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A Computer Simulation of the Plastic Waste Sorting and Recycling

Esteban Cortes-Lesmes[1], Alexander Troncoso-Palacio[2], Paulo Carrillo-López[3]
[1]SIGME, Universidad de la Costa, Barranquilla, Colombia.
[2] Productivity and InnovationDepartment, Universidad de la Costa, Barranquilla, Colombia
[3]SENA,pcarrillo1@misena.edu.coBarranquilla, Colombia
Corresponding Author: atroncos1@cuc.edu.cohttps://orcid.org/0000-0001-6034-695X

Abstract: *The materials that generate the greatest amount of waste worldwide are plastics, which cause negative effects on the environment because plastic is a polymer derived from petroleum. Plastics are non-renewable elements with high durability and no self-decomposition. For this reason, recycling is a strategy fundamental to the reuse of plastic waste. Currently, approximately one-third of urban solid waste in the main cities of Colombia is plastic. These have exponential growth every year. The purpose of this project is to realize an analysis of a virtual model for the classification and use of plastic waste with the data of a polypropylene recycling company, where the points or operational phases to determine the deficiencies that arise are analyzed with the application of improvement proposals to strengthen decision-making, which optimizes the operations of the company to reduce the growth of that waste. Therefore, it was proposed to follow the following steps: First, perform an input analysis of the entities and resources. The second is building the model simulation in the software Arena. Third, running the simulation model. Fourth, analyze the results. Fifth, present improvement proposals, and based on the results obtained, increase the productivity of the company*

Keywords: *Digital Model, Plastics Recycling, Plastics Waste*

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I. INTRODUCTION

A digital model is a representation of a process, product, or service in software. This virtual representation may need to collect data from sensors, devices, computers, and anything else that should serve to create a reflection of reality. Analyze them and transform the data into information that allows decisions to be made about the physical reality. Much has been said on this subject about the scope of plastic since it is directly related to the management of usable waste. The urgent need to have materials at less cost, in daily life and advances in technology have led to an increase in mass consumption and the consequent growth of waste throughout the world [1].Concepts such as recycling, reuse, reduction of natural resources, environmental responsibility, and other similar concepts have become more frequent nowadays. This reality has prompted the search for recycling proposals. Among these we find plastic pollution, that is why we are based on implementing in this type of company the 6R's which are known as Repair, Redesign, Resell, Reproduce, Recycle, Reuse. Thus, there is a wide range of companies providing recycling services, ranging from collection, sorting, and use of these to their treatment for other industries. Colombia generates more than 12 million tons of waste every year, of which only 17% is recycled, leaving a high margin for the growth of reuse [2].Therefore, digitization and analysis through digital twins can be very useful in this sector, because each company is unique, with characteristics that are rarely shared by the rest. An example of this is the management of all types of waste, whether industrial, construction, or urban.

II. LITERATURE REVIEW

The effect of plastic products in an economy is fundamental: an average consumer uses various plastic products daily, whether for personal consumption (clothing, furniture, office supplies, kitchen utensils, among others) or through other productive activities, such as construction, communications, transportation, storage. The versatility of plastic allows its incorporation into any productive process or final product, which is why it is undeniable that currently the market for plastic products has an outstanding place in the economy [3]. During 2015, about 380 million tons of plastics were produced in the world, and since the 1950s more than 8300 million tons of them were accumulated, which is equivalent to a stock of more than one ton of plastic per person present on the planet. Most of these plastics are used as packaging and for the construction and textile industries. Approximately 76% of the plastics produced have become waste, and if we consider that only 18% of this waste

is recycled in the world, we find ourselves with some 5.2 billion tons of plastic waste accumulated across the globe. Finally, it is estimated that by 2050 production will increase to 2000 million tons per year [4].

The plastics contained in municipal solid waste (MSW) are mostly polyethylene (PE) and polypropylene (PP) and in smaller proportions are polystyrene (PS), polyvinyl chloride (PVC), polyethylene terephthalate (PET), polystyrene-butadiene (PS-BD), poly (methyl methacrylate) (PMMA) [5]. Among the harmful consequences of the COVID-19 pandemic is the resurgence of single-use plastics. To avoid the risk of infection by the virus, many plastic products, mostly disposable, have become almost indispensable in everyday life. That is, masks, gloves, protective screens, bottles of hand sanitizer, test kits, containers for carrying food and a long etcetera [6]. In Colombia, in 2018 the utilization rate corresponded to 48.8% (12.1 million tons), of the total solid waste and waste products generated, presenting a decrease of 1.8% compared to the previous year. The behavior of the indicator is explained by the growth of 3.6% in the amount of waste used and 5.5% in the total supply of waste and waste products[7]. The most recent report of the National Planning Department, DNP, states that if Colombia continues with the same dynamics of waste generation, without finding solutions to improve waste utilization, in 2030 the country will have sanitary emergencies in most cities and a high generation of greenhouse gas emissions, which affects air quality [8].

