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ANALYSIS AND COMPUTATIONAL MODELING OF THE ADHESIVE RIBBONS MANUFACTURING PROCESS IN A COMPANY OF THE MANAUS INDUSTRIAL HUB: AN APPLICATION IN FLEXSIM® SOFTWARE

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ABSTRACT

Whether in the product or the process, the strategy of investing in innovation is necessary for companies to remain in a dynamic, fast-paced, and fiercely competitive economy. Industry 4.0 is a global reality, and the factories installed in the Industrial Pole of Manaus (PIM) need to restructure to absorb the technological advances of this new industrial paradigm. With this in mind, this research, subsidized by investments in research and development (R & D) in the Western Amazon, proposes to optimize a production cell in a company located in the PIM that operates in the adhesive ribbon sector. The study was based on one of the pillars of Industry 4.0: digital discrete event simulation using Flexsim® software. The model's data was collected from June to November 2021 and processed using the ExpertFit® tool, a statistical software supplement. Due to the large number of products processed by the company, this study focused its analysis on only one ribbon type; however, its results can be mirrored for all products of this family. The construction and subsequent comparative analysis of seven scenarios with optimized proposals reached an ideal solution with significant reductions. If implemented in the physical process, it would result in cost savings for the company through increased productivity and reduced inventories in the production process, thus achieving the objectives of optimizing the production cell.

Keywords: Industry 4.0; Computer Simulation; Process Optimization; FlexSim® software.

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INTRODUCTION

With an increasingly dynamic economy and fierce competition in all sectors, companies need to invest in innovation in their products and production processes to remain in the market (Censi *et al.*, 2014).

Industry 4.0 has been proposed as a new phase of industrial maturity, based on the connectivity provided by the Industrial Internet of Things (IoT) and various digital technologies such as cloud computing, big data, and artificial intelligence (Dalenogare *et al.*, 2018; Frank *et al.*, 2019).

Industry 4.0 (I4.0) is also known as the Fourth Industrial Revolution, named by the German government for the "smart factory" creation. In implementing I4.0, the social challenges are as far-reaching as the systemic ones, even for companies with a history of years of experience in adopting new automation technologies (Santos *et al.*, 2018). Industry 4.0 is nothing more than a production system.

The Fourth Industrial Revolution is inserted in an environment where changes occur continuously and rapidly. Computer simulation is an innovative and powerful tool for saving time and financial resources, gaining productivity and quality in analyzing complex processes and systems, and enabling the study, analysis, and evaluation of situations (numerous scenarios) that would not be possible in real life. In a world of increasing competition, computer simulation has become an indispensable problem-solving methodology for decision-makers in many different areas since it allows testing alternatives before applying them, proving or not the benefits of future investment (Shannon, 1998; Abreu *et. al.*, 2017).

The Manaus Industrial Pole (PIM) is one of the largest poles in Latin America and is the mainstay of the Manaus Free Trade Zone (Suframa, 2019 apud Silva, 2021). Its industries need and are being restructured to absorb the technological advances of this new industrial paradigm. According to Silva (2021), the PIM ranked level 3 (transition) on a scale ranging from 1 to 4 in the Industry 4.0 Maturity and Readiness Measurement test and thus is able to compete with other regions of the country and with the foreign market. However, there is still much to be done so that strategies and the application of innovation and technology in production processes are implemented to ensure that industries remain competitive.

The company, which has been in business for 15 years and where the research was conducted, is in the context presented above and continuously seeks to adapt and transform its adhesive ribbon manufacturing into a process adherent to Industry 4.0.

The article aims to assess the production cell entitled "Guzzetti" of an adhesive ribbon factory located in the Industrial Complex of Manaus that produces, among its product families, the polyethylene ribbon 48mm x 5m, chosen as the base product for developing the computational simulation. The study used computer simulation via Flexsim® software to analyze and verify ways to optimize the efficiency of the cell globally.

In order to meet the objectives, this paper presents the following structure: The initial chapter modeling the production process of adhesive ribbon manufacturing will address the steps of data collection and initial process analysis; the next chapter, simulation and analysis of the results of the adhesive ribbon production cell, will deal with the development of the model and the results of the initial simulation analyses; finally, the chapter optimizing the production process of adhesive ribbon manufacturing will discuss the implications of the improvement scenarios elaborated.

METHODS

According to Shriber apud Freitas Filho (2008), simulation is the result of modeling a process or system to imitate the responses of the real system using events that occur over time. To prepare for this study, we used the procedure presented by Banks and Carsen (1984), as illustrated in **Figure** 1.

The company under study is an entirely national-capital organization founded in 2005 and specialized in manufacturing adhesive ribbons. The Guzzetti cell currently produces four different types of products on its production lines among the existing production cells. The company has a growing demand; however, its production presents discontinuous flows, excess stock in process, and bottlenecks in the production flow, thus limiting its growth.

The Guzzetti cell comprises the following machines: rewinder, slicer, and wrapper. The workforce within the cell is divided as follows: one operator is responsible for handling the rewinder, one for the slicer, and two operators in the wrapper.

For the simulation studies, the goal is that the production gains generated through the adjustments should be within a minimum margin of 10% above the cell's current productivity. In addition, the adjustments should contemplate the reduction of in-process inventory through line balancing, and a more efficient layout should be found to improve the production system.

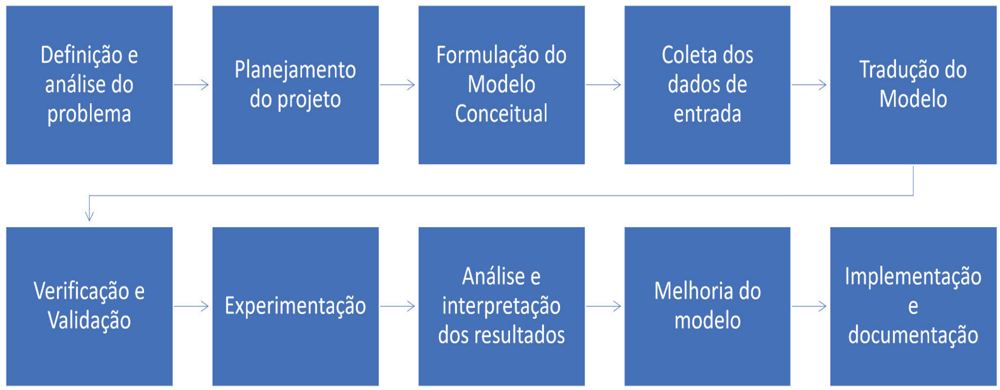

Figure 1. Procedure applied in a simulation study
Source: Adapted from Bank and Carsen (1984)

Data collection and processing

Regarding data collection, technical visits were scheduled to catalog information. During these visits, the teams, equipped with stopwatches and clipboards, were divided among the machines in the cell to establish a chronoanalysis process to collect the operators' and machines' activity times.

The main difficulties observed were processes with long durations and the lack of operators working in some steps, which impacted the flow progress. It was observed that the slicer operator performed activities in parallel, and as there was only one researcher in each machine, the timing had to be done simultaneously, using two devices.

There was also the factor of the data collection availability for the packaging machine since, as it was the final output of the system, its operation only occurred after all the ribbons of the sliced production order, thus depriving the observation during the visits. This fact greatly affected how the model would work because only after recordings of its processes were made during the scheduled visits specific to this machine was it possible to realize which components and physical processes should be modeled.

