Artículo Original

Mejora del rendimiento en la producción de la industria textil mediante simulación

Performance improvement in the production of textile industry using simulation

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Resumen

Desde el punto de vista de la gerencia, existen decisiones relevantes para el futuro de las industrias, muchas de las cuales involucran el uso considerable de recursos e inversión. Una alternativa para agilizar este proceso es la utilización de la simulación de entornos de trabajo. Por esta razón, el objetivo de la presente investigación es demostrar que la simulación de manufactura permite mejorar los procesos productivos dentro de la industria textil, haciéndola más eficiente y sin la necesidad de invertir una gran cantidad de recursos. La metodología utilizada es la réplica del entorno manufacturero en un modelado virtual, considerando los comportamientos estocásticos y procesos secuenciales mediante la simulación con el software FlexSim. Los datos resultantes del experimento en múltiples escenarios han mostrado una mejora del 194% en la capacidad del producto terminado, sugiriendo que se debe hacer una gran inversión en esa línea de montaje. La decisión final la tomarán los directivos correspondientes una vez lo hayan analizado a fondo. Además, los hallazgos de esta investigación, incluidas las herramientas utilizadas, pueden ser útiles para futuros investigadores que enfoquen su trabajo en sectores industriales similares o en las herramientas empleadas

Palabras clave: producción, simulación, FlexSim, industria 4.0, industria textil.

Abstract

From the perspective of management, there are significant decisions that shape the future of industries, many of which involve substantial resource use and investment. One effective way to streamline this process is through the use of work environment simulation. Therefore, the aim of this research is to demonstrate that manufacturing simulation can improve production processes within the textile industry, making it more efficient without requiring large investments. The methodology involves replicating the manufacturing environment in a virtual model, considering stochastic behaviors and sequential processes through simulation using FlexSim software. The data resulting from experiments in multiple scenarios showed a 194% improvement in finished product capacity, highlighting increased throughput. While a substantial investment in the assembly line is recommended, the final decision will be made by the management team after thorough analysis. Additionally, the tools and findings from this study could prove valuable for future researchers focusing on the textile industry or similar industrial sectors, as well as those exploring the use of simulation technologies.

Keywords: production, simulation, FlexSim, industry 4.0, textile industry.

1. Introducción

Organizations over the years have had to face various industrial changes and revolutions, and the advent of industry 4.0 (I4.0) technologies (Kalwar et al., 2022), has generated smart factories that possess autonomy and virtualization of their processes (Prause, 2019). This allows for higher productivity, lower costs, high mass production and reduced processing times (Sima et al., 2020). Two of these technologies present in I4.0 are virtual and augmented reality (Castillo & Fernández, 2023), which allow interaction between virtual information and the physical environment through 3D simulations of production processes. In line with this, the objective is to find faults in the system in advance (Machala et al., 2022).

Currently, the simulation of manufacturing processes is gaining great importance within the different industries, since it allows the elaboration of dynamic models of a logistics system (Mourtzis, 2020). It also makes it possible to analyze the behavior of these systems in several scenarios to ensure the correct decision making in the implementation of the best solution (Grznár et al., 2020). In addition, this technology provides the opportunity to identify bottlenecks, possible operational failures, opportunities to save resources, validate the performance of the facilities, among other benefits (Florescu & Barabas, 2020). Thus, these simulation tools facilitate decision making within an organization (Zhang et al., 2019).

As for simulation software, one of the most widely used alternatives currently on the market is FlexSim. This aims to perform an accurate analysis of the variables involved in the system under study (Ishak et al., 2020), which makes it possible to modify variables such as speed, location, time and capacity (J. Liu et al., 2021). Thanks to these features, it is possible to model and understand the problems faced by a manufacturing industry (Wu et al., 2018). In addition, this vision looks for different alternatives that adapt to the needs of the companies (Cheng et al., 2020).

On the other hand, the textile industry is one of the world's leading employers (Hussain et al., 2020). In Ecuador, it is in second place, generating around 170,000 jobs, in addition to contributing 7% to the national manufacturing GDP (Bravo, 2022). However, there is a major disadvantage, which is the excessive cost of production, which forces entrepreneurs to reinvent themselves and look for ways to optimize their processes with the least amount of resources, in order to offer a quality product without increasing their costs, but rather to reduce them (Gaspar et al., 2022). Thus, this analysis reveals the need to use simulation software to graphically represent the different scenarios faced by a company, without investing so much money and interfering with the productivity of the system. Consequently, the objective of this study is to apply simulation to improve the production processes within a textile industry, making it more efficient in operational and economic terms.