Due to this, the need arises to create companies that collect, classify, and process these wastes, in the case of [9] developed a proposal for the optimization of the classification process of polyethylene terephthalate in a company dedicated to the recycling of paper and plastic waste. Likewise, [10] demonstrates that there is a business opportunity in the implementation of a plant for the classification and recycling of paper, cardboard, and PET plastic, showing that the necessary investment for this project is US$160,000, obtaining an NPV of US$282,912.82, a discount rate of 13% and an IRR of 55%. [11] carried out the Recoplast SAS business project, which consisted of the mechanical recycling of post-consumer and post-industrial plastic products, to market them to production companies as raw material for their production processes. Also, in the study of [12] we can observe the initiative for the "Creation of a Recyclable Material Commercialization Company in the Municipality of Valledupar -Cesar" takes strength, due to the benefits it offers not only in the economic aspect but also in the direct way it influences the conservation of the environment and why not, considering it as a complement to a culture on the management of reusable waste.

In addition, in the research of [13] it is concluded that production costs have positive implication on the profitability of solid waste recycling companies in the city of Tarapoto, year 2018; where the way how production costs are currently structured reflects positively on the profitability of the evaluated recycling companies. Likewise, the use of digital twins can bring benefits such as facilitating compliance with Time Vs Quality parameters; planning and cost control; facilitating engineering designs; processes and mass balance calculations, finding possible obstructions in designs for modifications and improvements; reduction in the probability of unscheduled stops; and reduction of human errors in the collection of information [14]. However, the Digital Twin is still a developing concept that, in addition, presents several technological barriers for its adoption in the industrial fabric. On the one hand, there is a technical difficulty to massively monitor and digitize processes in the industry, with a great variety of equipment, isolated legacy systems, field buses, proprietary protocols, as well as a strict architecture of integration and industrial automation [15]. [16] Made a simulation study on efficiency of woven matrix wire and tube heat exchanger.

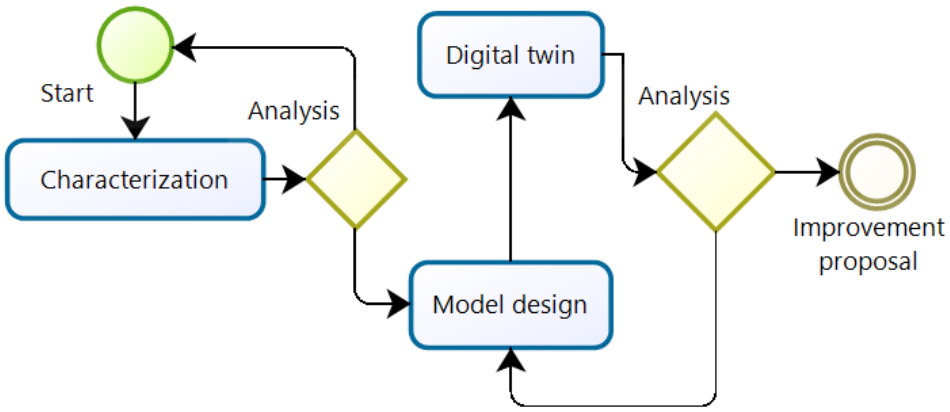
Likewise, in the investigation of [17] the Monte Carlo simulation tool was applied to use backscatter radiography for in-situ detection of depositions inside the metallic pipelines. In the research of [18] a simulation was performed in PROMODEL software to project a monthly acquisition of plastic waste, estimating monthly sales revenue, and projecting a cash flow for 1 year. Likewise, the research of [19] proposes a simulation model of the direct and reverse logistics of PET plastic focused on the mitigation of negative impacts on retailers, using ARENA simulation software, obtaining that the adoption of negative impact mitigation policies in refundable deposit systems is a great incentive for retailers since the economic benefits are significant even under different scenarios and facilitate the reverse channel flow at its most critical point which is the collection.