The way the production processes are executed also lacked standardization among the shifts, resulting in times with high standard deviation, thus hindering the approval of the statistical sampling tests required for validating the times in the computational model.

Added to the fact that a Production Order (PO) takes more time than the available observation period per visit, there was an increase in planned visits, and the video cameras were used to more accurately capture the many activities occurring simultaneously.

At least 100 times were collected for each of the activities performed. "The sample size should be between 100 and 200 observations. Samples with less than 100 observations may compromise identifying the best probabilistic model, and samples with more than 200 observations do not yield significant gains to the study" (Medina and Chwif, 2006).

The times of each production process were supported by the ExpertFit tool for statistical analysis, which ranked the best formula among its various types of statistical distributions in its database. Thus, the sample can be submitted to a statistical test module that divides it into intervals that evaluate its distribution: Anderson Darling, Kolmogorov-Smirnov, and ChiSquare. In the case of failure in these tests, the sample is submitted to a data treatment to extract the outliers identified using a boxplot of the sample. The samples and recommended distributions for each proven process are shown in **Table** 1.

Besides the statistical data collection, the cell layout was graphically represented in AutoCAD® software to be later included in the computational model to represent the actual distances the operators will travel to execute the activities.

MODELING THE PRODUCTION PROCESS OF ADHESIVE RIBBON MANUFACTURING

Conceptual model

The conceptual model is paramount to building a complete and valid computational model (Chwif, 2010). Wang and Brooks (2007) state that conceptual modeling deals with how the virtual world of the simulation model should work and usually contains all the interactions and rules that determine the behavior of the entities present in the system. The authors also state that although there are several methods available for developing the conceptual model, it has been shown that the most widely used representation technique is the flowchart.

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Table 1. Statistical distributions and error rate of productive activities

Variable	Recommended distribution	Average Chronoanalysis	Average Simulation	% ERROR
Rewinding machine feed	loglogistic (0.000000, 3.610153, 14.229032)	13.79	13.74	0.36%
Rewinding (machine)	johnsonbounded (7.438481, 18.187610, -0.891039, 2.332411)	8.79	8.62	1.93%
Manual rewinder settings	loglaplace (4.648260, 3.531613, 2.599906)	3.87	3.72	3.88%
Removal of logs from the rewinder	loglaplace (1.730584, 1.859416, 4.544446)	3.68	3.95	6.84%
Slicing machine feeding	erlang (0.061244, 0.487545, 37.000000)	18.1	18.45	1.90%
Slicing start programming	johnsonbounded (2.559744, 26.759565, 1.700215, 0.946911)	7.04	7.37	4.48%
Slicing (machine)	loglogistic (104.808941, 12.537654, 6.980450)	117.29	117.72	0.37%
Busy Slicer Operator	beta (13.912238, 86.974348, 0.614132, 0.843935)	44.74	44.15	1.32%
Removing slivers from slicing machine	loglogistic(17.654637, 6.826998, 3.377454)	25.45	25.52	0.27%
Straightening ribbons on the wrapping machine conveyor	erlang (1.985722, 1.647209, 2.000000)	5.28	5.66	6.71%
Wrapper (machine)	erlang (0.023470, 0.114380, 139.000000)	16.39	15.86	3.23%
Labeling boxes	johnsonbounded (8.952412, 97.240539, 0.839510, 0.485406)	32.04	31.42	1.94%
Robot	uniforme	7	7	0.00%
Box assembly	erlang (0.005465, 0.732972, 10.000000)	7.34	7.51	2.26%

Source: The authors (2021)

Furthermore, Pereira (2010) states that the lack of a conceptual model or its poor preparation may lead to a computational model that requires rework and/or will not be able to capture the simulation objectives.

Thus, a flowchart of the company's production process was prepared (see **Figure** 2), in addition to vertical flowcharts for each machine. These representations helped build the conceptual model of the simulation since it enabled identifying the flow of movement of materials, products, and people from the receipt of raw materials to the final product, providing the opportunity to analyze and investigate the possible causes that generate the problem to be solved by the simulation.

The production process begins with the jumbo's (raw material) transportation to the rewinding machine; then, the core is inserted into the machine, and the jumbo is rewound according to the product's length, becoming a log; finally, it is placed on a cart to be transported to the slicing machine.

The ribbon-cutting (slicer) consists of a process where the log inserted into the machine undergoes a transformation and becomes a ribbon. The machine used in this process can slice up to two logs at a time and release 22 ribbons per log.

Finally, the wrapper will pack the ribbons individually. A robot will do the labeling and take them through a conveyor belt to cardboard boxes with the capacity to store up to 15 ribbons per box. They are then placed on a pallet and wait to be shipped to the final destination.

Creating the Scenarios: Actual and Standard

All collected data becomes concrete in the computational model and is inserted into simulation software, where it is verified, validated, and analyzed so that improvement proposals can be suggested and implemented (Medina and Chwif, 2010).

According to Banks (1998), computer simulation allows studies to be carried out about systems that do not yet exist, considering the development of efficient projects without any physical change having been initiated.

The computational model was built using FlexSim® software version 21.2.4. This software was chosen for its ease of use, flexibility in modeling the manufacturing system, and the use of ExpertFit, which assists in defining statistical distributions, and Process Flow, which guides the movement of

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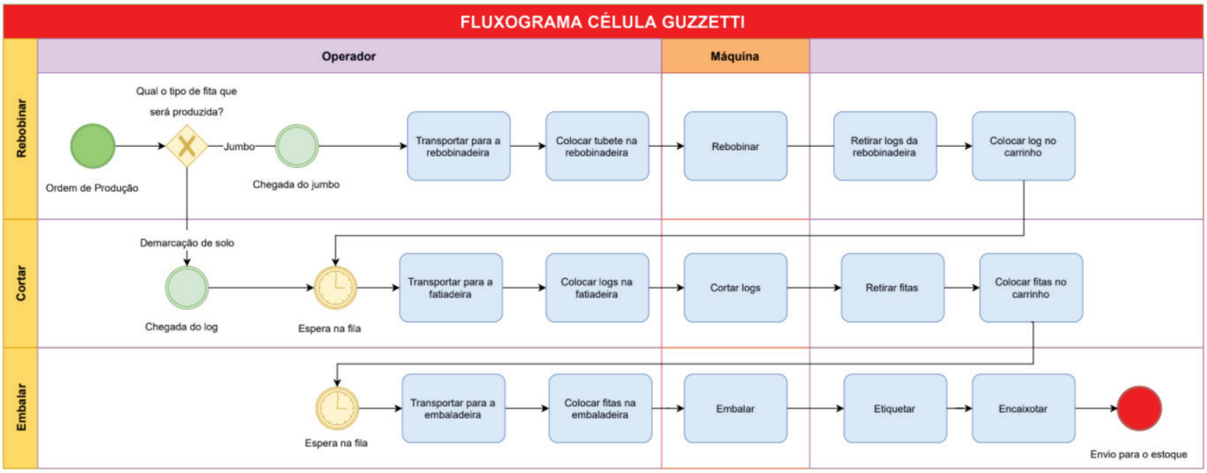

Figure 2. Flowchart used to elaborate the conceptual model of the production process

Legend: GUZZETTI CELL FLOW CHART; Operator – Machine; Rewind (Vertical); Production Order; What type of ribbon will be produced?; Jumbo; Jumbo arrival; Transport to rewinder; Place core in the rewinder; Rewind; Remove logs from rewinder; Put log in cart; Slice (Vertical); Ground demarcation; Log Arrival; Waiting in line; Transport to the slicer; Put logs in slicer; Cut logs; Remove logs; Put logs in cart; Wrap (Vertical); Waiting in line; Transport to the wrapper; Putting ribbons on the wrapper; Wrap; Label; Package; Ship to stock.

