Production Line Virtualization Process Using Plant Simulation Tool

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Abstract

The constant changes in the world generate demands for improvements in processes, either by reducing costs or increasing capacity. One of the most used methods today for process optimization is Discrete Simulation. This research presents a discrete simulation application, using the Tecnomatix Plant Simulation software to simulate a production line in the Manaus Industrial Pole. Mathematical modeling made it possible to understand the parameters involved in the production process and worked as a guide for the production line's composition in the Plant Simulation environment. The production line modeled in Plant Simulation used real input data obtained in two months of production in 2020. The results obtained showed that the modeling reached the objective of virtualizing the production process, once that the differences between the simulation and the real process were at most 1.07%.

Keywords: Optimization, Simulation; Plant Simulation; Engineering; Decision-Making.

1. Introduction

Due to high competitiveness in the current market, in the most different segments, and due to the constant evolution present in the globalized world, there is a need for every process to be optimized, applying continuous improvement.

Specific changes require resources, both financial and human. Managers need to anticipate the impacts of these changes and understand their impacts on the modified process. For this, simulation is used as an ally to avoid expensive implementations that may not bring the results promised by the creators.

The process of virtualization has a connection to the theme Industry 4.0, Zhong et al. (2017) explain that Industry 4.0 can create digital twins and make smarter decisions through real-time communication and greater cooperation between system members.

There is a new trend in the applicability of virtualization and process simulation concerning decision making, as explained by Rolle, Martucci, and Godoy (2020). They define digital twins as a solution to the problem of simulating physical products realistically.

That is reinforced by Dalenogare et al. (2018), who, when listing the main technological contributions of Industry 4.0 to industrial performance, list simulations and analyzes virtual models as a technology inherent in Industry 4.0.

Based on this trend, the present work presents an objective approach to applying discrete simulation using engineering software in a real plant present in the Manaus Industrial Pole in Brazil. The collected data present analyze carried out in Plant Simulation, as described in the next sections of this work.

2. Literature review - Optimization - Discrete Simulations and Virtual Commissioning

Dumitrascu, Dinca, and Predincea (2017) show that the concept of Virtual Commissioning has become one of the essential phases in the development and simulation in an industrial automation process.

Guerrero, López, and Mejía (2014) show that the current development of products and manufacturing processes are built-in 3D environments and confirm this idea. They also explain that this strategy allows creating the entire manufacturing process in a virtual environment and covers all stages of the process, from the adaptation of materials and tools, to production management.

The research of Siderska (2016) corroborates these statements, which talks about the current need for production data to plan, simulate, and supervise production. Moreover, nowadays, companies are increasingly using IT solutions to optimize logistics systems. Simulations are the most used tools to understand Production, Logistics, and Industrial Engineering.

Siderska (2016) also explains that computer simulations are tools that can test solutions in a virtual model before its implementation. From the simulations, it is possible to use advanced analytical methods, such as studying the bottleneck, cycle times, and others, which can be applied in different production scenarios and assist in decision making.

Daneshjo et al. (2018) show that the advantage of simulations about the real world is the reduction in costs, as there is the possibility of analyzing a virtual environment, which has a lower cost compared to real experiments.

Computer simulations have become a significant and influential research methodology in the contemporary world, as Kikolski (2016). For him, the simulations are an approximate imitation of a studied phenomenon or a system's behavior. Moreover, they are mathematical models usually represented in computational software.

Tecnomatix Plant Simulation software is a great ally and powerfully used for system modeling and industrial optimization. Behunova, Behun, and Knapcikova (2018) explain that this software helps create digital models, which allows the exploration of the system's characteristics and optimization of its performance. Using Plant Simulation, it is possible to create models and simulate industrial systems and their processes. From this, it is possible to optimize flows, use of resources, and logistics.

The research presented by Rostkowska (2014) that deals with how to choose the right software for simulations, shows that simulation is a method where digital models replace the real objectives. Using this is possible to obtain the necessary information and make it possible to understand how a given system works and how it reacts to its input parameters' variation.