The rest of this paper is organized as follows. Section 2 contains a bibliographic review of the most relevant terms for the research, section 3 details the methodology for the development of the 3D modeling, section 4 shows the results obtained from the study, section 5 contains a discussion of the results based on previous studies and finally section 6 contains the conclusions and an agenda for future research.

2. Literature review

I4.0 technologies play an important role within the different industries and their manufacturing processes (Khan et al., 2023). These industries incorporate technologies such as the internet of things (IoT), artificial intelligence (AI), big data, virtual reality, and simulation into their processes, which allows them to have a complete system that helps them to make decisions in an adequate manner (Marinagi et al., 2023). These technologies allow organizations to improve their processes, automate them completely and, above all, achieve a level of efficiency that was not possible years ago (Ghadge et al., 2020). Thus, manufacturing simulation, through its predictive ability, gives the possibility of simulating failures and adopting different scenarios, allowing the systems the ability to make decisions autonomously and without the need to make large investments. In other words, simulation allows to test different scenarios to find an alternative that adapts to the reality of the company and with which better results are obtained (Ojstersek, R.; Acko, B. & Buchmeister, 2020). Among the current alternatives of simulation software is FlexSim, which is widely used by industries because it allows solving problems that arise in organizations and facilitates decision making. It also makes it possible to create from scratch any type of simulation in a simple way. Due to its wide variety of resources, the system is usually very similar to the reality of the companies (Aliyu & Mokhtar, 2021).

When improving performance with simulation, it is important to analyze queuing theory, which is a mathematical study of waiting lines in order to find the most viable way to operate a queuing system. In this way, it is possible to find the right balance between the cost that a given service will have and the waiting time. Consequently, thanks to the simulation it is possible to represent these queuing systems in order to determine where a waiting time is being generated and to look for a solution that can be adapted to the inconvenience presented (F. Liu & Wang, 2021).

Complementarily, Little's law is a theory and formula used to estimate the queuing process in a company, allowing to improve productivity and efficiency within the company. It can be applied to any queuing system or subclass within an organization. Equation 1 relates the waiting time of an item to the average number of products arriving at the queuing system within a given time, in order to estimate the average number of items in a queuing system (Hendijani, 2021). Here L represents the average number of items in a queuing system; λ is the number of items arriving per unit time; and W is the time each item must wait in a queuing system.

$$L = \lambda \cdot W \tag{1}$$

On the other hand, the theory of constraints (TOC) is a methodology that allows process improvement and focuses on identifying and rectifying the constraints or elements that generate a bottleneck. According to this theory, there is a premise that states that every company has at least one constraint that causes a limited capacity and, therefore, the company's objectives cannot be met. For this reason, the TOC allows to improve the workflow and to obtain an efficient performance in the whole company (Pacheco et al., 2021).

3. Methodology

This research is developed within a quantitative context in a case study of a textile industry. Simulation is used as a facilitating technology to obtain the solution. Also, an experimental approach is used to obtain the most effective results. As for the case study, the analysis of the problem is focused on the Stone service, since it is the one that presents the highest demand within the company. This service consists of 9 stages: weighing, handcrafting, stone, centrifugation, drying, sanblas, neutralizing, final centrifugation and final drying, with a processing time of 365.60 min and a production capacity of 34.63 batches/week. In addition, based on the experimentation, a simulation is developed in FlexSim 2022 Update 2 software. This provides facility to emulate, model, manage different manufacturing models in a 3D environment. The graphical implementation is contrasted with the simulation of discrete and stochastic events typical of a company. Thus, simulation allows to test, control and improve changes in logistics operations and possible scenarios in an agile and accessible way, which would not be feasible in real life. These behaviors present statistical distributions of different types, which will be mentioned later.

A. Characterization

Since the industry under study is a textile industry, real information is collected that can be contrasted with the information resulting from the simulation in the FlexSim software. First, a flow chart, a path diagram and the time study in each process are used to obtain the jeans called Stone as well as 3 handicrafts. The result is the specific sequence of the production process and the standard time of the 9 stages that make it up.

