EVALUATION AND SELECTION OF THE LAYOUT OF AN INSTALLATION WITH THE USE OF A HYBRID APPROACH MULTIATRIBUTE SIMULATION

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ABSTRACT

The successful performance of the production organizations of material goods or service necessarily involves the correct location of the elements that make up the productive system, so as to satisfactorily respond not only to current situations but also to possible future scenarios. Among the techniques of Operations Research, which are useful for analyzing the behavior of systems, there is Simulation, which has demonstrated its advantages in the quantification of output variables or indicators of interest, associated with each designed scenario. In particular, this article demonstrates the convenience of using Simulation to evaluate the layout of an organization in different scenarios and multiple criteria. The steps of a hybrid approach based on Simulation and Multicriteria techniques and their application to two case studies are shown. To evaluate the behavior of the systems according to the designed layout, respective models of Simulation are generated and solved through the ARENA language version 15.0. In addition, as multi-attribute techniques for the selection of the preferred layout the following methods are applied: lexicographic and EDIPO; in the latter case with the use of the DECISION software.

KEYWORDS: Layout; Simulation; Multi-criteria techniques; Hybrid approach.

INTRODUCTION

The rapid increase in demand for products requires from industries, a greater capacity to increase their production rate and at the same time make processes more efficient by lowering the cost with high effectiveness.

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The conformation of a distribution in plant in agreement with the objectives and requirements of the organizations constitutes a potential reserve to improve the productivity. Scholars estimate that 20 to 50% of total operating expenses incurred within the manufacturing area can be attributed to the layout of the plant, and that an efficient layout likely reduces those costs by 10 to 30% (Chase and Jacob, 2013), (Marcoux et al, 2005). It can then be added that plant distribution is one of the most significant tasks and one of the most critical to improve the productivity rate and improve the work flow in the production and / or service route.

There are several procedures developed to perform an efficient plant design (Panwar and Patra, 2017), (Wiendahl, et al, 2015), however, there is little use of quantitative tools to evaluate the alternatives generated from the layout and thus verify the effectiveness of the behavior of the productive systems (of material goods and services) that were previously designed. Authors such as Mejía and Galofre (2008), Rodríguez et al, (2002), Suárez (2017), Pochamarn et al, (2008), Acuña et al, (2002), recognize the usefulness of Simulation models of discrete events in the floor layout and express the need to consider the stochastic nature of problems in the real world.

The use of Discrete Simulation with the support of the ARENA simulation language allows to evaluate the layout design to solve a given situation. This mathematical technique makes it possible to predict the behavior of manufacturing or service systems, by observing the movements or the interaction of the elements of the system. Among the advantages that the Simulation has that make it applicable to evaluate the design of the plant distribution are:

- Test the feasibility of the proposed system.
- It is not necessary to reach the interruption of operations in the company, resulting to be more economical to imitate the system.
- It provides information on the behavior of the system in different scenarios that can be explored.
- It allows to provide employees and managers with information about the new proposed systems.

Although it has already become clear the evident advantage that constitutes the application of the Simulation as a tool for the evaluation of the alternatives of layout we must bear in mind that only with this evaluation is it not enough to make the decision of which distribution to implement if we wish to consider multiple variables or attributes where some values are obtained through the Simulation, while others are available with our own distribution made.

There are several practical situations whose decisions depend on more than one measure of effectiveness, so that a monocriteria approach is insufficient to reach a solution, in this way we can talk about the existence of a multicriterial paradigm where a series of trade- offs that include conflicting criteria and covers both decision-making problems with multiple objectives and with multiple attributes, the latter also known as multicriteria decision problem in discrete spaces. In the development of Decision Theory, two schools are recognized: a normative and a descriptive one.

The first, developed primarily by the United States and England, is based on prescribing rules, so that the decision maker thinks systematically; helps you to know the coherence of your decisions with your preferences. This current has a broad mathematical foundation in the modeling of the problem, the set of defined axioms, etc., and uses rationality as a model. To solve decision problems Multicriterio in discrete spaces has developed the construction of a multi-attribute value function. On the other hand, the descriptive school developed by Continental Europe (France, Holland and Belgium), renounces the idea of the rational and tries to make a reflection of the way in which the decision maker makes the decisions, helps him modeling his behavior just as is. Although less impressive than the normative school, it also has a mathematical formulation.