Source: The authors (2021)

the 3D model through block diagrams, keeping the logic in a convenient location and allowing adjustment as shown in **Figure** 3 (FlexSim®, 2021).

The input data provided by the company and those obtained by the chrono analysis were used to build the model. An average loss of 3% of the ribbons was considered, evaluated as defective, and discarded based on the analysis of the production orders, as shown in **Table** 2.

As the beginning of the development of the computational model took place concomitantly with data collection, the logic of the computational model was constantly modified because the initial data had a high standard deviation, hindering statistical test approval. Moreover, due to the limited history of documented production data, it was decided to simulate both the real and the standard scenarios. Chart 1 describes the main differences between the two scenarios.

Simulation and analysis of the results of the adhesive ribbons production cell based on Flexsim® software

The simulation was designed to represent a production order (PO) of 300 logs, according to the approximate value

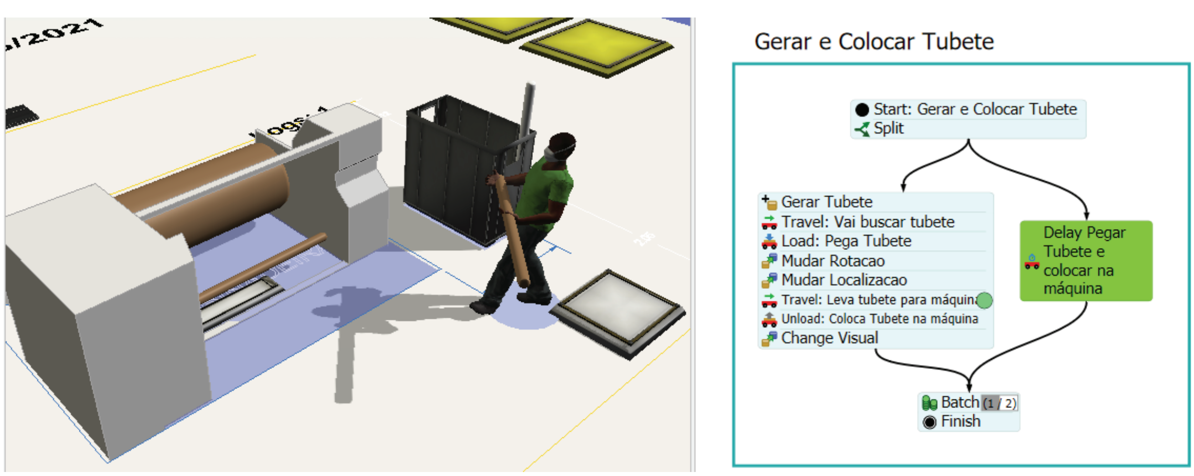

Figure 3. Features used in the FlexSim® software to represent core feeding

Legend: Generate and Place Tube; Start: Generate and Place Tube; Generate Tube; Travel: Search Tube; Load: Pick up tube; Change rotation; Change location; Travel: Take tube to machine; Unload: Place tube in machine; Change Visual; Delay Pick up tube and put it into the machine (Green box); Batch; Finish.

Source: The authors (2021)

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Table 2. Production loss of production orders (POs) of the studied product

Measurement	Programmed	Executed	Non-compliant	% Error
Average production	8,725.00	8,457.00	268.00	3.07%
Standard deviation	7,321.00	7,122.00	199.00	2.72%

Source: The authors (2021)

Variable	Actual Scenario	Standard Scenario
Material flow between machines	According to the historical survey of production data, it is characterized by presenting the average waiting time between machines. After the production of the first cart on the rewinder, it waits for the stipulated time to be transferred to the slicer.	It represents the movement of batch products between machines in the production cell. Once a batch is finished on the rewinder, it is sent to the slicer; similarly, a batch finished on the slicer is sent to the wrapper.
Slicing machine	The operator worked on two slicers in this scenario, but only one machine operated the studied product. The time the operator was away from the studied machine was counted as the idle time of the slicer. In this scenario, the operator did not prioritize the machine under study.	The operator worked on two slicers in this scenario, but only one machine operated the studied product. The time the operator was away from the studied machine was counted as the idle time of the slicer. In this scenario, the operator did not prioritize the machine under study.

Chart 1. Description of the current and standard scenarios

Source: The authors (2021)

of the historical average production from January to September 2021 of 48mm x 5m polyethylene ribbons, as shown in Table 3.

Table 3. Historical average of the production orders (POs) of the studied product

Measurement	Programmed logs	Produced logs
Average production	343.21	310.16
Standard deviation	452.30	450.79

Source: The authors (2021)

The model's input variables (arrival) were the execution times of each step of the production process, the interval between the arrival of production orders at each machine, and some setup times. These variables were inserted into the computational model using the distributions obtained and approved by ExpertFit®.

The computational model was developed considering the following operation sequence: after feeding the rewinder with a jumbo (raw material), the machine performs the rewinding, and the operator places the logs on the cart; when it completes 60 logs, it is transported to the intermediate stock; the slicer operator acquires the logs that were rewound and placed on the cart and inserts them into the machine to start slicing. When 90 logs (1,980 strips) are completed, the slicer operator prepares the pallet to be taken to the intermediate stock of the wrapper.

The wrapper operator feeds the machine, where seven ribbons will be wrapped simultaneously with individual packages. After packaging, the ribbons are transported by conveyor belts to the device that inserts product identification labels, and then a robot places them in cardboard boxes of three to five units until 15 ribbons are completed. Then the boxes are packed in the third machine and are palletized by the same operator, who feeds the machine at the beginning of the process. When the quantity of 180 boxes is complete, the pallet is transported to shipping.

The model's output variables were: the hourly production rate of the machines; the utilization and idleness status of the operators and machines; the distance traveled by the operators (total and per hour); the amount of product in stock between machines; and production order duration.

Verification and validation of the model were necessary before experimentation and analysis of the output data. "A model is ready to be verified when it works in the manner intended by the modeler" (Bateman *et al.*, 2013, p. 37). Sargent (2007) argues that validation is concerned with the correct model construction and addresses how closely it approximates the actual system, ensuring its use for the purpose it was developed.

For validation of the computational model, machine processing times (**Table** 4) and average cycle times (**Table**

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5) were compared with the outputs of the computational model, considering an error rate of up to 10%.

Table 4. Validation of machine processing time

Machine	Real	Simulated	% Error
Rewinder	13.79	13.65	1.02%
Slicer	117.70	117.42	0.24%
Wrapper	16.39	15.99	2.44%

Source: The authors (2021)

Table 5. Validation of the average cycle time (seconds)

Machine	Real	Simulated	% Error
Rewinder	22.40	22.00	1.79%
Slicer	83.58	90.00	7.13%
Wrapper	76.95	77.00	0.06%

Source: The authors (2021)

Furthermore, Law (2015) states that this step is one of the biggest challenges present in simulation analysis, as it is necessary to ensure that the computational model is, in fact, a valid representation of the actual system for the specific goals of the study.

Outputs and analysis of the results

By analyzing the current factory process simulations, possible problems and their possible causes were identified. Based on this identification, optimized solutions could be proposed to make the cell more efficient, decrease the work in the process, and increase productivity.

Two scenarios were analyzed to identify the cell's problems: the actual scenario and the standard scenario representing the plant's current process.

