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Simulation of elements of industry 4.0 applied to the production processes of a company dedicated to the manufacture of plastic products

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Abstract

In Mexico, micro, small and medium-sized enterprises (MSMEs) are the basis of job creation and an important pillar in the country's economy. However, despite their great importance, they face considerable challenges in terms of innovation and development (R&D), their limited financial resources, the lack of adequate machinery and personnel have made them highly vulnerable to internal and external market factors. On the other hand, at present it seeks to replace the current (linear) economic model with a more sustainable one such as the circular economic model, whose focus on plastics offers a vision where this material never becomes waste, but rather acquires the possibility of be transformed and implemented as raw material. Taking into account the above approaches and contributing to the topic, it was proposed to use a simulation model applied to the case study of a micro-company dedicated to the manufacture of plastic products, the purpose of this model is to provide information to the company to consider the factors that influence their performance and allow them to reduce the costs associated with production and waste. The results of the simulation model supported the company's decision-making regarding its production processes (including elements of the so-called Industry 4.0).

Keywords: process simulation; industry 4.0; circular economy

1. Introduction

The current linear economic model seeks to promote the consumption of goods and services in the short term and is based on extraction, use and disposal, without taking into considering the consumption of large amounts of energy and natural resources. To understand the consequences of the linear economic model, it must be known that since 1990 humans have been living above the carrying capacity of the planet and that since 2003 its generation capacity was exceeded by 25% (Aguilar, 2007).

The growing concerns for the environment have increased the interest in the development of innovation projects with a vision of a circular economy where the main objective is to promote the use of clean energy, sustainable products, and services. CONAMA (2018) considers as a circular economy that economic model that:

- Use the minimum amount of necessary resources, including water and energy, to satisfy the needs required at all times.
- Smartly select resources, minimizing non-

renewables and critical raw materials, and favoring the use of recycled materials whenever possible.

- Efficiently manages the resources used, maintaining and recirculating them in the economic system as long as possible and minimizing the generation of waste.
- Minimizes environmental impacts and favors the restitution of natural capital and encourages its regeneration.

Thus, the need to have processes that increase the efficiency of energy consumption and transformation of raw materials is highlighted, minimizing the generation of waste and favoring the use of recycled raw materials, thus reducing environmental impact.

On the other hand, the so-called fourth industrial revolution or industry 4.0 defines a new transformation of processes based on the connection between physical and digital systems. This concept integrates a new level of organization and control over the production chain and the life cycle of products by combining technologies such as the Internet of Things (IoT), smart manufacturing, cloud-based manufacturing and the industrial Internet of things (IIoT); The objective of which is to add value to production activities, increase the efficiency of processes and minimize the amount of waste (Vaidya, 2018). As is evident, Industry 4.0 is a key factor for the success of the circular economy.

In turn, in Mexico Small and medium-sized enterprises (SMEs) are the pillars of national economic development since they generate 72% of formal jobs and contribute 52% of GDP (Senate of the Republic, 2020). Despite this, MSMEs face various challenges that cause 75% of them not to survive the first two years of life (Deloitte, 2018). It is at this point that investment in research and development that allows improving efficiency and productivity become essential factors. However, technological development and implementation are expensive and the financial factor of MSMEs prevents them from making a large capital investment. Among the most important costs are the acquisition of machinery, the hiring of trained personnel, as well as the time necessary to carry out the tests and adjustments necessary for the proper operation of the processes. Therefore, simulation models are one of the main tools to initiate research on the proper adoption of the elements of Industry 4.0.

The simulation models are very flexible and allow to analize different configurations and behavior derived from the interactions between the elements that intervene in the systems. In this way, the time and economic impact associated with the different tests and purchases of physical elements are minimized. Consequently, successful simulation models can be developed that allow making the right decisions that increase the productivity and efficiency of the processes.

In this work, a simulation model was used that allowed a company dedicated to the manufacture of plastic resins to make decisions about the advantages and disadvantages of investing in the development of human capital or in the semi-automation of production processes to optimize their processes in order to use recycled plastic resins.

Plásticos "M" is a Mexican company dedicated to the manufacture of plastic products by low pressure molding. Low pressure molding, also called plastic blowing, is a procedure that consists of shaping a plastic sheet (parison) by applying heat and pressurized air until it adapts to a mold. Plastics "M" like many of the MSMEs in Mexico has manual machinery, which implies that the success of the manufacturing process depends on its user (worker).

