Available online at http://www.journalijdr.com

IJDR

International Journal of Development Research
Vol. 12, Issue, 10, pp. 59757-59770, October, 2022
https://doi.org/10.37118/ijdr.25632.10.2022

ISSN: 2230-9926

RESEARCH ARTICLE

OPEN ACCESS

USE OF FLEXSIM TO SIMULATE IMPROVEMENT PROPOSALS IN A REMOTE CONTROL PRODUCTION LINE

*[1]Katlen Araújo Raposo and [2]Jandecy Cabral Leite

[1,2]Postgraduate Master in Engineering, Process Management, Systems and Environmental (EPMSE/ITEGAM), Manaus – Amazonas, Brazil. ZIP CODE: 69020-030; [1,2]Institute of Technology and Education Galileo of Amazon (ITEGAM), Manaus-Amazonas, Brazil. ZIP CODE: 69020-030

ARTICLE INFO

Article History:

Received 10th September, 2022
Received in revised form
19th September, 2022
Accepted 17th October, 2022
Published online 30th October, 2022

Key Words:

Flex Sim, Simulation, Production Processes, Remote Control, Production Capacity.

****Corresponding author:***
Katlen Araújo Raposo

ABSTRACT

Computational simulation is a tool with the potential to generate a large reduction in operating costs, since it is possible to model a process in a controllable environment, test modifications and analyze the results, without necessarily changing the actual structure of the production process. In this article, it was sought to propose productive scenarios through simulation that aims to eliminate the presence of non-compliant products due to the use of flux NC215 in the wave soldering process and to increase the productive capacity for production of remote controls in a company located in the Industrial Pole of Manaus/AM, identify the best proposed scenario from the use of computer simulation with Flexsim software. Data was collected regarding the current production process. The computational model built, was verified and validated successfully in comparison with data from the real process. Through the results obtained by the computational simulation it was possible to identify the best proposed scenario.

Citation: ***Katlen Araújo Raposo and Jandecy Cabral Leite.*** "Use of flexsim to simulate improvement proposals in a remote control production line*", International Journal of Development Research*, 12, (10), 59757-59770.

INTRODUCTION

The rapid evolution of the current competitive market is a consequence of the emergence of new facilitating technologies for the analysis of its processes, this scenario in front of companies, requires more and more excellence in performing their activities. Simulation and modeling have been widely used in several areas, since they are powerful tools that allow the creation of a computational system without the need to change the real physical system, allowing analysis of the system as a whole, which implies the development of increasingly efficient productive systems (CHWIF AND MEDINA, 2010; SAMPAIO; OLIVEIRA, 2013). When using simulation, the expected is that favorable or unfavorable situations are generated that serve to support decision making, always seeking the organization of the system under analysis. The simulation model seeks the representation of the behavior close to the real system, but there must be concern in avoiding a complexity greater than the system itself, which would end up generating a bigger problem to be solved than the very system under analysis (BANKS; CHWIF 2010). Through modeling and simulation systems, it is possible to identify possible failures in production, thus, corrective measures can be taken for better effectiveness of the system, besides providing a systemic view of the entire process involved (CARNEIRO; PINTO, 2010). The FlexSim software is a powerful tool for modeling and simulation, which was used to prepare this research project. The software has its main use in areas of warehouse optimization projects, logistics and improvements in the production line. The area in which the FlexSim software is applied in this project is of improvement in production line, specifically in a production line of electronic plates for dishwashers. The real problem of the study is a previous analysis of proposed scenarios for the elimination of defects in remote control boards generated by the residual flow NC215 and the increase of the productive capacity of the process and guaranteeing the quality of the product according to the specifications of the customer. Understanding the actual problem of the study, subsequently the computational modeling of the proposed scenarios using Flexsim software is performed. The research is an empirical case study, of descriptive quantitative character. In Production Engineering, the use of simulation is fundamental to Decision Support Systems, because it is possible to find bottlenecks and sources that generate errors, problems or waste to the process and, according to the generated result, suggests alternatives of improvement to decision makers. Many of these concepts can be found in the works of (BATEMAN et al. (2013; ZHU et al., 2014; MIGUEL, 2011; CORRÊA et al., 2001).

Some works related to simulation study some part of the production process, either in production or distribution of the finished product. In this study, the productive process of remote controls for air conditioners was modeled in a company that has as segment the manufacturing branch and the objective of the study is to analyze proposals for process improvement in order to eliminate defects by residual accumulation of NC215 flow and increase the productive capacity, using the FlexSim simulation software. As the proposals for improving the production process require changes in machinery and investments in new devices to assist in the welding of components, the work played an important role not only to justify the feasibility of these investments, but also to show that these changes in the process will generate significant positive impacts on production capacity.

BIBLIOGRAPHIC REVIEW

Industry: Artificial intelligence, robotics, cloud and internet of things. Terms that a few years ago were not at all known, today are already part of everyday life for all of us. These technologies are part of a very familiar concept in the industrial sector: Industry 4.0. Also called the 4th Industrial Revolution, this phenomenon is changing, on a large scale, automation and data exchange, as well as production stages and business models, through the use of machines and computers. Innovation, efficiency and customisation are the key words to define the concept of Industry 4.0. Industry 4.0 has a significant impact on productivity, since it increases efficiency in the use of resources and in the development of large-scale products, besides enabling Brazil's integration in global value chains. The incorporation of Advanced Robotics, Machine-Machine Connection Systems, the Internet of Things and the Sensors and Actuators used in this equipment enables machines to "talk" throughout the industrial operations. This can allow the generation of information and the connection of the several stages of the value chain, from the development of new products, projects, production, until the after-sales. Examples of technologiesused in Industry 4.0 are:

- ***Artificial intelligence:*** application of advanced analysis and techniques based on logic, including machine learning, to interpret events, analyze trends and behaviors of systems, support and automate decisions and perform actions (MEIRING and MYBURGH, 2015);
- ***Cloud computing:*** is the distribution of computing services - servers, storage, databases, networks, software, analytics, intelligence - over the Internet, using memory, storage capacity and calculation of computers and servers hosted in a Datacenter, providing flexible resources and economy of scale. Cloud computing allows companies to access abundant computing resources as a service and from different remote devices. This way, high investments in equipment and support staff are avoided, allowing companies to focus their investments on their core activities (RIMAL, CHOI and LUMB, 2009; SAIYEDA, 2017);
- ***Big data:*** is an approach to act on data with greater variety and complexity, which arrive in growing volumes and with increasing speed, used to solve business problems. These data sets are so voluminous that traditional data processing software cannot manage them. Statistical and machine learning techniques are used to extract business-relevant information, inferences and trends not possible to obtain with human analysis (CHE, SAFRAN and PENG, 2013; TRNKA, 2014;
- ***Cyber security:*** is a set of hardware and software infrastructures aimed at the protection of information assets, through the treatment of threats that endanger the information that is processed, stored and transported by information systems that are interconnected (LEZZI, LAZOI, and CORALLO, 2018; CORALLO, LAZOI and LEZZI, 2020);
- ***Internet of things:*** interconnection between objects through enabling infrastructure (electronics, software, sensors and/or actuators), with distributed computing capacity and organized into networks, which begin to communicate and interact, and may be remotely monitored and/or controlled, resulting in efficiency gains (MIORANDI, 2012; ATZORI, IERA and MORABITO, 2010);
- ***Advanced robotics:*** devices that act largely, or partially, autonomously, that physically interact with people or their environment and that are able to modify their behaviour based on sensor data (BEER, FISK and ROGERS, 2014; SIMOENS, DRAGONE and SAFFIOTTI, 2018);
- ***Digital manufacturing:*** is the use of an integrated, computer-based system consisting of simulation, 3D visualization, analytics, and collaboration tools to create manufacturing process and product definitions simultaneously (GUERRA-ZUBIAGA, 2021; АННА ОЛЕГОВНА; ПАКЛИНА, СОФИЯ НИКОЛАЕВНА; ПРОКОФЬЕВА, АЛИЯ СЕРГЕЕВНА. 2017; PERUZZZINI et al, 2021);
- ***Additive manufacturing:*** consists in manufacturing parts from a digital design (made with a three-dimensional modelling software), overlapping thin layers of material, one by one, by means of a 3D Printer. Materials such as plastic, metal, metal alloys, ceramics and sand, among others, can be used (SINGH, RAMAKRISHNA and SINGH,2017; TOURI et al. 2019; JAVAID and HALEEM, 2019);
- ***Systems integration:*** joining together different computing systems and software applications physically or functionally, to act as a coordinated whole, enables the exchange of information between the different systems. It allows companies a comprehensive look at their business. Real-time information about the production process influences managerial decision making more quickly and strategic decisions about the company's business can be more easily implemented in the production plant. Only the installation of ERP packages does not fit, but its integration to industrial production control systems does (GIACHETT, 2004; HEGERING, ABECK and NEUMAIR, 1999; CHALMETA and GRANGEL, 2001);
- ***Simulation systems:*** use of computers and set of techniques to generate digital models that describe or display the complex interaction between various variables within a system, mimicking real-world processes (LAW, KELTON and KELTON, 2007; SCHLUSE and ROSSMANN, 2016);
- ***Digitalisation:*** consists of the use of digital technologies to transform production processes, product development and/or business models, aiming at process optimisation and efficiency. Digital transformation covers: design and implementation of digitization plan, sensing, acquisition and data processing (BRAGA TADEU et al., 2019; STOFFELS, 2017; URBACH et al., 2019).