In the research of [20]it designs a plastic shredding machine using mechanical simulation software for the processing of plastic waste in the community of Limoncocha province of Sucumbios, Ecuador. choosing to perform the design of a rotary cutter blade shredder, from this the conceptual design and detailing of each component of the shredding machine was performed. In addition, in the research of [21] a simulation was performed for 25 years and the variation in the recycling rate of 24%, 30% and 40% was considered. This simulation was performed in Vensim® software according to the Forrester diagram. The data used corresponds to information related to PET container manufacturing, waste generation and PET recycling in Valle del Cauca, Colombia. In the research of [22], three design proposals are proposed to be evaluated by the weighted methods criterion to choose the best option, SOLIDWORKS software is used in the modeling of the proposals to have a geometric approach of the elements to be used in the same. The best option must demonstrate efficiency, industrial interest, and effective help in the recycling industry, improving the elaboration and quality of this product in such a way that it contributes to the production of compaction blocks.

III. METHODOLOGY

The research conducted is considered explanatory considering that in addition to describing the problem, it approaches the causes and possible solutions and this will be done as follows: in the first step the processes will be characterized in order to measure the time of use of resources; then an input analysis of the entities that in this case will be the purchase of recycled plastic and ground plastic, also to all system resources; then the design of the conceptual model is performed, which details how the behavior of the processes is. After this, a compilation of the necessary data to simulate these processes will be carried out, establishing the size of the sample that must be taken for these and finding the respective distributions of the entities and resources that will be needed to implement the simulation. Next, the possible variables that may occur in the process and that may affect the simulation in the software are defined; then the model is simulated in the program and validated with the data of the real process and finally, according to the use of the resources, possible improvements to the company will be presented. Figure 1 it can be seen methodology is developed below. The sequence.

Figure 1. Proposed methodology.

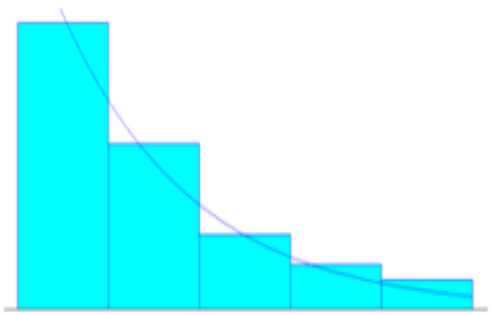


IV. DEVELOPMENT

Applying the proposed methodology starts with the characterization of the process, then an input analysis of the entities and resources is performed, following this the design of the conceptual model is performed, then the simulation model will be executed, continuing with the process, the possible variables are defined, then the previously designed model is run and finally present possible improvements with respect to the use of the resources. Data were collected for the input analysis of the model for each of the entities and resources. A goodness-of-fit test was applied to these data using the Input Analyzer software to determine which type of distribution is similar.

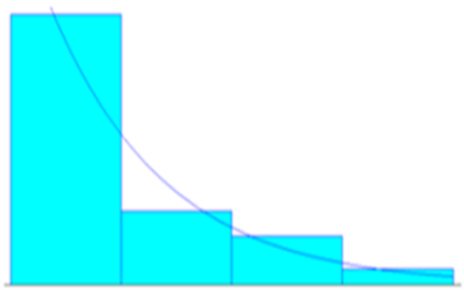
Entity input data analysis. In figure 2 shows the goodness-of-fit test for the arrival of recycled plastic. Figure 3 shows goodness-of-fit test for the arrival of ground plastics, in addition to the report issued by the software which clarifies the distribution of best fit to the data.

Figure 2. Goodness-of-fit test for the arrival of recycled plastic.



Distribution Exponential	
Min Data Value.	15
Max Data Value.	19
Sample Mean.	15,9
Sample Std Dev.	1,18
Test	Chi Squared
Corresponding p-value.	0,604

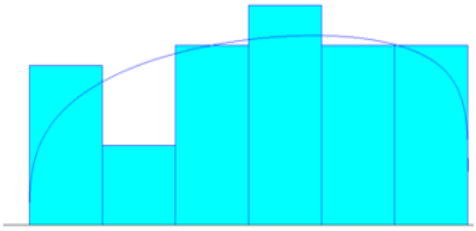
Figure 3. Goodness-of-fit test for the arrival of ground plastic.