There are multiple methods developed to solve a multi-attribute problem (Fernández and Escribano, 2012), (Lara, 2016), (Saaty and Vargas, 2012), (Soto de la Vega et al, 2014), (Aragonés, 2010), (Berumeny and Llamazares, 2007), although there is no evidence that one is the best. There are even different articles where a comparison is made between some of the methods, reaching the conclusion that the same solution is obtained regarding the selected alternative (Garza et al, 2012), (Tavella et al, 2014). (Fernández and Escribano, 2002). The choice of method used is based on the information available and the objective pursued with its application.

It could then be stated as a problem to solve the following: How to obtain the layout that more satisfactorily considers the stochastic and contradictory nature of the elements of the productive system that make it up?

To decide which is the best distribution and to respond to the problem, the authors make the following statement: the use of a hybrid approach Simulation and multicriteria decision making techniques in discrete spaces (multiattribute), will allow, taking into account the interests of decision makers, select which of the designs performed best meets the defined attributes, constituting this approach the hypothesis.

The objective of this article is to show the application of the Simulation and a multi-attribute method to evaluate and select the most convenient layout, according to preferences of the decision maker. For this, two case studies are used, one referring to a production facility for beverages and another for gastronomic service.

DEVELOPMENT

The use of quantitative tools for the evaluation and selection of the layout is an essential aspect in the development of this work.

The following is the set of steps that are developed in a hybrid approach with the use of simulation and multicriteria techniques. For more detail you can consult the procedure of González, et al, (2014). These steps are:

1. Approach of the situation to solve.
2. Generation of decision alternatives.
3. Simulation model through ARENA 15.0
4. Obtaining results.
5. Application of a multi-attribute technique to obtain the best decision alternative.

In the presentation of both cases of study, the problem is considered. This is a brief qualitative description of the decision situation that will be analyzed, as well as the fundamental information collected that characterizes the system, identifying which are the variables that respond to a random behavior and which is the probabilistic distribution that follows each a. Afterwards, reference is made to the decision alternatives, which in this case are the layout that have been generated. The possibilities of the use of the Discrete Simulation to evaluate the effectiveness of the designs of distribution in plant in two cases of study, which present different characteristics, are shown. Another aspect of interest that is offered is the application of multicriteria decision support techniques that will allow selecting the best layout considering the results of the simulation and the decision makers' interests.

Case study 1: Productive installation

This case study refers to a beverage bottling and packaging facility. It has the appropriate machinery for the production of four types of beverages (two brands of beer and two flavors of soft drinks).For this, it has the following equipment: 4 bottlers, 5 packaging machines (2 for 350 ml bottles and 3 for 1.5 liter plastic bottles) and 3 conveyor belts.

The production process consists of the entry of the raw materials (knobs and bottles) through the conveyor belts to the bottling companies that are automatically responsible for the work and a quality control is carried out. Once bottled, the bottles and knobs pass through the conveyor belt to the container station where packets of 6 beer bottles and 9-pack knobs of soda are formed in said station. Finally, they are stored for later distribution to the different commercial entities. In figure Nº 1 shows in a summarized way how the bottler's workflow behaves.

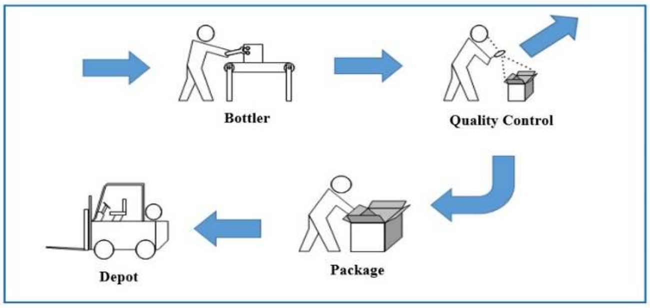

Figure N° 1. Workflow in the production facility
Source: Own Elaboration

The current design of the plant causes material losses and setbacks that make cycle time excessive, so it is desired to redesign the plant in order to obtain better results in this regard.

