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AN INNOVATIVE DISCRETE EVENT SIMULATION TOOL TO IMPROVE THE EFFICIENCY OF A COMPLEX BEER PACKAGING LINE

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Abstract

Discrete event simulation (DES) techniques cover a broad collection of methods and applications that allow imitating, assessing, predicting and enhancing the behavior of large and complex real-world processes. This work introduces a modern DES framework, developed with SIMIO simulation software, to optimize both the design and operation of a complex beer packaging system. The proposed simulation model provides a 3D user-friendly graphical interface which allows evaluating the dynamic operation of the system over time. In turn, the simulation model has been used to perform a comprehensive sensitive analysis over the main process variables. In this way, several alternative scenarios have been assessed in order to achieve remarkable performance improvements. Numerical results generated by the DES model clearly show that production and efficiency can be significantly enhanced when the packaging line is properly set up.

Key words: optimization; simulation; packaging line

Resumen

Una herramienta innovadora de simulación de eventos discretos para mejorar la eficiencia de una línea compleja de envasado de cerveza. Las técnicas de simulación de eventos discretos (DES) abarcan una amplia colección de métodos y aplicaciones que permiten imitar, evaluar, predecir y mejorar el comportamiento de procesos complejos del mundo real. Este trabajo presenta un ambiente moderno de DES, desarrollado con el software de simulación SIMIO, para optimizar tanto el diseño y funcionamiento de un complejo sistema de envasado de cerveza. El modelo propuesto proporciona una interfaz tridimensional gráfica que resulta fácil de usar y permite la evaluación de la operación del sistema a través del tiempo. A su vez, el modelo de simulación se ha utilizado para llevar a cabo un análisis de sensibilidad sobre las principales variables del proceso. De esta forma, se han evaluado diferentes escenarios alternativos con el fin de conseguir notables mejoras en el rendimiento. Los resultados numéricos generados por el modelo DES muestran claramente que la producción y la eficiencia se pueden mejorar de manera significativa cuando la línea de envasado presenta una adecuada configuración.

Palabras clave: optimización; simulación; línea de envasado

1. Introduction

In the current context of increasingly competitive markets, production activities must be properly accomplished in order to ensure high quality products. This often translates into a better product presentation, which needs to fit today's market requirements. In this way, the demand growth and the trend to specialize the presentation of products are putting pressure on companies to perform more diversified tasks on their packaging lines, which have become more complex in the last years.

This paper aims to analyze the operation of the main packaging line of an international beer company located in Argentina. The simulation study is mainly motivated by the low efficiency of the line, according to the level desired by the managers. This implies a reduction on the current production level due to the packaging process is an essential stage in the whole production process.

The main objective of this work is to identify, analyze and reduce the causes affecting the productivity of the packaging line. Modern simulation techniques has recently emerged as proper tools to cope with complex decision making problems [1, 2]. Therefore, a comprehensive simulation-based model has been developed in order to determine the potential changes to improve the performance of the facility. The modern SIMIO modeling software was used for developing the simulation model. After being created and validated, different alternative scenarios (current, suggested and theoretical) were assessed in order to determine the more suitable line design and operation that allows increasing economical benefits [3].

The manuscript is organized as follows. Section 2 describes the main features of the bottling beer process. Afterwards, in Section 3, an explanation of how the simulation model was developed is given. Section 4 shows how simulation results are used to validate the performance of the current operation of the line and highlights its potential improvements. Finally, the article concludes with some discussion and remarks in Section 5.

2. Features of the beer production process

The beer production process involves eight manufacturing stages: (i) Malting, (ii) Malt Milling, (iii) Mashing, (iv) Cooking, (v) Wort Cooling and Clarification, (vi) Fermentation, (vii) Maturation, and (viii) Packaging. The amount and type of raw material to be processed in each stage depend on the beer type to be produced [4].

2.1. Packaging line

This work is focused on the packaging step. In a packaging line, the beer drawn from a holding tank is filled into bottles, which are then capped and labeled. A flowchart of a generic beer packaging process is depicted in Fig. 1.

