Proceedings of the 21st International Conference on Modelling and Applied Simulation (MAS), 013
19th International Multidisciplinary Modeling & Simulation Multiconference

2724-0037 © 2022 The Authors.
doi: 10.46354/i3m.2022.mas.013

Repacking line simulation for a small enterprise supplier of the dairy industry

Jorge Luis Torres Miranda[1], Azahed Arturo Hernández Cuéllar[1], Cristina Delval González[1], Sergio Iván Lozada Reyes[1]

[1]Universidad Nacional Autónoma de México, México

Abstract

This work is applied in a small company with problems of delays in its deliveries since they don't have the parameters that allow them to decide whether to carry out their processes by hand or by machine, and the number of operators that should work based on the size of their demand. To solve this problem, the objective is to obtain the production capacity in both lines, which is the key performance indicator, through a limited data collection solved with the implementation of a triangular distribution model, and through discrete events simulation using the FlexSim® software. The results of the simulation thrown in this work will allow to graphically visualize the bottlenecks, adjust the number of operators required in each section of the process, redistribute the plant to reduce said bottlenecks, and give an analytical way by implementing the "experiments module" that provides a certain number of replicas of manual and hopper filling events; finally allowing to obtain the productive capacity of the business, and propose a model that meet variable demands without compromising unnecessary deployment of machinery and personnel.

Keywords: Simulation; Fulfillment; Production Capacity; Small Enterprise; Discrete Event Simulation; Industry 4.0.

1. Introduction

In Mexico, small enterprises correspond to 4.03% of the Economic Units, which represents the 79% of total contribution of business, and 14.83% of the Employed Personnel in the country, similarly, they produce more than 14 percent of the Gross Domestic Product (González and Chiatchoua, 2021).

Due to this, it represents one of the main engines of economic growth in Mexico; however, given that these companies face various problems to survive against large companies, economic imbalances have become more productive and efficient, it is important to identify the tools we have in order to strengthen the Mexican business ecosystem.

Thus, given that there are small production enterprises that must manufacture variable quantities due to dynamic demand and a variety of products to satisfy the most demanding markets at the lowest possible cost, it is convenient to use technological tools, which is a part of pillars of industry 4.0, since its implementation offers a competitive advantage over the rest.

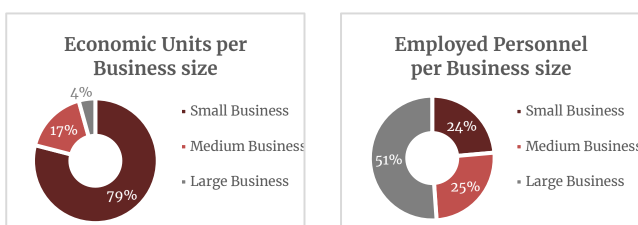


Figure 1. Business contribution to Economic Units and Employed Personnel.

One advantage is to model processes using simulation. Its application represents a powerful tool to improve competitiveness and decision-making, since it allows anticipating the behavior of the production system in different scenarios, detects inefficiencies and analyzes possible alternatives to optimize them without the need to interrupt the process to make improvements, thus incurring unnecessary costs.

Simulation is essential when the model under study is complex, contains random variables and a visual representation is sought; **therefore, simulation is an analysis tool applied when the system cannot be evaluated analytically.**

Simulation is based on three main paradigms, whose main objective is to represent the behavior of systems: The System Dynamics Paradigm, The Discrete-Event Simulation, and Agent-Based Simulation. (Behdani, 2012).

In particular, the Discrete Simulation shows us a real approximation of systems that evolve over time through instantaneous changes in state variables (Sarmiento & López, 2017). The use of this tool allows us to analyze industrial processes, which generally have a high content of work in each product to be produced, so these processes have many variables to consider for their modeling. Furthermore, unexpected occurrences or events occur and the randomness and interdependencies between threads are high.

The company on which this article was based is a small business that is dedicated to filling packages with lactic cultures that are imported from Europe to Mexico and are later packaged and distributed to different areas nationwide. It has a considerable number of orders that can be dynamic, sometimes they receive small orders where the process can be done manually; while, less frequently, they usually receive large volume orders, for which another process is carried out that implements a hopper, which is a tool used to contain substances and direct them to another package or container in a dosed manner. Orders must meet certain specifications, such as delivery time, product quantity, and each package must meet a specific weight. This, coupled with the randomness of the demand, justifies that it would be fruitful to model the lactic culture repackaging line using discrete-event simulation.