Lean Manufacturing: Lean, in general, serves to identify and eliminate waste that is found on a production line. By eliminating the "waste" on the line, quality can be increased and costs reduced. In practical terms, eliminating "waste" refers to eliminating unnecessary operations, equipment, materials, space and unnecessary movements. By doing the elimination of the previously mentioned points, companies are able to focus their resources on what is really important and on what customers ask for (POWELL et al. 2014). In relation to costs, due to the strong competition that is felt at the level of vendors, the production prices have to be as low as possible in order to have a price that the customer is willing to pay. Quality is achieved by making problems visible, including where and when they occurred, and by taking the necessary measures to solve the problem, so that future repetitions of the same problem can be prevented. Thus, quality becomes a constant improvement of prevention, where all errors that do not occur again are analysed as a cost gain (BLACK & HUNTER, 2003). Near the year 1950, the concept 'muda' (waste decrease) became one of the biggest and most important concepts in the improvement activities of the Toyota philosophy. Ohno upon returning to Japan decided to stabilise the work groups and soon after encouraged them to work together in the best possible way to meet the proposed goals. In a next step, Ohno created new tasks in the work team, including repair tools, quality control and tasks to keep the workstations organized and clean, such as the lean tool called "5S" (DAHLGAARD-PARK & DAHLGAARD, 1999). The "5s" system is based on the general organisation of the workstation.

The 5s, originally named Shitsuke, Serei, Seiton, Seiso and Seiketsu, refer to five important points that should work to keep a place organised. One must eliminate, separating what is necessary from what is not, removing everything that is useless. Then one must order each "thing" in its place, clean the area, find problematic points, and also find solutions to keep them clean. After the three points mentioned above, it is necessary to normalise, creating rules for cleaning and tidying up. Finally, one must respect the defined rules so that everything works properly. Another tool invented to reduce waste was Just-in-Time (JIT), whose associated control tool is Kanban. In this system a card (Kanban in Japanese) is used as a tool to inform different production lines (DAHLGAARD-PARK & DAHLGAARD, 1999). The JIT system arises from a recurring problem which is that customers always want the best type of products at the lowest possible prices, and also as quickly as possible. The production system envisages fulfilling all customer orders in a productive and efficient way, maintaining a strong link between production activities and market sales. JIT indicates that a given process produces some items for the next stage, which it will only withdraw in case of need. In other words, each station removes the items it needs and the previous station produces again to replace the items that were removed. Thus, each station only produces to replace products that are missing. The work in process (WIP) is specified according to what is needed. In short, only what is needed and in the quantity required is produced. This system has several advantages: it eliminates the waste that occurs when there is a change in the specifications, which makes everything in stock useless; it empties storage space with the costs associated with stocking products that are not currently required by customers; it helps in the search for a defect found on the production line, so that it can be guaranteed that more products do not have the same defect and, for this, the entire existing stock must be viewed, and in a JIT system the sorting becomes much easier (BLACK & HUNTER, 2003).

Thus, it can be said that a basis for JIT is a balanced system, where the idea of being able to produce the product for the customer as quickly as possible becomes a very favourable factor. According to Stevenson (2011) there are important points that one should pay attention to in order to have a good JIT system:

- Eliminating interruptions: the different types of interruptions that a production line can have, namely variability in quality issues, problems with equipment that gets damaged, schedules that change, are aspects that should be eliminated as much as possible. This will make the production line become better and run in a smoother way;
- Making the system more flexible: the flexibility of the system is conveyed by the ability of the production line to be able to work with various references of products, and for any situation the line is in a balanced way and with the same speed;
- Elimination of waste: Lean Manufacturing is related to the elimination of waste. As such, Ohno (1988) created a list with the wastes, i.e., all the activities that in a system do not add value. This list was named the seven wastes (OHNO, 1988);
- Defects: a product has defects when it does not meet the quality requirements. These should be prevented through systems such as Poka-Yoke and standard work;
- Waiting times: periods in which there is no use of available resources. Setup times, as well as equipment breakdowns are examples of this type of waste, which give rise to inconstant flows;
- Overproduction: excessive production, which comes from economies of scale or poor production planning;
- Unnecessary production: creation of a given product more than is requested by the customer;
- Useless movements: movements caused by poor workplace ergonomics, such as disorganisation and clutter in the workplace, resulting in wasted time;
- Transportation: related to movements of people, materials or equipment that do not add value to the system;
- Stocks: products and/or raw materials stored in excess resulting in loss of space and sometimes in malicious organisation.

Process Simulation: The simulation of production processes is the virtual representation of a given process by means of a mathematical computational model. We can say that it is a faithful and dynamic copy of a system, implemented in a risk-free environment, in which different experiments can be performed to provide the analysis of the production process (ZHU et al., 2014). The result is assertive planning capable of avoiding the waste of resources in an industry. The simulation of production processes is a tool capable of dealing with the randomness of production systems effectively. By adding creativity to the problem-solving process and predicting results, it enables managers to make decisions based on reliable results, even before implementing them in practice. It is extremely useful, since the action alternatives can be readily tested, determining the effects of changes in the system performance (CARNEIRO; PINTO, 2010). Its operation occurs through software that digitally reproduces the manufacturing processes of industrial plants. Through technologies such as virtual reality, the tool allows to design, configure, validate and simulate the performance of production, before being put into practice in a real factory. Any equipment can be reproduced. The difference is that the impacts caused by any changes in the simulated production will not be felt in the real operation. Using the data collected in the simulation, processes are adjusted for maximum efficiency. This eliminates the need for trial and error dynamics in the physical process, improving efficiency at the lowest possible cost. In other words, simulating production processes allows us to evaluate the impact of changes in the real system, contributing to decision making and bringing a series of benefits to organisations.

Simulation Models: Operations can be analysed through real experiments or represented by models to meet some particular interest. Simulation models are dynamic in nature (state changes over time), random (use random variables) and are made up of entities that interact logically for some purpose. They are particularly used to answer questions of the type: "what happens if... "and can be classified in three dimensions Law (2007):

- ***Static vs. dynamic:*** Static models are used to represent systems where time plays no role. Monte Carlo models, used to evaluate mathematical functions, financial models or scenario building, are examples of static models. On the other hand, dynamic models represent systems that evolve over time, such as a system in a factory.
- ***Deterministic vs. stochastic:*** Deterministic models have no random components. Examples of deterministic models include a system of differential equations describing a chemical reaction, or integer-mixed linear programming models. The output of these models also has no random components. The presence of random elements generates the need to elaborate stochastic models. Most queuing systems are modelled stochastically.
- ***Continuous vs. discrete:*** In continuous models, the values of the variables change gradually over time and are generally represented by differential equations, such as the growth of a plant, the filling of a car tyre or the variation in the level of a fuel tank. Discrete events, on the other hand, evolve as the system states are changed and are easily identified, such as a train stopping at a station or the assembly of the base of a chair. Discrete event simulation is our object of study.
- Although it is one of the most used tools in the operational research world, it is necessary to highlight what simulation is not Chwif and Medina (2006): simulation is not a crystal ball (it does not predict the future), it is not a mathematical model (closed analytical expression), it is not optimization (descriptive tool), it does not replace intelligent thinking (in the decision making process), it is not the technique of last resort (when other techniques fail) and it is not a panacea (only to very specific problems). Once the defined problem can be modeled by simulation, its advantages, disadvantages and risks are highlighted (BANKS and CARSON, 1984); LAW, 2007):

Advantages

- Most real systems cannot be accurately evaluated analytically. Simulation is the only way possible.

- Allows estimation of the performance of a system under designed operating conditions.
- Allows comparison of operating system designs.
- Allows control of experiment conditions (variance reduction), which would be possible only by experimentation.
- Allows time compression of long operations, or even time expansion.

Disadvantages

- Stochastic simulation produces estimates, and they depend on several rounds. If problem characteristics can be estimated by exact parameters, optimization is preferable.
- Software can be expensive and model development is time consuming.
- Realistic animations can be impressive, but there is a risk that the model is not valid (Type Zero Error).

Risks

- Not defining the objectives at the beginning of the simulation study.
- Involving everyone in the project from the beginning.
- Inadequate level of detail.
- Failure to communicate with management during the course of the study.
- Management team not understanding simulation.
- Treat simulation as programming.
- Not having staff knowledgeable in simulation methodology.
- Not collecting good data.
- Using inappropriate simulation software.
- Use poorly documented simulation software.
- Believing that good simulation software requires little technical competence.
- Misuse of animation.
- Using arbitrary distributions.
- Analyze results from one replication only and treat the result as "response".
- Do not consider warm-up time.
- Use wrong performance measures.