The first operation in a packaging line is the depalletizing stage, where the empty bottles are removed from the original pallet packaging. Then, an inspection operation named 100% control is performed manually by an operator so that defective items or bottles that could harm machines on the line are removed. After that, bottles and drawers are separated and then sent to washer machines in different lines. The bottles must be rinsed with filtered water or air before being refilled. This physical and biological cleaning is performed to remove dirt, labels, adhesive, and foil from the glass bottles. The bottle enters then to a container inspector which controls that all cleaning agents that were used in the previous stage have been removed. Next, a filling machine is used so that the beer drawn from a holding tank be filled into the clean bottles. After that, a cap is applied to each bottle to seal it. To ensure the quality of product, the filled and capped bottles are then sent to a pasteurization stage, where they are kept until "minimum durability date". Once the bottles reach this date, they enter to a labeling machine where a label is applied to each one. Then, a level-cap inspection is performed to reject bottles that do not satisfy required characteristics as filling level, internal pressure, and missing labels and caps. Finally, the product is located into drawers, which are packed into pallets and warehoused, ready for sale.

3. Simulation model of the beer packaging process

Process simulation and modeling tools have become an issue of increasing importance to the industry in process design and operation [5, 6]. The operation of a real-world process evolving over time can be studied in detailed by developing a discrete event simulation model [7].

To build a model, it is first necessary to understand how the real process is operated. In

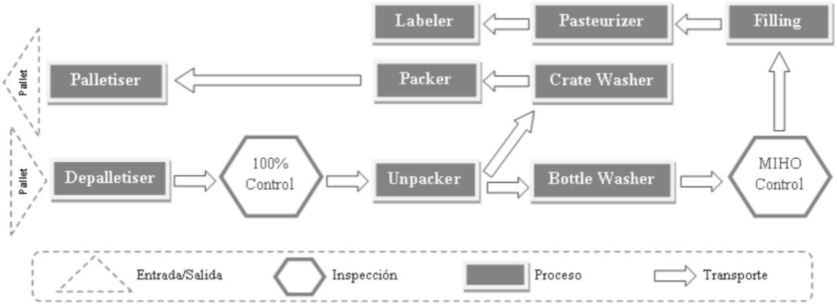


Fig. 1. Beer bottling process

this way, all the necessary data from the brewing company under study was collected by using several alternative techniques [8]: *(i)* staff interviews, *(ii)* in-situ observation, and *(iii)* historical data collection, among others. The information gathered was then analyzed, filtered and documented [9]. Such procedure allows to identify critical points and potential problems to be solved in the current and desired operation of the packaging process [10,11].

Once data collection was completed, statistical analysis of data was performed to determine the probability distributions that best fit the data collected [12,13]. For this task, the Input Analyzer Arena simulation software was used [14]. The computational model was developed by using the SIMIO modeling environment. In order to represent the operation of the bottling line, the following components are to be considered within the model:

- Bottles, Drawers, and Pallets running on the line.
- Machines performing filling, labeling, and cleaning operations.
- Belt conveyors locating between machines.
- Operators working on the line.

3.1. SIMIO Simulation Software

SIMIO is a novel and innovative object-oriented modeling framework for flow simulation of complex discrete event systems and procedures. This computational tool allows building graphical animation models in both 2D and 3D, which simplify the viewing and validation of simulation results [15].

In SIMIO, each physical component of the real process, such as bottles or machines, is represented by an object with a predefined behavior, which can be extended by adding additional user procedures in the model. Three animation views of the simulation model are given in Fig. 2.

3.2. Packaging line model

Standard SIMIO objects as source, server, and sink, connected by paths, have been used to build the simulation model. A detailed description of how the bottling line has been modeled computationally is given below.

Pallets, Drawers, and Bottles: They are the dynamic entities processed on the line, as shown in Fig. 3.

The arrivals of pallets full of empty bottles are generated by a “Source Object”. Illustrated by Fig. 3, the bottles enter to the line once they are removed from their original pallet packaging by the depalletizer machine.

Depalletizer Machine: As shown in Fig. 4, a “Separator Object” is used to represent how the depalletizer machine loads empty bottles from pallets onto the belt conveyor. The “Processing Time” property determines that each pallet is

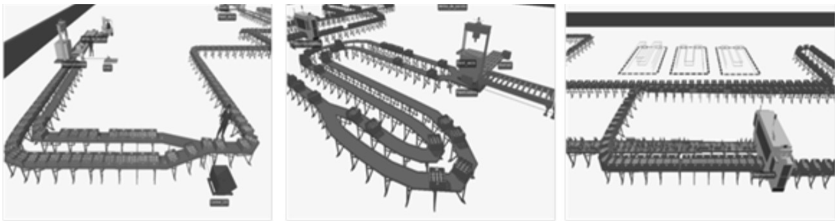
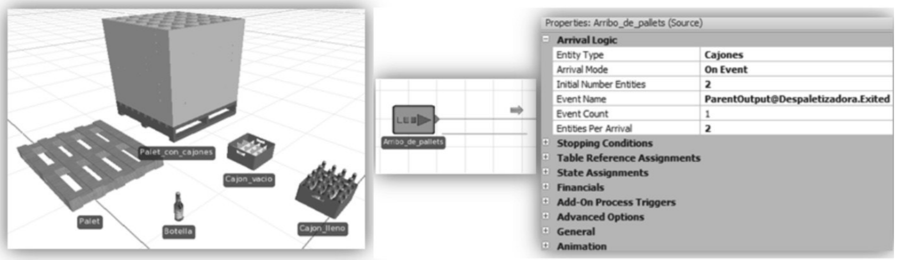