It is essential to analyze the enterprise's production capacity since a correct analysis will allow a broader picture of its current and future situation, providing fundamental information that allows it to satisfy the variable demand generated. On the other hand, it is extremely important to identify inefficiencies that may exist in the production line, as this will allow maximizing its performance.

In this manner, the objectives pursued with the implementation of the simulation in the dairy supplier business are:

1. Determine the production capacity for the manual packages filling process and for the hopper filling process.
2. Find the point where demand is no longer being met by the manual fill “product” repack line.
3. Establish if improvements can be implemented to make the productive flow more flexible and increase the capacity to respond to dynamic demand.

One limitation in the development of this model was the taking of measurements of the assembly of the hopper. Obtaining accurate data was necessary to implement at least thirty measurements of assembly time.

Due to the short time available and the number of requests where that were required, it was not possible to carry out the required number of measurements. As a solution, the present work was based on the experience of the operator, who indicated what the maximum and minimum time is, and thus it was possible to generate a function with triangular distribution that allowed modeling the assembly time.

Another limitation was the impossibility of modeling the start-up time, referring to the time it takes for the primary actions to start the process and carry it out all at once, i.e., defrosting the product and heating the sealer. To fix this, the total time was subtracted from the amount of time required to boot.

The simulation model will make it possible to eliminate gaps in unsatisfied demand, reducing delivery times and reallocating the number of operators in each thread to eliminate bottlenecks. This model can be replicated by companies that wish to determine the production capacity by having the option of doing it manually and with the machine, and thus establishing a parameter that allows them to decide based on their demand by eliminating waste such as energy and delays in their deliveries.

Thus, this article consists of a reference to work done in the past that have served to improve production lines, diagrams that facilitate the reader's understanding of the process, a sample of the execution of the simulation in FlexSim®, as well as the statistical analysis produced by the software to conclude with a proposal for improvement in the existing model of implementation of machinery and manual process.

2. State of the art

The business on which this project was developed executes different operations with different processes involved, which sometimes causes the process of filling the packages to take a long time, resulting in delays in the delivery of orders.

This is due to the lack of productive capacity in relation to the demand since there are times when very large or simultaneous orders arrive, it is necessary to attack this problem. These delays cause negative effects on the relationship with costumers, the reputation of the company, planning, production and distribution of the product.

The random nature of a model means that its output or result is also random. This is a key aspect to consider when performing a simulation and especially when analyzing the results. Thesen and Travis call this principle RIRO (Random Input, Random Output). (Thesen, 1991).

In addition, when going through the interpretation of the data obtained, the elaboration of the improvement proposal focused on satisfying the needs of the business, the result in the implementation is even more different.

An example of this is the simulation of the production line of the Company Alimentos Pepsico S.A., where different scenarios were proposed, such as the increase and decrease in the demand for the product. Where the results indicate that the enterprise can increase the capacity of its operations, and therefore increase its performance (Pernía, Ramírez and Torres, 2006).

Regarding production paradigms, there are works such as the modeling of a production system through Petri nets, to study the behavior and support decision making to strategically improve the system through the integration of the lean production paradigm. (Morales, Hernández and Jiménez, 2019).

Finally related to the production capacity determined with the support of FlexSim®, as is the present work, there is an article on the production of french fries (Galindo, Facundo, Sánchez, and Quijada, 2020), although they do not receive the treatment of a lactic culture, in which not respecting the temperature and portion intervals seriously compromises the quality of the product. These are perishable foods that must also be stored under certain parameters while they do not enter the production process, equivalent to the packaging process of the business under study.

3. Materials and Methods

3.1. Methodology

Simulating a process requires precision in each of the steps to be developed because it involves an investment of time and money that is reflected in the economy of the companies that make use of this tool. Therefore, it is strictly necessary to establish each of the stages that will be developed to perform the simulation of the process under study, these stages are made up of a series of activities that define the methodology to be used for the development of the simulation, which will be a guide to obtain the desired results and avoid future mistakes.

Correspondingly, to conduct the simulation study, the methodology that would allow analyze the production line of the enterprise is the one proposed by Harrel, Ghosh and Bowden (2012), which was adapted to the problem in question and is described below:

1. Define objective and plan the study.
2. Collect and analyze system data.
3. Build the model.
4. Validate the model.
5. Conduct experiments.
6. Present the results.