Using the Systematic Layout Planning (SLP) different alternatives of new designs of the beer and soft drink bottling plant were obtained, presenting the two most interesting ones, which are described below.

Alternative 1

The design of this alternative is fundamentally given by the sequence of operations that requires the production of beverages, which would be warehouse-bottling-packing-warehouse, as well as the form of the installation, so it is proposed to use a distribution in U. Other considerations consist of reserving certain spaces and requirements as specified below:

- An area of the facility for the 50 m^2 warehouse (both for raw materials and materials and for finished production).

• Two areas: one dedicated to the dining room (23 m^2) and another to the offices (20 m^2).

• It is required that the warehouse be contiguous to the area that will be used for the circulation of the trucks that will be in charge of transporting products and materials, so it must have access to the road and have enough space to allow the circulation of 3 trucks of dimensions 3 x 2 x 3 m.

• The Directorate has established that the warehouse and production activities can be controlled from the offices.

This alternative tries to exploit the available resources to the maximum. In the figure N° 2 the distribution obtained from alternative 1 is shown.

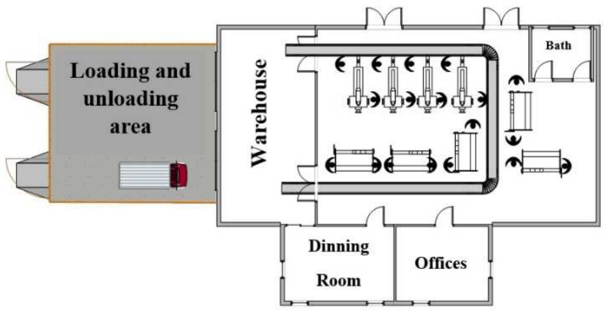

Figure N° 2. Distribution of the machines in the production area for alternative 1

Source: Own Elaboration

Alternative 2

The design of alternative 2 was developed considering a new approach that aims to optimize the production cycle by reducing transport times between jobs, since it tries to make the most of the space occupied. With this variant, the transport time between the work stations is eliminated by assigning a bottling machine to each of the bottling machines, the main difference being with alternative 1. The other specified requirements are maintained. In the figure N°3 the design of said alternative is shown.

Once the most useful alternatives are generated, the variables and attributes of interest are defined to evaluate their effectiveness. In this application (Case Study 1) the variables or quantitative and qualitative criteria that will affect the final decision were determined, these being the following:

• Quantity of packages of products produced (packages/day).

• Dead times (minutes/day).

• Production cycle (minutes).

• Use of resources (%).

• Total amount of resources used.

• Preferences of proximity between the different areas of the installation

• Reversals (non-linear order of the sequence that the product follows through the productive installation).

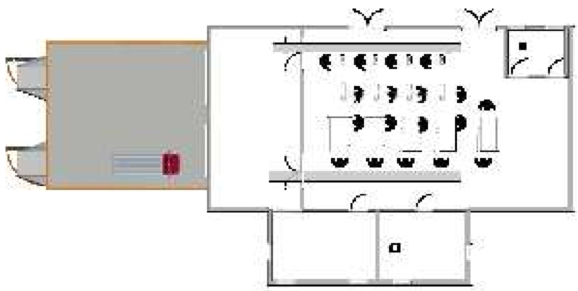

Figure N°3. Distribution of machines in the product ion area for alternative 2

Source: Own Elaboration

The values of the quantitative variables are obtained through the Discrete Simulation, specifically using the ARENA language version 15.0, while the qualitative variables are considered and obtained directly from the layout. For the last two variables, an evaluation pattern is used whose scale ranges from 0 (most favorable result) to 1 (most unfavorable result).

It is useful to animate the behavior of the system under study, taking advantage of the ease of the ARENA language (Kelton et al, 2009) in the figures N°4 and N°5 appear the animated simulation models of the two designed alternatives.