B. ABC Analysis

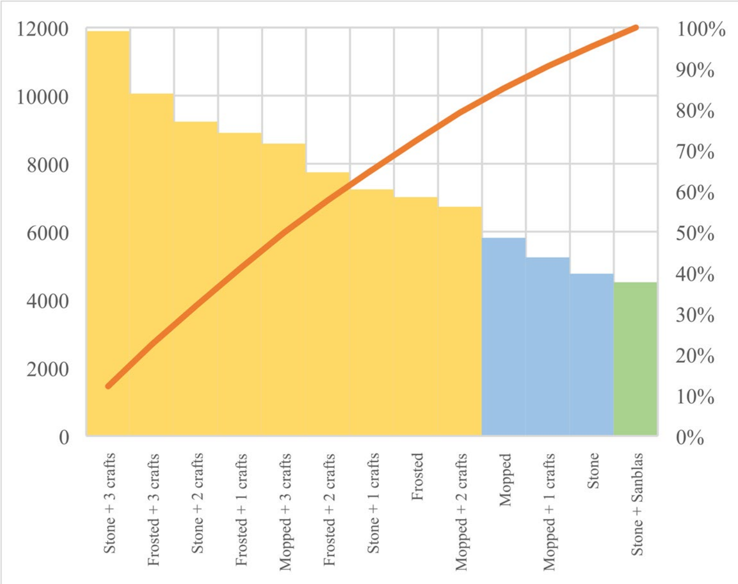

Fig.1 ABC Diagram

Fig.1 shows the use of historical sales data in an ABC diagram. Thus, the product type A is obtained, which has the largest share of sales and on which the simulation of this research is focused (Stone + 3 crafts). Then, the route to produce the Stone service within the production plant is identified. Fig.2 shows this flow diagram through the textile company's facilities, from the green starting point to the red end point. The standard process of the 9 operations indicated above is numbered and starts at weighing and ends at storage.

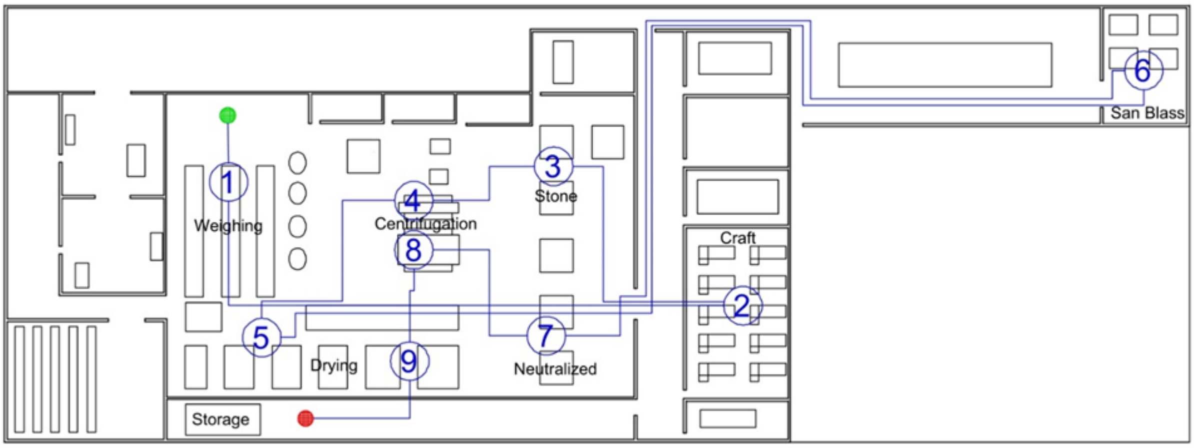

Fig. 2 Route diagram

C. Time study

The calculation of the standard time (Ts) involves the process of taking times by stopwatch in seconds (s) and minutes (min), the inclusion of supplements and the evaluation of the work rhythm. This results in the standard time presented in Table 1.

Tabla 1. Ts calculation summary

Process		**Ts (s)**	**Ts (min)**
1	Weighing	1206,41	20,11
2	Crafts	1386,89	23,11
3	Stone	4157,87	69,30
4	Centrifugation	1006,69	16,78
5	Drying	2629,33	43,82
6	Sanblas	3045,02	50,75
7	Neutralized	3676,17	61,27
8	Final Centrifugation	1131,08	18,85
9	Final Drying	3696,58	61,61
Total		21936,04	365,60

To establish the production capacity (Cp), a working day of 8 hours per working week is considered. Thus, the table of capacities per production process shown in Table 2 is created.

Tabla 2. Capacity calculation summary

Process		**Cp (lot/day)**	**Cp (lot/week)**
1	Weighing	23,87	119,36
2	Crafts	20,77	103,83
3	Stone	6,93	34,63
4	Centrifugation	28,61	143,04
5	Drying	10,95	54,77
6	Sanblas	9,46	47,29
7	Neutralized	7,83	39,17
8	Final Centrifugation	25,46	127,31
9	Final Drying	7,79	38,95
Total		1,31	6,56

