Simulation, a Tool to Improve the Medical Equipment Production Line

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Abstract. Population growth affects human activities and increases the demand for healthcare goods and services. This results in companies seeking to serve customers better while maintaining quality, timeliness, and fair pricing. This paper presents a discrete event simulation exercise carried out by implementing a 6 steps methodology of our own to achieve greater efficiency in the production of orthopedic products and be able to meet sales commitments. For this, different preliminary activities were carried out, such as the identification of work areas, the process mapping, the recording of operational data linked to production and their analysis, the elaboration of an influence diagram and the development of the model for the simulation.

Using simulation allowed us to identify factors of use in machinery and operators, bottlenecks, use of resources (raw material), among other aspects. Likewise, variations were made in the model to solve the problems encountered and prepare the final recommendations to achieve a better operation. The significance of implementing a related methodology and the advantages of using scientific knowledge to resolve issues are highlighted by this simulation exercise. The article's value is demonstrated using prescriptive simulation as an analytical tool for decision-making in small businesses.

Introduction

Mexico is a country with a medical industry that is growing exponentially. According to the institution “Instituto Nacional de Estadística y Geografía” (INEGI - for its acronym in Spanish), the production value of the disposable medical material sector in Mexico reached 740 million dollars in 2021 growing 11.1% with respect of 2020. Mexican exports of medical equipment experienced a growth of 8.6% year over year from 2003 to 2020 [1].

The market intelligence company “Espicom” points out that in 2011 the Mexican medical equipment market valued at 3.5 billion dollars, and thus consolidates as the second most important in Latin America, behind Brazil [2]. In addition, ever since 2017 Mexico has maintained the eighth place in exportation of medical devices globally, and it is also the leading supplier to the biggest market in the world (United States of America) with a market value that reached 9 653 million dollars in 2021 [1].

Due to this information, it is easy to perceive how important the medical sup-ply industry is for the Mexican economy, or at least it is perceivable how much potential this industry has in said country. Due to this, we have decided to con-duct research in a small company dedicated to the production and distribution of medical equipment to analyze the opportunity areas it has in terms of its production line and how simulation can help improve its processes.

The research will mainly focus on what this small company´s owner has detected is its main problem: Delays. This will have especially insight value due to being a common problem among small Mexican companies whose failures to deliver on time often results in them losing the confidence of their clients and, therefore, also results in financial loses.

The research this will also be extremely useful in understanding how this kind of problems affect at a big scale Mexican economy since, as stated by research conducted by the United Nations, as the size of the companies increases, the added value and investment also rise. The greatest dispersion is located in micro companies and large companies [3]. Meaning the smaller the company, the less productive it is, this is quite problematic they represent 99.8% of the total businesses in Mexico [4].

Researching this scenario, we worked on a discrete event simulation model that compared the system as it is to a proposed process with an additional number of workers performing in each sample of the process.

We also approach a solution corresponding with the implementation of new production machines for some of the most time-consuming activities (bottlenecks), and finally comparing the full time of a process (in certain products) against the older machine models as well as total production for a typical day.

1 State of the Art

As previously stated, and since this paper´s focus is on a small company, minimizing production costs is critical to keep the process of this company flowing. Therefore, analyzing the efficiency of the machinery utilized by the company is critical, since it is speculated that poor maintenance and years of work of the machinery is one of the primary causes of the company's production problems.

As stated, every tenth of a second shorter production cycle led to severe cost advantages, but machinery is not only important because of this, but also because some parts are only produced in the desired design and characteristics, if primary shaping technologies are used [4], for this reason we are not only analyzing and simulating the as is process with just the already available assets of the company, but also considering the comparison between only using the old machinery and utilizing newer models to prove the hypothesis that this is a major problem in the production line.

Obsolete machinery is one of small businesses main issues, especially in the medical products manufacturing industry. The advancement in various technologies have changed the way the healthcare industry approaches its work and the way they take corrective steps for betterment in their work routine [5].

Due to the pandemic, the healthcare and medical industries were forced to adopt newer technologies. This was a huge blow to small manufacturing companies like the one we are studying, that's why analyzing the upgrading of equipment is so important papers must be written in English. Make good use of the spellchecker and ensure that automatic hyphenation is activated.