2. Literature review

2.1. Transition to circular economy

For decades, society has depended on a traditional or linear economic model that promotes the consumption and generation of waste destined for environmental contamination without further treatment (Melgarejo, 2019). This economic model is governed by the over exploitation of natural resources and has generated negative impacts that increasingly affect society and its balance with the environment (Espaliat 2017).

The rate of exploitation of natural resources and consumer behaviors by society are unsustainable, both due to excessive energy consumption and the production of accelerated waste (Sánchez, 2019). According to the Global Footprint Network (2019), on July 29, 2019, humanity would have used nature's resource budget for the whole year, which means that humanity is currently consuming natural resources 1.75 times faster than the ecosystems of our planet can regenerate.

In these circumstances, it is imperative to adopt new approaches that allow modifying or replacing the traditional economic model with a more sustainable model such as the circular model, which "is presented as an alternative with the potential to solve environmental challenges" (Arroyo, 2018). The transition to a circular economy represents a complete systemic change in consumer behavior patterns, financing methods and policies (Rodríguez, 2017). According to Espaliat (2017), innovation is one of the key elements to achieve a successful transition towards a circular economy. New technologies applied in business processes, services and models are necessary to make them increasingly efficient in terms of energy production and consumption.

2.2. Industry 4.0

Innovation has played an important role in societies, allowing them to develop, meet their needs and improve their quality of life (Ecosistema de Innovación Social en México, 2016). Today innovation and technological development are evolving rapidly and have become protagonists of the progress of humanity (Ordoñez, 2007).

The Industry 4.0 concept is associated with a set of emerging technologies whose purpose is to give a new impetus to the manufacturing process through collaboration between the academic, political and industrial sectors (Reischauer, 2018). The concept of Industry 4.0 contemplates the introduction of technologies such as: big data, robotics, simulation, IoT, cyber security, cloud computing, additive manufacturing and augmented reality. These technologies transform the traditional manufacturing process by a fully interconnected process known as "smart manufacturing" (Contreras 2019).

In turn, Rüßmann (2015) mentions that Industry 4.0 is driven by nine fundamental technological pillars which are: autonomous robots, simulation, augmented reality, the cloud, cybersecurity, IIoT, big data, horizontal and vertical system integration. Some of these elements have already been used in the industrial sector individually, however, the integration of all these technologies allows to potentiate and optimize manufacturing processes, achieving greater sustainability, flexibility, productivity and efficiency (Vaidya, 2018).

Without a doubt, the implementation of the elements of Industry 4.0 promises to bring great benefits to the industrial sector, allowing it to make more accurate decisions based on real- time information, proper management of its resources, and the reduction of its operating costs. For this reason, many companies understand that the early adoption of these technologies will increase their competitiveness (Deloitte, 2015). However, the success of the implementation of these technologies will largely depend on the ability of companies to facilitate the creation of flexible and reconfigurable manufacturing systems (Ynzunza, 2017).

2.3. Industry 4.0 challenges for SMEs

MSMEs are considered by many countries as the backbone of the local economy. In Latin America, approximately 99% of formal Latin American companies are MSMEs and generate 61% of formal employment (Dini, 2018). However, despite their importance, MSMEs face various challenges that compromise their growth and permanence.

According to Cruz, López, Cruz and Meneses (2016), among the greatest challenges faced by MSMEs in Latin America are: socioeconomic problems derived from their low profit margins and their lack of negotiation capacity, technological problems derived from little or no culture of technological adoption, as well as its obsolete machinery and the lack of updating of its processes, and financial and administrative problems. These problems increase the technological, financial and commercial gap, making it impossible for MSMEs to compete with large companies.

On the other hand, the concept of industry 4.0 is being developed mainly around large industries and this could put the MSMEs sector at risk by compromising its competitiveness, resulting in a negative economic impact (Andulkar, 2018). Therefore, it is important to consider the feasibility, the response, and the effect that the adoption of industry 4.0 technologies will have on its value chain (Müller, 2018). Although the introduction of Industry 4.0 offers great benefits in terms of innovation and development to companies that adopt these technologies, at the same time it represents a great challenge, especially for MSMEs.