From a usual system, it is possible to carry out simulations that will show this system's behavior in the face of adverse conditions, allowing predicting individual variations before they occur physically. As previously mentioned, this method reduces the costs involved in implementing real tests, involving prototypes or other methodologies that assist in this end and have a high cost of implementation.

For software definition, Rostkowska (2014) shows that the project or process needs will define the appropriate software. Tecnomatix Plant Simulation is suitable for visualizations were more than just the logical diagram of the process desired, once Tecnomatix Plant Simulation has a set of tools that enable an analysis of the process bottleneck, generation of various statistical studies, graph models, and the evaluation of the most different production scenarios.

Competitiveness in the current market, among the companies present in the most diverse branches, is relatively high, and in order to have a competitive advantage, companies need to focus on improving their processes, reducing costs, and simulations are great allies. Kliment and Trebuňa (2014) corroborate this idea and claim that this advantage is in new product planning, product innovation, and marketing.

The authors also highlight a fact already addressed by other authors already presented in this work, where it is possible to obtain cost savings when using simulations for process analysis and the possibility of presenting the process to customers and investors more dynamically and adequately. Kliment and Trebuňa (2014) explain that simulations can adopt in processes already being implemented, where optimization sought and processes in the planning phase. In this case, the simulations will assist in the correct decision making.

Rodič (2017) deals with the so-called simulation paradigms, where he shows the evolution of its main applications. The author shows how this evolution occurred in the 1960s, where simulation modeling was developed based on accessible technologies only for computing and mathematics specialists. Then in the 1980s, simulations start to be a standard tool for engineering questions. At the beginning of the 2000s, the simulations allow systemic approaches for multi-level and multi-disciplinary systems, and now it is possible to use the digital twins that are a powerful tool for solving project problems and making decisions.

Dragovic, Tzannatos, and Park (2016) say that the simulations' progress is established based on the development of Information Technology and the demand for fast and reliable answers to complex problems that arise during a given process. This demand is governed by the competitiveness of the market in which the process is inserted. Dragovic, Tzannatos, and Park (2016) also conclude that simulation modeling has been an essential tool for decision-making.

Debevec, Herakovic, Simic (2014) explain that in small factories, machine and assembly operations represent only 5% of production time, and all the remaining time is devoted to preparing the necessary resources for production.

In addition to the applications already mentioned, simulations can also be applied for teaching and training. Debevec, Herakovic, Simic (2014) show that this is a simple way to analyze the different production behaviors, based on the modifications inserted in the simulation's scope. Moreover, using these analyzes, it is possible to acquire the expertise to understand the functioning of a productive system and its reactions to the most various modifications.

In the simulation software, discrete mathematics applied to simulate discrete events; discrete mathematics used, as shown by O'Regan (2017) since it serves as an aid to engineering in delivering high-quality software. Also, the author explains that the use of mathematics guarantees precision and allows the identification of inconsistencies.

O'Regan (2016) explained that the use of mathematics allows rigorous analysis and avoids the dependence on intuition, in addition to the fact that mathematics is accurate, which avoids the ambiguity present in the description of a system with natural language.

3. Material and Methods - Case Study - Manaus Industrial Pole Literature review

In order to have the practical part linked to the theory previously presented, we proceed to a Practical Case Study in a real production line at the Industrial Pole of Manaus in Brazil. Since the study's purpose is to present a practical approach to what is seen in the literature and strategic industrial issues, the products will not present nor the company's name where the study carried out.

Fourteen interdependent machines are arranged in series and work similarly to an assembly line formed production line since, at the entrance, there is a finished product (produced in another department), which has added value throughout the process.

The central problem is obtaining a model that works as a tool to define the plant's optimized operational conditions, taking into account the organicity or interdependence between the machines.