2 Methodology

[6] affirms that simulation can be defined as the imitation of the operation of a real-world process or system over time. It can be classified by the variables being used as: static or dynamic, stochastic, or deterministic and discrete or continuous events; depending on the use case you can use one or another.

To conduct the simulation project for this paper we used the following 6 steps, to identify the problem of the company and construct a model that represents reality for it to be adjusted to propose changes. These 6 steps align to [8] and [9] proposed methodologies (Figure 1).

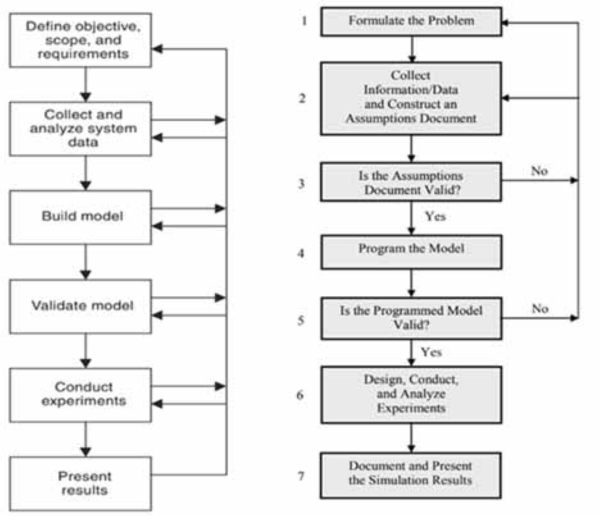

Figure 1: Proposed methodologies to conduct a simulation study by Harell (left) and Law (right). Source: [7] & [8].

2.1 Problem formulation

Small and medium Mexican companies are trying to fulfil the increase in medical equipment demand due to greater consciousness of health necessity. In this paper we discuss about a small company dedicated to the manufacture and distribution of a wide range of orthopedic products.

There are six workers at its facilities located in Mexico City, the roles are composed by a general manager, a person in charge of the director's personal administration area, the reception area, one person in the manufacturing area, one in the billing area, and another one in the shipping area where the finished product is received and distributed, the layout of the facilities is presented on Figure 2, as seen the company has little space to work with, this may result challenging when proposing changes to the system, the material flow diagram will be discussed in a later section, providing a more detailed analysis of the physical arrangement of the company's infrastructure.

The main focus of the analysis is on the company's total production output. This includes an examination of the production process, capacity utilization, and any factors that may impact the company's ability to meet production targets.