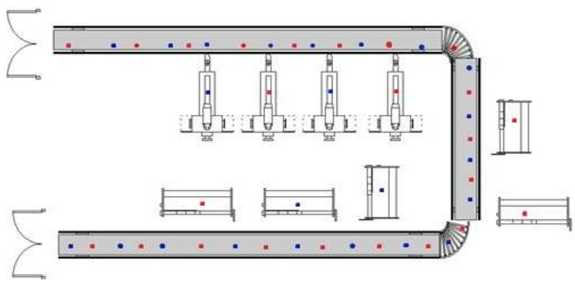

Figure N°4. Simulation model for alternative 1

Source: Own Elaboration

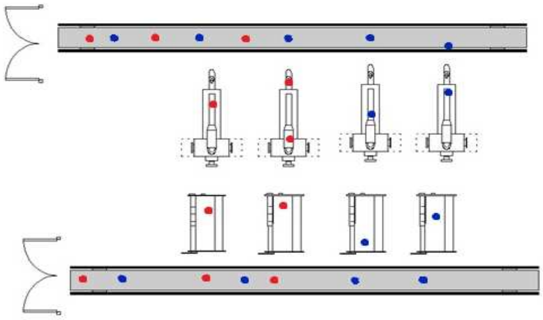

Figure N°5. Alternative simulation model 2
Source: Own Elaboration

In order to guarantee the reliability of the results obtained through the Simulation, it is necessary to perform a design of experiments on it (Kelton et al, 2009) (Martínez et al, 2018); which consists in determining the number of replicas and the length of the replicas. The length of the runs is in correspondence with the characteristics of the productive installation, in this case it is a system with term and is fixed by the working regime that is 12 hours of working time. To determine the number of replicas, the independent variable is defined as the average time spent in the system (that is, the time it takes to produce a batch).

To calculate the number of necessary replicas (n) of the selected variable, ec. 1, (Kelton, WD et al, 2009):

$$n = n_0 \left(\frac{H_r}{H_d}\right)^2 \qquad (1)$$

Where:

n_0: number of pilot replicas.
H_r: is the semi-amplitude of the interval (half-width) in the output of the pilot sample.
H_d:is the semi-amplitude of the desired interval.
On the table the results obtained for the two alternatives are shown.

Table N°1. Number of replicas for each Simulation m odel

	Alternative 1	Alternative 2
N_0	5	5
H_r	16.9935	21.936
H_d	4	4
n	91	151

Source: Own elaboration

As can be seen from the table, the run length is given by 91 and 151 runs for alternatives 1 and 2 respectively.

A comparative summary of the results of the Simulation of the alternatives is shown in Table N° 2, including the favorable variation (Δ_1 and Δ_2) obtained in alternatives 1 and 2 respectively for each criterion.

Table N°2. Results obtained in the Arena of the var iables studied

Criterion	Alternative		Δ 1	Δ 2
	1	2		
Amount of packages of beers produced	118	113	5	-
Amount of refresh packets produced	57	57	0	0
Dead times	1.99	0.52	-	1.47
Beer production cycle	55.5	58.65	3.15	-
Soft drink production cycle	12.47	29.09	16.62	-
Utilization of bottling	89.96	86.85	3.11	-
Use of packaging machines	47.22	44.88	2.34	-
Total amount of resources used	9	8	-1	-
Closeness preferences	0	0	-	-
Setbacks	0	1	1	-

Source: Own Elaboration

Considering the multi-criteria character of the decision to be taken, the lexicographic method is applied (Lara, 2016). From the results obtained it can be seen that only in the dead times criterion, alternative 2 is better than 1, so the latter is selected as the best one.