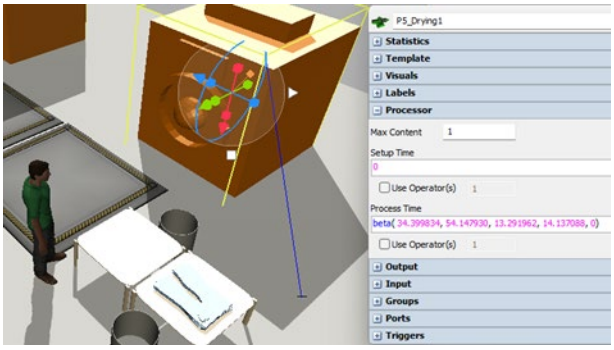

Fig.3 Process time according to statistical distribution, from FlexSim

4. Results and Discussion

A. Littles's Law

In a theoretical context, to know the amount of production in process that exists, we start from a yield of 0.87 batches per hour and a processing time of 6.09 hours for the complete cycle. Here, applying Little's law, we obtain a value of 5.29 batches in the production chain.

$$L = 5.29\ lotes \tag{2}$$

B. Modeling development

Then, the modeling starts with the import into FlexSim of the background made in the AutoCAD software. This is how the work objects are placed following the sequence of the production line. Here the 3D format and the statistical distribution of each element is imported so that the working sequence is as realistic as possible, see Fig.4.

Fig.4 Simulation environment, from FlexSim

In addition, the 9 areas of the Stone + 3 Crafts jean washing process are configured in FlexSim so that the following objects exist: a combiner, a processor and a separator at each point of the processes. This allows to configure later the number of elements to be entered in this, in the same way each one of these is attended by an operator, respectively. Also, Fig.5 shows the FlexSim scheduling of work shifts to limit travel within the facility. Thus, personnel work each shift from 8:00 a.m. to 5:00 p.m. with one hour for lunch.

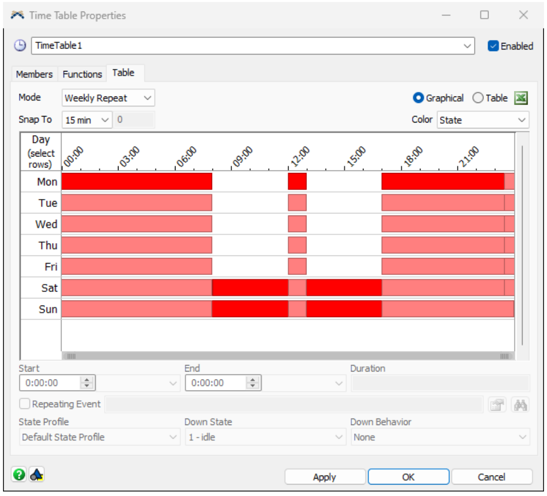

Fig.5 Working hours, from FlexSim

As for the fluid tool, this emulates the supply and drainage of horizontal washers by integrating the 3D model and Process Flow in FlexSim. Processes 3 and 7, Stone and Neutralized respectively feature the use of fluids with 1000-liter capacity tanks. Its actuation is activated independently in the Process Flow algorithm for each of the tanks, either for liquid inlet or outlet between objects as shown in Fig.6.

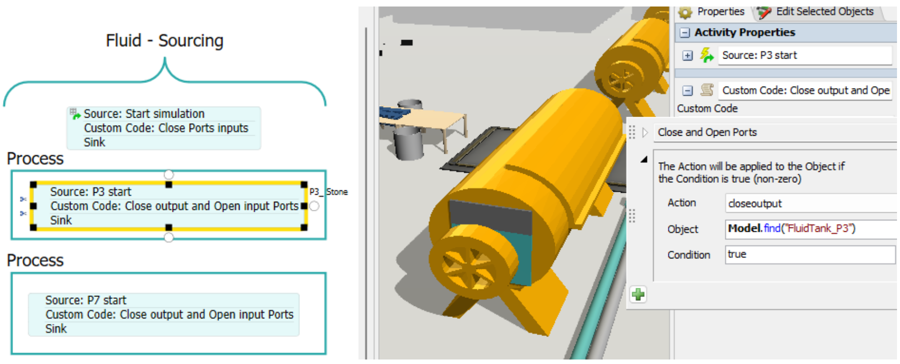

Fig.6 Fluid supply, from FlexSim

Additionally, within Process Flow a transport is configured with the use of a TaskExecuter and ItemList, which are triggered to load, transport and unload the element when required, according to Fig.7, from point 8 to point 9 of the sequence.

Fig.7 Transport algorithm, from FlexSim

To visualize the results, Dashboard is used in FlexSim. This provides a customizable interface where the capacity of batches entering the processors and the uniform used by the operators can be modified. These elements are linked to the 3D modeling as shown in Figure 8.