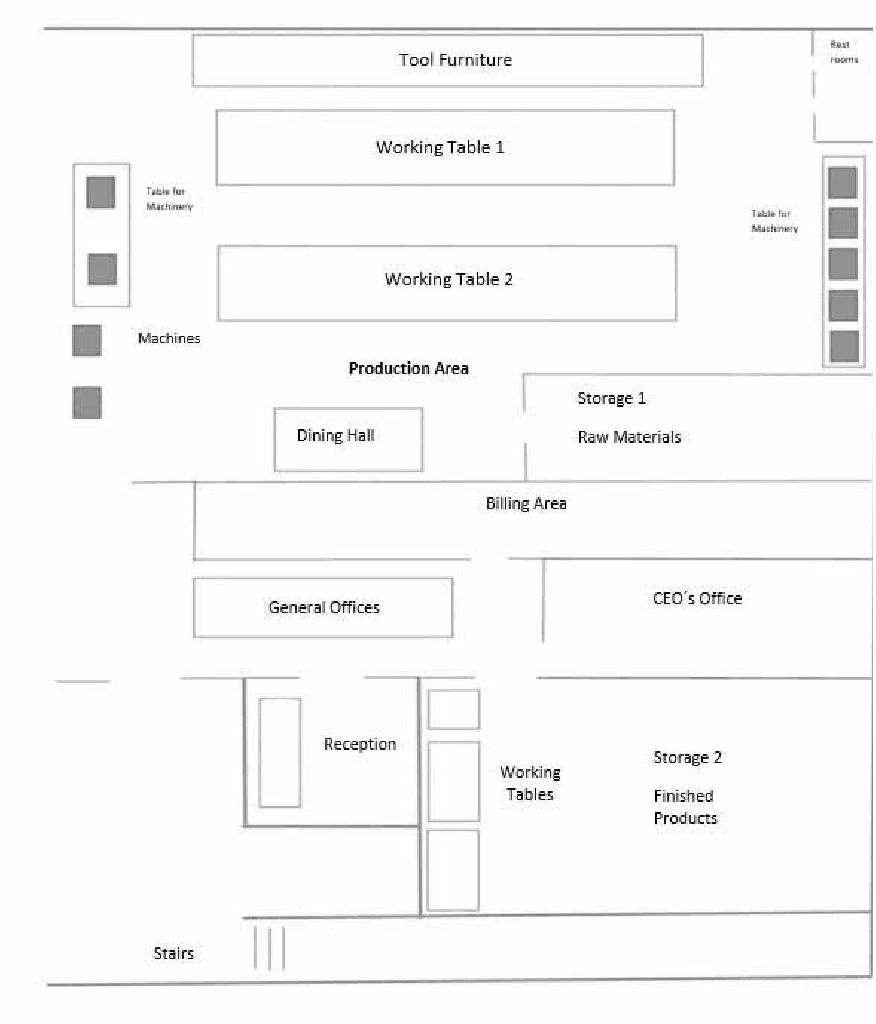

Figure 2: Company layout. Source: Own elaboration.

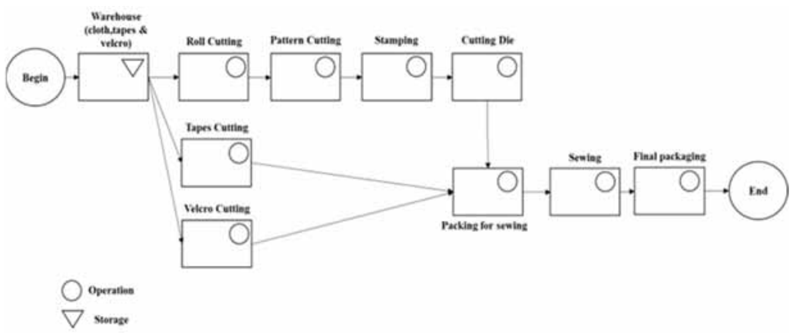

Figure 3: Slings production process. Source: Own elaboration.

By assessing these factors, and with the help of simulation, we can identify areas for improvement and implement strategies to enhance overall production efficiency.

The company must fulfill daily orders of at least 30 slings to keep up with demand, have a positive return of investment and not damage client relationships. Upon analyzing the process, it becomes apparent that the operator faces challenges in meeting their delivery targets. Additionally, the operator relies on only two fabric cutting machines, which are now deemed outdated and may result in potential delays in meeting deadlines.

To identify the root cause of issues within the production line, it was determined that a discrete event simulation could be employed.

During the formulation stage, the objective was defined as simulating the production line of a slings order to ascertain daily production rates and determine the utilization factor of both the operator and machinery.

2.2 Data Collection

For collecting the data, we used a mixed methodology in which we recorded the production of various badges of slings as well as using stopwatches and verifying the times with the managers and owners. The collection was done in different days and times considering external factors that may affect the productivity, such as operator fatigue, climate, and light conditions.

To identify the data to collect used the classification propose by [7]; first structural data what refers all the areas, objects and resources of the system to simulate, operational data this explain how the system objects are processed in the different areas using the resources of the system and finally the numerical data some examples of numerical data are the number of resources (machines, people, etc.), process times and routing probabilities.

Area	Activity	Activity Resource	Next area	Distance meters	Moveent Resource
Warehouse	Supply	Operator	Cut	2.3	Operator
Roll cutting	Cut	Operator	Pattern cutting	1.1	Operator
Ribbons cutting	Cut	Operator	Packing for sewing	2.2	Operator
Velcro cutting	Cut	Operator	Packing for sewing	2.6	Operator
Pattern Cutting	Cut	Operator	Stamping	1.6	Operator
Stamping	Stamp	Operator	Cutting Die	1.3	Operator
Packing for sewing	Pack	Operator	Sewing	4	Operator
Sewing	Sewing	Operator	Final Packing	4	Operator
Final packing	Pack	Operator	-	4.6	Operator

Table 1: Flow chart description (operational data). Source: Own elaboration.

The structural data for the production line are warehouse (cloth, ribbons and velcro), roll cutting, pattern cutting, stamping, cutting die, ribbons cutting, velcro cut-ting, packaging for sewing, sewing and final packaging (see Figure 3). The operational data consists in observing the sequence of the processes of the different components in the areas (see Table 1). Some numerical data are showed in table 1, this refers to the distance between areas.