The methodology was carried out iteratively, since the activities that were developed in each step were improved and redefined in each iteration. This, in accordance with the objectives that were wanted to be achieved and with the limitations that the process presented. These iterations were carried out until a simulation with significant results was achieved.

On the other hand, it's important to mention that the tools used to perform the analysis and solution of the problem addressed in this article were the following: Process mapping and layout, influence diagrams, statistical analysis of input data and software of simulation.

To obtain the distribution of the simulated processes, a data independence test and a goodness-of-fit test were performed, using two software packages for greater certainty in the results: StatFit and Minitab with the objective of comparing the results obtained with each one and verifying that in both cases the results were consistent.

In the case of the independence test, we carried out runs test as well as the realization of scatter plots while for the goodness-of-fit tests we used the CHI-SQUARE test.

Verification: To verify that our model had no errors, we used the actions suggested by Harell, Ghosh y Bowel (2004) which consisted of:

- Check the code of the model
- Corroborate that the results were reasonable
- Observe that the animation of the model will behave correctly
- Use the software tools for error debugging

Validation: For the validation of the elaborated model, we use the expert test (technique proposed by Law (2015) and Harrell, Ghosh and Bowel (2004))

Which consisted of sharing the model with the managers of the plant and that they determine if the model reflected the real system.

Regarding the software, FlexSim® was chosen due to its ease of use, competitive price, capacity, and features. It is object-oriented and developed in a three-dimensional environment, which allows a greater visualization of the production flow under study, the generation of different scenarios and varied conditions are easy to program, finally, the graphs, reports and everything related to statistics can be reviewed in detail. (Díaz, et al, 2018, p. 100).

3.2. Data Collection

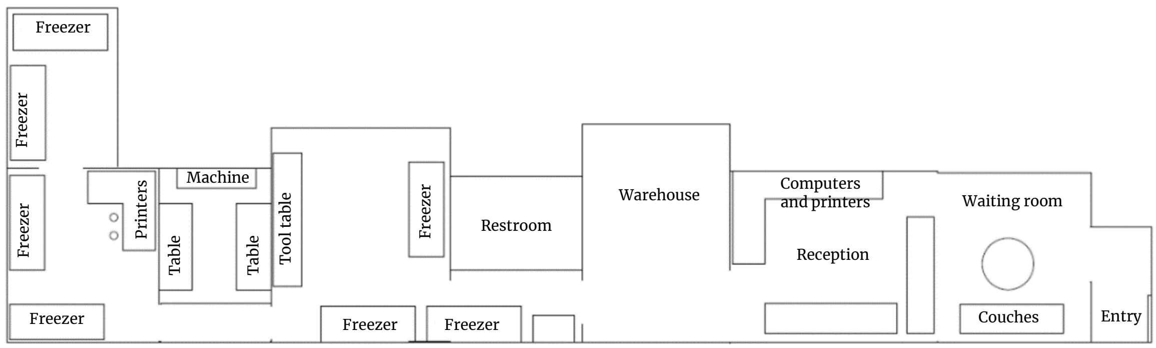


Figure 2. Layout of the workspace.

To perform an investigation with real data, visits were made to the company under study where an *in-situ* observation of each of the operations was carried out, as well as interviews with the operators involved in the process. This allowed to obtain the description of the flow of the operations that are executed in the production line, along with the collection of the necessary information for the simulation study that includes the structural and numerical data (times) involved in the process, from which the simulation model was made.

3.2.1. Operational Data

The company carries out a production process that varies based on the volume of customer orders. If the order is small, a manual process is executed. On the other hand, if the order is large, an automated process (with a hopper) is used, which covers a ***greater production.***

To adequately visualize and understand the description of the operations that take place in the lactic culture repackaging line, the enterprise's layout was developed, which is shown in Figure 2.

The process begins with the reception of the order that includes the specifications required by the client. Subsequently, the weight of each imported package is calculated considering the Activity Units. Afterwards, the imported packages are removed from the freezers and, since it is a repackaging line, two types of packages (the imported ones that contain the product and the empty ones from the new order) are transported to the emptying room. While these operations are being carried out, the room is cleaned before the packages arrive, the labels are printed describing the type of product and the quantity in grams that each package of the order is contained and are glued to each package, taring a scale, and if necessary (for large orders), the hopper is prepared.