The following output variables were analyzed to ensure the simulation goals and improvement analysis:

Hourly production rate of the machines

See Figures 4 and 5 in the Gantt chart of the machines. For both scenarios, see the times for each machine and the time when the PO processing starts (when the "Suspend" ends).

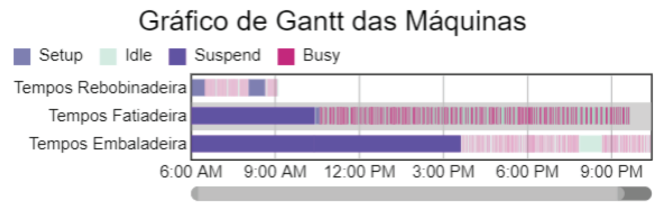

Figure 4. Processing times for each machine - actual scenario

Legend: Gantt chart of the machines; Setup – Idle – Suspend – Busy; Times in the Rewinder; Times in the Slicer; Times in the Wrapper.

Source: The authors (2021)

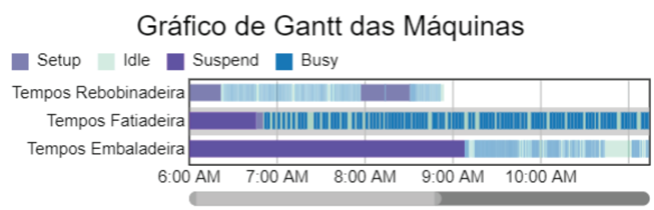

Figure 5. Processing times for each machine - standard scenario

Legend: Gantt chart of the machines; Setup – Idle – Suspend – Busy; Times in the Rewinder; Times in the Slicer; Times in the Wrapper

Source: The authors (2021)

In both scenarios, it can be seen that the processing speed of the rewinder is higher than that of the other machines. Figure 6 illustrates the log production per hour of the rewinder and slicer in the standard scenario.

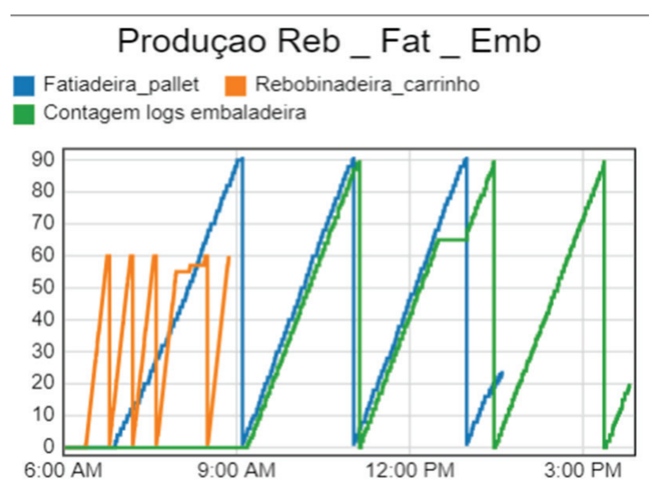

Figure 6. Production rate per hour in the standard scenario

Legend: RewinderSlicerWrapper Production; SlicerPallet; Rewindercart; Log counting in the wrapper

Source: The authors (2021)

In Figure 7, it is possible to notice the difference in time for the start of production in the slicer compared to the end

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of production of the rewinder in the actual scenario and the standard one; this is due to the rewinder having a shorter production time than the others.

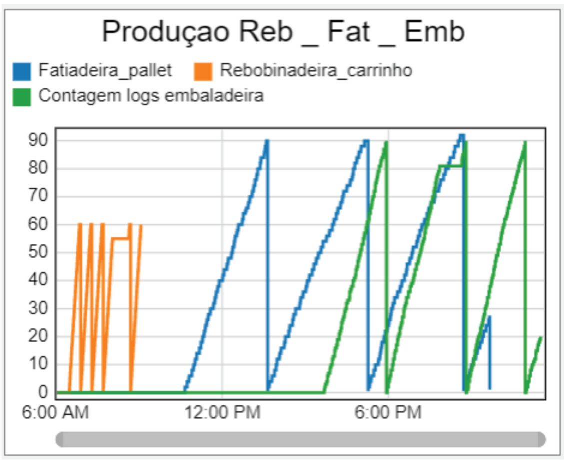

Figure 7. Production rate per hour in the actual scenario

Legend: RewinderSlicerWrapper Production; SlicerPallet; Rewindercart; Log counting in the wrapper

Source: The authors (2021)

PO duration time

The PO duration time comprises the time required to process the 300 logs from their entry into the system to the exit of the packed boxes. Table 6 illustrates the difference between the actual and standard scenarios.

Table 6. Production order duration between scenarios

Production order duration (PO)	
Actual Scenario	17:30:00
Standard Scenario	09:49:12

Source: The authors (2021)

The standard scenario processes the same PO (production order) in six hours less than the actual one since it does not consider the waiting interval between the machines (see **Table** 7). The use of this variable allows the activation of the slicer and wrapper machines to take a significant amount of time, making the PO duration longer.

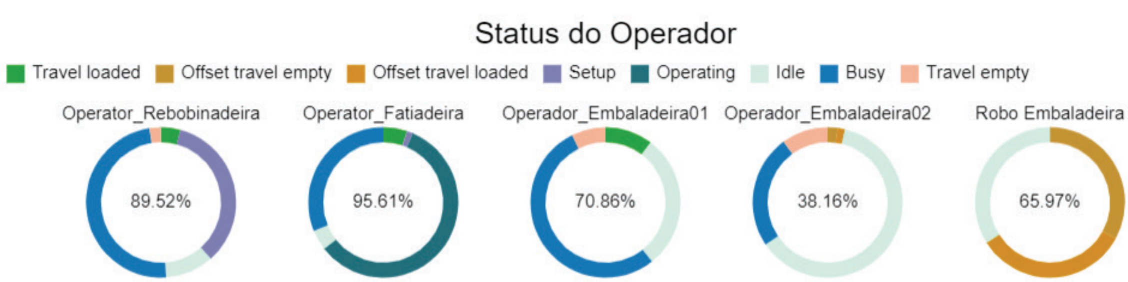

Figure 8. Referenced operator times - actual scenario

Legend: Operator Status; Travel loaded - Offset travel empty - Offset travel loaded - Setup - Operating - Idle - Busy - Travel empty; RewinderOperator - SlicerOperator - WrapperOperator01 - WrapperOperator02 - WrapperRobot

Source: The authors (2021)

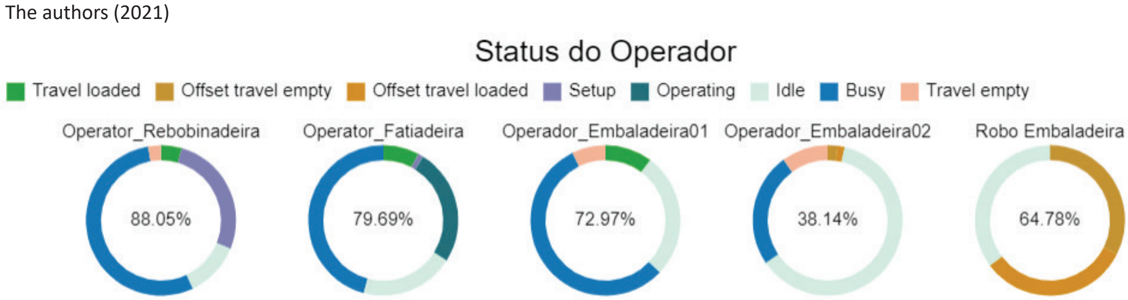

Figura 9. Referenced operator times - standard scenario

Legend: Operator Status; Travel loaded - Offset travel empty - Offset travel loaded - Setup - Operating - Idle - Busy - Travel empty; RewinderOperator - SlicerOperator - WrapperOperator01 - WrapperOperator02 - WrapperRobot

Source: The authors (2021)

Table 7. Waiting time between machines (hours)

Measurement	Rewinder – Slicer	Slicer – Wrapper
Mean	4.40	5.20
Standard Deviation	0.15	3.55
Minimum	0.07	0.65
Maximum	11.83	11.50

Source: The authors (2021)

Operator utilization and idle status

The simulation provides their idle rate with the operators' activities validated, as seen in **Figure**s 8 and 9.