Additional numerical data that was collected includes process times for each activity we used 50 data points and this data was analyzed with descriptive statistics, independence tests and goodness-of-fit tests.

In the Figure 4 we show one example of the scatter plot used to determine the independence of the data, this scatter point diagram represents the data in a plane composed by the current data point observed vs the next data point [xi+1,xi], in Figure 5 see an example of an autocorrelation dia-gram, another way to determine the independence of the data, in the x axis 1/5th of the data introduced to the analysis is presented since data was collected in an stationary production thus the variance for the whole sample can be used to represent the variance of any subset. For a simulation study, this may mean discarding an early warm-up period [10].

And finally in the Figure 6 we show an example of run test (median & turning points) on the software StatFit® which determines the randomness of a dataset considering first the number of runs of points above or be-low the median and then the number of times the series changes direction, here level of significance must be low for it not to reject the hypothesis that the data set is random.

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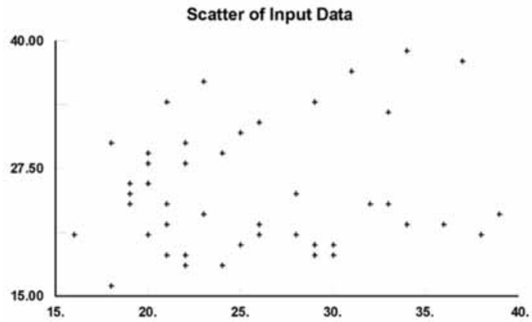

Figure 4: Example of scatter point diagram. Source: Own elaboration.

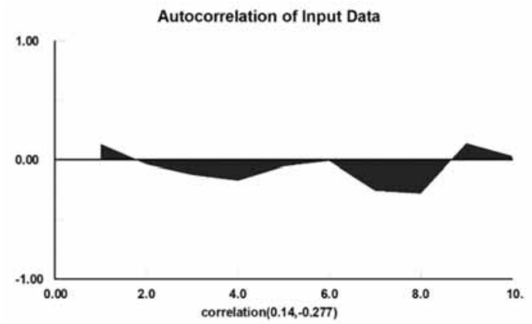

Figure 5: Example of autocorrelation diagram. Source: Own elaboration.

In the Figure 4 we show one example of the scatter plot used to determine the independence of the data, this scatter point diagram represents the data in a plane composed by the current data point observed vs the next data point [xi+1,xi], in Figure 5 see an example of an autocorrelation dia-gram, another way to determine the independence of the data, in the x axis 1/5th of the data introduced to the analysis is presented since data was collected in an stationary production thus the variance for the whole sample can be used to represent the variance of any subset.

Area	Roll Cutting	Pattern Cutting	Ribbons Cutting	Velcro Cutting	Stamp-ing	Cutting Die
Mini-mum	252	1,057	301	5,083	9	1.8
Maxi-mum	284	1,129	338	5,445	33	2.19
Mean	262.72	1,094.6	320.1	5,279.3	18.34	1.9864
Median	262.5	1,090	320	5,287.5	16.5	1.975
Mode	263	1,126	325	5,280	9	1.865
Standard deviation	6.01712	21.2948	10.8801	78.9653	6.69636	0.114031

Table 2a: Descriptive statistics for process time part a (seconds). Source: Own elaboration,

Area	Packaging for Sewing	Sewing	Final Packaging
Minimum	16	316	16
Maximum	26	344	39
Mean	21.44	327.36	25.38
Median	21.5	327	24
Mode	20	327	19
Standard deviation	2.56475	7.92506	5.92432

Table 2b. Descriptive statistics for process time part b (seconds). Source: Own elaboration.

Area	Scatter Plot	Autocorrelation Di-agram	Run Test Median	Run Test Turn-ing Points
Roll Cutting	Ind	Ind	Ind	Ind
Pattern Cutting	Ind	Ind	Ind	Ind
Ribbons Cutting	Ind	Ind	Ind	Ind
Velcro Cutting	Ind	Ind	Ind	Ind
Stamping	Ind	Ind	Ind	Ind
Cutting Die	Ind	Ind	Ind	Ind
Packaging for Sewing	Ind	Ind	Ind	Ind
Sewing	Ind	Ind	Ind	Ind
Final Packaging	Ind	Ind	Ind	Ind

Table 3: Results of independence of data. Source: Own elaboration.