After completing these operations, each one of the order packages is filled on the scale and the weight is inspected to what is indicated. Then, the sealer is heated, which is also in the emptying room, and when It's ready, the packages are transported, both the imported ones that contain surplus crops and those of the order so that they are all sealed; the former are taken back to the freezer, and the order is packaged including a bag, a cooler and a box. Finally, these are stored for future collection.

Below is a flowchart that summarizes the operations involved in the process:

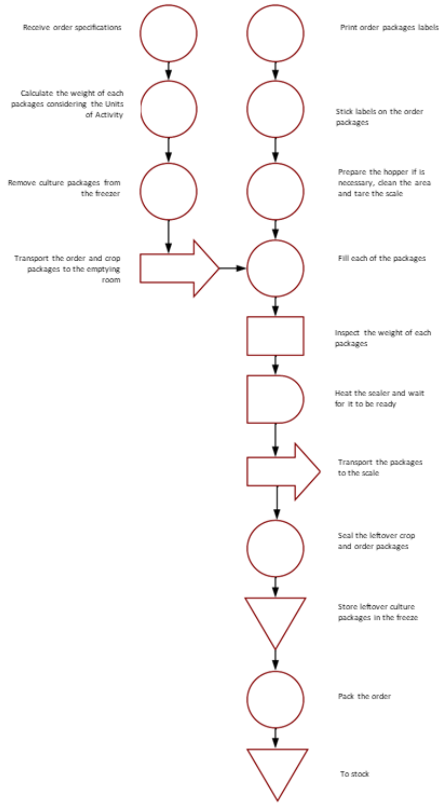


Figure 3. Process diagram for repackaging lactic cultures.

3.2.2. *Structural Data*

The resources that the enterprise has that are directly related to the process are listed below:

Infrastructure:

- Warehouse
- Production area

Equipment:

- 7 industrial freezers
- 3 sealers
- 1 computer
- 4 label printers
- 1 Hopper
- 4 scales
- Filling tools
- 3 strapping machines
- Air dryer (mini split)
- Tuppers (containers to support the packages on the scale)

Human Resources:

- 4 production workers
- 1 supervisor
- 1 quality manager
- 2 hopper assembly and cleaning operators

3.2.3. *Numerical Data*

Observations were made for the two types of productive lines, manual and automated; of which, the time it takes to perform each operation that integrates the process was collected and documented. The operations considered for the study are printing and gluing of labels, filling, weighting, sealing and packaging packages.

In the case of the preparation for the automated production line, the configuration of the hopper is needed, for which the basis was the experience of the operator who indicated what the maximum and minimum configuration time is. From this information, an approximated distribution was generated for the time of this operation.

Although one way to calculate the sample size in data collection is by using a statistical formula with a certain confidence level, in our case the size of the population was variable, which complicated the proper use of the formula. At the same time, one of our limitations in establishing a sample size that adhered to a given confidence level was the complexity of the process and the time and resources that this exhaustive sampling represented.

A representative sample is one whose size is appropriate, has been obtained by random procedures and whose observed characteristics correspond to or reflect the behavior of the population to which they belong (Ras, 1980; Cochran, 1976; Scheaffer, Mendenhall y Ott, 1987). Therefore, we decided to use a standard sample size of 30 data, which guarantees (statistically speaking) a representative sample of a considerable size according to the central limit theorem, which states that the distribution of sample means approximates a normal distribution as the sample size gets larger, regardless of the population's distribution. Sample sizes equal to or greater than 30 are often considered sufficient for the CLT to hold.

Table 1 presents a summary of the times of the operations involved in the process.

Table 1. Summary of process times.

OPERATION	OBSERVATIONS	TIME [seconds]			
		MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM
Label printing	30	4.88	0.87	3.37	8.1
Label pasting	30	6.22	1.07	5.03	8.67
Manual filling	30	43.36	12.39	14.26	66.77
Automated filling	30	8.04	1.05	6.38	10.23
Post fill adjustment with hopper	30	14.97	5.73	7.21	30.16
Sealing	30	4.8	Constant time for each package		
Packaging	30	629	Constant time for every 40 packages		

Source: Own Elaboration

3.3. Conceptual Model

Since the system is an online production, a black box or "input-output" model was obtained as a first approximation to represent it and understand the input and output variables in the system. Thus, the input variable is the number of packages ordered and the output variable is the number of repackaged orders.