The rewinder operator has the lowest idle time because the machine cycle is short. On the other hand, operator 01 of the wrapper has the longest time in "travel loaded" because he needs to supply the wrapper according to his pace.

Wrapper operator 02 has the lowest busy time in both scenarios because his function is basically to align the ribbons on the conveyor belt after they leave the wrapper and to make sure that all the ribbons have an identification label before they are boxed.

Machine utilization and idle status

In the analysis of the machines (**Figure**s 10 and 11), it was possible to observe a significant setup time of the rewinder, resulting from the need for adjustments and intermediate setups for jumbo changes during the production process.

In both scenarios, the wrapper machine presented a high idleness rate of 48.74% and 48.55%, respectively. This fact occurred due to the unbalanced interval for ribbon arrival in the machine. In the actual scenario (**Figure** 10), we have a high idleness rate of the slicer because, in this scenario, the operator worked on two slicers, but only one machine operated the studied product. The time that the operator was absent from the studied machine was counted as idle machine time, and, as described in the scenario creation step, the operator did not prioritize the machine under study.

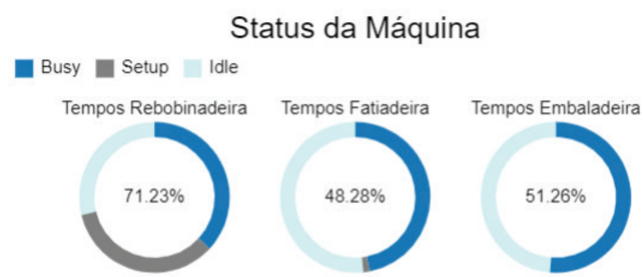

Figure 10. Operation times of each machine - actual scenario

Legend: Machine Status; Busy - Setup – Idle; Times in the Rewinder; Times in the Slicer; Times in the Wrapper

Source: The authors (2021)

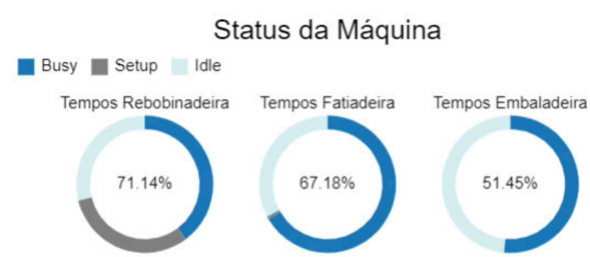

Figure 11. Operation times of each machine - standard scenario

Legend: Machine Status; Busy - Setup – Idle; Times in the Rewinder; Times in the Slicer; Times in the Wrapper

Source: The authors (2021)

Total distance traveled by the operators

The inclusion of the cell layout allowed extracting the travel distances of the operators during the production process. This indicator enables evaluating the performance of new cell layouts based on the current arrangement. Figu-

Figure 12. Distance traveled by operators - actual scenario

Legend: Distance traveled by the OperatorKilometers; RewinderOperator - SlicerOperator - WrapperOperator01 - WrapperOperator02

Source: The authors (2021)

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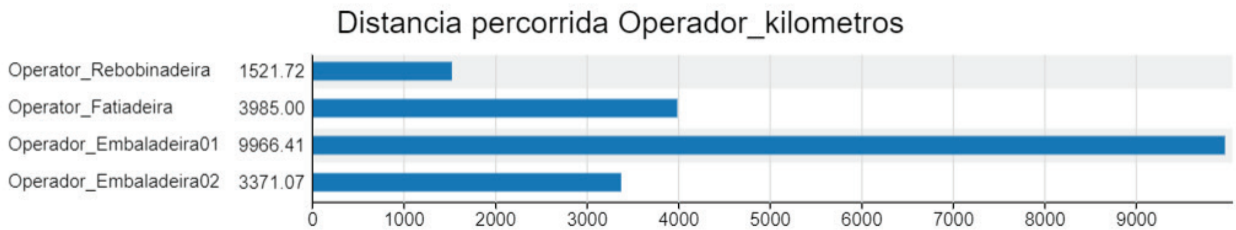

Figure 13. Distance traveled by operators - standard scenario

Legend: Distance traveled by the OperatorKilometers; RewinderOperator - SlicerOperator - WrapperOperator01 - WrapperOperator02

Source: The authors (2021)

res 12 and 13 show that operator 1 of the wrapper machine travels the greatest distance during the process because he alternates between the regular feeding and the completion of the boxes in the wrapper, thus making these movements numerous times during the machine cycles.

Duration and amount of product in stock between machines

Figures 14 and 15 show the behavior of the stock waiting to be processed before the slicer and the wrapper. In the actual scenario, the rewinder finishes the production of all 300 logs and sends them to stock, thus reaching the maximum point in the graph. When the slicer is activated, the operator starts removing these logs from the stock for processing, thus leading to a decrease in stock, as shown in **Figure** 14. In addition, there is the stock of ribbons waiting to be packaged, which reaches up to 2500 ribbons for the actual scenario.

By analyzing **Figure** 15, it is possible to verify that the stock of logs waiting to be sliced reaches a maximum value of 200 and then exhibits falling behavior. Meanwhile, the stock of ribbons waiting to be packaged reaches its maximum value of 1982 and presents an average of 1035 ribbons during the simulated time. Thus, a large number of ribbons or logs awaiting processing can be seen in the stock.

Figure 14. Intermediate Stock per machine - actual scenario

Legend: Stock to be sliced; Log stock; Stock to be packed; Sliced ribbon stock

Source: The authors (2021)

Figure 14. Intermediate Stock per machine - standard scenario

Legend: Stock to be sliced; CartFAT; Stock to be packed; Sliced ribbon stock

Source: The authors (2021)

Table 8. Improvement scenarios with the current layout and its lot sizes

Cenários	Quantidade de Fatiadeiras	Lotes	
		Rebobinadeira -> Fatiadeira (Logs)	Fatiadeira -> Embaladeira (Logs fatiados)
Cenário 3.1	1	60	60
Cenário 3.2	1	40	60
Cenário 2.1	2	60	90
Cenário 2.2	2	60	60
Cenário 2.3	2	40	60

Legend: Scenarios (Column 1); Scenario 3.1; Scenario 3.2; Scenario 2.1; Scenario 2.2; Scenario 2.3; Quantity of Slicers (Column 2); Lots (Columns 3 and 4); Rewinder -> Slicer (Logs) (Column 3); Slicer -> Wrapper (Column 4); (Sliced Logs)

Source: The authors (2021)

OPTIMIZATION OF THE PRODUCTION PROCESS

In this topic, we intend to demonstrate how computer simulation can contribute to improving production processes. Thus, seven (07) scenarios were prepared for simulating the production of polyethylene adhesive ribbon model 48 mm x 5m:

- Five scenarios that had the current factory layout proposed a change in the lot size of intermediate manufacturing stocks in an attempt to reduce the production order time; and
- Two scenarios contemplated a new production layout so that the production flow is more continuous without the need for constituting lots between processes.