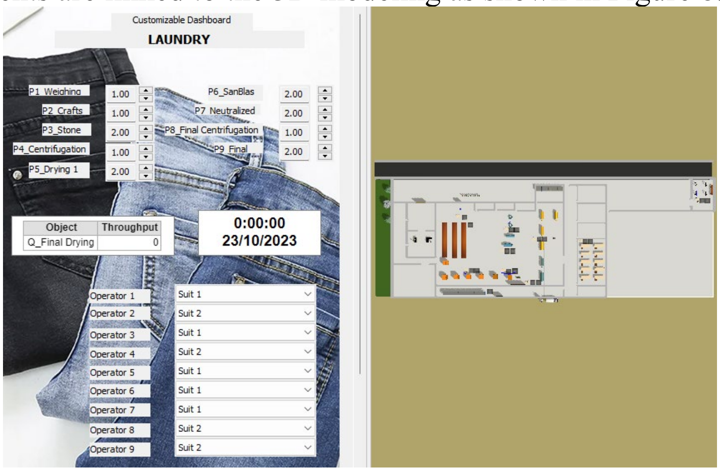

Fig.8 Customizable interface, from FlexSim

C. Running the simulation

As a starting point to verify if what was previously codified is correct, the simulation is run for a period of time of a full week. Thus, the throughput is observed that in comparison with the theoretical results of the production capacity (34.63 batches/week), the simulation results present a value of 34, which reveals a low degree of standard deviation in the drying process, see Figure 9. Finally, with the mentioned values, an error percentage of 1.8% is obtained, see Table 3.

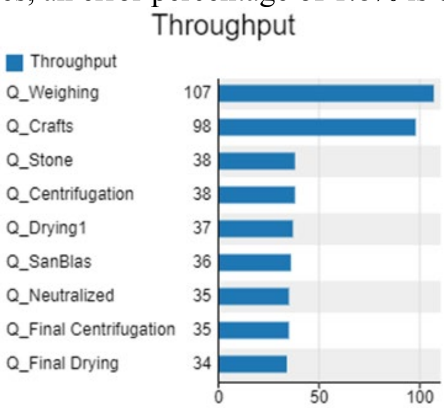

Fig.9 System performance results, from FlexSim

Tabla 3 Percentage of error

Time study	34,63
Simulation	34
Difference	0,63
% error	**1,8%**

D. Tailing analysis

The wait analysis is performed with the Staytime and Work in Process (WIP) tool, which show the variables of the process that is the busiest and the amount of work in process. Here Figure 10 indicates that the Stone process (P3_Stone) has the longest busy time followed by Neutralized. Additionally, the Stone queue is quite high with 58 batches and the following processes are adapting to this. On the contrary, the Centrifugation process (P4_Centrifugation) and the Final Centrifugation (P8_ Final Centrifugation) show values of zero since they must wait for the previous process. Finally Fig.11 shows the histogram of the WIP variable.

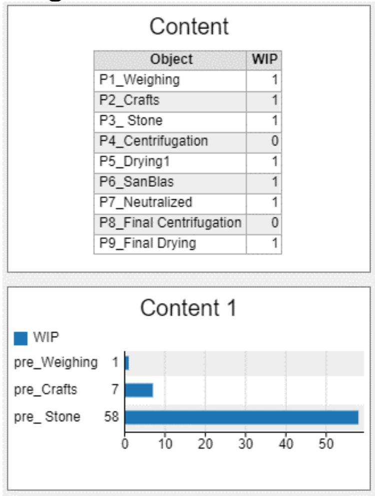

Fig.10 WIP variable counters

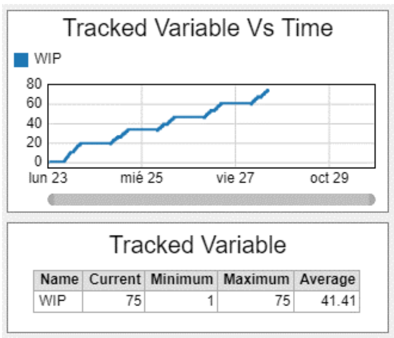

Fig.11 Histogram of the WIP variable, from FlexSim

Fig.12 shows the permanence of time that has high values in the Stone process and the Neutralized process, since after the crafts and weighing that are required at the beginning, these are the only processes with a high percentage of utilization, leaving the following processes with prolonged waiting times, see Fig.13. These are the only processes with a high percentage of utilization, leaving the following processes with prolonged waiting times, see Fig.12. The result is an overall yield measured at 58.95%.