FlexSim: FlexSim is a discrete-event simulation software package developed by FlexSim Software Products, Inc. FlexSim Software Products' technical team has made a name for itself in the market by developing simulation software for 20 years. The company's goal is to create the best simulation software and the most powerful and user-friendly tools in the world. In FlexSim it is possible to perform discrete event simulation (DES) analysis, continuous simulation and because it has its open structure and developed with object-oriented programming, one can easily incorporate agent-based simulation (ABS) (FLEXSIM BRAZIL, 2017). Leading companies and universities are already adopting FlexSim as their solutions for process simulation and for production engineering labs. Among the Universities, UNICAMP, ITA, UNIFEI (Itajubá-MG campus), UFRN, UFC, USP, UFF, FACAMP, UFSCAR, UEM, UNISINOS, UDESC, FAI-MG, IFRN, UFOB, FAINOR, IFMG, UFSM (Production Engineering and Administration), PUC-GOIÁS, UNIT, UEPA, UNIVALI, UNESC, CEFET-MG, MAXPLANCK, UNINOVE, UNIFEI-Itabira/MG, UFPR (campus Jandaia do Sul-PR), PUC-MG, UFSJ, PUC-SC are all already FlexSim users in their laboratories. Among the companies, we have Tetrapack, AB-Inbev (AMBEV) and John & Deere global clients that use the simulator around the world in their facilities. DHL, FIAT, Coca-Cola, SENAI-PR, SENAI-SC, VALE, BMS-LOGÍSTICA, GOODYEAR, INVENSYS, FALCARE, POYRY, USINA GUARANI, NESTLE, JOHN DEERE, NOVARTIS, UNILEVER and, recently Embraco (Whirlpool) and VALE are some of the companies that are using FlexSim.

Production Lines: A production line is defined as a production set formed by several work posts (or stations), where there is a fluid movement system. Normally, tasks are divided by all workstations in an equal time format, where the product is transported consecutively from station to station, undergoing changes until it reaches the last station, which can be called the final product of the production line (BECKER & SCHOLL, 2006). A production line needs to have a good functioning, and as such, there are different important points to discuss, namely: paying attention to the number of operators, as it must be in concordance with the demand, so that there is no lack of production, but also no overproduction; the tidiness and cleanliness of the workstations, as well as the tools used by the operators must be of quick and easy access; the shortening of the distances between the operators, as well as performing the tasks standing, as it will allow transporting the parts to the next station with greater ease, obtaining less losses in temporal terms (SUZAKI, 2010). In the past, production lines produced a low variety of products in large volumes, which allowed low production costs, reduced time cycles and still with high levels of quality. However, over time the trend has been changing (SIMARIA et al., 2010), and currently, production lines produce a varied type of products, which even allows distinguishing different types of production lines. The major groups can be called single-model line, multi-model line or mixed-model line. The first classification mentioned refers to production lines that produce identical products with no differences between them. The multi-model line is a production line that presents significant differences in the process, and the central objective of these lines is to try to produce the largest quantity of the same model in order to minimize setup times (BECKER & SCHOLL, 2006). Setup times are understood as the period in which production is interrupted so that equipment can be adjusted to the new products. The mixed-model line refers to production lines that, despite producing different types of product, have a similarity in the processes, and there are no significant setup times to the adjustment of the process (BECKER & SCHOLL, 2006). According to Sarker and Pan (1998), in a production line there are several issues that must be addressed due to their importance, such as:

- Defining the cycle time;
- Determine the number of work stations;
- Balancing the production line;
- Determining the production order of the different models (if any).

The cycle time of a work station is the period between the production of two pieces, and in each of these periods the operator performs an operation, of each of the elements, which is his responsibility and in a sequential manner. The number of workstations is given by the quotient of the sum of all individual operations by the Takt Time, and is expressed by equation (1). The result of this expression indicates the minimum number of jobs that is necessary to meet market demand (SARKER & PAN, 1998), in other words, the minimum number of operators necessary to produce within Takt Time. .

$$Number\ of\ jobs = \frac{Sum\ of\ all\ the\ times\ of\ the\ individual\ tasks}{Takt\ time} \quad (1)$$

Sarker and Pan (1998) argue that another important indicator of a production line is the maximum production capacity, which shows the maximum number of parts that the line can produce. To determine the production capacity, it is necessary to identify the bottleneck of the production line. A bottleneck is understood as the position that limits the capacity or performance of a system. Finally, one can then calculate capacity by formula (2) (SARKER & PAN, 1998).

$$Production\ capacity = \frac{Time\ available\ in\ period\ p}{Time\ of\ the\ bottleneck\ positions} \quad (2)$$

Balancing Production Lines: Balancing the different jobs that make up a production line, adjusting it to the demand, is not always an easy task, especially when the process works to meet different products and various demands.

Production managers often make calculations in order to find the number of workstations that provide a constant flow to the process, reducing as much as possible the idleness of equipment and people. In the end, when rationalization is achieved and losses avoided, productivity reaches the desired levels, resulting in lower costs. When actions are aimed at reducing waste and optimizing resources, organizations gain competitive power, desire and quest of them all. Only in this way can they acquire greater market share and ensure the gains that will enable new investments. It is with the purpose of optimizing resources that balancing is supported and with such focus will be studied here. Balancing a production line is to adjust it to the needs of the demand, maximizing the use of its stations, seeking to unify the unit time of execution of the product. A production line is formed by a sequence of workstations, each with a well-defined function, aimed at the manufacture or assembly of a product. The stations are the steps that will allow the construction of the item to be manufactured. In a shoe industry, for example, sewing the fabric (leather) is one workstation and joining the leather to the sole is another. If the sewing of the leather goes faster than the joining of the leather to the sole, that is, it spends less unit time, a workstation made up of several posts of the sole can be composed, aiming to balance the system and make the two stations have equal or approximately equal times. In the manufacturing stages of the product, each post or workstation spends a certain amount of time to perform its task. If the time that each of the stations spends to make a product is the same, balancing has no problem. It already happens and producing more or less depends only on the cadence or speed imposed on the system. If the times are different, additional studies are needed.

Balancing steps: The line is composed of a series of phases which complement each other. The work stations are organised in a logical sequence, following a flow. But before going into the actual analysis of the phases, a few comments should be highlighted:

On the line, the product takes some time to go through all the stages. If the production of the system, for example, is 60 units per hour, a product comes out every minute. This time is called cycle time. It is determined by dividing the work time of the station by the quantity of products it releases or manufactures in the same time. In the exposed situation, the time spent is one hour (60 minutes) and in this interval 60 products are released. The division results in one product per minute. Thus, the cycle time (Tc) can be calculated by (3):

$$Tc = \frac{Total\ number\ of\ products\ produced}{Total\ time\ needed\ to\ produce\ the\ products} \quad (3)$$

Davis (2001) describes the steps required to balance a line as follows:

- Specify the sequential relationship between tasks using a precedence diagram;
- Determine the cycle time required;
- Determine the minimum theoretical number of workstations;
- Select a basic rule in which tasks have to be allocated to workstations and a secondary rule to break the tie;
- Delegate tasks one at a time to the first station until the sum of the times equals the cycle time. Repeat the process at the following stations;
- Evaluate the efficiency of the line.

Time and Methods Analysis: The analysis of times and methods, also known as Chronoanalysis, is an advanced quality tool that consists of the study of times and movements in a production line or logistics activity, with the aim of optimizing processes and eliminating waste in production (BARNES, 2009). In this way, the timing of each production process is done, in order to document the data and make an optimization study on top of the production flowchart. Thus, the Chronoanalysis can be applied at any stage of work, obtaining reliable results on the speed of tasks and movements performed, making it possible to determine the productive capacity of any sector or unit, besides comparing performances and generating essential information for management decision making. With this method, it is possible to discover the fastest and most efficient way to carry out a certain task, taking into account all the time and movement variables. Thus, productivity levels are boosted by faster processes, executed in the correct average time and with the minimum effort necessary to maintain the desired quality standard. Moreover, one of the most important points about Chronoanalysis is the prioritization of quality, since it is not enough to perform tasks quickly and accurately, but it is also necessary to maintain the standardized characteristics of the product to meet customer expectations (BARNES, 2009). Therefore, by applying the analysis of times and methods, it is possible to generate more agile processes and, at the same time, gain a higher quality in the final product, which will certainly eliminate waste and have a positive impact on sales. This methodology is applied when there is no concrete knowledge of the times and movements of production or of a certain process. This way, it is feasible to implement this analysis to identify the real lead time of each action, which consists as the time between the moment of the client's order and the delivery of this order. Thus, it is possible to diagnose the need for analysis of times and methods when it is necessary to have knowledge of costs and production flow and when there are imbalances in the flowchart, such as idle employees and/or overload in certain steps.