Distribution Exponential	
Min Data Value.	60
Max Data Value.	63
Sample Mean.	60,5
Sample Std Dev.	0,862
Test	Chi Squared
Corresponding p-value.	0,254

Considering that the p-value is greater than significance 0.05, the hypothesis that they belong to the specified distributions is accepted with 95% confidence.Resourse analysis. In figure 4 shows the goodness-of-fit test for the classification of recycled plastic.

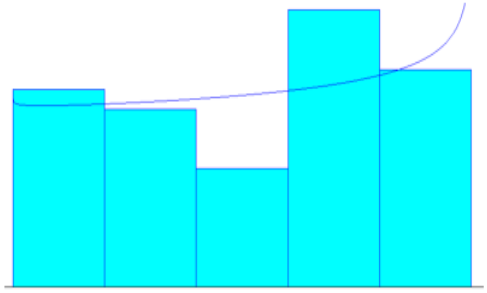
Figure 4. Goodness-of-fit test for the classification of recycled plastic.



Distribution Beta	
Min Data Value.	20
Max Data Value.	25
Sample Mean.	22,7
Sample Std Dev.	1,68
Test	Chi Squared
Corresponding p-value.	0,338

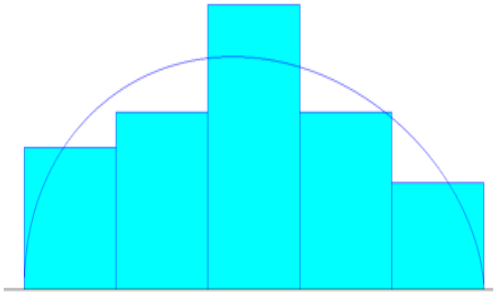
Figure 5 shows goodness-of-fit test for the crushing process #1. Figure 6 shows goodness-of-fit test for the washing process. Figure 7 shows goodness-of-fit test for the drying process. Figure 8 shows goodness-of-fit test for the crushing process #2 and packaging. Figure 9 shows goodness-of-fit test for the pelleting process, in addition to the report issued by the software which clarifies the distribution of best fit to the data.

Figure 5. Goodness-of-fit test for the crushing process #1.



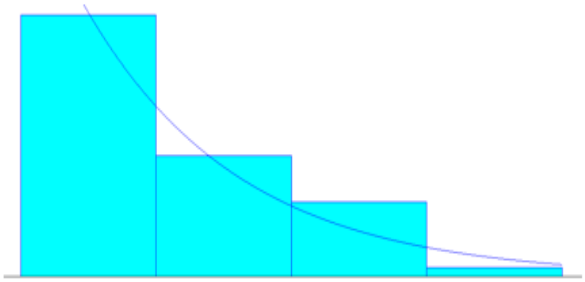
Distribution Beta	
Min Data Value.	8
Max Data Value.	12
Sample Mean.	10,1
Sample Std Dev.	1,047
Test	Chi Squared
Corresponding p-value.	0,235

Figure 6. Goodness-of-fit test for the washing process.



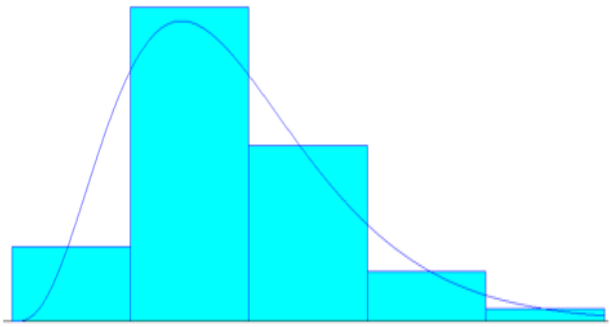
Distribution Beta	
Min Data Value.	5
Max Data Value.	9
Sample Mean.	6,92
Sample Std Dev.	1,24
Test	Chi Squared
Corresponding p-value.	0,514

Figure 7. Goodness-of-fit test for the drying process.



