Discrete event simulation: Case study in an extractive sector company

R Quintana-Londoño1,2, A García-Pérez1,3

1Universidad Tecnológica de Bolívar, Faculty of Engineering, Department of Industrial Engineering. Cartagena de Indias.
2raul.quintana1997@hotmail.com, 3agarcia@utb.edu.co

Abstract. At present, companies are obliged to continually improve their productivity to remain in a very competitive industry, that said, the development of processes must be done efficiently and due to this, meet the various requirements of their customers. In order to offer and execute all these services, it is necessary to carry out an analysis to each area of the company, that is, prior analysis and error processes must be implemented, in such a way, the present investigation will aim to determine the faults present in the system produced in the company and provide a viable alternative for the improvement of its system. The ProModel software will be used as the main tool for the development of the current system model and its analysis to interpret the difficulties of the system and look for an improvement alternative, later the development of the model of this alternative to compare with the statistical analyzes thrown by the software between models. As a result, a clear improvement was achieved with the proposed alternative, obtaining a significant increase in production and also a reduction in costs in the medium and long term thanks to the reduction in the amount of resources used.

Keywords: discrete-event simulation, system analysis, improvement proposal.

1. Introduction
A quarry is a mining industry of all kinds of raw materials for different industries. This industry works mainly with all types of heavy machinery such as backhoes, loaders, screens, and vehicles for transporting this raw material. All these interactions within a quarry can be simulated to analyze and seek improvements within the system to increase productivity. On the other hand, the simulation of discrete events is a “set of logical, mathematical, and probabilistic relationships that integrate the behavior of a system under study when a specific event occurs. The objective of the simulation model consists precisely in understanding, analyzing, and improving the relevant operating conditions of the system ” [1].

Discrete event simulation modeling using software has proven to be an effective method for troubleshooting manufacturing process problems and service system problems [2][3][4] and, in turn, to be a reliable support for decision making. Decisions have been made based on the use of simulation in the search for the best possible scenario for companies. Emphasizing on improving the production process of this, employing a reasonable allocation of spaces from plant design to be more productive [5].

This article aims to develop the simulation model of the internal process of the company CIMACO SAS, using the ProModel software, where the construction of the current system in the software is proposed
for the analysis of its productivity and in turn the identification of their problems. Subsequently, an improvement alternative is developed within the software to finally describe the comparison of these. Next, the company undergoes a process of analysis and decision-making in which the information provided with the model is validated and a decision is made regarding the execution of the proposal provided.

The procedure necessary for the development of the simulation model of the extraction and processing process of the CIMACO SAS quarry is as follows.

The simulation comprises an indispensable set of technological tools and methods for the successful implementation of digital manufacturing since it allows experimentation and validation of the design and configuration of products, processes, and systems. Especially in today's turbulent manufacturing environment, which is affected by megatrends such as globalization and the ever-increasing requirements for a greater degree of product customization and customization, the value of simulation is evident.

2. System
The quarry has multiple stations, transport vehicles, and heavy machinery of different types for various operations. One type is the excavators, they are in charge of extracting the raw material from the worked land, the company has four units of excavators of different sizes and brands such as CATERPILLAS and DOOSAN. Another type of machinery is the screens that are in charge of classifying the raw material between grading, crushing and foundation stone, the company has 2 TESAB brand screens. Another type of machinery is the loaders, these are in charge of handling the raw material between different stations, the company has three units of the brand VOLVO, LIUGONG and CATERPILLAR. The vehicles to transport the raw material inside and outside the company are dump trucks with buckets of 15 mt2 capacity of multiple brands. And the central station of the company is the crusher that is in charge of processing and classifying the raw material to obtain the final products of the company such as dust, gravel, foundation stone, gravel, crushed ¾ and ½ inch.

2.1. Formulation of the model
Once the extraction and processing system of the quarry has been finalized, the flow diagram that fully represents the quarry system is proposed. In Figure 1, which corresponds to the flow diagram of the system, you can see the steps of the raw material extraction and processing system. The process that is carried out is as follows: The excavators are in charge of extracting the raw material from the ground in the extraction area and loading it onto the screens, then the filters are in charge of classifying the material, then a load collects the resulting material and it loads the dump trucks of the company or individuals, then the dump trucks of the company transport the material to the main area and unload the material, then another loader picks up the material and loads it to the crusher, and finally the crusher processes the material to obtain the resulting products.
2.2. Data collection
The data collection of the duration of each step of the process was carried out directly in the work area. The time measurement was performed on a sample of 30 repetitions of each process and the mean and standard deviation of each process were identified. These times were implemented respectively in the model developed.

2.3. Implementation
The simulation of the mining-type raw material extraction and processing process begins with the analysis of the system, examining the interaction between different elements, seeking to create a model for decision making, with which the parameters can be modified and different scenarios. Said model can be developed by taking advantage of the computational capacity of specialized systems such as "ProModel, which is designed for modeling manufacturing systems ranging from small workshops to large-scale production machining cells" [6]. Within our model, we worked with different elements to represent the extraction and processing of raw material.