Data Processing: Data collection is the first stage of the empirical study. Equally important, was the prior definition of the Methodology and research design. At a later stage, data processing and analysis allows coding, categorising and grouping the data into a meaningful database appropriate to the research objectives and hypotheses. The choice of method (quantitative or qualitative) for data processing and analysis is fundamental to any type of research. It is important to ensure that the method chosen is the most appropriate to the type of data, the nature of the variables, and the research objectives and hypotheses.

Quantitative Data Analysis: Quantitative Data Analysis relies on statistical techniques and procedures that allow the processing and analysis of a large number of variables and observations. This analysis approach is based on the need to carry out an analysis focused on finding patterns of relationships between variables: association relationships, causality relationships between a dependent variable and (several) independent variables, studies of proportion and comparison of populations. Quantitative Data Analysis also allows obtaining statistical measures, indicators and parameters capable of describing behaviour, pointing out future trends and making inferences for the target population from the sample. In epistemological terms, Quantitative Data Analysis and Processing is based on a positivist position and develops a methodology based on quantitative tools aimed at validating previously defined hypotheses arising from a supporting theory.

Qualitative Data Analysis: Qualitative Data Analysis is based on the application of techniques which enable a more complete and profound perception of a more restricted reality. Through NVIVO and MAXQDA it is possible to proceed to the analysis of categories and units of information from interviews or participant observation (as qualitative data collection techniques) and thus gather the following indicators of analysis:

- Creation of Meaning Units;
- Creation of Nodes and Categories;
- Matrix and Structure of Analysis;
- Data triangulation.

The qualitative research paradigm does not focus on such a vast universe as in the quantitative approach, but rather aims to obtain the maximum amount of information on the values, beliefs and the process of the social fact under study, so as to provide the researcher with a vision of knowledge of the specific world, by means of the study and analysis of its actors. Qualitative Data Treatment and Analysis is therefore associated with an interpretative stance which seeks, through a massive collection of data, to find links between categories and concepts in order to build sufficiently valid theoretical assumptions that allow for generalization.

MATERIALS AND METHODS

Research Type: The type of research used for this project is the case study with quantitative emphasis which generally consists of a way of delving into an individual unit. It serves to answer questions that the researcher does not have much control over the phenomenon studied. This method is useful when the phenomenon to be studied is broad and complex and cannot be studied outside the context in which it naturally occurs. The tendency of the Case Study is to try to clarify decisions to be made. It investigates a contemporary phenomenon starting from its real context, using multiple sources of evidence. It is necessary to have different theoretical views about the studied subject, because they will be the basis to guide the discussions about a certain phenomenon constitute the orientation for discussions about the acceptance or not of the alternatives found. For this it is necessary to have a sample of various evidences. It is an investigation that deals with a specific situation, seeking to find the characteristics and what is essential in it. This study can help in the search for new theories and questions that serve as a basis for future investigations.

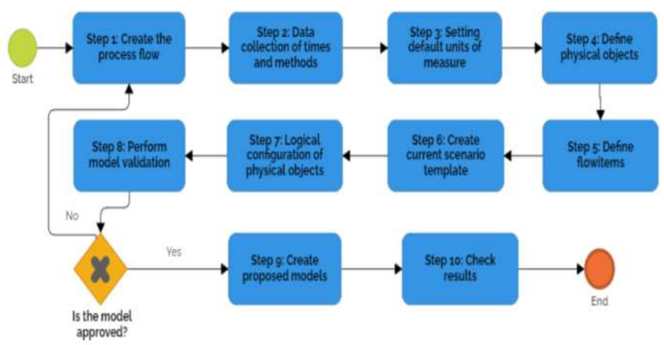
Data Collection: The exploratory case study will be used as techniques for data collection, in order to go deep into the production process to be analyzed and the analysis of times and methods so that it is possible to be verified if there are differences between the actual data and the documented data.

- The documentations will be analyzed the process flowcharts and operational balancing charts provided by the company that will be the environment of this study;
- Through videos and in loco observations will be collected the processing times of each workstation and machines used in the process;
- Visits will be made to the production process during a period of 15 days to analyze the behavior of operators and their efficiency at different times of the day;
- The data collected will all be checked and treated so that there is no presence of data that leave the analysis of the study biased.

Activities Balancing: After data collection, the balancing of the activities will be performed so that the bottlenecks are clear and allow for the creation of new balancing charts of operations, one for the current scenario and three new ones for the scenarios proposed by the study. Four charts will be created, one for each scenario, contemplating the time measurements of the jobs and identifying the bottlenecks and their limitations.

Using FlexSim to Simulate the Proposed Scenarios

After the data treatment, a simulation for the real scenario will be performed to validate the obtained data and then a simulation for each proposed scenario, allowing the survey of important results as the productive capacity and productivity values. With this it will be possible to define which of the proposed scenarios will be ideal for application in the process as shown in Figure 1 (Flowchart).



Source: Authors, (2022).

Figure 1. Flowchart Stages of FlexSim

The simulation creation steps have the following descriptions

- ***Step 1:*** in this step a mapping of the process flow and its activities is performed, which will serve as a basis for designing the simulation layout;
- ***Step 2:*** in this step, for each workstation and machine, the study of times and methods is performed, which will help in the future in the creation of the logic of each physical object present in the simulation;
- ***Step 3:*** initializing the software is necessary to configure the standard units of measure for time, distance and volume. For this study it was defined time in seconds (s), distance in meters (m) and volume in litres (l);
- ***Step 4:*** define the physical objects of the simulation. The physical objects represent the input inputs (Source), the activities present (Processor), the queues (Queue) and the outputs (Sink);
- ***Step 5:*** define the fluid objects of the simulation. They represent the product that passes through all the physical objects that in this case will be the product;
- ***Step 6:*** create the model of the current study scenario. In this step the physical objects are interconnected and associated with them the fluid objects;
- ***Step 7:*** configure the logic of the physical objects. In this step the logical parameters of each physical object are configured, such as the operating times, the probabilistic distributions that best suit it, the input or output constraints;
- ***Step 8:*** validation of the proposed model. In this step the simulation of a working day is performed for the model and then it is verified if the data referring to the simulation reflects the real data. If the simulation has the validation approved, we move on to the next step, otherwise we return to the first step;
- ***Step 9:*** creation of proposed models. Based on the simulation results of the current scenario new models are created with the implementation of process improvements;
- ***Step 10:*** verification of results. The results of each new model created are verified and based on them the choices of improvements to be implemented will be justified.

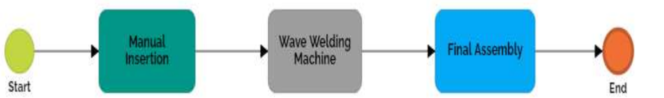
RESULTS AND DISCUSSION

Case Study Application - Scenario Description

Company Profile: The company chosen for this project is a Brazilian company that for over 32 years has been providing technology solutions in Brazil, Latin American countries, United States and Africa. Its portfolio includes products and services for TV, Internet, Connected Home and Solar Energy which together offer a complete experience of connected and sustainable life, as well as enterprise solutions in professional security, infrastructure for providers and manufacturing. The company's head office is in Valinhos (SP) where the administrative team, e-commerce, engineering, call-center and technical assistance are located. The factory is in Manaus (AM), in an area of 10,000m² allocated in the Free Trade Zone with our production line and storage teams. To facilitate research and enable business with international partners, has a unit in Shenzhen in China.

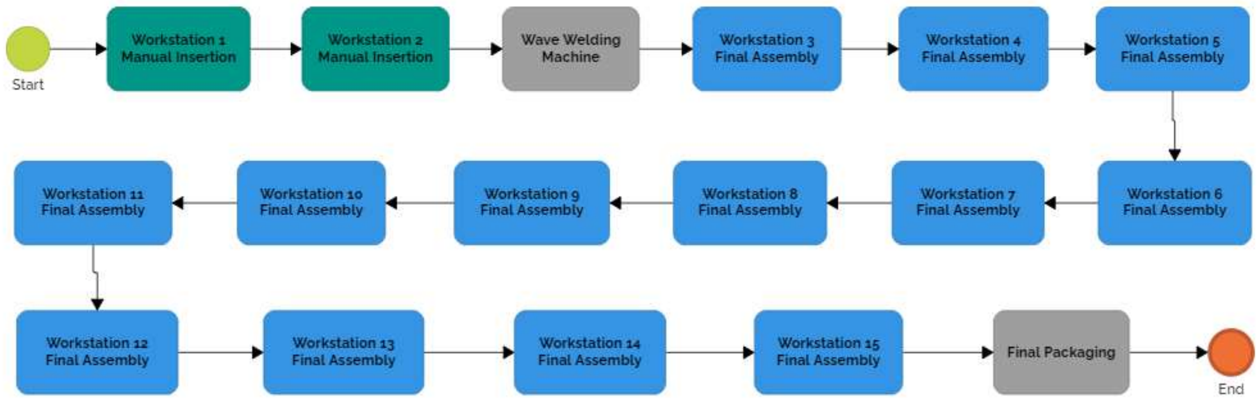
Production Process of BETA CR

The production process of BETA CR has three main steps: Manual Insertion, Wave Soldering and Finishing (Figure 2). The focus of the study will be on redesigning the process so that the Manual Insertion and Wave Welding steps no longer exist. In all, the process has seventeen work stations (Figure 3) and the daily target for finished products is 2000 units.