Each machine in the line has a cycle time that is a function of processing time and machine capacity, as described in Equation 1.

$$CT = \frac{PT}{Qty} \quad (1)$$

Where,

- $CT = Cycle\ Time;$
- $PT = Processing\ Time;$
- $Qty = Number\ of\ parts\ held\ in\ the\ machine\ simultaneously.$

The crossing time of the line is equal to the sum of the processing times, according to Equation 2.

$$CrossingTime = \sum_{i=1}^{14} PT_i \quad (2)$$

The number of parts present with the line fully loaded is given the sum of each machine's capacities individually, according to the Equation3.

$$Loading = \sum_{i=1}^{14} Qty_i \quad (3)$$

The productive capacity of the line is a function of the bottleneck's productive capacity, that is, the machine with the longest cycle time and consequently, less capacity, according to Equation 4.

$$Capacity/hour = \frac{3600}{CT_{BOTTLENECK}} \quad (4)$$

The graph shown in Figure 1 shows each machine's hourly capacity individually and the respective cycle time.

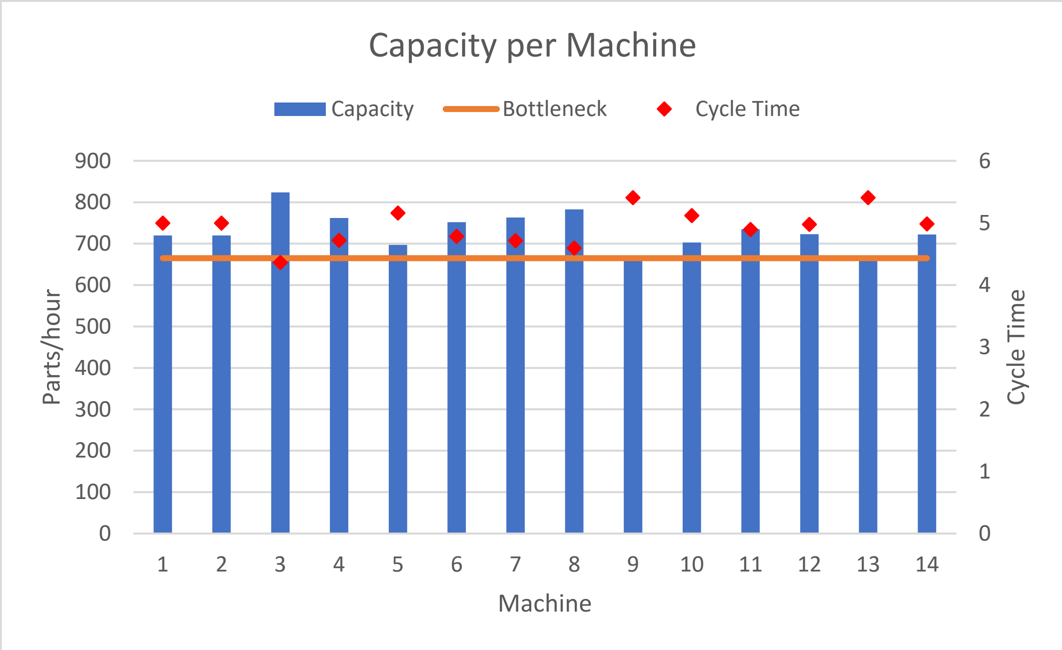

Figure 1. Capacity and Cycle Time per Machine.
Source: Authors

From the mathematical modeling presented, the analyzed line was modeled in Tecnomatix Plant Simulation using real information of capacity per equipment, processing time, MTBF - Mean Time Between Failures (Equation 5), MTTR - Mean Time To Repair (Equation 6), availability (Equation 7), among others.

$$MTBF = \frac{WorkingTime}{Quantity\ of\ Failures} \tag{5}$$

$$MTTR = \frac{Time\ to\ Corrective\ Maintenance}{Quantity\ of\ Failures} \tag{6}$$

$$Availability = \frac{MTBF}{MTBF + MTTR} \tag{7}$$

Measurements of the capacity and processing time of the entire component machines of the modeled line were performed, which are necessary inputs during modeling in Plant Simulation.

The processing time data is inserted in the Input Analyzer tool of the Arena software, which outputs the statistical distribution. This distribution is used as an input parameter in Plant Simulation.

The Table 1 presents data on statistical distributions, capacity, MTTR, availability for each machine in the line analyzed in February 2020.