For a simulation study, this may mean discarding an early warm-up period [10] and finally in the Figure 6 we show an example of run test (median & turning points) on the software StatFit® which determines the randomness of a dataset considering first the number of runs of points above or be-low the median and then the number of times the series changes direction, here level of significance must be low for it not to reject the hypothesis that the data set is random.

In Tables 2a and 2b, is shown the summarize about descriptive statistics for the process times of the nine activities (roll cutting, pattern cutting, stamping, cutting die, ribbons cutting, velcro cutting, packaging for sewing, sewing and final packaging), the range of each of the 9 activities is small and this can also be seen by looking at the standard deviation.

The independence test used with the data are scatter plot, autocorrelation diagram, run test (median & turning points), in the Table 3 summarize the results of the four tests for each of nine activities; in this case all the data are independent.

runs test on input

runs test (above/below median)

data points	50
points above median	25
points below median	25
total runs	28
mean runs	26
standard deviation runs	3.49927
runs statistic	0.571548
level of significance	0.05
runs statistic(0.025)	1.95996
p-value	0.567628
result	DO NOT REJECT

runs test (turning points)

data points	47
turning points	33
mean turnings	31
standard deviation turnings	2.83431
turnings statistic	0.705638
level of significance	0.05
turnings statistic(0.025)	1.95996
p-value	0.480413
result	DO NOT REJECT

Figure 6: Example of runs tests (median and turning points). Source: Own elaboration.

Finally in the table 4 summarize the distributions used to represent the process times for each activity, this is the result of goodness-of-fit test (Chi square, Kolmogorov Smirnov & Anderson Darling).

Area	Theoretical Distribution	Parameters	Values (seconds)
Roll Cutting	Lognormal	(μ, σ, min)	(244,2.9,0.302)
Pattern Cutting	Uniform	(min, max)	(1060,1130)
Ribbons Cutting	Normal	(μ, σ)	(320,10.8)
Velcro Cut-ting	Normal	(μ, σ)	(5280,78.2)
Stamping	Lognormal	(μ, σ, min)	(2.78,0.391,0.892)
Cutting Die	Uniform	(min, max)	(1.8,2.19)
Packaging for Sewing	Lognormal	(μ, σ, min)	(6.63,0.00337, -733)
Sewing	Lognormal	(μ, σ, min)	(2.88,0.414, 308)
Final Pack-aging	Lognormal	(μ, σ, min)	(2.49,0.451,12.1)

Table 4: Distributions used for process time (seconds). Source: Own elaboration.

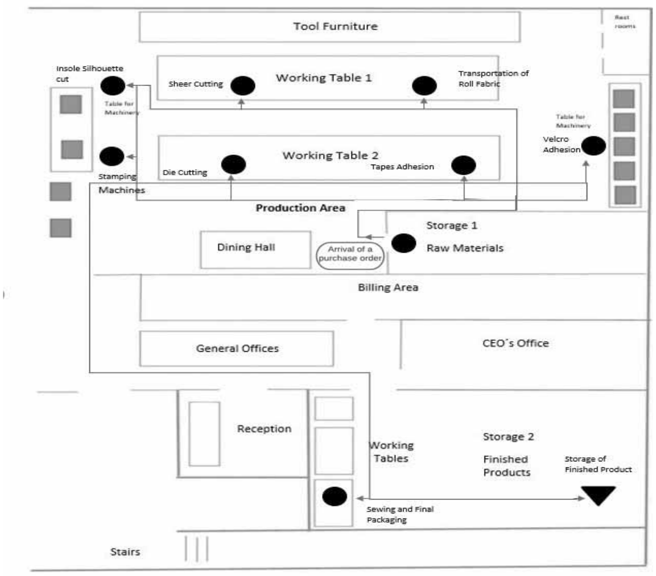

Figure 7: Material flow diagram over layout of the process to simulate. Source: own elaboration.