Source: Authors, (2022).

Figure 2. Process Flowchart



Source: Authors (2022).

Figure 3. Flowchart of the current process

Product and Process Data Survey

Product Description: Information pertaining to its configurations, features and functionality will also be kept confidential.

Source: Authors (2022).

Figure 4. Image CR BETA

Description of Process Steps - Manual Insertion: Process stage in which operators manually fit PTH type components onto the boards.

In this step 2 assembly stations are used:

- ***Workstation 1:*** in this activity two components are manually inserted into the PCB (Printed Circuit Board) the components are a thermistor and a crystal;
- ***Workstation 2:*** in this activity two components are manually inserted into the PCB (Printed Circuit Board) the components are a spring for positive polarity and a spring for negative polarity;

Wave Soldering Machine: Process stage in which the boards pass through a soldering machine and the components are soldered on the boards by means of soldering waves. At this stage an operator is responsible for the use of the machine.

Finishing: Process stage where activities are carried out to finalise the product, such as: cabinet assembly, tests and packaging. At this stage 13 assembly stations are used:

- ***Workstation 3:*** in this activity the soldering of the boards are reviewed, manually corrected if necessary and the boards are separated as they are soldered in the soldering machine in sets of seven boards;
- ***Workstation 4:*** at this stage per PCB a led is manually inserted and soldered;
- ***Workstation 5:*** at this stage glue is applied to the thermistor and crystal terminals using a gun;
- ***Workstation 6:*** at this stage the metaldome is applied to the PCB. The metaldome is a metallic adhesive that is used to make contact between the control keys and the PCB;
- ***Workstation 7:*** at this stage a blanket of rubbery consistency is applied to the sides of the PCB;
- ***Workstation 8:*** at this stage the display and the zebra connector are connected to the PCB;
- ***Workstation 9:*** at this stage the display and zebra connector are connected to the PCB;
- ***Workstation 10:*** at this stage the PCB is screwed into the bottom cabinet of the control;
- ***Workstation 11:*** at this stage the top cabinet and keyboard are plugged into the bottom cabinet;
- ***Workstation 12:*** at this stage the display is cleaned with an ionised air jet and a film is applied to the display;
- ***Workstation 13:*** at this stage the electrical functional test of the control is performed by means of a test Jig, in case it is approved or not approved the label present in the control cabinet is read and the status is catalogued in Tamba (System developed by the company to control production indicators);
- ***Workstation 14:*** in this step is performed functional electrical test of the control through a test Jig, if approved or failed the label present in the control cabinet is read and the status is catalogued in Tamba (System developed by the company to make the control of production indicators);
- ***Workstation 15:*** at this stage a test is performed in which a camera captures images from the display and verifies if all segments are working properly, if approved or failed the label on the control cabinet is read and the status is catalogued in Tamba (System developed by the company to control production indicators).

Defects

- Failure to operate the remote control: corresponding to 5% of the defects, its cause is the fitting of components with the polarity inverted;
- Failure to use the keys: corresponding to 80% of the defects, caused by the accumulation of NC 200 flux on the plates during the welding process;
- Open cabinet: corresponding to 15% of the problems, the cause is non-compliant raw material coming from the supplier.

Data Collection

- Data regarding machine processing times were acquired through interview with the technician responsible for programming the wave soldering machines and the soldering robot machines;
- Data referring to times and methods were at first collected through process documentations. However later it was detected that the documentations were biased because they considered the operator performing his activities with 100% efficiency. Thus, a new data collection was performed based on the observation of the operators performing their activities during the day.

Machine Analysis - Wave Welding Machine: In order for the process to have the expected production capacity of 1800 units per day it is necessary to use a wave soldering machine, known as Wave Machine MS-450 (Figure 5). The machine uses Tin Lead solder and NC215 flux to perform the soldering.

Source: Authors (2022).

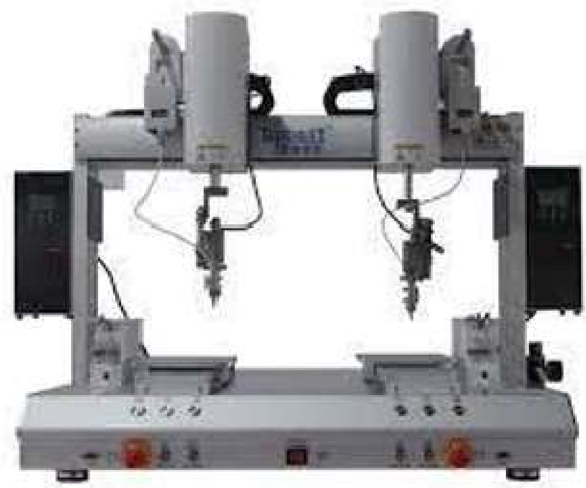
Figure 5. Wave Welding Machine

The machine is not dedicated this means that other products besides the BETA CR and this makes it necessary to use welding pallets (Figure 6) with a capacity of 7 plates per pallet, on which the plates are fitted before going through the Manual Insertion.

Source: Authors (2022).

Figure 6. Welding Pallet

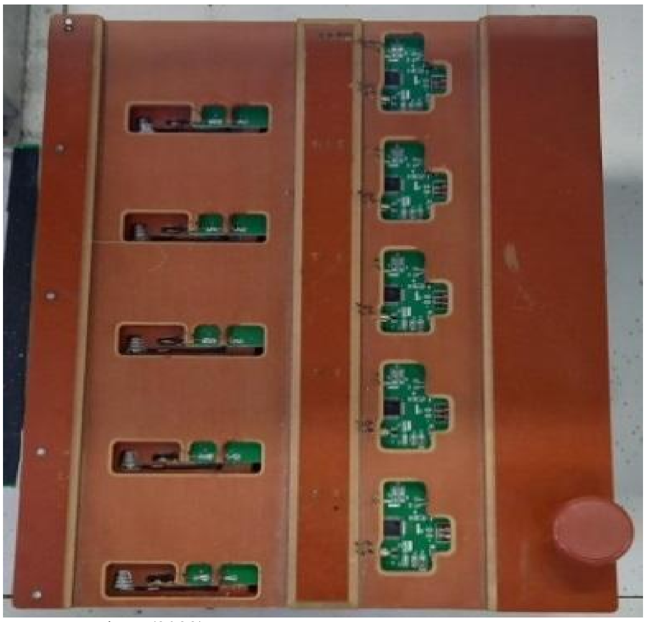
Robot Welding Machine: In order to eliminate the defects caused by using NC215 flux, a welding robot machine is required (Figure 7). The machine uses Tin Lead solder on wire to perform the soldering. The machine features high precision in soldering PTH components as it does the soldering point by point.



Source: Authors (2022).

Figure 7. Welding Robot Machine

The machine is dedicated this means that no more than one product is used in addition to the BETA CR and this makes it necessary to use welding bases (Figure 8) with a capacity of 5 plates per base, in which the plates are fitted and the components are manually inserted into the machine.



Source: Authors (2022).

Figure 8. Welding base

Analysis of Substances - Tin-Lead Solder: The tin-lead solder is still widely used in Brazil and one of the main advantages is its wetting and excellent finish. But we can enter the study of resistance of materials, the tin-lead solder has a temperature of ± 180 ° C to melt, so it has a great tenacity and ductility, or can resist vibrations and impacts, thus bringing great reliability to the metal alloy. Evidencing the good reliability in electronic manufacturing, tin-lead solder is used in industry sectors where reliability is required, such as Automotive; Medical; Aeronautics and Military.

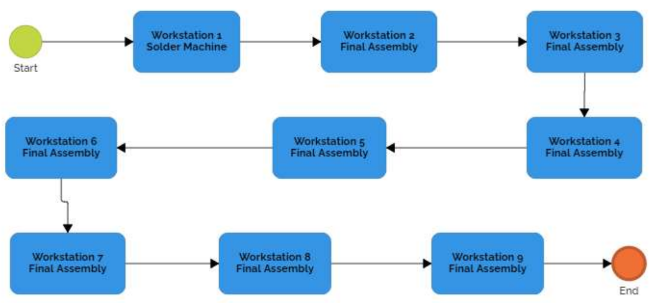
Tin-Lead Bar Solder, Flux-cored Tin-Lead and Flux-cored NC215: Tin-bar solder is commonly used in the THT process, where solder bars are inserted into the tanks of the solder wave machine. The use of this type of weld requires the use of some type of flux in conjunction to ensure good weldability. This weld is used in the current scenario because the product has a lower production volume and is welded together with other products with a larger volume in the Wave Solder Machine. These are welds with greater scope, being used in the reworking of components in the electronic manufacturing process. This process commonly uses manual or automated welding stations. In the proposed scenarios the use of this type of solder is of vital importance because the Soldering Robot Machine is compatible only with solder wire and the product is compatible only with solder tin lead. Soldering flux, or soldering flux as it may also be called, is a product used to prepare the area where soldering will take place. It is generally used on printed circuit boards to chemically remove oxidation from the terminals on the surface. The soldering flux for tin is strongly recommended in cases where a quick, clean and efficient soldering is desired, and extremely indicated in cases where the soldering will be done with solid soldering wire (it does not have internal flux, as well as the resin soldering wire) and in cases where the area to be soldered has dirt, rust or grease. The flux used in the process is NC215. The fluxes that have the inscription NC (No-Clean) are those odorless, free of lead in its composition, which prevents the release of smoke with bad smell.