Table 1. Statistical data, capacity and maintenance information. February / 2020

Machine	Distribuition	$\bar{x}$	s	Capacity	Availability	MTTR	Cycle Time
1	Uniform	-	-	1	99.96%	4940	3.60
2	Uniform	40.0	-	8	99.08%	5250	5.00
3	Normal	61.1	2.31	14	99.83%	1280	4.36
4	Uniform	406.0	1.42	86	99.92%	870	4.72
5	Weibull	25.8	1.02	5	95.83%	7280	5.16
6	Const	5527.4	-	1155	99.75%	2850	4.79
7	Triangle	61.3	1.6	13	99.56%	10080	4.72
8	Uniform	331.0	1.56	72	98.75%	9540	4.60
9	Erlang	32.4	0.962	6	97.93%	4734	5.41
10	Triangle	51.2	0.642	10	-	-	5.12
11	Normal	63.7	1.58	13	99.92%	1800	4.90
12	Const	234.0	-	47	99.90%	2220	4.98
13	Erlang	32.4	0.962	6	99.49%	1680	5.41
14	Constant	698.0	-	140	99.88%	2820	4.99

Source: Authors

Table 2 presents data on statistical distributions, capacity, MTTR, availability for each machine in the line analyzed in March 2020.

Table 2. Statistical data, capacity and maintenance information. March / 2020

Machine	Distribuition	$\bar{x}$	s	Capacity	Availability	MTTR	Cycle Time
1	Uniform	-	-	1	99.93%	9540	3.60
2	Uniform	40.0	-	8	97.28%	4902	5.00
3	Normal	61.1	2.31	14	99.55%	3480	4.36
4	Uniform	406.0	1.42	86	99.86%	3300	4.72
5	Weibull	25.8	1.02	5	98.33%	3924	5.16
6	Const	5527.4	-	1155	-	-	4.79
7	Triangle	61.3	1.6	13	-	-	4.72
8	Uniform	331.0	1.56	72	99.37%	4940	4.60
9	Erlang	32.4	0.962	6	99.13%	2923	5.41
10	Triangle	51.2	0.642	10	99.84%	3840	5.12
11	Normal	63.7	1.58	13	-	-	4.90
12	Const	234.0	-	47	99.90%	2220	4.98
13	Erlang	32.4	0.962	6	99.92%	1920	5.41
14	Constant	698.0	-	140	-	-	4.99

Source: Authors

Table 3 presents other activities carried out on the line and their respective durations for the months analyzed.

Table 3. Description of productive calendar activities

	Feb	Sea
Daily Cleaning	1 hour / day	1 hour / day
Weekly Cleaning	2 hours / week	2 hours / week
Preventive Maintenance	16 hours	13.4 hours

Source: Authors

Table 4 presents the components used in modeling the line in Plant Simulation.

Table 4. Description of productive calendar activities

COMPONENT			*QUANTITY*
	Source	A	1
	SingleProc	B	1
	ParallelProc	C	13
	PickAndPlace	D	5
	Line	E	2
	AngularConverter	F	1
	Drain	G	1
	Connector	H	23
	EventController	I	1
	ShiftCalendar	J	1
	Display	K	4
	Chart	L	1

Source: Authors

Figure 2 shows the planned view of modeling in Plant Simulation with the indication of each component used, according to the code described in the third column of Table IV.