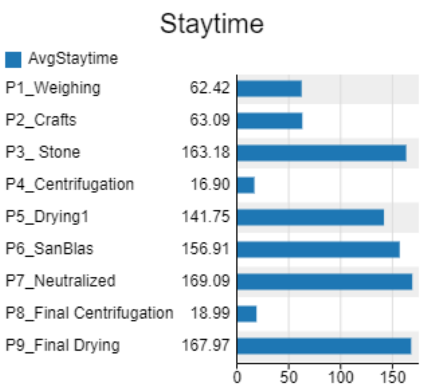

Fig.12 Permanence of processes over time, from FlexSim

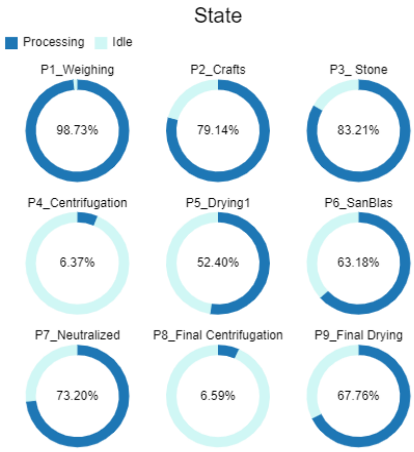

Fig.13 State procesing by process, from FlexSim

E. Process performance and operators

Fig.14 shows that the operators of the first processes are the only ones who are continuously active because they are manual activities, so the following operators will only be active when supplying and unloading the machinery, consequently their performance is not as good throughout the day, resulting in an average of less than 50 percent of the workers.

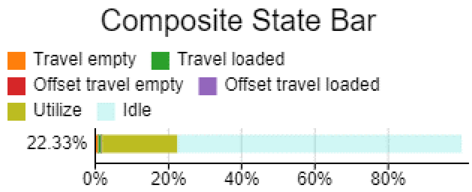

Fig.14 Efficiency of operators globally, from FlexSim

F. Theory of contrainst

The results and the start-up of the simulation are also validated using the Experimenter tool to generate various simulation scenarios. Once it is identified that the Stone process is the bottleneck with a time of 69.30 min and a Staytime of 163.18 min, then the Experimenter tool is used to program different scenarios of processor capacities.

Fig.15 presents the scenarios proposed for the simulation experimentation. The first one represents the initial situation of the company, and the second one increases its capacity in the Stone and SanBlas process. Scenario 3 increases capacity in almost all processes except Weighing, Crafts and Final Centrifugation, and finally the fourth scenario further increases capacity in the Stone and Neutralized process

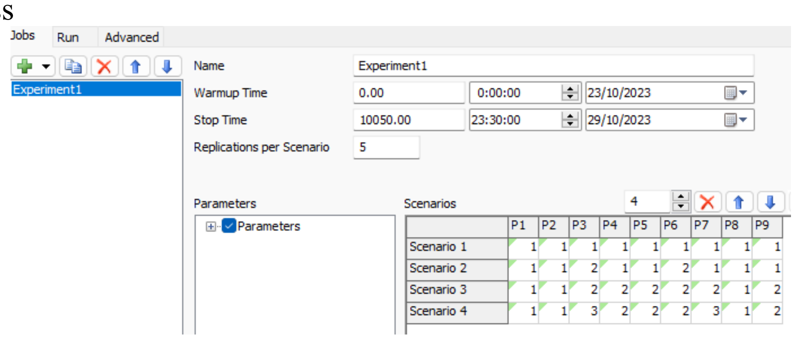

Fig.15 Simulation setup in Experimenter, from FlexSim

Consequently, from the four scenarios and considering the performance measure of units produced at the end of the production line, it is obtained that the third scenario contains the highest amount of production which stabilizes the bottleneck, see Fig.16.

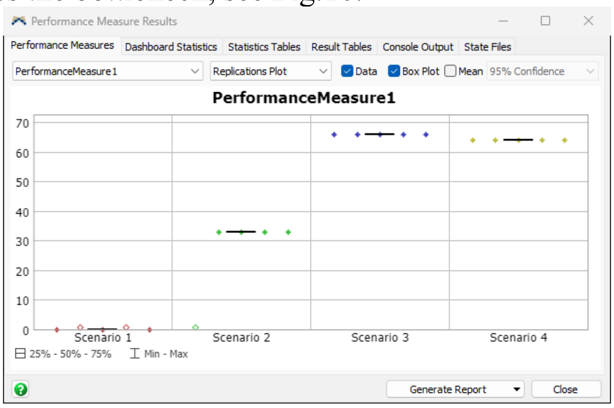

Fig.16 Result of performance measure 1, from FlexSim

Table 4 shows the initial scenario, here there are 34 batch units. In addition, the proposal represented by scenario 3 shows 66 batch units, which generates a performance improvement of 194%. The fourth scenario is not considered as the best proposal because it consumes more resources and the result is similar to the third one, see Fig.17.