Case study 2: Design of an international and Creole food restaurant

In this case it is a business that is currently a cafeteria and it is desired to extend the renovations to the original house, which will no longer be used as a dwelling by its occupants to be converted into a restaurant/cafeteria with the amenities and services that allow to provide an excellent service. The specifications to take into account for the new design are as follows:

- Make use of the areas that the house has. These are:
  - ➢ Portal
  - ➢ Dining room
  - ➢ Study
  - ➢ Kitchen
  - ➢ Garage (in the sublevel)
  - ➢ Bathroom (upper floor)
  - ➢ Bedroom (upper floor)

- Maintain the location of the bathroom and the kitchen, evaluating introducing the improvements that are required.
- Maintain the current cafeteria area, ie in the garage.
- Locate one of the areas of the house for the creation of a warehouse.
- Decide other customer service areas including an area for the dispatch of beverages, being able to consider a climate-controlled environment in some of its areas.

The design of the layout of the house must respond to the requirements of the owner of the property, expanding the ability to flange the gastronomic service and with it the income.

This case corresponds to an infinite tail service system (Hillier and Lieberman, 2015). The input variables follow the probabilistic distribution shown in Table N°3.

Table N°3. Probabilistic distribution of input vari ables

Variable	Distribution
Arrival of clients (minutes)	GAMM (0.18, 5.51)
Time to serve liquids (minutes)	1 + 1.56 * BETA (2.19, 2.1)
Time to prepare orders (hours)	0.35 + LOGN (0.556, 0.303)
Time to serve the kitchen order (minutes)	NORM (1.44, 0.365)
Customer consumption time (minutes)	TRIA (2, 11.1, 17)
Time for dessert order (minutes)	0.05 + LOGN (0.355, 0.281)
Time to serve the dessert (minutes)	0.03 + LOGN (0.732, 0.56)
Time to eat the dessert (minutes)	NORM (5.98, 1.45)
Making the voucher (minutes)	UNIF (0.1, 0.12)
Account delivery time (minutes)	NORM (0.691, 0.178)
Calculation of the return (minutes)	UNIF (0.1, 0.15)
Return delivery (minutes)	NORM (0.974, 0.208)
Average consumption (Cuban convertible pesos or CUC)	27

Source: Own Elaboration

With the use of the SLP method two design alternatives of the new restaurant were generated. Below is explained what each proposed alternative consists of, as well as the distribution made.

Alternative 1

The distribution of the different areas of the house are as follows: An air-conditioned room, which will occupy the room and the original study of the house, in which 5 tables will be placed: 2 for 4 people and 3 for 2 people, closest to the kitchen without affecting the circulation of staff or customers. A bar will be incorporated for the delivery of drinks to the clients, where the payment box will be found to make the closing of the accounts.

In the portal you will find the outdoor area with a table for 4 people and one for 2 people, this area will be intended for those customers who prefer the coolness of the environment or for those customers who smoke.

The garage will remain in place with minor changes in aesthetics and a painting renovation running to serve customers who prefer to enjoy a quick meal or just to pick up an order.

To the kitchen will be added locks for orders and dirty dishes that will be located with access to the living room in the area where the study was previously.

On the second floor the bathroom will maintain its location, only eliminating the bathtub and placing a new shelf with sinks and the toilet in a way that allows the greatest mobility to the client. The store will be located in the old bedroom and will have a door that gives direct access to the stairs to facilitate the speed of the transit of employees.

In Fig. N°6 the layout of alternative 1 (described above) is shown.

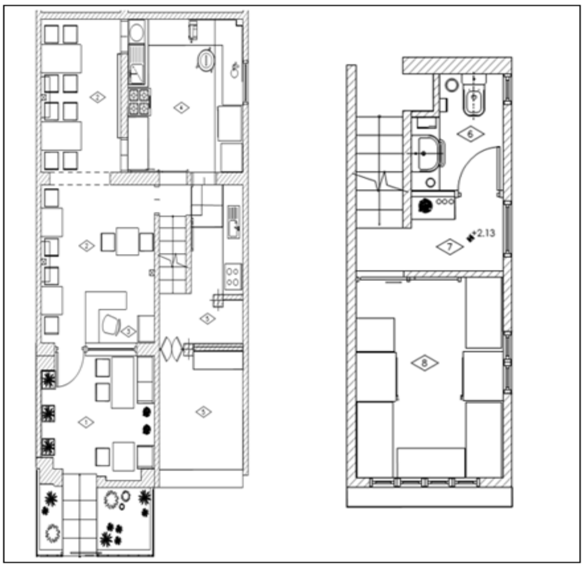

Figure N°6. Plan view of alternative 1
Source: Own Elaboration

Legend

1. Attention area in the portal (outdoor), 2. Main service area (air-conditioned room), 3. Bar, 4. Kitchen, 5. Garage, 6. Bathroom, 7. Corner, 8. Store.