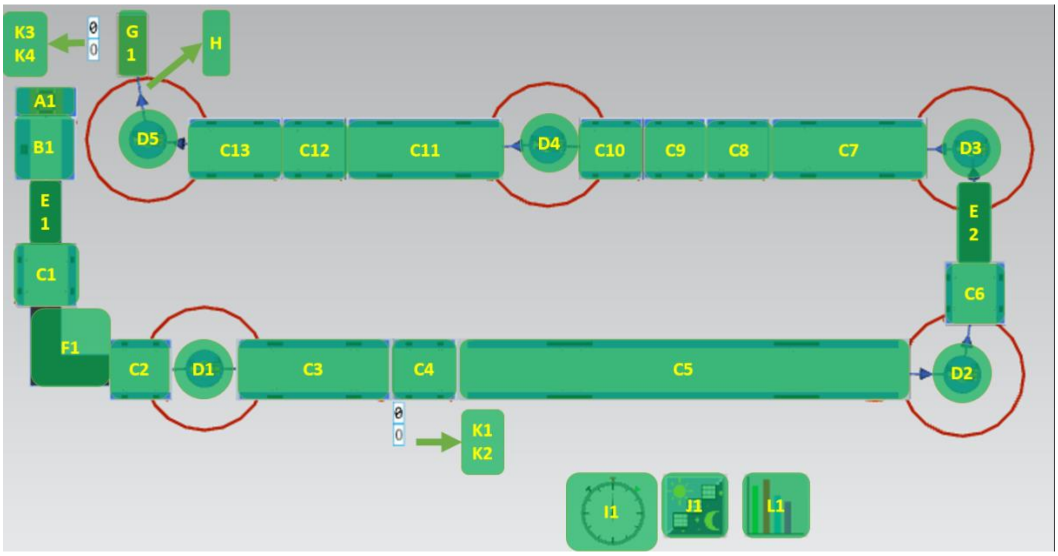

Figure 2. Line modeled in Tecnomatix Plant Simulation with the indications of each component used
Source: Authors

In the image are four dials (K1, K2, K3, and K4) that show the total of parts processed in the simulated time interval (K1 and K3) and the production per hour (K2 and K4). Dials present in the middle of the line (K1 and K2) were added to compare data to validate the results since this is the reference equipment for the studied line's capacity metrics.

The data presented in Table IV are inserted in the Shift Calendar (J1), linked to all machines (B and C). Moreover, the simulation is managed through the EventController (I1). Figure 3 shows a completed simulation for February 2020.

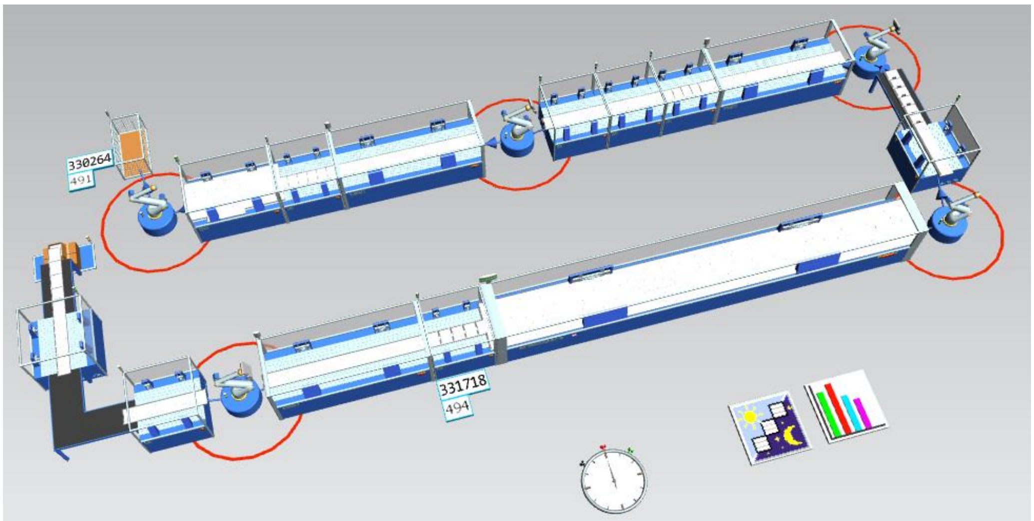

Figure 3. Simulation with parameters of MTBF, MTTR, Preventive maintenance and weekly shutdown
Source: Authors

The software allows display graphs (L1) for analysis of the use of resources in each equipment of the line, as shown in Figure 4.