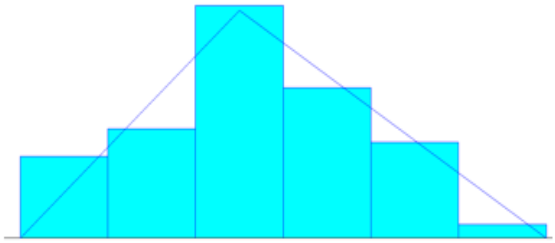
Distribution Exponential	
Min Data Value.	3
Max Data Value.	6
Sample Mean.	3,64
Sample Std Dev.	0,827
Test	Chi Squared
Corresponding p-value.	0,143

Figure 8. Goodness-of-fit test for the crushing process #2 and packaging #1.



Distribution Gamma	
Min Data Value.	8
Max Data Value.	12
Sample Mean.	9,38
Sample Std Dev.	0,878
Test	Chi Squared
Corresponding p-value.	0,393

Figure 9. Goodness-of-fit test for the pelleting process and packaging #2.

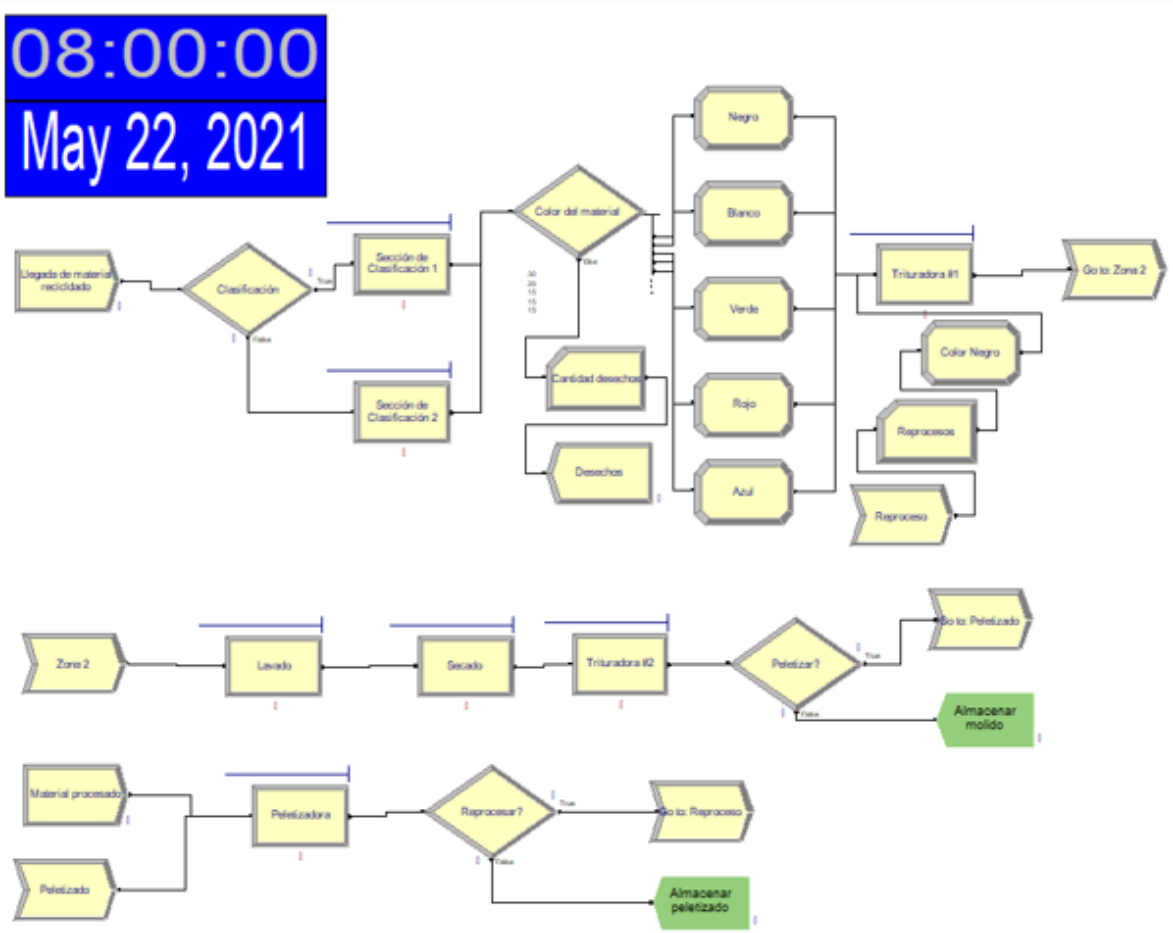


Distribution Triangular	
Min.	17,5
Mode.	20
Max.	23,5
Sample Mean.	20,2
Sample Std Dev.	1,27
Test	Chi Squared
Corresponding p-value.	0,75

Considering that the p-value is greater than significance 0.05, the hypothesis that they belong to the specified distributions is accepted with 95% confidence.