Tabla 4 Percentage increase in production

Initial	34
Proposed	66
Difference	32
% error	**194,1%**

With the results of the best simulation scenario, the parameters prior to the Stone process and Neutralized process are modified in FlexSim where two batches are entered instead of only one, i.e. 200 pants are processed instead of 100, which is like having a second machine in these processes. Thus, it is verified that with the configurations made, an increase in production capacity is obtained from 34 to 66 batches, similar to those observed in the Experimenter scenarios, with the difference that they are now implemented in the model.
This levels the capacity of all the system processes and at the same time optimizes resources, see Fig.15. However, in spite of the modification, there is still a high permanence of time in the stone process, which is observed in the Staytime of Fig.18.

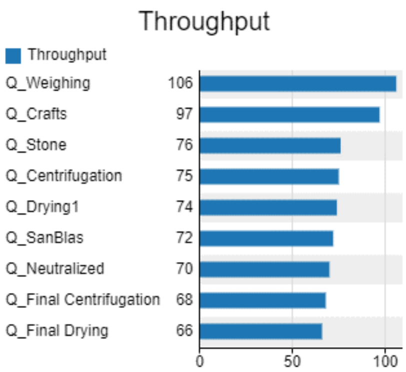

Fig.17 Accountant with the proposed capacity, from FlexSim

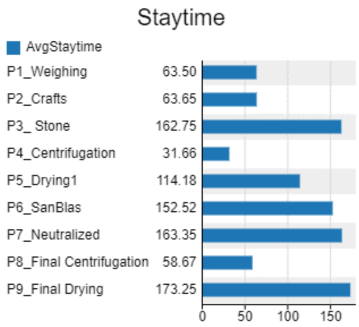

Fig.18 Permanence in time with the capacity of the proposal, from FlexSim

Finally, to modify the capacity of the processors both initial and default values in an accessible way to control the possible scenarios, the custom interfaces of the Dashboard created in FlexSim can be used. This is done using the Spinners up or down shown in Fig.19.

Fig.19 Modification of capacities from the customizable interface, from FlexSim

G. Fluid statistics

Fig.20 shows that the tanks are supplied and drained only during working hours. It also shows that the Stone process (FluidTank_P3) works more than the Neutralized (FluidTank_P7) considering its utilization percentage because it is earlier in the production line, leaving the Neutralized process with pending work. It is also indicated that the Stone process made 39 water inlets of 1000 liters each, since that is the capacity of the tank.

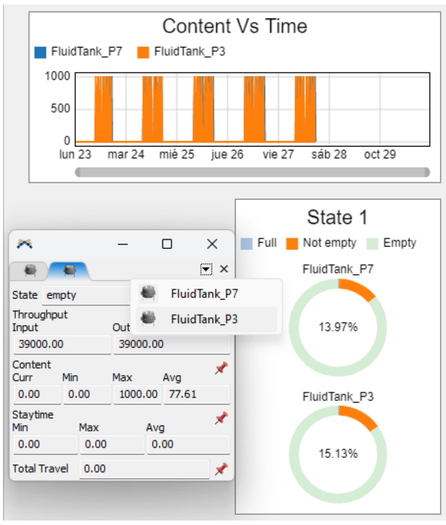

Fig.20 Fluid statistics, from FlexSim

H. Implementation cost

Considering the improvement proposal that requires a second piece of equipment for certain processes, this generates an improvement implementation cost with a value of $ 28,272.00, represented in Table 5. Here the average prices of the machinery, installation costs and external supplies are considered.

Tabla 5 Improvement implementation costs

Detail	Subtotal
Machinery	$ 26.790,00
Installation costs	$ 1.110,00
External supplies	$ 372,00
Labor	-
Total cost	**$ 28.272,00**

Discussion

Using the FlexSim tool allows an effective analysis of production systems. This facilitates decision making for top management, since it provides the opportunity to save resources and manage possible scenarios with performance improvement alternatives. In addition, the software virtualizes processes in a 3D environment by integrating the physical environment with the virtual one through the use of simulation as an I4.0 technology.

Regarding the results of the simulation, the operation process with the longest delay is Stone. Thus, at the end of this production line, the final product was 34 batches or its equivalent to 3400 pants, and with the modification of the improvement proposal, 66 batches of final product were obtained with an increase of 194% and of the working day that is carried out within the established schedule.