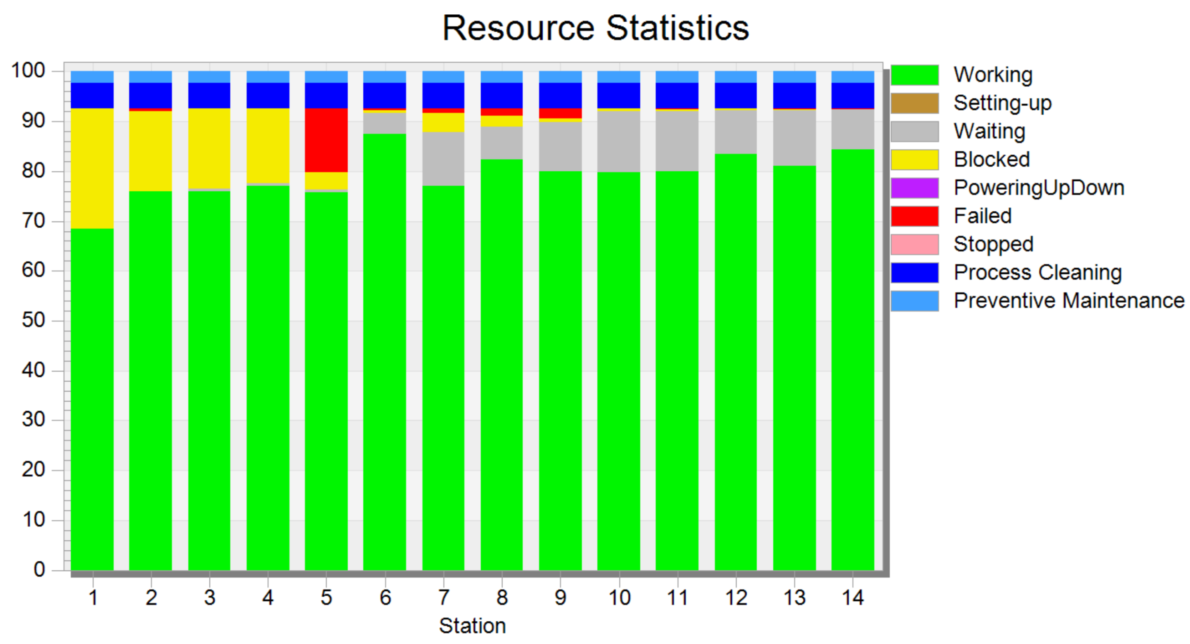

Figure 4. Graph of use by equipment

Source: Authors

The data obtained can be used for production planning and studies related to the use of productive resources available on the line. In the next section, approaches to model validation will be discussed.

3.1 Data validation

For model validation purposes, comparisons were made between the factory's actual production data and the data obtained through simulations in February and March 2020, as shown in Figure 5.