Figure 4. Black box diagram.

Based on the above, influence diagrams were elaborated to graphically visualize the variables involved in the repackaging process with their interrelationships to understand how they impact each other and the expected result. The influence diagrams for the manual and automated process are shown in Figure 4 and 5, respectively.

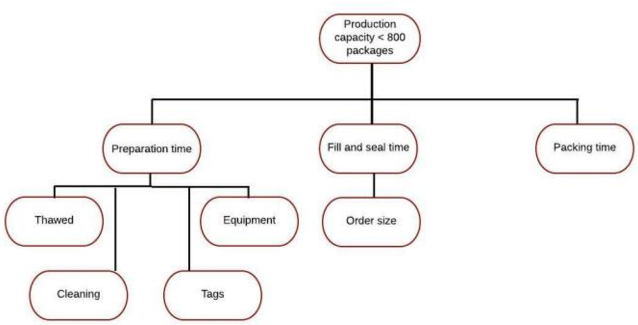


Figure 5. Influence Diagram (Manual Process).

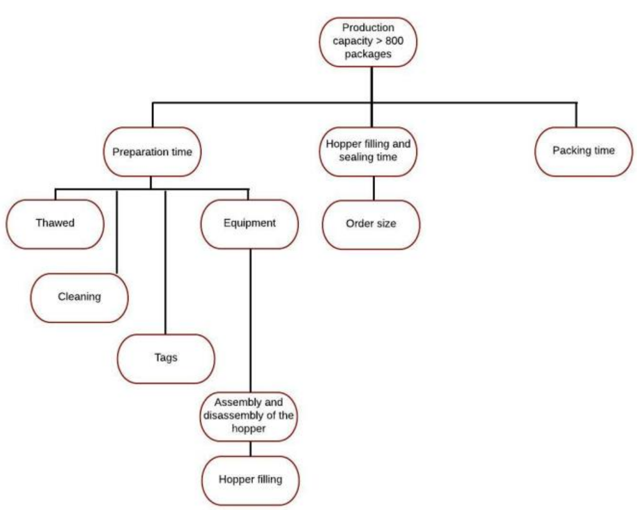


Figure 6. Influence diagram (Automated Process).

3.4. Simulation and Scenarios

Based on previously elaborated influence diagrams, the two production lines that the enterprise uses were represented going from a conceptual model to a simulation model using the Flexsim® software, as well as the variables that determined production (such as the time available in each working day, preparation times, etc.).

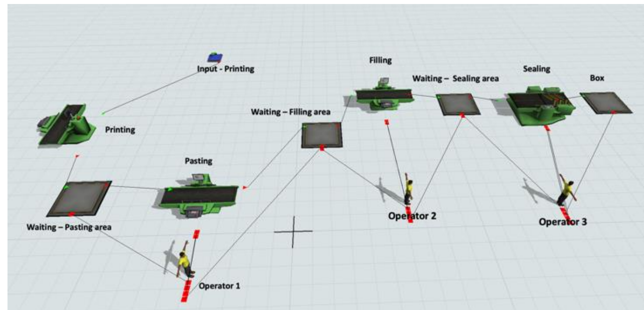


Figure 7. Manual process on FlexSim® interface.

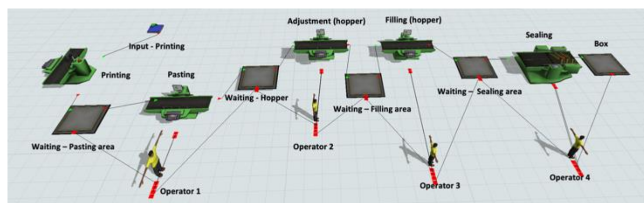
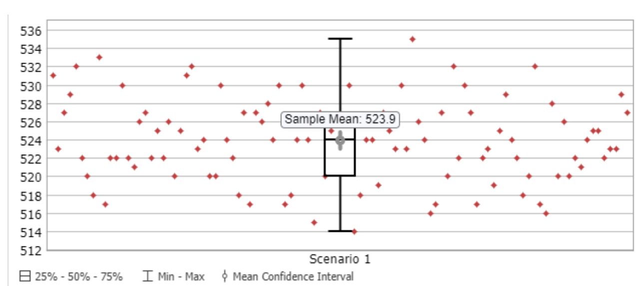


Figure 8. Hopper process on FlexSim® interface.