2.4. Entities
The first element defined as the entity called "Material" which represents a "Trip" of 15 m³ since it is the unit of measure within the company and as can be seen in Figure 2., three graphs were assigned to it an entity to represent the changes that the material undergoes within the processing.
2.5. Layout

Subsequently, the graphic representation where the entire model is worked was located, it can be seen in Figure 3. This layout was developed with images taken from the Google Maps digital platform and represented an area of 7.5 km².

![Figure 3. Layout of the study area.](image)

The graphic representation of the model is divided into three main areas: The first area located in the lower-left part consists of the central area of the company where the office, the workshop, the dump truck parking lot and the shredder are located. The second zone located in the upper middle right part of the model that consists of the extraction zone. This area is where the raw material extraction area, the different screens and machinery parking are located. The last region of the model that makes up most of the model represents the entire path required for transportation between the two previous zones. This area is not part of the property of the company but instead constitutes a public road. Transportation is done through this area by dump trucks. The three zones can be seen in greater detail in Figure 3. Zone 1 corresponds to the central region, zone 2 belongs to the extraction zone and zone 3 corresponds to the outer area of the company in greater detail in Figure 4.
2.6. Locations
Afterward, he was given the step to define the different locations with their respective capacities and units. The areas were limited as follows, as shown in Table 1.

| Name                     | Capacity | Units |
|--------------------------|----------|-------|
| ZonaExtraccion           | INF      | 1     |
| ParqueaderoMaquinaria    | 4        | 1     |
| ZonaCarga                | INF      | 1     |
| ParqueaderoVolquetas     | 10       | 1     |
| ZonaDescarga             | 100      | 1     |
| Trituradora              | 5        | 1     |
| ZonaFinal                | 100      | 1     |
| Zaranda1                 | 3        | 1     |
| Zaranda2                 | 3        | 1     |

The placement of these locations in the different zones was as follows: The area of “ParqueaderoVolquetas” was located in the upper part of the central zone at point number 1, the locations of “ZonaDescarga”, “Citruradora” and “ZonaFinal” were located in the lower part of the main zone at point number 2, the locations of “Extraction Zone”, “Zaranda1”, “Zaranda2”, “Loading Zone” and “ParkingMachinery” were located in the extraction zone at point number 3. You can see the points in greater detail in Figure 5.
Figure 5. Layout with the different locations points.

Afterward, the input element of the entity “Material” was developed, as can be seen in table 2.

Table 2. Arrivals.

| Entity  | Location       | Qty Per Arrival | Occurrences | Frequency |
|---------|----------------|-----------------|-------------|-----------|
| Material| ZonaExtraccion | 1               | INF         | 5         |

2.7. Route networks

Subsequently, the different routes where the resources worked with their respective nodes, routes and interfaces were developed. As can be seen in Table 3.

Table 3. Route networks.

| Name           | Routes | Interfaces | Nodes |
|----------------|--------|------------|-------|
| RExcavadoras   | 4      | 4          | 4     |
| RCargador      | 3      | 4          | 4     |
| RCargador2     | 1      | 2          | 2     |
| RVolquetas     | 5      | 3          | 4     |

The route corresponding to "RVolquetas" is distributed throughout the model, as shown in Figure 6. And it was necessary to extend this route to the upper part since the dump trucks need to cross to connect the two areas of the company on the public highway and as it has two lanes in one direction, it is necessary to travel extensively to the nearest return that is in the upper part of figure.
2.8. Resources
Subsequently, it was given step to establish the resources that will work in the already established route networks. These will be in charge of transporting the material between the different locations of the model. These resources were created with different specifications reflecting the current state of the company. In table 4 you can find the different resources.

| Name   | Units | Speed without entity | Speed with entity |
|--------|------|----------------------|-------------------|
| Excavadora | 3    | 15                   | 10                |
| Cargador1  | 1    | 25                   | 20                |
| Cargador2  | 1    | 25                   | 20                |
| Volquetas  | 10   | 50                   | 30                |

This difference in speeds is since as the entity “Material” represents 15 mt3 of quarry materials, this unit has a considerable weight for all these machines, which means that its transport activity is forced to be carried out with less speed when they count with the entity of "Material".

2.9. Processing
To finalize the main elements, it was given step to establish all the processing of the model that represents the behavior of the different stations with the entity and how the resources interact with the entity to perform the different transports within the model, all the processing can be found in more detail in table 5.
Table 5. Processing

| Entity       | Location       | Operation | Blk | Departure | Destination | Rule | Movement logic                                      |
|--------------|----------------|-----------|-----|-----------|-------------|------|---------------------------------------------------|
| Material     | ZonaExtracción | - Wait N(20,3) | 1   | Material  | Zaranda1    | LU   | 1 - Move With Excavadoras Then Free                |
| Material     | Zaranda1       | - Wait N(5,1) - Graphic 2 | 1   | Material  | ZonaCarga   | FIRST 1 | - Move With Cargador1 Then Free                   |
| Material     | Zaranda2       | - Get Cargador1 And Volquetas - Wait N(10,3) - Free All | 1   | Material  | ZonaDescarga | FIRST 1 | - Move With Volquetas Then Free                   |
| Material     | ZonaCarga      | - Wait N(5,2) | 1   | Material  | Trituradora | FIRST 1 | - Move With Cargador2 Then Free                   |
| Material     | ZonaFinal      | - Wait N(30,3) - Graphic 3 | 1   | Material  | ZonaFinal   | FIRST 1 |                                                    |

With this, the entire model of the company's internal system is observed and by varying the parameters of the different elements, it will be possible to see how the results of the model will affect.