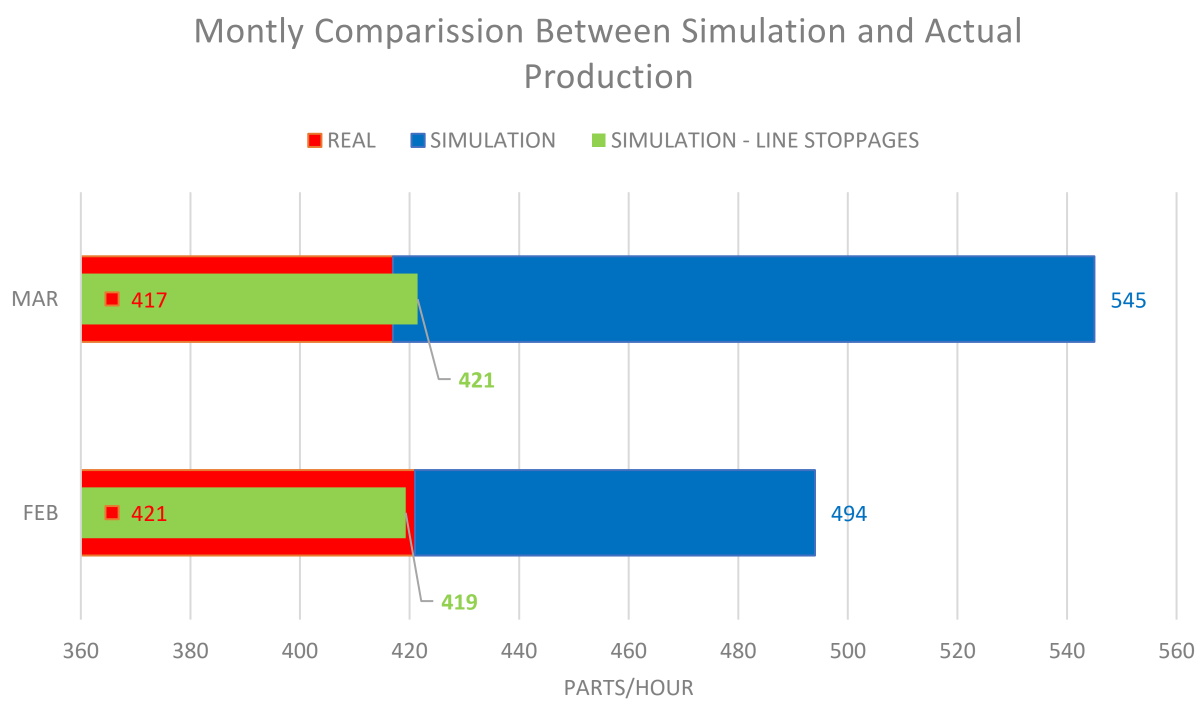

Figure 5. Monthly comparison chart between values obtained by simulation and actual production

Source: Authors

After analyzing the data, it is possible to observe that an hourly production in the simulations in February and March was 494 and 545 pieces per hour. These results are higher than the actual production on the line, which was 421 and 417.

Considering the data of actual stoppages occurring on the line, which is not included in the simulation, it is possible to calculate the production lost because of these stops. Then, there are new productivity values that were 419 and 421, respectively, which represents a difference of 0.40% in the first month and -1.07% in the second month.

In order to increase the reliability results and the model, we have the same comparative analysis in weekly terms, as shown in the graph of Figure 6.

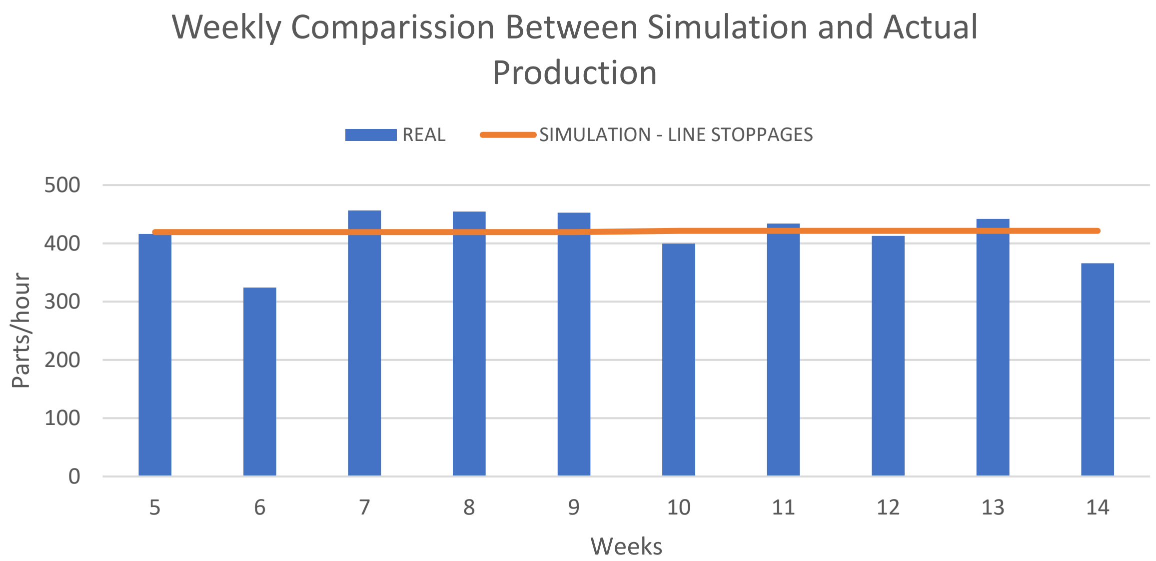

Figure 6. Weekly comparison chart between values obtained by simulation and actual production
Source: Authors

There are a total of 60 days of production for February and March 2020. Figure 7 represents the statistical distribution of the 60 days with the class histogram, the standard distribution curve, and the production indicator obtained through computer simulation in the indicated period.