Once the system was represented with the simulation model, different scenarios were run assuming a constant input of orders, with the objective of challenging the system. In this way, it was possible to identify the maximum production capacity according to the pre-established distribution functions for each operation of the lines.

After the experimentation and iterating the process 100 times with each line obtained, and with a confidence level of 95%, the average production of each line with its standard deviation as well as the possible minimum's and maximum's capability were as follows:



	Mean (95% Confidence Interval)	Sample Std Dev	Min	Max
Scenario 1	523.870 ± 0.912	4.579	514.000	535.000

Figure 9. Hopper production.

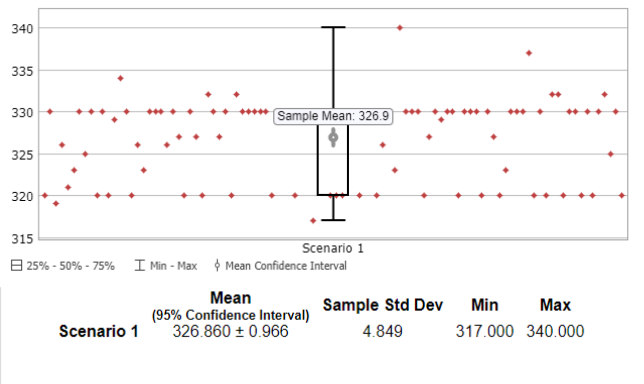


Figure 10. Manual production.

4. Results and Discussion

As shown in the Figures 9 and 10, the results of the simulation model point out that in the manual production line there is an average of 326.9 packages per workday while the hopper production line has an average of 523.9.

A relevant insight for the case is that the company uses a pre-established interval with which they changed the type of line used; in other words, when they have a demand for 800 packages or more, they use the hopper line, and when the order is less than 800 the manual line is used.

Another important consideration is the delivery time since there are two business days of production before the orders must be delivered. With that in mind and calculating the production capacity for two days, it was found that there was a small interval within which the demand was not met:

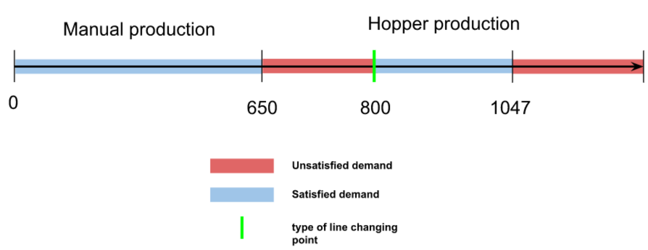


Figure 11. Unmet demand gap.

Therefore, if an order of between 653 and 799 packages arrives any day, the most likely thing to happen is that the demand will not be satisfied in the established laps of time, causing delays in delivery and unsatisfied customers.

On the other hand, an order of 1,047 packages or more someday is unlikely to happen, but if this is the case, the enterprise will hardly be able to meet the demand.

With this in mind, we proposed a readjustment of the line change point to 650 envelopes so that the demand in that interval would be better met.

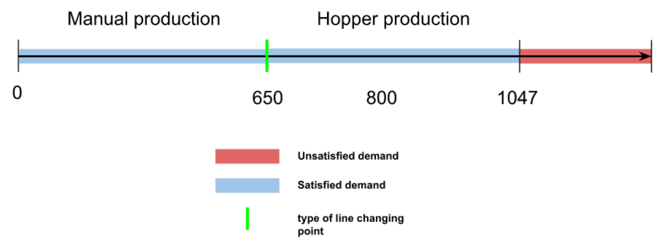


Figure 12. Demand gap suppressed.

5. Conclusions

From the analysis of the results obtained with the simulation model, it is possible to conclude that it is probable that the line switching point used by the company has been established empirically and / or without considering the true yield of each of the arrangements.

Furthermore, when considering the demand interval that is uncovered by the manual line, it becomes clear the need to readjust the line switching point to 650 orders since in this way the hopper model will be able to satisfy the demand of this interval, reducing the number of orders that are not delivered in a timely manner.

Finally, even when the switching point is readjusted, the capacity of both lines will remain the same, so if a production greater than 1047 packages is required in a period of two days, the enterprise will not be able to cover it. This is where the system was analyzed to identify bottleneck points and possible improvements that could be made based on their feasibility, cost, and percentage increase in capacity.