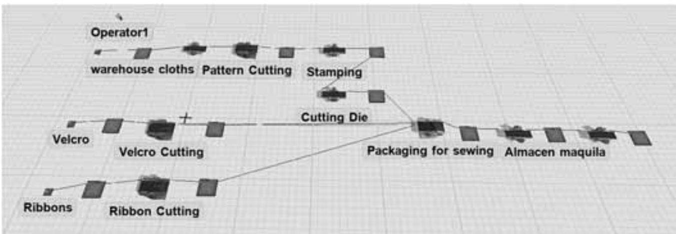

Figure 8: Base model simulation using FlexSim®. Source: own elaboration

2.3 Conceptualization & building a Base Model

Collected data (structural, operational, and numerical data) are used to document the process as closely as possible to the reality and understanding the added value of each step, this conceptualization of the system first was used to elaborate the material flow diagram of the process showed in the Figure 7 which describes how the product is moved from one station to the other in the facilities of the study company. After that a model of the process was created, a representation of this model is in Figure 8.

2.4 Validation of the Model

This step included the verification stage, first the simulation model was executed in the FlexSim software, verifying that no errors were reported and that it operated properly without reporting inconsistencies and checking that the material flow through the production line was respected.

Consequently, with the results obtained from the simulation run, we held a meeting with the stakeholders to determine if the model represented the reality of an 8-hour production of slings in a normal day, doing this meant not only having the approval of the stakeholders but re-measuring each step of the real process to compare the data obtained with the software with the data measured by us. While doing the validation we observed that the model did not present mayor inconsistencies and generally it represented the reality of the production of slings in the company.

2.5 Experimentation

The use of simulation offers a unique advantage in that it enables the generation of various scenarios by adjusting multiple factors, such as changing the layout of the production line, adding new machinery, increasing personnel, modifying parameters, among other possibilities.

By simulating these different scenarios, we can evaluate the impact of each change on production output, efficiency, and resource utilization. This allows for a more comprehensive analysis of potential solutions and provides decision-makers with valuable insights to identify the most effective strategies for optimizing the production process.

Area	Theoretical Distribution	Parameters	Values (seconds)
Pattern Cutting	Uniform	(min, max)	(41.2,48.6)
Ribbons Cutting	Normal	(μ, σ)	(30.8,3.85)
Velcro Cutting	Normal	(μ, σ)	(3.6,5.22)

Table 5: Distributions of new machinery (seconds). Source: Own elaboration.

Area	Mean	Standard Deviation	Minimum Maximum
Base model	30	0	30, 30
2 Operators	60	0	60, 60
New machinery with 2 operators	85.89	3.496	75, 90

Table 6: Scenarios of sling production (daily). Source: Own elaboration.

Different scenarios were tested to increase production output; the two main ones were: having an extra operator to help with the first steps of production and buying machinery to help with the most time-consuming process by replacing old machinery with new one.

The first scenario was discussed as the creation of working stations for each operator, by doing this we ensure both work without crossing and disturbing each other. Operator 1 oversaw Roll Cutting, Pattern Cutting, Ribbons Cutting, Velcro Cutting, Stamping and Cutting Die process, while Operator 2 had Packaging for Sewing, Sewing and Final Packaging process. Operator 2 started to work later than Operator 1 since he depends on the later to finish the first batch. For the second scenario we used the data collected to identify the bottleneck, we determined that Pattern Cutting, Ribbons Cutting and Velcro Cutting, were the slowest processes.

With the help of the supplier's expertise and the machine datasheet we developed and iterated two mathematical models to generate a similar distribution for each addressed process and finally using Statfit® software we obtained the parameters for each process. To generate a normal distribution, we used (1) and to generate a uniform distribution we used (2). In addition to the new machinery, a second operator was introduced in the same manner as the first scenario.

$$Ln(F^{-1}_{(p|\mu,\sigma)}) = x \qquad (1)$$

$$(\mu - \sigma/2) + (\sigma * p) = y \qquad (2)$$

Here

Ln is the natural logarithm,
$F^{-1}_{(p|\mu,\sigma)}$ is the inverse of the lognormal distribution,
p is a random probability,
μ is the mean of the expected distribution, and
σ = is the standard deviation.

Finally in Table 5 we present the distributions and its parameters for the new equipment:

2.6 Results Presentation to Stakeholders

The results of the simulation and of the different scenarios were presented to the stakeholders for them to use as best suits them.

3 Results and Discussion

This section presents the study's findings and provides an in-depth analysis of the findings. The collected data was analyzed using descriptive statistics in the form of box and whisker plots, and the results were compared to the collected data to deter-mine whether the objectives had been met.