The results of a study conducted by Müller (2018) in Germany on how MSMEs approach business model innovations in Industry 4.0, revealed that Industry 4.0 represents an intimidating concept for many of them due to the lack of experience in the implementation of these technologies. Furthermore, although MSMEs are aware of the benefits offered by Industry 4.0, they are reluctant to modify and / or acquire new machinery, sensors and software due to the high investment, which represents a high risk in financial terms (Hirsch- Kreinsen, 2016). Hence, the degree of automation of MSMEs is low and that a large part of the activities are carried out manually (Andilkar, 2018).

Due to the above, MSMEs tend to rely more on the skills of their employees, but at the same time they are aware that the early adoption of these technologies by their competitors could soon remove them from the market.

Another study by Ynzunza Cortés, Izar Landeta, Bocarando Chacón; Aguilar Pereyra, Larios Osorio (2017) in Mexico, highlighted as main challenges, on the one hand, the strong investment that implies the adoption of the aspects of industry 4.0, as well as the need to have consultants and experts to advise these units economic on the subject and, on the other hand, the need for the training of human talent capable of taking advantage of the benefits and facing the challenges of current technological advances was exposed. Therefore, emphasis was placed on the set of skills that staff must acquire, such as: data management and analysis, computer-aided production, online simulation, programming, predictive maintenance, and the like.

For his part, Tadeu (2019) highlights that another of the main challenges that MSMEs face is the lack of a comprehensive strategy to implement the elements of Industry 4.0. To face this challenge Ganzarain and Errasti (2016) propose that MSMEs should be guided and trained based on a strategic and systematic orientation that allows them to identify new opportunities within the environment of industry 4.0.

2.4. Simulation

Simulation is defined as an experimental technique, encompassing a wide collection of methods and applications that allow the behavior of complex real-world systems to be imitated, evaluated, and projected (Berardo, 2017). It is used to predict the behavior of complex manufacturing or service systems, by observing the movements and interaction of system components. By means of simulation software, detailed reports and statistics are generated that describe the behavior of the system that is studied based on these reports, physical distributions, equipment selection, operation procedures, allocation and use of resources, inventory policies, and other important system features; therefore, simulation is a tool for the final validation of a model (Meyers, 2010).

For the simulation systems, different mathematical functions are applied to help calculate the distribution of resources and obtain results that visualize the operating times of each process. The essential simulation techniques currently used are: agent simulation and discrete event simulation. The simulation of agents allows to dynamically model techniques, which are used in artificial intelligence (Tinoco, 2017).

The simulation, due to its characteristics and the computational developments that have been achieved in recent years, continues to present a series of advantages that not only make it the most appropriate procedure in many cases, but also make it the only technological alternative in cases in which the characteristics of the system to be studied make direct experimentation on the system unfeasible, for physical or cost reasons. The simulation uses industrial production, traffic, aeronautics, the automobile industry, among others. Even in those cases where direct experimentation is possible, simulation can offer advantages such as lower cost, time (Prieto, 2015).

Simulation is a tool that has not yet been widely used in the MSMEs sector as a decision support tool for performance evaluation.

3. Materials and methods

The methodology used for this work is as follows:

1. Compilation of data on the production process of the plastic manufacturing microenterprise.
2. Formulation of the manufacturing process problem.
3. Definition of the variables necessary to build the simulation model.
4. Data analysis to identify a distribution to which the collected data fits.
5. Formulation of the simulation model.
6. Carry out the simulation of the model to obtain results and observe its behavior.
7. Finally, the validation of the model.

3.1. Data collection

Data collection was carried out through interviews, direct observation and collection of historical data, these data being essential to understand and identify the processes and areas of opportunity in the company's productive activity.

The manufacturing process is divided into two consecutive operating sub-processes, the first consists of processing the raw material whose main element is machinery, and the second consists of obtaining the final product whose main actor is the user of the machinery.

3.1.1. Raw material processing

The first phase of the manufacturing process depends on the machinery shown in figure 1; Raw material processing is divided into two phases, which are described below.

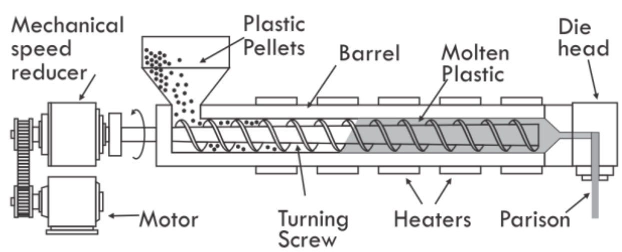


Figure 1. Manual machinery for the processing of plastic resins.