It was identified that there was a bottleneck in the hopper line in the package adjustment operation, therefore it is proposed to increase an adjustment station as well as an extra operator inside the hopper line, which eliminates the bottleneck and increases production capacity from 523.5 to 653 packages per day of operation (equivalent to an increase in production capacity of 19.83%).

As a suggestion for those companies that will use our model and for future works, it is considered pertinent to record the events necessary for the measurement of times in the automated process, so that the size of the sample when determining the distribution on which it is simulated, this is closer to reality. However, by using a triangular distribution it can be ensured that this process can be modeled, as it is considered a tool for use in cases where data collection is not feasible.

As for the other limitation of not contemplating repetitions of operations such as extracting the sample from the freezer at the beginning of the process, success is attributed to the contemplation of the fact that they are simple movements, which although they may vary from one event to another, or between two operators who perform the activity, the margin of error is not greater than three seconds, which does not significantly alter our result.

Using the simulation model to define and manage the productive capacity of the process had a great impact on the final results, since with this it was not only possible to visualize and understand the process in a more holistic way in its entirety, but it also allowed to interact and make changes to the model which reflected the responses or results that the real model would have in a fraction of the time it would take to test them directly in the system.

The model proposed in this work can be replicated and scaled by those enterprises whose working day time is constant, their demand is dynamic, their process is dependent on two or more methods and their result is the same product; in such a way that if a company has not yet invested in machinery, it can consider the results of the simulation model, and if it already has it, the company can manage its processes optimally.

References

Behdani, B. (2012). *Evaluation of paradigms for modeling supply chains as complex sociotechnical systems*. In Proceedings of the 2012 Winter Simulation Conference, Berlin, Germany.

Cox, D. R. (1972). Regression models and life tables (with Discussion). *J. R. Statist. Soc.* B, 34:187–220.

Díaz, M., Zárate, R., & Román, R. (2018). Simulación FlexSim, una nueva alternativa para la ingeniería hacia la toma de decisiones en la operación de un sistema de múltiples estaciones de prueba. *Científica*, 22(2), 97-104.

Fan, J. and Peng, H. (2004). Nonconcave penalized likelihood with a diverging number of parameters. *Ann. Statist.*, 32:928–61.

Flores, A., López A., Ambrís F., Loyo, J., Delgado, J., Montenegro O., López R. (2020). *Análisis de la capacidad de la producción de papas fritas mediante el programa de simulación FlexSim.* Tecnológico Nacional de México en Celaya, México.

Ghosh, B. K., Bowden, R., Gladwin, B., & Harrell, C. (2012). *Simulation Using ProModel*. New York: McGraw-Hill.

González, E. V., & Chiatchoua, C. (2021). Supervivencia de las micro, pequeñas y medianas empresas mexicanas frente al COVID-19. *Revista Latinoamericana de Investigación Social*, 4(1), 1-17.

Heard, N. A., Holmes, C. C., and Stephens, D. A. (2006). A quantitative study of gene regulation involved in the immune response of Anopheline mosquitoes: An application of Bayesian hierarchical clustering of curves. *J. Am. Statist. Assoc.*, 101:18–29.

Law, A. M., Kelton, W. D., & Kelton, W. D. (2007). *Simulation modeling and analysis* (Vol. 3). New York: McGraw-Hill.

Morales, A., Rojas, J., Hernández, L., Morales, A., Jiménez, M. (2015). *Modelo de un sistema de producción esbelto con redes de Petri para apoyar la toma de decisiones.* Ingeniare, Revista de Ingeniería, Chile.

Pernía, Y.; Ramírez, V., Márquez, R. (2011). *Un modelo de simulación del proceso de producción de la Línea DTC-2000 de Alimentos Pepsico.* Universidad de los Andes, Venezuela.

Sarmiento Vásquez, Alfonso, & López Sandova, Eduardo (2017). *Una comparación cualitativa de la dinámica de sistemas, la simulación de eventos discretos y la simulación basada en agentes*. Industrial Engineering, (35),27-52.

Thensen, A., Travis, L. (2001). *Introduction to Simulation.* Proceedings of the 1991 Winter Simulation Conference, Phoenix Arizona, USA.

Dunna, E. G., Reyes, H. G., & Barrón, L. E. C. (2012). Simulación y análisis de sistemas con ProModel. Mexico: Pearson Education.