Fig. 2. 3D graphical views of packaging line



Properties: Arribo_de_pallets (Source)

Arrival Logic

Entity Type	Cajones
Arrival Mode	On Event
Initial Number Entities	2
Event Name	ParentOutput@Despaletizadora.Exited
Event Count	1
Entities Per Arrival	2

Stopping Conditions
Table Reference Assignments
State Assignments
Financials
Add-On Process Triggers
Advanced Options
General
Animation

Fig. 3. Dynamic entities (bottles, drawers, and pallets) and pallets entity arrivals

processed in 50 seconds while the “Copy Quantity” property specifies that 50 new entities, which represents a drawer full of empty bottles, are removed from every incoming pallet.

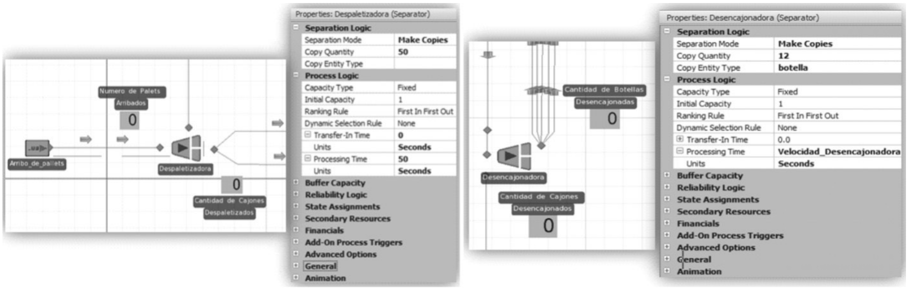
Unpacker Machine: Fig. 4 shows the “Separator object” representing to the unpacking operation, which is similar to the depalletizing one. In this second stage of the bottling line, 12 new entities, representing empty bottles, are removed from each entry drawer.

Between the two operations described above, there is an additional process (Control 100%) that inspects the drawers entering to the line. In this way, a “SIMIO process”, which uses a probabilistic function, was defined to reject defective entities (see Fig. 5).

Bottles Washing: This operation is represented by placing 40 “Conveyor objects” into the SIMIO model. Each of them represents a real belt conveyor and can transport until 710 bottles. The input/output logic of this stage, described in Figure 5, assures that bottles will be within washing machine by at least 45 minutes.

Here, it is important to remark that SIMIO standard elements as “Event” or “Timer” have been used in order to represent input logic of the washing machine (see Fig. 6). The bottles enter the equipment through “hits”; there is a palette that, every 2 seconds, places 40 bottles onto “pocket inputs” for then being washed. To model this behavior, whenever a bottle wants to enter to the washing machine, it must wait until an event called “Active_Washing” is activated. A “Timer element” is used so that such event can be triggered every 2 seconds. Thus, we ensure that each group of bottles will enter to the machine at the same time and consequently the input speed of the equipment is fulfilled.

Empty Bottles Inspector (MIHO): This process stage aims to verify the bottles that have been previously processed in the washing machine. As shown in Fig. 6, a “SIMIO basic node”



Properties: Despaletizadora (Separator)

Separation Logic	
Separation Mode	**Make Copies**
Copy Quantity	**50**
Copy Entity Type	
Process Logic	
Capacity Type	Fixed
Initial Capacity	1
Ranking Rule	First In First Out
Dynamic Selection Rule	None
Transfer-In Time	**0**
Units	**Seconds**
Processing Time	**50**
Units	**Seconds**
Buffer Capacity	
Reliability Logic	
State Assignments	
Secondary Resources	
Financials	
Add-On Process Triggers	
Advanced Options	
General	
Animation	

Properties: Desencajonadora (Separator)