Initial setup process:

- Speed adjustment: the speed of rotation of the screw is mechanically adjusted through gears and drive belts and depends on the type of product manufactured.
- Thermal adjustment: the temperature is adjusted through on/off controllers which govern the connection and disconnection of the heaters.
- Adjusting the thickness of the molten plastic (parison).

Raw material processing:

- The screw rotates with a uniform speed moving the plastic pellets through the barrel.
- The plastic melts runs through the barrel, and is extruded by the die head.
- The parison comes out of the die head with a predefined thickness and moves downwards with a length sufficient to encompass the mold.

3.1.2. *Obtaining the final product*

The second phase of the manufacturing process depends on the machinery operator, who follows the process (figure 2) described below:

- Place the mold of the product to be manufactured under the die head (position A).
- Wait until the parison is long enough to cover the length of the mold, close the mold and cut the parison.
- Move the mold to position B, lower the blow pin and apply pressurized air.
- Disconnect the pressurized air and raise the blow pin.
- Open the mold, remove the product, and move the mold to position A.
- Refine and obtain the final product.

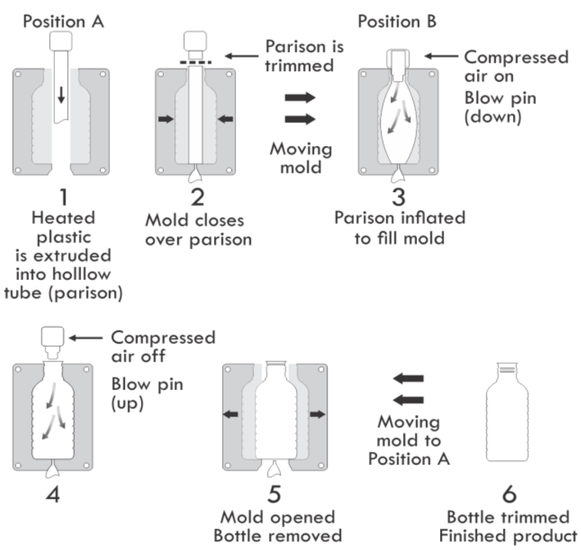


Figure 2. Manufacturing process

3.2. Problem formulation

From the data collection (historical data) the main problems related to the manufacturing process were determined, these are: technical aspects, workforce, and raw material.

The factors related to the technical aspects are: 40% efficiency of the machinery, maintenance 30% and installed capacity 30%. The factors related to workforce are: fatigue 40%, staff turnover 30% and lack of commitment 30%. In turn, the factors related to the raw material are: 50% price, 30% quality and 20% existence.

As a result of the analysis, it was concluded that one of the biggest problems of the company is related to the efficiency of the manufacturing process. Since the success of the process depends on the operator's experience, factors such as fatigue, staff turnover, and training time decrease productivity and increase the number of defective products. For its part, the low flexibility of machinery configuration makes it difficult to use recycled raw materials.

3.3. Defining the model variables

The physical components and variables of the simulation model are described below:

- Physical components: manual machinery for the processing of plastic resins, automatic machinery for the processing of plastic resins, experienced operator, and novice operator.
- Variables: service time at the station, simulation time, number of finished packages, defective products, products without defects.

3.4. Data analysis

Data on processing times as well as error rates were obtained through direct observation over a period of one month and data company history.

The manufacturing process data shown in table 1 was adjusted by comparing the square error using Excel 2016, taking into account that the higher the square error, the further away is the adjusted distribution of the actual data (Kassu, 2015).

Table 1. Plastic product manufacturing process

Process	Distribution	Square error
Granular plastic pellets melted move to die head and extruded into mold	Uniform (33,35)	0.0071
Close mold - parison inflated	Uniform (17,18)	0.0032
Compressed air off - finished product	Uniform (14,16)	0.0081

For its part, the worker type error rate was adjusted using Goodness-of-Fit Test for Poisson Distribution in MINITAB 17.1.0, based on the calculation of p-value that allows knowing how well the real data fits to the probability distribution. Romero (2012) and López (2019) stipulate three possible conclusions to verify the significance of the test:

- p-value <0.001: the null hypothesis is not credible and is discarded.
- 0.001 <p-value <0.05: the rejection or acceptance of the null hypothesis depends on the value of α assigned.
- p-value> 0.05: the null hypothesis is not rejected and is taken as true.

Given the results in Table 2, the data were better fitted to the Poisson distribution.