With the TOC it is proposed to increase the capacity of some of the processes in order to have more production at the end of the line. It starts with the Stone process, then with the SanBlas process, and finally with all the processes involved in reduced time. In the case under study, it is increased from one batch per process to two or three batches per process. In addition, there are possible options and others that are limited considering the company's resources. Also, the exact values both in the time study and in the simulation are being combined so that improvements in organization, sequence and production capacities can be applied, thus allowing to have a better recreated virtual environment.

In the jean washing production plant, the main product to be handled is the pants, but it implicitly involves the use of fluids for the Stone and Neutralized machines, many know them as horizontal washing machines. In order to cover this condition, FlexSim's complementary fluid library is used to project the supply and drainage of the tanks of this machinery as the activity is carried out in the process flow. Additionally, the statistical tools give us values consumed in liters for each of the tanks, and the visual representation is much more parallel to reality.

Both fluids and operator operations, e.g. transports are linked to FlexSim's Process Flow tool. This is a sequential code where you have access to the 3D modeling with all its objects, functions and information that can show their operation. In this research a transport between 2 objects is programmed without the need of interconnections, involving only a TaskExecuter and an ItemList, in addition to the supply and drainage drive of the complementary fluid in the washing processes. This type of programming has a greater possibility of manipulation and control over the objects, since, compared to the connections made in 3D modeling, there is no risk of confusing interconnections or visually overloading the modeling.

Considering scenario 3 as the improvement proposal within the simulation, the requirement of a second machine in the Stone, Neutralized, Intermediate Drying, Final Drying and Sanblas process is proposed, so that with a cost analysis a financial value of $ 28,272.00 is determined, which should be investigated by the top management to make the implementation decision. Although it may seem a simple change in the simulation, it may involve multiple important changes within the plant and the company's economy.

In comparison with another study on productivity improvement in textile industry companies through I4.0 technologies (Pirola et al., 2021), it is found that the virtualized intelligence of the company's activities provides greater awareness of the current status of the activities, in this case it is intended to improve the management system and production scheduling, using IoT technology. In addition, through the collection of data in real time, in contrast to the present research is also used another of the technologies of the I4.0 which is the virtualization through 3D simulation allowing an increase in production capacity with the identification and management of the bottleneck. Both in the comparative research and in the present one, scenarios are used to compare the possible results and select the most viable alternative.

5. Conclusions and future research

By means of the information collected in the laundry it was possible to determine the product with the highest demand in the company, for which the sales history was used, obtaining as a result the Stone in addition to 3 handicrafts, this process has 9 activities that are carried out by a total of 9 operators, one for each of them, these are carried out according to a flow and sequence diagram that was developed based on the description of the production process. The work environment was also graphically represented to have a space as similar as possible to the reality of the company and finally, a time study was carried out, which was useful to determine the work times of each of the stages that are part of the star product.

With the support of the time study, the layout of the company and the information of the environment, the modeling of the Stone pants production process was proposed. This resulted in a theoretical weekly production of 34.63 batches and a queue value of 5.29 batches according to Little's Law. Consequently, with the use of additional tools such as ExpertFit, Experimenter and extra resources, a virtual replica of the company's activity was carried out. In addition, the fluids tool was used to incorporate liquid elements in the processes of the horizontal washing machines, and its operation was carried out with Process Flow. A transport between two different tasks was also controlled with a sequential programming method, and each complement mentioned contributed to the simulation being virtually replicated, resembling the daily activity of this company.

Once the simulation was carried out, it was found that the company has the capacity to produce 34.63 batches per week, compared to the simulated value, a closed value of 34 batches was obtained. In addition, through the analysis of the statistical graphs of the Staytime and Throughput, the bottleneck was found in process three or Stone. This information contrasts with the TOC and by applying it within the Experimenter tool, four different scenarios are proposed, which allow an improvement within the modeling, going from 34 to 66 batches in scenario 3, so this is considered as the improvement proposal. Aligned to this, in order to manipulate the initial version and the improvement, there is a customizable interface to modify the capacities fluently. Finally, the simulation provides background for decision making in a real implementation in the company under study, with which an economic cost of almost $30,000.00 was obtained.

The limitations presented in the research are the non-standardization of the processes, which makes it difficult to collect accurate and reliable data to represent the simulation. Also, the variability of the demand, the variability of products in stock and the internal organization of the personnel for the execution of internal activities to be performed.

Additional future research emerges from the results of this case study. Based on the data resulting from the simulation and calculated by formula, it is proposed to make semi-periodic scaling in the company to adjust the behavior as close as possible to reality with the new information collected, as well as updates within the production chain. In addition, it should be considered if the improvement chosen by the top management is applied.

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