The five scenarios for the same current cell layout were named in Table 8. It also contains the respective sizes of intermediate batches and the number of slicers driven to process the analyzed PO.

Two scenarios were created with the new layout: one scenario has one slicer to process the studied ribbon, and the other scenario has two slicers processing the same studied ribbon, called scenarios 3.1 and 3.2, respectively.

It is worth noting that the criterion for the duration of the improvement scenarios simulation remains the average of the POs of 300 logs, equivalent to 6,600 ribbons produced, with an expected output of 425 cases, considering the 3% loss rate.

Problem Analysis

Since the batch size delimitation in the topic “Output and data analysis” could directly influence the addressed problems of the cell for developing the improvement scenarios, it was decided to test models with smaller lot sizes and analyze how the cell would behave.

The lot sizes were as follows: rewinder cart to the slicer with lots of 40 (reducing the current lot by 20 units) and 60 logs; and the slicer pallet to the wrapper with lots of 60 and 90 logs, respectively, making their possible combinations in the scenarios, as will be discussed later.

Regarding the issue of the rewinder processing being superior to the others, it was decided to simulate some scenarios with two slicers processing the same ribbon studied and, thus, try to equalize or approximate the outputs of both. The analyses concerning each simulated improvement scenario will be discussed below.

Scenarios 1.1 and 1.2 - Same layout with one slicer

Different lots were simulated between the machines in these two scenarios to see which scenario would have the most gains, considering that the lot sizes influence both the stock and the processing start of some machines.

Scenario 1.2 uses the same cell layout as Figure 16 and has the following lot sizes: a cart filled with 40 logs from the rewinder to the slicer; and a pallet filled with 60 sliced logs to be wrapped.

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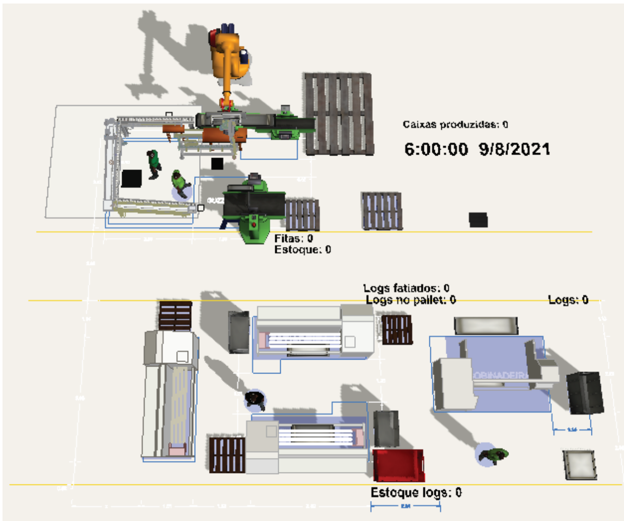

Figure 16. Scenario 1.2 in FlexSim®

Legend: Boxes produced; Ribbons; Stock; Sliced logs; Logs on the pallet; Logs stock

Source: The authors (2021)

These scenarios did not prove to be advantageous since they caused an increase in the idleness of the packaging machine because there are moments when the ribbon stock runs out, causing the wrapper to wait for more ribbons to arrive to continue operating, as illustrated in Figure 17.

Figure 17. Ribbon Stock for the Wrapper - Scenario 1.1

Legend: Stock waiting to be packed; Sliced ribbon stock; Zeroed ribbon stock (in the yellow box)

Source: The authors (2021)

Once the aforementioned problems were noted, the need to create new scenarios was perceived. Thus, the hypothesis was raised that two slicers processing the studied ribbon could help increase productivity, decrease stock between machines, and reduce the duration of the PO. With this, scenarios 2.1 to 2.3 were created to analyze if this hypothesis would bring improvements to the cell in question.

Scenarios 2.1 to 2.3 - Same layout with two slicers

In scenario 2, the operator operates on two slicers. Scenario 2.1 described the simulation with a 60-log cart from the rewinder to the slicer and a pallet with 90 sliced logs from the slicer to the wrapper. Version 2.2 had two slicers and lots of 60, and version 2.3 had two slicers but with lots of 40 for the slicer and a pallet filled with 60 logs sliced from the slicer to the wrapper.

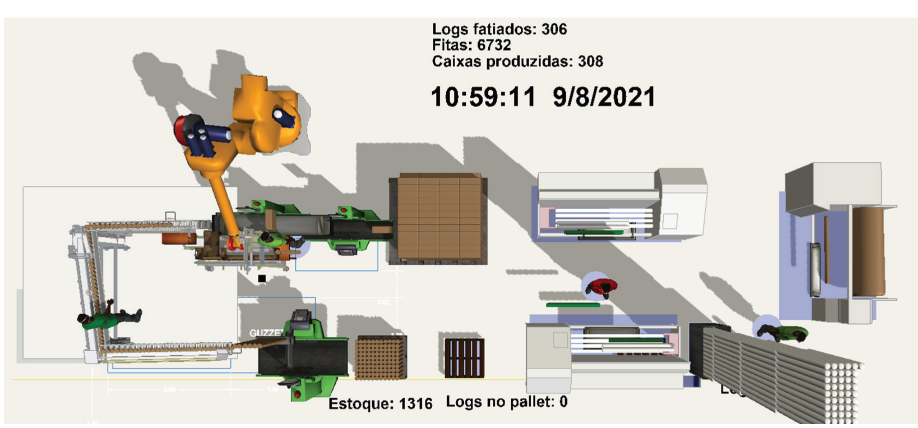

Figure 18. New layout proposal for scenarios 3.1 and 3.2 in FlexSim®

Legend: Sliced logs; Ribbons; Boxes produced; Stock: 1316 Logs in the pallet: 0

Source: The authors (2021)

These scenarios were elaborated to reduce the intermediate stock between the processes and solve the wrapper's idleness issue due to not having ribbons in its stock to wrap during the production of the PO.

Some results of the scenarios are significant, and others are not; however, it was still possible to optimize with a new layout, which allows for a more continuous flow without the need for batch transfers between machines and, consequently, a reduction of inventory concerning the current factory process. Thus, two more scenarios were created with new layout proposals called scenario 3.1 and scenario 3.2, which will be addressed below.

Scenarios 3.1 and 3.2 - New Layout

The new layout has a rewinder, two slicers, and a wrapper. Two scenarios were tested with this new layout proposal, one with only one slicer and another with two slicers, to verify which would be the best scenario. Scenario 3.1 is designed with one slicer operating the polyethylene ribbon, and simultaneously, the operator also works on the other slicer, slicing another ribbon. Scenario 3.2 has two slicers processing the polyethylene ribbon. The new layout proposal can be seen in **Figure** 18, which is common to the two versions developed.

RESULTS

As mentioned in the previous chapter, five improvement scenarios were created with the current factory layout, and two more scenarios were created with a new layout proposal. This way, the comparative analyses of the seven scenarios were made with both the standard and the actual scenario.

Table 9 compares the improvement scenarios 1.1 and 1.2, which refer to the models in which only one slicer processes the sliver studied. In it, it is possible to see that both scenarios reduced the stock between the slicer and the packer, but regarding the individual gains, the models did not benefit the three machines of the cell.