Scenario Proposals: As the wave welding machine will no longer be used, three scenarios were proposed considering the use of a welding robot machine, thus eliminating the manual insertion and wave welding process. All the stages are now concentrated in the Finishing.

The original process was balanced and now has nine assembly stations (Figure 9), including the use of the welding robot machine.

- ***Workstation 1:*** in this step the components assembly is done in the fixed bases of the robot machine and the machine performs the welding of five components, being them a led, a thermistor, a crystal, a positive spring and a negative spring;
- ***Workstation 2:*** in this stage the revision of the welding is made and its correction if necessary, the excess of the component terminals is also cut and glue is applied with the help of a gun in the crystal and thermistor terminals;

Scenario 1 - Robot Machine Welding Five Components

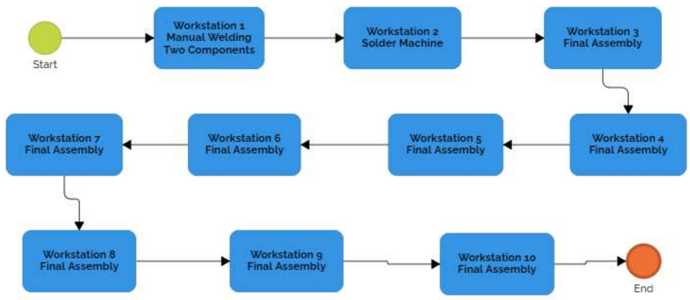


Source: Authors (2022).

Figure 9. Process Flowchart Scenario 1

- ***Workstation 3:*** at this stage labels and metaldome are applied to the PCBs (printed circuit boards);
- ***Workstation 4:*** at this stage the blanket is applied to the sides of the PCB, the Display is fitted to the PCB and the PCB is fitted to the top cabinet;
- ***Workstation 5:*** in this step the upper cabinet is fixed to the lower cabinet and a label is applied to the cabinet;
- ***Workstation 6:*** the current test is performed and the test status is linked to the label by Tamba (system developed by the company to generate process indicator control);
- ***Workstation 7:*** the control functions are tested and the test status is linked to the label by Tamba (system developed by the company to generate process indicator control);
- ***Workstation 8:*** the Display is cleaned with an ionized air jet and a protective film is applied;
- ***Workstation 9:*** products are packed in collective boxes.

Scenario 2 - Robot Machine Welding Two Components



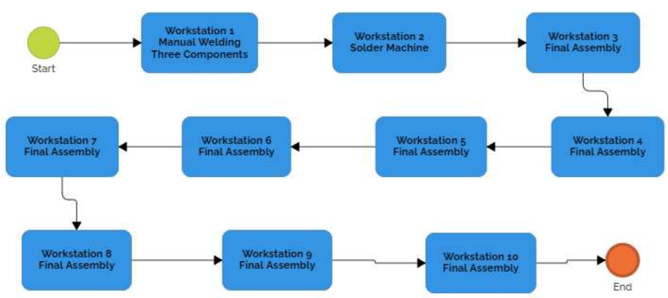
Source: Authors (2022).

Figure 10. Process Flowchart Scenario 2

The original process was balanced to have ten assembly stations (Figure 10), including the use of the welding robot machine.

- ***Workstation 1:*** at this stage the assembly and welding of three components, being them a led, a positive spring and a negative spring are done manually;
- ***Workstation 2:*** at this stage the assembly of the components is done on the fixed bases of the robot machine and the machine performs the welding of two components, being them a thermistor, a crystal;
- ***Workstation 3:*** at this stage the revision of the solder is made and its correction if necessary, the excess of the component terminals is also cut and glue is applied with the help of a gun on the crystal and thermistor terminals;
- ***Workstation 4:*** at this stage labels and metaldome are applied to the printed circuit boards (PCBs);
- ***Workstation 5:*** at this stage the blanket is applied to the sides of the PCB, the Display is fitted to the PCB and the PCB is fitted to the top cabinet;
- ***Workstation 6:*** in this step the upper cabinet is fixed to the lower cabinet and a label is applied to the cabinet;
- ***Workstation 7:*** the current test is carried out and the test status is linked to the label by Tamba (system developed by the company to generate process indicator control);
- ***Workstation 8:*** the control functions are tested and the test status is linked to the label by Tamba (system developed by the company to generate process indicator control);
- ***Workstation 9:*** the Display is cleaned with an ionized air jet and a protective film is applied;
- ***Workstation 10:*** products are packed in collective boxes.

Scenario 3 - Robot Machine Welding Three Components



Source: Authors (2022).

Figure 11. Process Flowchart Scenario 3

The original process was balanced to have ten assembly stations (Figure 11), including the use of the welding robot *machine.*

- ***Workstation 1:*** at this stage the assembly and welding of two components, being them a positive spring and a negative spring are done manually;

- ***Workstation 2:*** in this stage the assembly of the components is done in the fixed bases of the robot machine and the machine performs the welding of two components, being them a thermistor, a Crystal and a Led l;
- ***Workstation 3:*** in this stage the revision of the solder is made and its correction if necessary, the excess of the component terminals is also cut and glue is applied with the help of a gun in the crystal and thermistor terminals;
- ***Workstation 4:*** at this stage labels and metaldome are applied to the PCBs;
- ***Workstation 5:*** at this stage the blanket is applied to the sides of the PCB, the Display is fitted to the PCB and the PCB is fitted to the top cabinet;
- ***Workstation 6:*** in this step the upper cabinet is fixed to the lower cabinet and a label is applied to the cabinet;
- ***Workstation 7:*** the current test is carried out and the test status is linked to the label by Tamba (system developed by the company to generate process indicator control);
- ***Workstation 8:*** the control functions are tested and the test status is linked to the label by Tamba (system developed by the company to generate process indicator control);
- ***Workstation 9:*** the Display is cleaned with an ionized air jet and a protective film is applied;
- ***Workstation 10:*** products are packed in collective boxes.

Scenario Simulation using FlexSim - Current Scenario Simulation: Based on the time collection of the activities it was generated the Table 1, which consists in 10time measurements for each activity, each measurement is an average referring to 15 days.

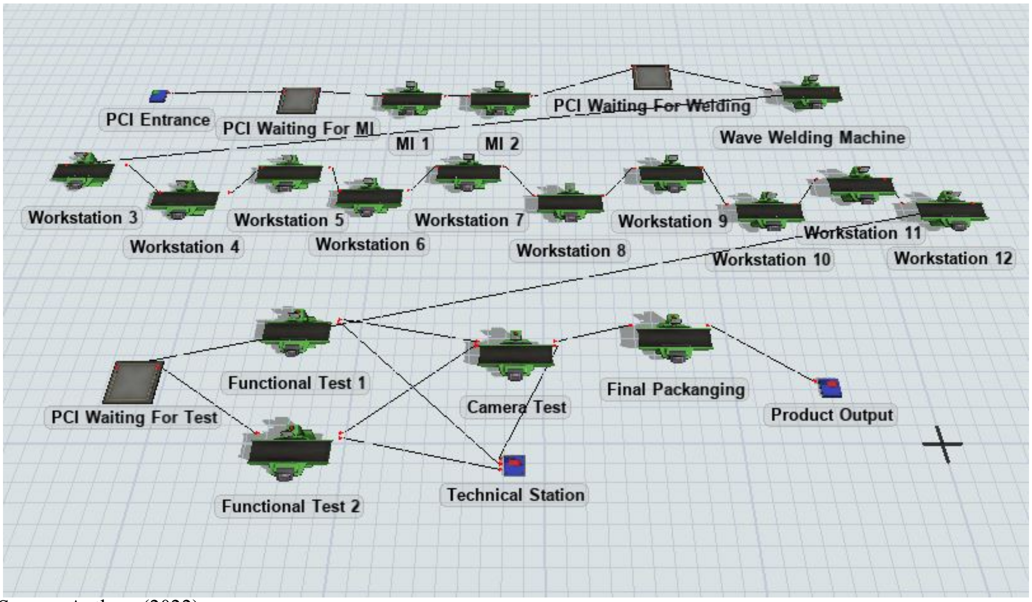
A sThe simulation was created in the FlexSim software based on the data in Table 1.1, getting the following layout according to Figure 12. Based on the simulation of an 8.75h shift we achieved results similar to the real ones and with that the actual scenario was considered valid.