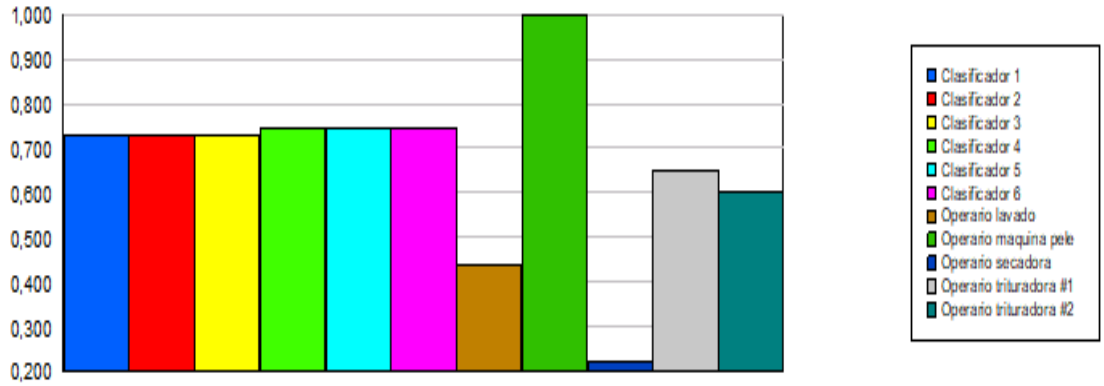
Model in Arena software. After a simulation run for one year, it was obtained that 4.9% of the pelletized material is reprocessed. In addition, 4.12% of the recycled material that enters the process is determined as NOT usable. Likewise, we can observe the high amount of material waiting in the pelletizing process. See Figure 10.

Figure 10. Arena Software Model.



Output Analysis. Next, the output analysis of the proposed model will be performed, taking into account resource utilization as a performance measure. A run length of one year will be established, which is the planning horizon defined by the company, and the number of replications will be determined. Figure 11 summarizes the results found.

Figure 11. Resource utilization.



can see that there is 100% utilization in the pelletizing machine, which reflects why such large tails are being generated in this process. why such large queues are being generated in this process.

V. RESULTS AND DISCUSSIONS

Given the low percentage of utilization of the washing and drying processes, and the high percentage of utilization in the pelleting process, the proposals will be made focusing on these processes, as shown in Table 1.

TABLE 1. Improvementproposals.

Proposal	Description
1	Use another supplier with shorter delivery times (EXPO (15)) and (EXPO (30)) for recycled and ground materials, and add another pelletizing machine, increasing productivity by 25%.
2	Adding another pelletizing machine, in addition to joining the washing and drying processes with a time of (NORM (10.6, 1.66)), increases productivity by 5%.
3	Use another supplier with shorter delivery times (EXPO (15)) and (EXPO (30)) for recycled and ground materials, and add another pelletizing machine, combining the washing and drying processes, increasing productivity by 28%.

The proposals were tested under the measures found in the output analysis, yielding the following results for the performance measures. See Table 2.

TABLE 2. Analysisofproposals.

Proposal	Unitsproduced	Use pelletized 1	Use pelletized 2	Use Washing	Use Dryer	Productivity
tnerruC	1071	100%	N/A	43%	23%	4,46 u/h
1	1421	73%	76%	46%	25%	5,92 u/h
2	1134	55%	52%	67%		4,72 u/h
3	1487	77%	78%	74%		6,19 u/h

VI. CONCLUSIONS

As can be seen in Table 2, the best proposal in terms of productivity is the that increases the productivity up to 6.16 U/h while maintaining a balanced utilization of the pelletizing machines, reducing at the same time the load with respect to the current development. The new proposal is. Based on the information obtained about the analysis in the company, it is advisable to use proposal 3 is recommended, although, it is invasive since it would require the purchase of a new machine, it is considered necessary, because this is the one that generates the most production for the company, and currently the company is over-occupied. As a recommendation to the company, it is left to their discretion the implementation of this proposal, and additionally, a change of suppliers is recommended.

Conflict of interest

There is no conflict to disclose.

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