Alternative 2

In this alternative it is proposed to use the space of the original studio of the house as a warehouse, to designate an area for reserved or VIP proposing the original bedroom that is on the second floor of the house, keeping the remaining areas as they were exposed in alternative 1 In the figure N°7 shows the design of said alternative.

Following the steps for the evaluation of the variants generated were defined as attributes to assess the following:

- Number of satisfied customers (receive the service).
- Number of clients leaving.
- Average time of stay in the restaurant (hours).
- Average wait time (minutes).
- Use of workers (%).
- Average income (CUC/day).
- Requirements for safety and health of the guests (there are or not locks for the entry-exit of clean and dirty dishes).
- Employee health and safety requirements (risk of falling).

Figure N°7. Plan view of alternative 2

Source: Own Elaboration

Once the variables were defined, the two alternatives designed for the new restaurant were modeled through ARENA 15.0. Using a pilot sample of 5 runs, we determined the number of replicas necessary to infer through the results of the simulation, with the application of expression 1, determining that with these 5 replicas the reliability of the results is guaranteed by obtaining a replica optimal size of 3.23 and 4.17 that approximate 4 and 5 replicas for alternatives 1 and 2 respectively. With regard to the length of the runs, is determined by the day of attention of the new restaurant and is 10 hours per day.

Among the criteria that are of interest to satisfy diners is the average waiting time. In the figures N°8 and N°9 the plotting of this variable by commensa l and for alternatives 1 and 2 respectively is shown. The behavior of this time can be appreciated both during the transient state of the system with a similar behavior in both alternatives (growing) and in the steady state where the waiting time to be served is maintained in a range of approximately 28 to 40 minutes for alternative 1 and between 30 and 44 minutes for alternative 2.

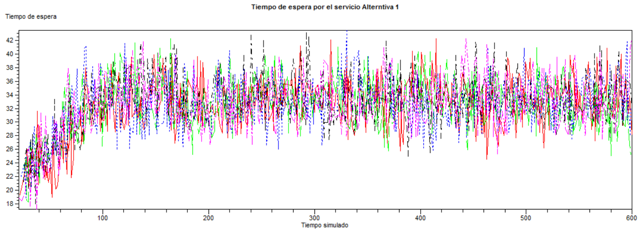

Figure N°8. Average wait time for the service in Alternative 1
Source: Own Elaboration

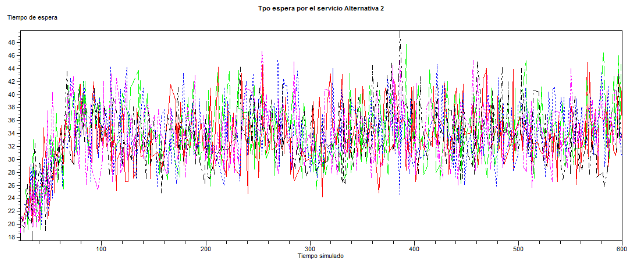

Figure N°9. Average waiting time for the service in Alternative 2
Source: Own Elaboration

Table N°4 shows the values of the selected quantitative criteria for decision making for each generated design alternative. They were obtained through the variables of the simulation with ARENA.