Simulation Scenario 1 - Robot Machine Welding Five Components

To perform the simulation of scenario 1 the information referring to Table 2 was considered. In this new scenario the activities were balanced due to the removal of the manual insertion and considering the use of the welding robot machine. The simulation was created in the FlexSim software based on the data in Table 1.2, getting the following layout according to Figure 13. Based on the simulation of a shift of 8.75h we got the following results:

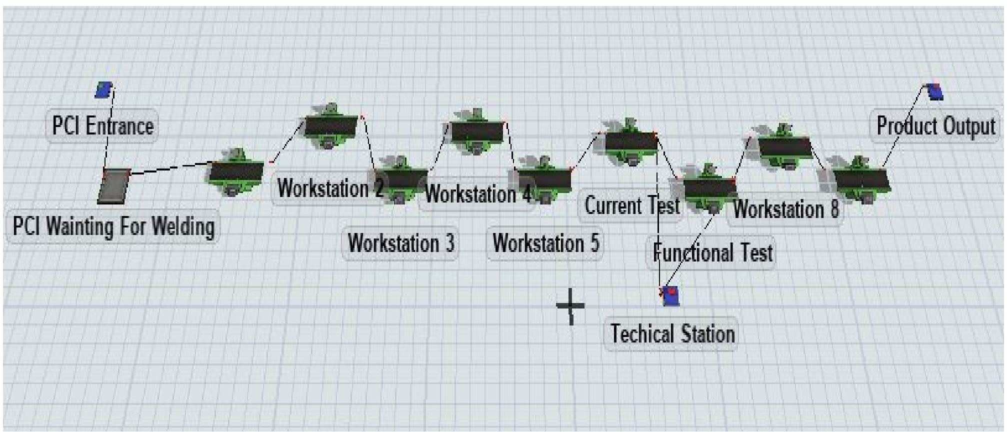
- The production capacity was limited to 1500 parts per shift, this result was due to the limitation of the robot machine;
- Its productivity increased by 47.06% compared to the real scenario.

Simulation Scenario 2 - Robot Machine Performs Welding of Three Components: To perform the simulation of scenario 2 the information referring to Table 3 was considered. In this new scenario the activities were balanced due to the removal of the Manual Insertion and considering the use of the robot machine welding three components.The simulation was created in the FlexSim software based on the data in Table 3, getting the following layout according to Figure 14. Based on the simulation of an 8.75h shift we obtained the following results:



Source: Authors (2022).

Figure 12. FlexSim simulation of the Real Scenario



Source: Authors (2022).

Figure 13. FlexSim simulation of Scenario 1

Table 1. Time of the activities of the Actual Scenario

MODEL: CR BETA	**DEMAND:**					**2000 UND/DAY**				**TAKT TIME:**			**15,8s**
FASE: M.I. AND F.A.	AVAIABLE TIME:					8,75 H				CYCLE TIME:			14,5s
ACTIVITY	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	AVERAGE	% LOSS	STANDARD TIME
Workstation 1 Manual Insertion	70,2	72,4	73,7	74,3	74,6	70,2	72,4	73,7	74,3	74,6	73,1	10%	11,5
Workstation 2 Manual Insertion	65,2	64,2	64,6	65,2	66,4	65,2	64,2	64,6	65,2	66,4	65,1	10%	10,2
WaveWeldingMachine	120,0	120,0	120,0	120,0	120,0	120,0	120,0	120,0	120,0	120,0	120,0	10%	18,9
Workstation 3 Final Assembly	94,3	90,2	89,6	91,2	92,4	94,3	90,2	89,6	91,2	92,4	91,6	10%	14,4
Workstation 4 Final Assembly	42,6	42,3	44,6	44,1	45,2	42,6	42,3	44,6	44,1	45,2	43,8	10%	12,0
Workstation 5 Final Assembly	7,5	7,7	7,8	8,0	7,1	7,5	7,7	7,8	8,0	7,1	7,6	10%	8,4
Workstation 6 Final Assembly	18,2	17,8	19,1	18,8	18,8	18,2	17,8	19,1	18,8	18,8	18,3	10%	10,1
Workstation 7 Final Assembly	13,3	12,6	12,4	12,4	11,3	13,3	12,6	12,4	12,4	11,3	12,4	10%	13,6
Workstation 8 Final Assembly	34,2	33,2	33,5	34,5	35,2	34,2	33,2	33,5	34,5	35,2	34,2	10%	18,8
Workstation 9 Final Assembly	36,2	35,3	35,4	34,8	36,9	36,2	35,3	35,4	34,8	36,9	35,7	10%	19,7
Workstation 10 Final Assembly	13,2	13,2	13,3	14,2	12,5	13,2	13,2	13,3	14,2	12,5	13,3	10%	7,3
Workstation 11 Final Assembly	11,2	12,4	11,8	12,4	12,0	11,2	12,4	11,8	12,4	12,0	12,0	10%	13,2
Workstation 12 Final Assembly	10,1	11,2	9,2	10,2	11,3	10,1	11,2	9,2	10,2	11,3	10,4	10%	11,4
Workstation 13 Final Assembly	18,5	17,0	17,6	17,7	17,2	18,5	17,0	17,6	17,7	17,2	17,5	10%	9,7
Workstation 14 Final Assembly	19,3	19,4	18,8	19,5	18,6	19,3	19,4	18,8	19,5	18,6	19,1	10%	10,5
Workstation 15 Final Assembly	13,1	13,4	12,5	13,5	13,0	13,1	13,4	12,5	13,5	13,0	13,1	10%	14,4
Final Packaging	12,3	11,2	12,3	13,1	12,5	12,3	11,2	12,3	13,1	12,5	12,3	10%	13,5

Source: Authors (2022).

Table 2. Time of the activities of Scenario 1

MODEL:CR BETA	DEMAND:					1280 UND/DAY				TAKT TIME:			24,6s
FASE: M.I. AND F.A.	AVAIABLE TIME:					8,75 H				CYCLE TIME:			22,6s
ACTIVITY	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	AVERAGE	% LOSS	STANDARD TIME
Workstation 1 SolderMachine	140,2	145,2	144,4	142,8	144,9	140,2	145,2	144,4	142,8	144,9	143,5	10%	13,1
Workstation 2	14,1	14,4	14,2	13,7	14,2	14,1	14,4	14,2	13,7	14,2	14,1	5%	11,9
Workstation 3	18,4	18,6	19,0	18,2	18,1	18,4	18,6	19,0	18,2	18,1	18,5	10%	15,5
Workstation 4	18,5	19,0	17,3	18,7	19,0	18,5	19,0	17,3	18,7	19,0	18,5	10%	15,7
Workstation 5	20,1	19,3	20,3	20,4	19,5	20,1	19,3	20,3	20,4	19,5	19,9	10%	14,9
Workstation 6	17,5	17,2	17,0	17,6	17,5	17,5	17,2	17,0	17,6	17,5	17,4	10%	15,5
Workstation 7	18,5	19,2	20,1	19,7	20,3	18,5	19,2	20,1	19,7	20,3	19,6	5%	15,8
Workstation 8	16,2	15,5	16,4	15,7	16,5	16,2	15,5	16,4	15,7	16,5	16,1	5%	14,7
Workstation 9	15,2	15,4	15,3	16,0	15,7	15,2	15,4	15,3	16,0	15,7	15,5	10%	15,5

Source: Authors (2022).