The discussion will delve into the implications of the findings and their significance in the manufacturing facilities. The sections that follow provide a detailed overview of the results and discussion.

The study aimed to compare the total production of slings in one day under three different scenarios: base model, two operators, and new machinery with two operators.

According to the study's findings, the average sling production in the base model scenario was always 30 slings being the maximum production for one opera-tor. The 2-operators scenario, on the other hand, resulted in a constant production of 60 slings with the same consideration of the first scenario.

Finally, adding new ma-chinery and with the same roles for the two operators the scenario produced 85.89 slings with a standard deviation of 3.496.

These findings suggest that combining new machinery with a two-operator system can significantly increase total sling production in one day when compared to the reality and two-operator scenarios.

In Table 6 we present a summary of production metrics obtained using the FlexSim® Experimenter.
The study also looked at how three different scenarios affected the utilization factor of operators 1 and 2. When compared to the two-operators scenario, the results showed that implementing new machinery in conjunction with a two-operator system significantly increased the utilization factor of operator 2.

In the new machinery and 2-operators scenario, operator 2's mean utilization factor was 94.137 (see figure 13), whereas in the 2-operators scenario, operator 2's mean utilization factor was 78.6294 (see figure 11). In the new machinery and 2-operators scenario, the utilization factor of operator 1 was slightly lower than in the 2-operators and reality scenarios.

In the new machinery and 2-operators scenario, the mean utilization factor of operator 1 was 98.32793 (see figure 12); in the 2-operators scenario, it was 99.30062 (see figure 10); and in the base model scenario, it was 99.32453 (see figure 9). The box and whiskers diagrams show that the differences in the mean utilization factor of operator 1 between the scenarios were relatively small.

Overall, these findings indicate that implementing new machinery in conjunction with a two-operator system can significantly increase operator 2's utilization factor while having a minor negative impact on operator 1's utilization factor. Making the process more productive while balancing the operator capacity. In addition, standard deviation went from 0.2634 to 0.1223 making the production process more consistent and predictable, therefore improving the quality of the final product.

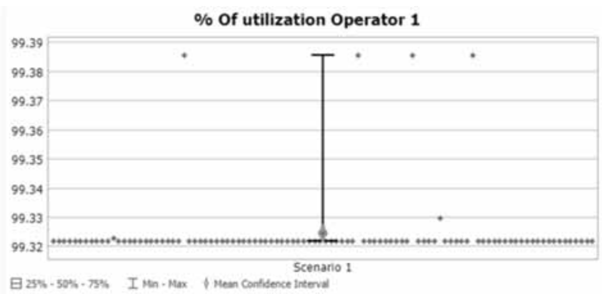

Figure 9: Percentage of operator utilization for base model. Source: own elaboration.

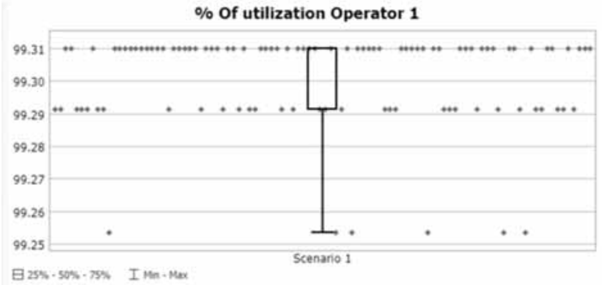

Figure 10: Percentage of operator 1 utilization in the 2 operators' scenario. Source: own elaboration.

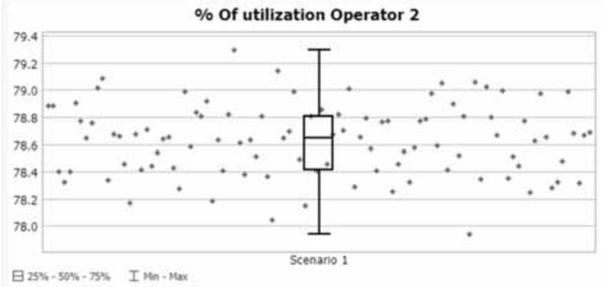

Figure 11: Percentage of operator 2 utilization in the 2 operators' scenario. Source: own elaboration.