Table 2. Worker error rate

Type of worker	Distribution	P-value
Experienced	Poisson (2.3)	0.366
Novice	Poisson (21.5)	0.210

3.5. Formulation of the model

The simulation model was developed using SIMIO software 10.181.17990. The main input is the raw material processing time (seconds). The result is the quantity of defective products in the production volume, the time of use of the machine and the type of worker in the process. The main entity is the parison, it determines the speed of the process. The design of the model mainly considers the efficiency of the operators based on their experience and quantifies the number of defective products. The selected product is one of the most frequently produced in the company.

The simulation time includes the company's working hours, being eight hours for five days. A constant input of raw materials is assumed, as well as constant performance by operators.

3.6. Model simulation

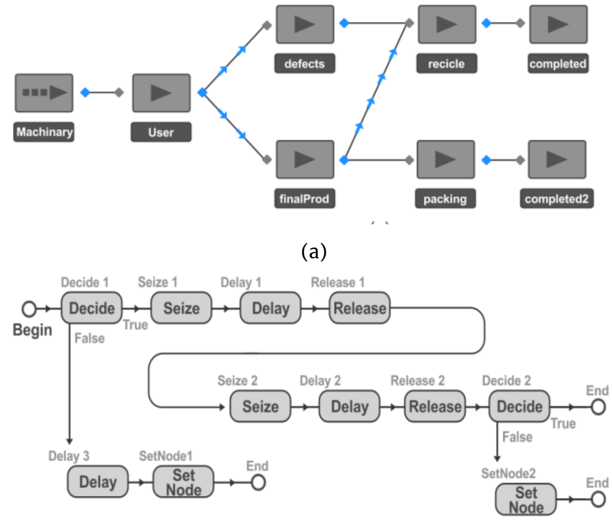
A simulation model was developed consisting of two parts that intervene sequentially in the manufacturing process, the first is the processing of raw material by machinery, the second is based on obtaining the final product by the operator (figure 3a). The processing of the raw material consists of the generation of entities (parison) which determine the speed of the process, this operation is performed in the "machinery" block. Obtaining the final product consists of the set of actions that the operator must carry out, these are illustrated in the "user" block in figure 3b.

To determine the number of defective products produced, the respective error rates were replaced according to the experience of the operator, in this way, the model contemplates the intervention of the human factor within the manufacturing process and facilitates the analysis of the system.

In addition, a simulation model was created consisting of an automated machine assuming elements of Industry 4.0 such as: automation, supervisory control and data acquisition (SCADA), smart sensors and IoT. And using the data that characterize the production process, the two parts proposed in the original model were merged (Figure 4a). The simulation model considers a sequence of automated events of the production process (figure 4b) and the activities of the operator to obtain the final product and the quality review (figure 4c).

3.7. Model validation

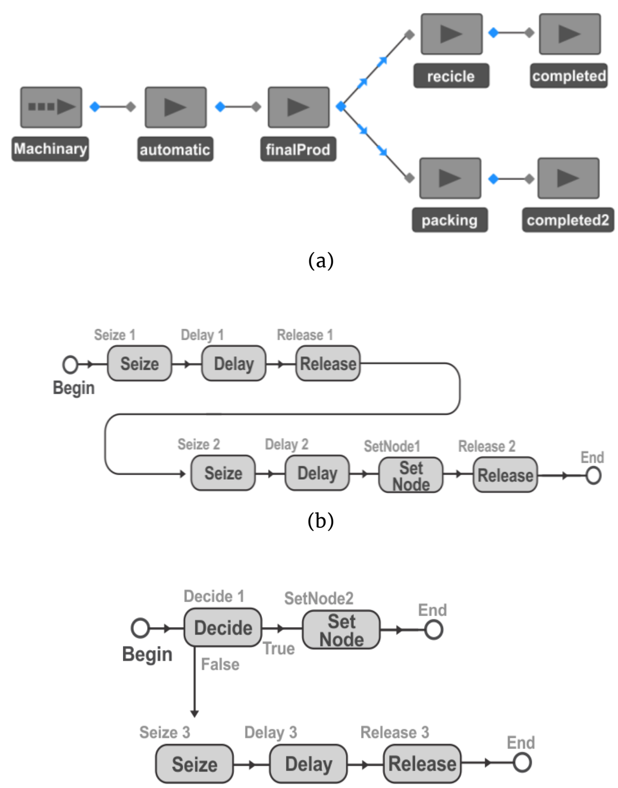
The model was validated using the t-test and verified by comparing the performance parameter and metric values of the study process with its model counterparts.