Table 3. Time of the activities of Scenario 2

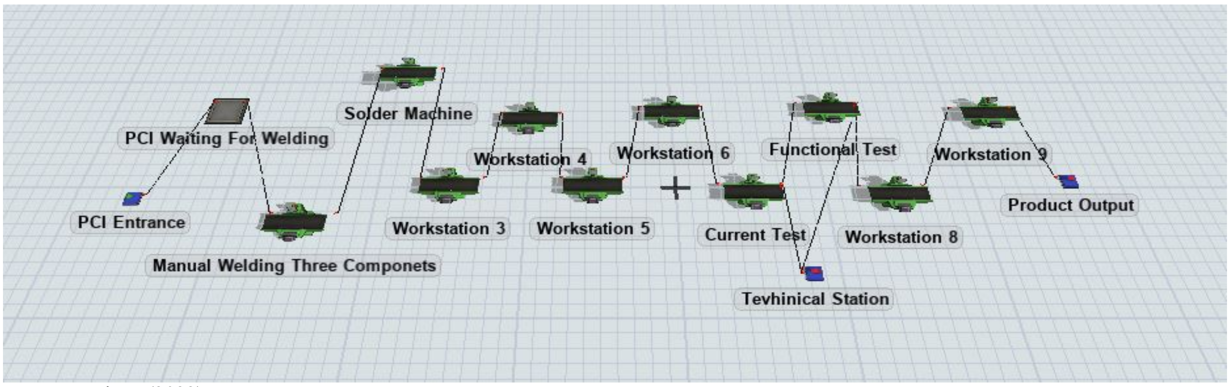
MODEL:CR BETA	DEMAND:					2000 UND/DAY				TAKT TIME:			15,8s
FASE: M.I. AND F.A.	AVAIABLE TIME:					8,75 H				CYCLE TIME:			14,5s
ACTIVITY	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	AVERAGE	% LOSS	STANDARD TIME
Workstation 1 Manual Welding Two Componets	10,5	11,1	10,9	11,2	10,8	10,5	11,1	10,9	11,2	10,8	11,9	10%	12,0
Workstation 2 SolderMachine	120,2	125,2	124,4	122,8	124,9	120,2	125,2	124,4	122,8	124,9	123,5	5%	13,0
Workstation 3	14,1	14,4	14,2	13,7	14,2	14,1	14,4	14,2	13,7	14,2	14,1	10%	15,5
Workstation 4	14,3	14,5	14,4	14,2	14,1	14,3	14,5	14,4	14,2	14,1	14,3	10%	15,7
Workstation 5	13,5	14,0	12,3	13,7	14,0	13,5	14,0	13,3	12,7	14,0	13,5	10%	14,9
Workstation 6	14,1	14,3	14,3	14,4	13,5	14,1	14,3	14,3	14,4	13,5	14,1	10%	15,5
Workstation 7	15,1	14,8	14,9	15,2	15,0	15,1	14,8	14,9	15,2	15,0	15,0	5%	15,8
Workstation 8	14,5	13,2	14,1	13,7	13,3	14,5	13,2	15,1	14,7	13,3	14,0	5%	14,7
Workstation 9	13,2	14,5	13,4	14,7	13,5	13,2	14,5	13,4	14,7	15,5	14,1	10%	15,5
Workstation 10	13,2	13,4	13,3	14,0	13,7	13,2	13,4	13,3	14,0	13,7	13,5	10%	14,9

Source: Authors (2022).

Table 4. Time of the activities of Scenario 3

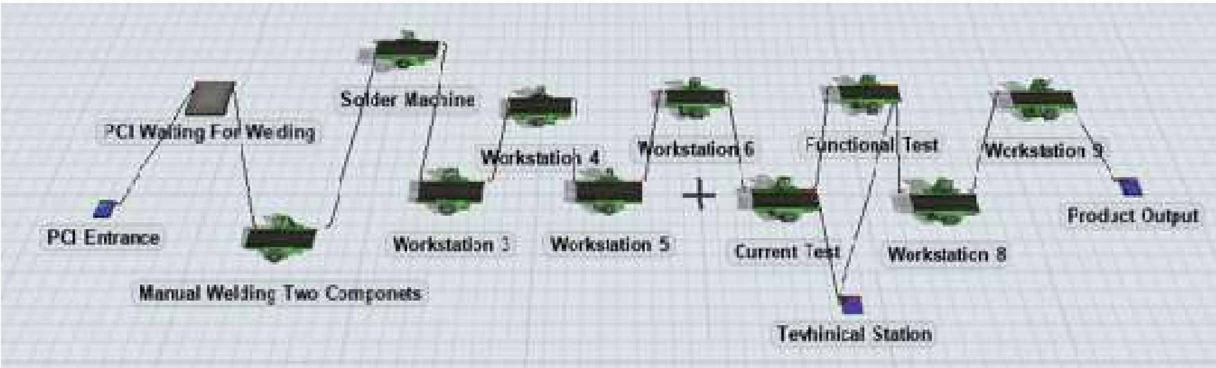
MODEL:CR BETA	DEMAND:					2000 UND/DAY				TAKT TIME:			15,8s
FASE: M.I. AND F.A.	AVAIABLE TIME:					8,75 H				CYCLE TIME:			14,5s
ACTIVITY	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	AVERAGE	% LOSS	STANDARD TIME
Workstation 1 Manual Welding Three Componets	11,5	12,1	11,9	12,2	11,8	11,5	12,1	11,9	12,2	11,8	11,9	10%	13,1
Workstation 2SolderMachine	110,2	115,2	114,4	112,8	114,9	110,2	115,2	114,4	112,8	114,9	113,5	5%	11,9
Workstation 3	14,1	14,4	14,2	13,7	14,2	14,1	14,4	14,2	13,7	14,2	14,1	10%	15,5
Workstation 4	14,3	14,5	14,4	14,2	14,1	14,3	14,5	14,4	14,2	14,1	14,3	10%	15,7
Workstation 5	13,5	14,0	12,3	13,7	14,0	13,5	14,0	13,3	12,7	14,0	13,5	10%	14,9
Workstation 6	14,1	14,3	14,3	14,4	13,5	14,1	14,3	14,3	14,4	13,5	14,1	10%	15,5
Workstation 7	15,1	14,8	14,9	15,2	15,0	15,1	14,8	14,9	15,2	15,0	15,0	5%	15,8
Workstation 8	14,5	13,2	14,1	13,7	13,3	14,5	13,2	15,1	14,7	13,3	14,0	5%	14,7
Workstation 9	13,2	14,5	13,4	14,7	13,5	13,2	14,5	13,4	14,7	15,5	14,1	10%	15,5
Workstation 10	13,2	13,4	13,3	14,0	13,7	13,2	13,4	13,3	14,0	13,7	13,5	10%	14,9

Source: Authors (2022).



Source: Authors (2022).

Figure 14. FlexSim simulation of Scenario 2



Source: Authors (2022).

Figure 15. FlexSim simulation of Scenario 3

- The production capacity was limited to 2650 parts per shift, this result was due to the removal of two components from the robot machine;
- Its productivity increased by 41.18% compared to the real scenario.

Simulation Scenario 3 - Robot Machine Welding Two Components: To carry out the simulation of scenario 3 the information referring to Table 4 was considered. In this new scenario the activities were balanced due to the removal of the manual insertion and considering the use of the robot machine welding two components. The simulation was created in the FlexSim software based on the data in Table 4, getting the following layout according to Figure 15.

Based on the simulation of an 8.75h shift we obtained the following results:

- The production capacity was limited to 2800 parts per shift, this result was due to the removal of two components from the robot machine;
- Its productivity increased by 41.18% compared to the real scenario.

Discussion of Results

Innovations Compared to the Current Scenario: The proposed scenarios present as main innovations the use of process simulation by means of FlexSim for decision making and the development of more resistant welding bases and the use of the welding robot machine that allows for greater precision in welding the PTH components.

Advantages and Disadvantages of the Proposed Scenarios

Advantages - Scenario 1: Reduced number of manpower; Better distribution of activities; Cost reduction by not using bar welding; Cost reduction by not using NC215 flux; Elimination of defects caused by using NC215 flux; Reduction of energy costs by not using IM's (Manual Insertion Line) and Wave Welding Machine; and Low rate of welding failure.

Disadvantages - Scenario 1: Limited production capacity; Machine with dedicated use; Use of direct labour in the operation of the robot machine.

Advantages - Scenario 2: Reduced manpower; Better distribution of activities; Cost reduction by not using bar welding; Cost reduction by not using NC215 flux; Elimination of defects caused by using NC215 flux; Reduction of energy costs by not using IM's (Manual Insertion Line) and Wave Welding Machine; Low rate of welding failure; Productive capacity 32,5% higher than the real scenario.

Disadvantages - Scenario 2: Machine with dedicated use; Use of direct labour in the operation of the robot machine; Need for one more direct labour for manual welding of PTH components.

Advantages - Scenario 3: Reduced number of manpower; Better distribution of activities; Cost reduction by not using bar welding; Cost reduction by not using NC215 flux; Elimination of defects caused by using NC215 flux; Reduction of energy costs by not using IM's (Manual Insertion Line) and Wave Welding Machine; Low rate of welding failure; Productive capacity 40% higher than the real scenario

Disadvantages - Scenario 3: Machine with dedicated use; Use of direct labour in the operation of the robot machine; Need for an additional direct labour for manual welding of PTH components.

CONCLUSION

The study aimed to propose production scenarios in which the main problem generated by the residual flux NC215 was eliminated and also to provide an increase in production capacity. To eliminate the residual flux NC215 it is necessary that there is the change of machinery to perform the welding of the PTH components, in this case the wave soldering machine will be changed by the soldering robot machine.In order that the simulation in FlexSim returns values close to the real ones, a simulation of the current scenario was created that served as a base for the creation of three proposed scenarios:- Scenario 1: Robot Machine Performs Welding of Five Components;- Scenario 2: Robot machine welds three components;- Scenario 3: Robot Machine Welds Two Components. Based on the results of the simulation the Scenario 3 presents the best results and it is the ideal as solution for the problem because it does not present the presence of defects generated by the flow NC215 and presents a productive capacity of 2800 parts per day, being superior to the current scenario and the other proposed scenarios.

ACKNOWLEDGEMENTS

To the Institute of Technology and Education Galileo from Amazonia (ITEGAM) and Postgraduate Master in Engineering, Process Management, Systems and Environmental (EPMSE/ITEGAM). Manaus-Amazonas, Brazil to finance and support the research.And a special thanks to my colleague and great friend William Bruno Soares Rodrigues. He was the person who most motivated and helped me toconcludethis article.

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