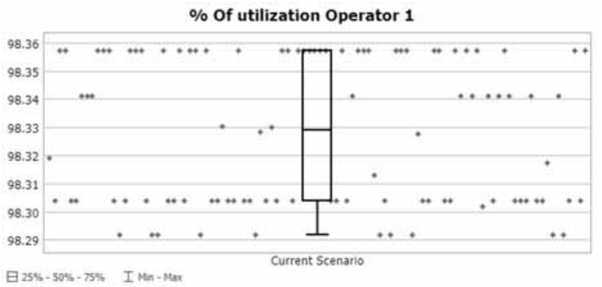

Figure 12: Percentage of operator 1 utilization new machinery with 2 operators' scenario. Source: own elaboration.

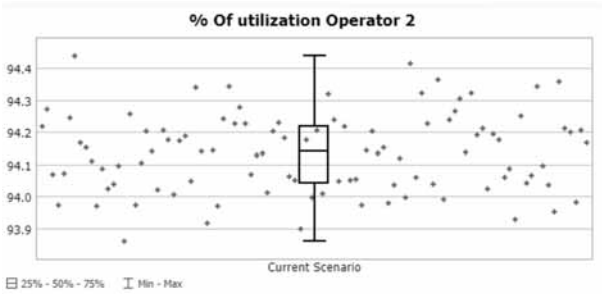

Figure 13: Percentage of operator 2 utilization new machinery with 2 operators' scenario. Source: own elaboration.

4 Conclusions

As we can see, the simulation results prove the initial hypothesis that both the number of workers and the quality of the machines had a significant influence on the production of the company that´s the subject of our study. The time improvements and the elimination of dead time allows us to prove that one of the main causes for delays on deliveries is the lack of workers, since the time the first worker spends preparing the machine and moving the materials around is extremely wasteful.

We can also see how the outdated machinery´s need for time is also a key factor in the delay of the process, since its speed and the time it needs to be prepared is too much in comparison to the one, we can see in more modern machines.

As theorized before, we can see that the main problem of this small Mexican company, which is like most small Mexican companies in the medical supplies industry, is that it tries to save money on things that usually process owners seem un-necessary but eventually, it ends up damaging the production process and generating delays which heavily damages the company's reputation.

In retrospect, the results of this simulation can be used to prove the damaging results of poor planning and the common desire of small businessmen to spend the least amount of money. This study highlights the importance of doing a good analysis of the resources a company has and the steps and methodologies employed in each process in order to understand if they manage to achieve the desired results or if it is necessary to modify anything in order to improve performance, something that unfortunately is done very little in small businesses in Mexico and something that should definitely be changed.

References

[1] Cedillo et al. Quality Control Applications in the Pharmaceutical and Medical Device Manufacturing Industry. Chapter 8., IGI Global, Baja California, 2022, Mexico.

[2] INEGI. Conociendo la Industria de Positivos Medicos.. https://www.inegi.org.mx/contenidos/saladeprensa/boletines/2022/especiales/CIDM_2022.pdf accessed Dec. 13, 2022.

[3] Bárcena A, Prado A, Beteta H. Productividad y Brechas Estructurales en México pg. 30 Naciones Unidas, Cepal, 2016, Mexico.

[4] INEGI. Micro, pequeña, mediana y gran empresa. Estratificación de los establecimientos. Censos Económicos 2019.

[5] Schönberger M, Hoffstetter M. Emerging Trends in Medical Plastic Engineering and Manufacturing. p 116, 2016, Elsevier, England

[6] Cedillo et al. Quality Control Applications in the Pharmaceutical and Medical Device Manufacturing Industry, Chapter 8, IGI Global, Baja California, 2022, Mexico.

[7] Banks J. Introduction to simulation. WSC'99. 1999 Winter Simulation Conference Proceedings. 'Simulation - A Bridge to the Future' (Cat. No.99CH37038), 1, 7-13 vol.1.

[8] Harrell, C., Ghosh, B. K., & Bowden, R. (2004). Simulation using ProModel. McGraw-Hill Science, Engineering & Mathematics.

[9] Law A M. How to Build Valid and Credible Simulation Models: 2019 Winter Simulation Conference (WSC), National Harbor, MD, USA, 2019, pp. 1402-1414: DOI 10.1109/WSC40007.2019.9004789

[10] Law AM, Kelton WD. Simulation Modeling & Analysis. 1991), McGraw-Hill.