Separation Logic	
Separation Mode	**Make Copies**
Copy Quantity	**12**
Copy Entity Type	**botella**
Process Logic	
Capacity Type	Fixed
Initial Capacity	1
Ranking Rule	First In First Out
Dynamic Selection Rule	None
Transfer-In Time	0.0
Processing Time	**Velocidad_Desencajonadora**
Units	**Seconds**
Buffer Capacity	
Reliability Logic	
State Assignments	
Secondary Resources	
Financials	
Add-On Process Triggers	
Advanced Options	
General	
Animation	

Fig. 4. 2D SIMIO model (depalletizer machine and unpacker machine)

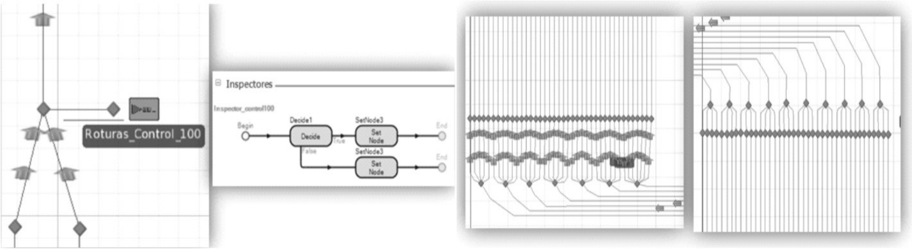
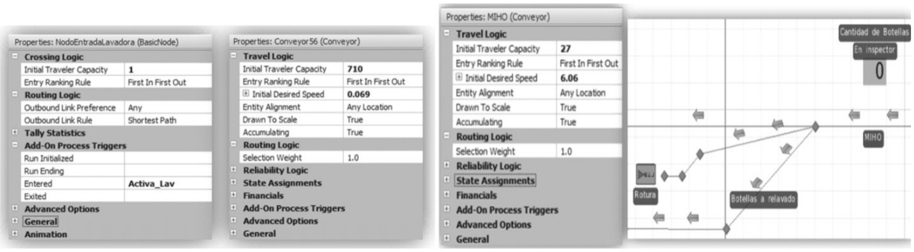


Fig. 5. 2D SIMIO model (Control 100% and washing machine)



Properties: NodoEntradaLavadora (BasicNode)

Crossing Logic	
Initial Traveler Capacity	**1**
Entry Ranking Rule	First In First Out
Routing Logic	
Outbound Link Preference	Any
Outbound Link Rule	Shortest Path
Tally Statistics	
Add-On Process Triggers	
Run Initialized	
Run Ending	
Entered	**Activa_Lav**
Exited	
Advanced Options	
General	
Animation	

Properties: Conveyor56 (Conveyor)

Travel Logic	
Initial Traveler Capacity	**710**
Entry Ranking Rule	First In First Out
Initial Desired Speed	**0.069**
Entity Alignment	Any Location
Drawn To Scale	True
Accumulating	True
Routing Logic	
Selection Weight	1.0
Reliability Logic	
State Assignments	
Financials	
Add-On Process Triggers	
Advanced Options	
General	

Properties: MIHO (Conveyor)

Travel Logic	
Initial Traveler Capacity	**27**
Entry Ranking Rule	First In First Out
Initial Desired Speed	**6.06**
Entity Alignment	Any Location
Drawn To Scale	True
Accumulating	True
Routing Logic	
Selection Weight	1.0
Reliability Logic	
State Assignments	
Financials	
Add-On Process Triggers	
Advanced Options	
General	

Fig. 6. 2D SIMIO model (input logic to washing machine and bottles inspector)

is used to represent this operation. Such node has one input path and three output paths. The first output path receives the bottles that have a physical defect. The bottles that have some dirt are sent to the second one. Finally, the accepted bottles continue their normal processing to the third output path.

Filling Machine: This operation has been modeled with a "Conveyor object". As shown in Fig. 7, the "Initial Traveler Capacity" object property indicates that 154 bottles can be transported at the same time. Such carrying capacity is equal to the amount of filling valves. Next operation, capping, it is modeled with the same processing capacity of filling machine.

Pasteurizer Machine: This equipment has two floors which have been represented in SIMIO by 60 conveyors working in parallel (processing capacity). In this stage, bottles cross through "rainfall areas" that provide water at different temperatures (see Fig. 7 and 8).

Labeler Machine: This equipment unit has an operation similar to the filling machine (see Fig. 8).