Table N°4. Results for the comparison of alternatives

Criterion	Alternatives	
	1	2
Satisfied customers	395	345
Lost customers	146	212
Average length of stay (h)	1.53	1.49
Average wait time (min)	32.588	34.0778

Use of workers	96.237	97.115
Income (CUC / day)	4008.2	3 352.8

Source: Own Elaboration

As can be seen (Table 3) the evaluations of the attributes or criteria obtained for each alternative favor (in four of the five criteria) alternative 1; that is, the choice is not determined by the existence of a dominant alternative, so some multi-attribute method of the existing manifolds must be applied. In this case, the choice of alternative 1 can be confirmed with the application of the EDIPO multi-attribute method, implemented in the DECISION software. It is based on the philosophy of ELECTRE III and the use of a fuzzy preference function. The weighting of the criteria can be introduced directly into the software or can be obtained by solving the equation of indifference interactively with the decision maker. In any case, the weighting coefficients of the criteria are normalized (Fernández, 1999), (Fernández et al, 2010).

Table N°5 shows the decision matrix used in the DECISION computer system used and in the figure N°10 some screens of it are shown ; in particular, the decision matrix appears first, once the indifference equations have been solved to obtain the weighting of each of the criteria considered and then the ordering of the alternatives with the associated value of the utility function is presented.

Table N°5. Decision matrix and weighted criteria

	Entry	T. esp.	Util rec.	C. perd.
Criteria	0.32258	0.25806	0.22580	0.19354
Alternative 1	MB	B	MB	R
Alternative2	B	B	MB	M

Source: Own Elaboration

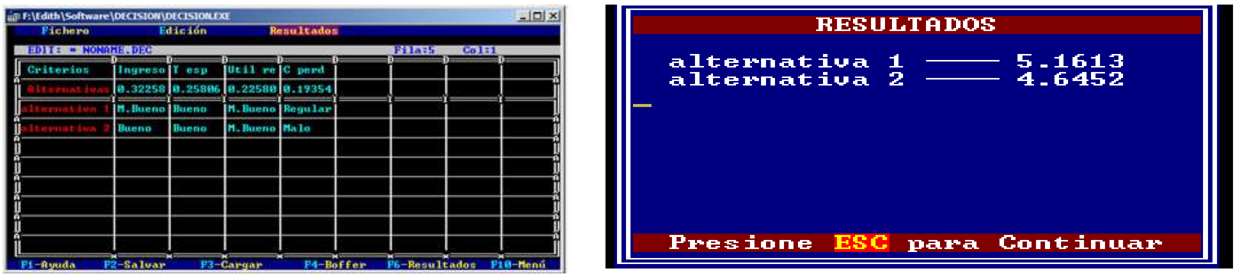

Figure N°10. Some outputs of the computer system

Source: DECISION Software

From the results obtained, it can be stated that the application of the Simulation of discrete events and the multi-attribute approach of the case studies, has allowed to quantitatively and qualitatively evaluate different layout variants, obtaining information that allows knowing the behavior of each one of the simulated systems. This in turn is information for the decision maker to make the final choice of the layout according to their convenience and preferences.

In the cases studied, it can be seen how the layout impacts on the output variables of interest, both those that characterize the productive system and other variables related to plant distribution. In the first case in which the behavior of the production process, packaging of bottles of beer and soft drinks is analyzed, you reach a layout with better results in terms of setbacks, enabling a reduction in the time cycle and an increase in the production of beverages. While in the second case, where the installation that provides a gastronomic service in a new restaurant is simulated, the distribution meets all the requirements requested, while offering diners a pleasant view and contains the largest number of tables will maximize the revenue.

CONCLUSION

The adaptation of the hybrid approach of the Simulation and multicriteria techniques to the evaluation of the distribution in plant of a production and (or) service facility allows to arrive at results that argue in greater measure the design to follow. On the one hand, the advantages of Simulation are exploited, which by experimenting different layout configurations achieves the obtaining of the own variables that have been defined in this technique, while on the other hand, with the use of a multi-attribute technique, the subjective character always present in the decision making and qualitative criteria, being possible to consider the total set of attributes of interest to reach the best decision according to the preferences of the decision maker.

Although in the cases of study that are exposed, the Lexicographical and EDIPO multi-attribute methods are applied, others are valid and can be used in the proposed hybrid approach.

REFERENCES

Please refer to articles in Spanish Bibliography.

BIBLIOGRAPHCIAL ABSTRACT

Please refer to articles Spanish Biographical abstract.