Table 9. Scenarios 1.1 and 1.2 (one slicer) compared to the standard scenario

PO DURATION	STANDARD SCENARIO	SCENARIO 1.1	Dif. (%)	SCENARIO 1.2	Dif. (%)
	9:49:12	9:06:00	-7.33%	9:48:00	-0.2%
Machine output per hour					
REWINDER (Logs)	100	100	0,00%	100	0,00%
SLICER (Sliced logs)	38	38	0,00%	33	-11.11%
WRAPPER (Ribbons)	915	905	-1.06%	801	-12.5%
TOTAL CELL (Ribbons)	652	704	7.88%	654	0.17%
Stocks					
Rewinder – Slicer (Logs)	202	202	0,00%	200	-0.99%
Slicer – Wrapper (Ribbons)	2329	1320	-43.32%	1320	-43.32%

Source: The authors (2021)

Table 10. Scenarios 2.1, 2.2, and 2.3 (two slicers) compared to the standard scenario

PO DURATION	STANDARD SCENARIO	SCENARIO 2.1	Dif. (%)	SCENARIO 2.2	Dif. (%)	SCENARIO 2.3	Dif. (%)
	9:49:12	8:31:00	-13.27%	8:09:00	-17.01%	8:05:00	-17.68%
Machine output per hour							
REWINDER (Logs)	100	100	0,00%	100	0,00%	100	0,00%
SLICER (Sliced logs)	38	50	33.33%	50	33.33%	50	33.33%
WRAPPER (Ribbons)	915	1068	16.67%	915	0,00%	915	0,00%
TOTAL CELL (Ribbons)	652	752	15.26%	786	20.45%	792	21.44%
Stocks							
Rewinder – Slicer (Logs)	202	152	-24.75%	146	-27.72%	106	-47.52%
Slicer – Wrapper (Ribbons)	2329	2441	4.81%	1998	-14.21%	1935	-16.92%

Source: The authors (2021)

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As for the production rate of the total cell, there was a 7.88% increase in scenario 1.1 compared to the standard scenario. Although positive, it did not reach the 10% target desired in this study. Still, in these scenarios with one slicer, it is worth noting that scenario 1.1 processed the same PO with a reduction of more than 7% of the total production order duration, while scenario 1.2 had a reduction of only 0.20%, evidencing the need for the use of two slicers processing the same ribbon in question.

Table 10 shows the most significant gains for the scenarios where the two slicers were activated to process the analyzed ribbon. Among the three improvement scenarios, scenario 2.3 stands out. Even without increasing the rewinder and slicer hourly production, scenario 2.3 shows a 17.68% reduction in the PO duration, a 47.52% reduction in intermediate stocks between the rewinder and the slicer, and a 16.92% reduction in the slicer-to-wrapper stock. Another highlight of this scenario is the 21.44% increase in the total cell production, standing out so far as the best scenario compared to the standard scenario.

The same previous analyses were redone but now compared to the actual scenario, and the gains were more expressive since the PO duration in the actual scenario is longer than in the standard scenario.

In the scenario with a slicer, it is possible to see more significant gains in scenario 1.1, where the cell increased by 104.61% in its production compared to the actual scenario. Furthermore, a reduction higher than 32% of intermediate stocks was observed between machines in both existing stocks throughout the cell, and a 48% reduction of the same PO duration, as shown in Table 11 below.

The gains for the two-slicer scenario were even greater in both scenarios; however, scenario 2.3 stands out once again, showing a reduction greater than 53% in PO duration, a 130.34% increase in cell production, and a 64% reduction in inventories between the rewinder and the slicer, and 24.77% between the slicer and the wrapper, as shown in Table 12.

The scenarios with a new layout enabled a decrease in movement and transport of materials and a more continuous flow in the cell, as well as a decrease in inventory during the process. All data from the two scenarios were tabulated and again compared to the standard and actual scenarios.

Table 11. Scenarios 1.1 and 1.2 (one slicer) compared to the actual scenario

PO DURATION	REAL SCENARIO	SCENARIO 1.1	Dif. (%)	SCENARIO 1.2	Dif. (%)
	17:30:00	**9:06:00**	**-48,00%**	**9:48:00**	**-44,00%**
Machine output per hour					
REWINDER (Logs)	60	100	66.67%	100	66.67%
SLICER (Sliced logs)	46	38	-18.48%	33	-27.54%
WRAPPER (Ribbons)	738	905	22.67%	801	8.49%
TOTAL CELL (Ribbons)	344	704	104.61%	654	89.99%
Stocks					
Rewinder – Slicer (Logs)	300	202	-32.67%	200	-33.33%
Slicer – Wrapper (Ribbons)	2572	1320	-48.68%	1320	-48.68%

Source: The authors (2021)

Table 12. Scenarios 2.1, 2.2, and 2.3 (two slicers) compared to the actual scenario

PO DURATION	REAL SCENARIO	SCENARIO 2.1	Dif. (%)	SCENARIO 2.2	Dif. (%)	SCENARIO 2.3	Dif. (%)
	17:30:00	**8:31:00**	**-51.33%**	**8:09:00**	**-53.43%**	**8:05:00**	**-53.81%**
Machine output per hour							
REWINDER (Logs)	60	100	66.67%	100	66.67%	100	66.67%
SLICER (Sliced logs)	46	50	8.7%	50	8.7%	50	8.7%
WRAPPER (Ribbons)	738	1068	44.65%	915	23.98%	915	23.98%
TOTAL CELL (Ribbons)	344	752	118.62%	786	128.46%	792	130.34%
Stocks							
Rewinder – Slicer (Logs)	300	152	-49.33%	146	-51.33%	106	-64.67%
Slicer – Wrapper (Ribbons)	2572	2441	-5.09%	1998	-22.32%	1935	-24.77%

Source: The authors (2021)

Table 13. Scenarios 3.1 and 3.2 compared to the standard scenario

PO DURATION	STANDARD SCENARIO	SCENARIO 3.1	Dif. (%)	SCENARIO 3.2	Dif. (%)
	9:49:12	**7:15:00**	**-26.17%**	**6:49:00**	**-30.58%**
Machine output per hour					
REWINDER (Logs)	100	100	0,00%	100	0,00%
SLICER (Sliced logs)	38	38	0,00%	50	33.33%
WRAPPER (Ribbons)	915	801	-12.5%	1068	16.67%
TOTAL CELL (Ribbons)	652	883.45	35.4%	940	44.01%
Stocks					
Rewinder – Slicer (Logs)	202	199	-1.49%	148	-26.73%
Slicer – Wrapper (Ribbons)	2329	107	-95.41%	1123	-51.78%

Source: The authors (2021)

Table 14. Scenarios 3.1 and 3.2 compared to the actual scenario

PO DURATION	REAL SCENARIO	SCENARIO 3.1	Dif. (%)	SCENARIO 3.2	Dif. (%)
	17:30:00	**7:15:00**	**-58.57%**	**6:49:00**	**-61.05%**
Machine output per hour					
REWINDER (Logs)	60	100	66.67%	100	66.67%
SLICER (Sliced logs)	46	38	-18.48%	50	8.7%
WRAPPER (Ribbons)	738	801	8.49%	1068	44.65%
TOTAL CELL (Ribbons)	344	883.45	156.82%	940	173.14%
Stocks					
Rewinder – Slicer (Logs)	300	199	-33.67%	148	-50.67%
Slicer – Wrapper (Ribbons)	2572	107	-95.84%	1123	-56.34%

Source: The authors (2021)

Table 13 shows the comparative analyses of scenarios 3.1 and 3.2 with the standard scenario.