(a)

(b)

Figure 3. (a) Manual process simulation, (b) user process



(a)

(b)

(c)

Figure 4. (a) Automatic process simulation, (b) automatic sequence of events, (c) user process.

The real average daily yield of the company's product is 847.5 ($\mu 0$), while the average yield obtained by the model for 10 runs of 847 with a standard deviation of 25. For its part, the actual average number of defective products produced by a novice worker is 169 (μ_0), while the average performance obtained by the model for 10 runs of 164 with a standard deviation of 17.08. On the other hand, the real average number of defective products produced by an expert worker is 18.8 (μ_0), while the average performance obtained by the model for 10 runs of 18.6 with a standard deviation of 0.53. To verify that the means obtained were statistically equal, a two-tailed t-test was performed with a 95% confidence interval with n-1 degrees of freedom, where "n" is the number of runs in the model. The hypotheses were formulated as follows

$$H_0: \bar{X} = \mu_0$$
$$H_1: \bar{X} \neq \mu_0$$

The calculation of the t statistic was performed using equation 1:

$$t_{calculated} = \frac{\bar{X} - \mu_0}{S \,/\, \sqrt{n}} \quad (1)$$

The value of the critical t was determined from the table of the "t" statistic, being a value of 2.26

Given that tcalculated < tcritical for product performance (0.0632 < 2.26), the number of defective products for a novice worker (0.9557 < 2.26) and the number of defective products for a skilled worker (1,193 < 2.26), showing that there was no significant difference between the real values and those obtained by the simulation, this statistically validates the model.

4. Results and Discussion

Table 3 shows the results of the number of defective products obtained by the simulation model.

Table 3. Simulation results

Type of worker	Average	Min	Max
Experienced	18.61	18	19
Novice	164.1	150	184
Automated machine	18.56	18	19

The results show that the percentage of the number of defective products obtained according to the type of worker is approximately 2.5% for an experienced worker and 20% for a novice worker (an excessively high percentage of defective products for a MSME).

In addition, recycled plastic resins present changes in their mechanical properties and molecular structures such as the flow and density index (Alzerreca, 2015), so that the processing of the raw material presents fluctuations that make it necessary to make continuous adjustments in the processing speed. Considering the high turnover of personnel and the null possibility that novice workers have to make any adjustment to the machinery, the manufacturing process becomes inefficient, this prevents incorporating 100% recycled plastic resins in the production processes.

On the other hand, the results of the automated process simulation model were very similar to those of an experienced worker. By decoupling the human factor from the manufacturing process, quality decision and review activity was added at the same cycle time. The results obtained by our research served the company to make decisions regarding the updating of its machinery and the automation of its production processes.

In order to achieve the results provided by the simulation model, it was necessary to approach the focus of the principles of industry 4.0 that allowed the mechanization and automation of data production and communication actions, which initially increased the efficiency and flexibility of the manufacturing process by diversifying the type of materials, the prototype built as a result of research is shown in figure 5 and figure 6.

Figure 5. Automatic machinery

Figure 6. SCADA system

5. Conclusions

The simulation is a tool that allows to obtain results from the modeling of the behavior of the processes, variables and components of a system, the purpose of simulating the processes of the traditional plastics industry is to analyze the results to undertake actions that improve the processes of manufacturing, product quality verification, as well as making decisions about hiring personnel with some experience or making an investment in automation or machinery change that reduces the percentage of defective products produced by the operator.

For the case study, the analysis of the simulation results led to the conclusion of automating the production machinery with the aim of reducing the amount of defective products due to a novice worker; Since the learning curve for a worker to be experienced in is approximately six months, in which the company has to cover hiring expenses, personnel training and costs for the number of defective parts.

MSMEs dedicated to the manufacture of products can use simulation as a tool to improve their manufacturing process and search for alternatives that allow them to make better use of the raw material used to manufacture their products; in the same way, they can propose processes to reuse the residues or surpluses of the raw material used and through simulation analyze the advantages of the process, required machinery and costs.

For the plastic industry taken as a case study, a future work is proposed, which consists of integrating a process to reuse plastic from defective parts and thereby verify that the reuse of plastic to generate a new product is viable that a favorable ecological impact is generated, as well as the use of all the raw materials and resources of the company to develop a circular economy model.

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