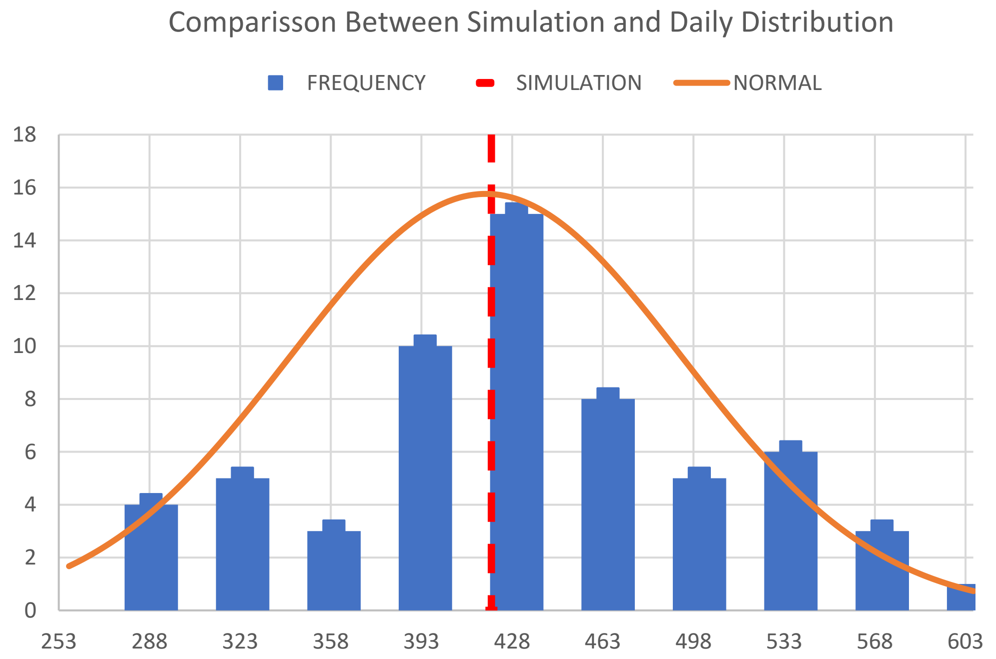

Figure 7. Daily Production Distribution
Source: Authors

It is observed that the values obtained in the simulation are close to reality in the studied line. Even if there are small variations, the model adopted can be used for future decision-making and the company's strategic planning. These variations represent the variability in the process and conditions that could not be noticed and transmitted to the simulation.

4. Conclusion

This subject is a topic that is widely discussed, and that is present in the most diverse processes today. It is a methodology widely used for decision making and optimization of products and processes. It has a tremendous competitive advantage related to costs when compared to other models.

It is also noticed that the Tecnomatix Plant Simulation software is one of the most used when it comes to process optimization, mainly due to its high power and high range of analysis and reports provided by the dynamic process analysis tools, in addition to the visualizations in 2D and 3D.

All processes are subject to optimization; however, there is the possibility of having high costs with the implementation and modifications inherent to the proposed improvements, with the risk of not obtaining the desired results. Because of this, the most viable way to prevent these obstacles from occurring is to carry out analysis before implementation, using mainly simulations, which will enable a complete view of the consequences of the proposed changes.

As described in section 3.1 of this work, the model adopted accurately represents the studied line. Therefore, it is clear that the discrete simulation acts as a strong ally for decision-making and planning in a company and will serve as a pillar in the consolidation of Industry 4.0 in the coming years.

The modeling presents a good approximation of the real conditions, given differences of + -1.07%, so it can be said that it is validated, but it still requires adjustments for small calibrations. Indeed, some variables or parameters in the real world could not be perceived and measured when formulating the model.

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