3. Analysis of the current situation
Subsequently, the statistical results on the entity worked are interpreted, shown by the model, shown in Table 6.

Table 6. Results

| Name        | Total departures | Current quantity in system | Time in system | Time in motion logic | Waiting time | Time in operation | Lock time |
|-------------|------------------|---------------------------|----------------|----------------------|--------------|--------------------|-----------|
| Material    | 22               | 62                        | 246,02         | 95,02                | 30,00        | 109,45             | 11,56     |

Figure 7. Baseline's pie chart.
According to the results obtained, it is possible to interpret that a large amount of time within the system is covered by the movement logic representing 38.6% as seen in Figure 7. This is identified as a bottleneck within the system since it causes the quantity within the system to be greater than the total output as shown in Table 5.

4. Improvement proposal

Taking into account the properties of the land owned by the company, it is identified that the extraction area is going to be the work area for the next 50 years, it is proposed to add a crusher in that area, in order to reduce the time in motion logic. But the current crusher cannot be neglected or moved, so a system is proposed where the two crushers work simultaneously in the different areas of the company. You can see a grass flow with the improvement implemented in Figure 8.

![Figure 8. Proposed flow chart.](image)

5. Implementation

First, the new locations are added in the extraction area with their respective capacities and units as shown in Table 7.

| Name       | Capacity | Units |
|------------|----------|-------|
| Trituradora_2 | 5        | 1     |
| ZonaFinal2   | 100      | 1     |

Subsequently, the route network "RCloader" was modified by adding the route for the new locations with their respective interfaces, later in the processing the registry of the "Loading Zone" was changed to implement the decision policy with priority in the new added crusher and also The records were added for the locations of “Trituradora_2” and “ZonaFinal2”. Finally, the optimal number of units of the “Volquetas” resource is determined, for which a parameter is established in the units of said resource called “Quantity of Volquetas”, which has a range from 3 to 10 units. Afterward, the SIMRUNNER statistical analysis tool is used, which is conFigure d with said parameter established for experiments lasting 7 hours. From this, it is possible to obtain the optimal solution of 6 units for the number of dump trucks, and in turn, developing the scenario with the said result.

Subsequently, the statistical results on the entity worked are deduced from the model of the improvement proposal, shown in Table 8.
Table 8. Results of the improvement proposal

| Name | Total departures | Current quantity in system | Time in system | Time in motion logic | Waiting time | Time in operation | Lock time |
|------|------------------|--------------------------|----------------|---------------------|-------------|------------------|-----------|
| Material | 40 | 44 | 167,99 | 63,77 | 0,00 | 96,08 | 8,14 |

Figure 9. Entity pie chart of the improvement proposal

It can be seen that the results were obtained from the proposed alternative (see table 10.) in comparison with the results obtained by the model of the current situation (see Table 6.) a significant decrease of 78.03 minutes in the time in the average system of the entity and also a considerable increase of 18 units produced in a time of 7 hours.

6. Conclusion
In the results shown, a definite improvement in the production capacity of the materials in the system can be seen with the proposed alternative, as evidenced above, and this information provided is beneficial in the following processes in the execution of company decisions. In addition, the great utility in decision-making is demonstrated thanks to the simulation of all kinds of situations in the ProModel tool with which statistical analysis is obtained quickly.

7. References
[1] Dunna, E. G., Reyes, H. G., & Barrón, L. E. C. (2006). Simulación y análisis de sistemas con ProModel. Pearson Educación.
[2] W Septiani et al 2020 IOP Conf. Ser.: Mater. Sci. Eng. 847 012054.
[3] Muthanna Jamil and Noraini Mohd Razali 2016 IOP Conf. Ser.: Mater. Sci. Eng. 114 012049.
[4] J Fernandez 2015 J. Phys.: Conf. Ser. 622 012002-
[5] Orozco, E., Cervera, J.: Design and Installations Distributions of Industrial Facilities Supported by the Use of Process Simulation Diseño y Distribución de Instalaciones Industriales apoyado en el uso de la Simulación de Procesos,” Investig. Innov. e Ing., vol. 1, pp. 6–12, (2014).

[6] Harrell, C. y Price R. (2003). Simulation modeling using ProModel technology. Proceedings of the 2003 Winter Simulation Conference.

[7] D Suhardini and S D Rahmawati 2019 IOP Conf. Ser.: Mater. Sci. Eng. 528 012062

[8] Sushma Rani et al 2019 J. Phys.: Conf. Ser. 1240 012002