It is worth remembering that scenario 3.1 is the new layout proposal with one slicer slicing the analyzed ribbon in question and scenario 3.2 with two slicers slicing that same ribbon.

Scenario 3.1 showed a decrease in PO duration by 26.17% compared to the default scenario, and scenario 3.2 shows a decrease of more than 30% in the duration of the same PO. The production increase in the cell also shows gains in both scenarios, as scenario 3.1 had an increase of 35.4%, and scenario 3.2 had an increase of 44.01%.

Regarding the intermediate stock reduction, scenario 3.2 had a decrease of more than 26% between the rewinder and the slicer and more than 51% between the slicer and the wrapper. Scenario 3.1 had a small reduction between the rewinder and the slicer, 1.49%, while the stock between the slicer and the wrapper was above 95%.

Finally, scenarios 3.1 and 3.2 were compared with the actual scenario, as shown in Table 14.

When analyzing scenario 3.1, we highlight the 156.82% gain in total production compared with the real scenario, in addition to the reduction of inventory between the rewinder and slicer by more than 33% and from the slicer to the wrapper by more than 95%.

Compared to scenario 3.2, the gains were even greater, as the PO duration was reduced by 61.05%, the total cell production was increased by 173.14%, and the intermediate stock in the cell was reduced by more than 50% for both existing stocks.

Having seen all the comparisons made with the real scenario, the standard scenario, and all seven improvement scenarios, the great gains of this study for the studied cell are clear. It is worth mentioning that the study also shows two main improvement options for the cell in question, where one would be the improvement option for Guzzetti with no need for changes in the physical arrangement of the machines in the cell, as in the scenario cases with the same layout, but also much more significant gains with the new layout proposal, thus requiring changes in the arrangement of the machines in the cell. Therefore, it is up to managers to analyze which option would be the most viable.

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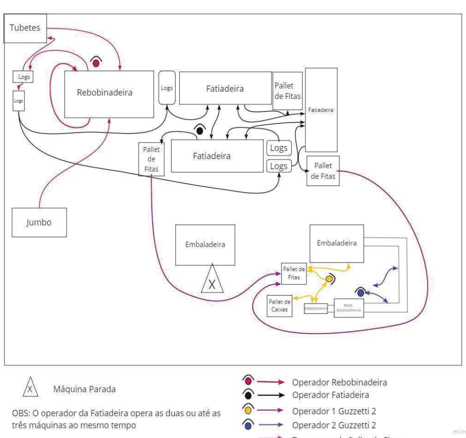
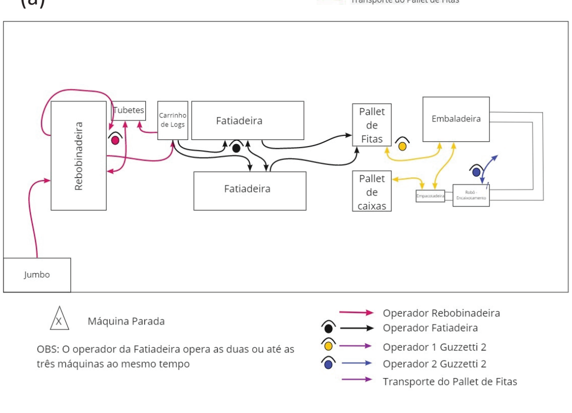
The best scenarios defined for this research are scenario2.3, which has slicers processing the polyethylene ribbon, lots of 40 for the rewinder and slicer cart, and lots of 60 sliced logs for the pallet from the slicer to the wrapper, and scenarios 3.1 and 3.2 for the new layout.

The study shows that the cell's layout can positively or negatively influence the production process, highlighting the transportation of materials and operators. Thus, it is necessary to constantly search for efficient layouts that enable productivity gains and waste reduction.

To evidence the above statement and the gains of the new layout proposal regarding the movements within the cell, two spaghetti diagrams were created, one referring to the current process of the factory and the other to the new proposed layout as follows—see Figure 19.



(a)



(b)

Figure 19. Spaghetti diagram of the movements within the cell - current layout (a) versus new layout (b)

Legend: (a) Tubes; Logs; Rewinder; Slicer; Ribbon Pallet; Slicer; jumbo; Wrapper; Pallet of Boxes; Machine Stopped; Note: The Slicer operator runs two or even three machines at the same time; Rewinder Operator; Slicer Operator; Operator 1 Guzzetti 2; Operator 2 Guzzetti 2; Ribbon Pallet Transport. (b) Rewinder; Tubes; Log Cart; Slicer; Ribbon Pallet; Wrapper; Pallet of Boxes; jumbo; Machine Stopped; Note: The Slicer operator runs two or even three machines at the same time; Rewinder Operator; Slicer Operator; Operator 1 Guzzetti 2; Operator 2 Guzzetti 2; Ribbon Pallet Transport.

Source: The authors (2021)

The new layout allowed for a reduction in the movement of operators and intermediate stocks. It made product transportation less complex since there is a corridor separating the rewinder and slicer from the packaging machine in the current plant scenario, thus making the transportation of ribbon pallets longer and more complex. In the new layout, there is the proposal of an arrangement with the machines closer together, without aisles between them, enabling a more continuous flow within the cell.

Studies such as this show the relevance of computational modeling and simulation of production processes for factories and companies in general because they enable and assist decision making and the search for improvements to their processes, thus decreasing their risk of error in a new change proposal that allows testing numerous hypotheses of improvements before applying them to the physical process.

CONCLUSION

The existing competitiveness among the companies producing adhesive ribbons in Brazil and the technological advancement characteristic of Industry 4.0 led the company to apply its Research and Development (R & D) resources in the computer simulation project for analyzing the production process of one of its production cells. Aside from the simulation project described here, the company has developed intelligent automation applications, robotization, online production monitoring systems, machine monitoring using sensors, and IoT (Internet of Things) devices in recent years.

The construction of several computational simulation models in Flexsim® software allowed identifying problematic points and improvement opportunities, performing several configurations and analyzing their impacts on the different variables of this complex process, and, thus, arriving at three distinct scenarios considered ideal.

The computer simulations' results assist the plant's strategic decision-making based on relevant information resulting from the analyses undertaken, besides allowing the testing and observation of previously unfeasible scenarios due to the high costs involved in their development.

This research showed that lot size changes require near-zero financial investments and still generate more than a 53% reduction in PO duration, a 130.34% increase in cell production, and a 64% inventory reduction between rewinder and slicer, and a 24.77% between slicer and wrapper. Regarding the production layout modification, arranging the machines in a continuous flow, the gains were even greater since the PO duration was reduced by 61.05%, the total cell production had an increase of 173.14%, and the intermediate stock throughout the cell was reduced by more than 50% in both existing stocks.

The study enabled a deep analysis of the process of the adhesive ribbon. It brought academia and industry closer together, generating scientific knowledge that, if applied, will result in cost reduction for the company by increasing productivity and reducing stocks in the production process, thus achieving the objectives of optimizing the production cell using computer simulation through the FlexSim® software and allowing relevant information and anticipated improvement actions for decision making.

For future work, computer simulation applied to the other production cells and integrated with the IoT of the machines and other systems will enable the production plant to have the ability to self-con**Figure** through the Digital Twins tools.

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