001 hour = 0.0006 minutes = 0.036 seconds, that is, 1 hour = 100,000 TMU, 1 minute = 1,667 TMU, 1 second = 27.8 TMU.

The methodology developed is exclusive to the production system of the company Transire, and its main objective is to guarantee the best performance of Air Burn-In. The following are designs of the main sketches developed in relation to calculation memory.

Table 6. Operating time for setup.

SETUP	Time Unit TMU												
Activity: Base setup of cradles	A	B	G	M	P	Sum of indices	Qty products	Index x Product	Time unit (TMU)	Time per Index (TMU)	Total time (TMU)	Operating time (S)	Total time per cradle (S)
Reach and pull empty cradle	1	0	1	1	0	3	1	3	10	30	300	0,87	8,70

SETUP	Time Unit	TMU											
Unlock pins	1	0	1	0	1	3	4	12		120		3,48	
Take base	1	0	1	0	0	2	1	2		20		0,58	
Put base	0	0	0	0	1	1	1	1		10		0,29	
Lock pin	1	0	1	1	0	3	4	12		120		3,48	

Source: Authors, (2021).

According to Table 6, the total time for setup execution to change the base of the cradle is represented, the analysis of setup time was relevant for future studies by Transire.

The operation analysis of the D150 product involved five main actions:

- Cradle assembly;
- Elevator ascent;
- Burn-In;
- Elevator descent;
- Delivery of tested products.

In each set of actions, micro-movements were considered, and the operating time was calculated. The tables below show the simulation of these times.

Table 7. Operating time for feeding cradles with D150 product.

D150	Time Unit TMU												
Activity: Assembly of cradles	A	B	G	M	P	Sum of indices	Qty products	Index x Product	Time unit (TMU)	Time per Index (TMU)	Total time (TMU)	Operating time (S)	Total time per cradle (S)
Reach and pull empty cradle	1	0	1	1	0	3	1	3		30		0,87	
Reach and position the product	1	0	1	0	1	3	8	24		240		6,96	
Reach the cable	1	0	1	0	0	2	8	16	10	160	540	4,64	15,66
Connect the cable to the product	0	0	0	0	1	1	8	8		80		2,32	
Reach and push full cradle	1	0	1	1	0	3	1	3		30		0,87	

Source: Authors, (2021).

For the foreseen scenario, the cradle is estimated to be fed with eight D150 products; this action takes 15.66 seconds.

Table 8. Operating time for raising cradles.

D150	**Time Unit TMU**								
Activity: Elevator ascent	**X**	**Sum of indices**	**Qty products**	**Index x Product**	**Time unit (TMU)**	**Time per Index (TMU)**	**Total time (TMU)**	**Operating time (S)**	**Total time per cradle (S)**
Cradle transport: cradle leaves the S0 station, enters the elevator and goes up to the Burn-In conveyor belt. Considering: Height 1.50m. Ascent rate of 1.50m/1.74s = 0.86m/s	6	6	1	6	10	60	60	1,74	1,74

Source: Authors, (2021).

Going up in the elevator was calculated at 1.74 seconds, the descent time of the elevator being the same as the ascent time.

Table 9. Burn-In cycle operation time.

D150	**Time Unit TMU**								
Activity: Burn-In	**X**	**Sum of indices**	**Qty products**	**Index x Product**	**Time unit (TMU)**	**Time per Index (TMU)**	**Total time (TMU)**	**Operating time (S)**	**Total time per cradle (S)**
Cradle transport: 2 hours elapsed time. Considering: 8 products per cradle.	0	0	1	0	10	0	0	0	35,49

Source: Authors, (2021).

There is a time of 35.49s for each product during the cycle of the Burn-In.

Table 10. Table 7 - Operating time for delivery of tested products.

D150	Time Unit TMU												
Activity: Delivery of tested products	**A**	**B**	**G**	**M**	**P**	**Sum of indices**	**Qty products**	**Index x Product**	**Time unit (TMU)**	**Time per Index (TMU)**	**Total time (TMU)**	**Operating time (S)**	**Total time per cradle (S)**
Reach and pull full cradle	1	0	1	1	0	3	1	3	10	30	540	0,87	15,66
Reach the power cord	1	0	1	0	0	2	8	16		160		4,64	
Disconnect the cable from the product	0	0	0	0	1	1	8	8		80		3,32	
Reach and withdraw product	1	0	1	0	1	3	8	24		240		6,96	
Reach and push empty cradle	1	0	1	1	0	3	1	3		30		0,87	

Source: Authors, (2021).

The delivery of the cradle with the removal of the products takes 15.66 seconds. The total cycle time is the sum of these operations with a duration of two hours for the D150 product, obtaining a time of 7,234.8 seconds.

This time will be considered for Transire for future project replication studies, as these operations will be added to those existing in the current process.

5. Conclusion

Companies have invested in strategies that improve product quality, optimizing time and resources. The testing area, among others, has received particular attention. One of the most commonly used tests on electronic devices is the stress test, also called the Burn-In test.

Burn-In Tests are exhaustion tests that seek to simulate the real environment in which the equipment will be submitted while still in the production phase. However, tests are typically carried out in a test area physically separated from the production line, making it necessary for the equipment to be tested to be taken to that area and then returned to the production area.

Therefore, this article presents a Burn-In test proposal integrated into the production line, thus gaining travel time and physical space reduction, factory modernization, and ergonomic improvement since the tests use the same area already used by the production line.

The proposal has two main parts. The first is the transfer area, which also has an elevator responsible for carrying the cradles with the payment terminals to the test area and taking them back to the production belt after the tests. The second part is the test area. In the test area positioned above the production line, two floors of conveyor belts are prepared to carry out the Burn-In test throughout the course.

The proposal is under development at the payment terminal producer, Transire. All parts that make up the proposed solution were tested in the laboratory through the development of prototypes. In a preliminary analysis, there was a 17% reduction in production time, the possibility of moving employees to other activities, and the optimization of the use of physical space.

In the future, there is an intent to implement the solution in the manufacturing environment, carry out tests on-site and perform statistical analysis on the generated data. Furthermore, the usage data stored in a database contemplates using machine learning algorithms to evaluate patterns in the data proposing improvements in the testing and production process.

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