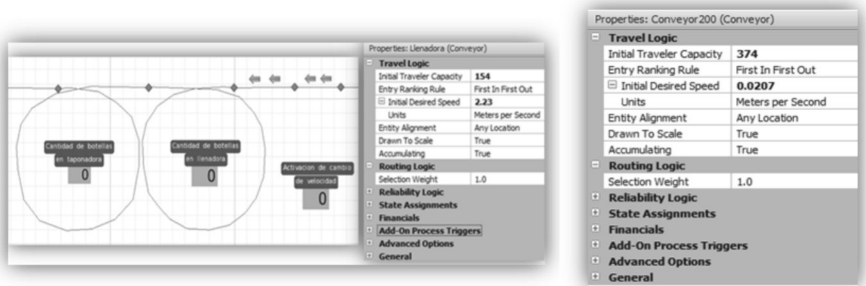
Once bottles were labeled, two inspectors control them. This process is defined similarly to the Control 100% described above. In order to compute the total amount of rejected bottles, two "sink objects", named HUEFT and FT_50, have been defined into simulation model.

Packer and Palletizer Machine: A "Combiner module" has been used to model the behavior of the packer and palletizer machine (see Fig. 9). For packing, 12 bottles are assembled into a drawer. After that, the palletizer machine puts together 50 drawers in a pallet (10 drawers per stack, 5 stacks per pallet). Then, the pallets are sent to the storage area which has been modeled with a "Sink module".

Accumulation Tables: Since the machines are exposed to internal faults, the accumulation tables guarantee the uninterrupted running of the beer bottling line. These tables assure that bottleneck equipment, in this case the filling and capping machine, may continue processing when either a lack of bottles in the input or bottle accumulation in the output takes place.

Along the packaging line, there are three accumulation tables, two for bottles and one for drawers. The first accumulation table is located between the empty bottles inspector and the filling machine (see Fig. 10). The second one is located between the pasteurizer equipment and the labeling machine, while the drawer accumulator is situated between the unpacker machine and the packer unit.

Fig. 10 shows a "Monitor element" which has been used to control the capacity of the conveyor located above the accumulation tables for bottles. If this capacity changes, a process called



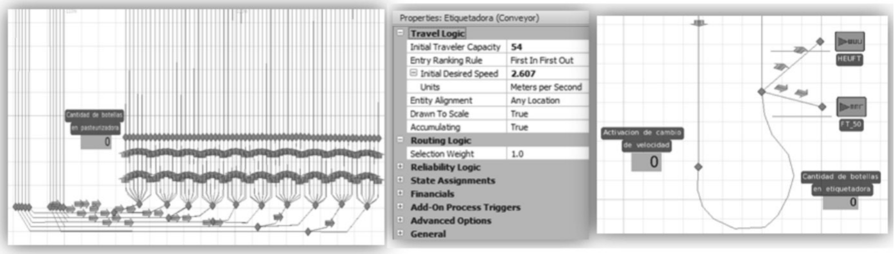
Properties: Llenadora (Conveyor)

Travel Logic	
Initial Traveler Capacity	**154**
Entry Ranking Rule	First In First Out
⊟ Initial Desired Speed	**2.23**
Units	Meters per Second
Entity Alignment	Any Location
Drawn To Scale	True
Accumulating	True
Routing Logic	
Selection Weight	1.0
⊞ **Reliability Logic**	
⊞ **State Assignments**	
⊞ **Financials**	
⊞ **Add-On Process Triggers**	
⊞ **Advanced Options**	
⊞ **General**	

Properties: Conveyor200 (Conveyor)

Travel Logic	
Initial Traveler Capacity	**374**
Entry Ranking Rule	First In First Out
⊟ Initial Desired Speed	**0.0207**
Units	Meters per Second
Entity Alignment	Any Location
Drawn To Scale	True
Accumulating	True
Routing Logic	
Selection Weight	1.0
⊞ **Reliability Logic**	
⊞ **State Assignments**	
⊞ **Financials**	
⊞ **Add-On Process Triggers**	
⊞ **Advanced Options**	
⊞ **General**	

Fig. 7. 2D SIMIO model (filling machine and pasteurizing machine)



Properties: Etiquetadora (Conveyor)

Travel Logic	
Initial Traveler Capacity	**54**
Entry Ranking Rule	First In First Out
⊟ Initial Desired Speed	**2.607**
Units	Meters per Second
Entity Alignment	Any Location
Drawn To Scale	True
Accumulating	True
Routing Logic	
Selection Weight	1.0
⊞ **Reliability Logic**	
⊞ **State Assignments**	
⊞ **Financials**	
⊞ **Add-On Process Triggers**	
⊞ **Advanced Options**	
⊞ **General**	

Fig. 8. 2D SIMIO model (pasteurizing machine and labeler machine)

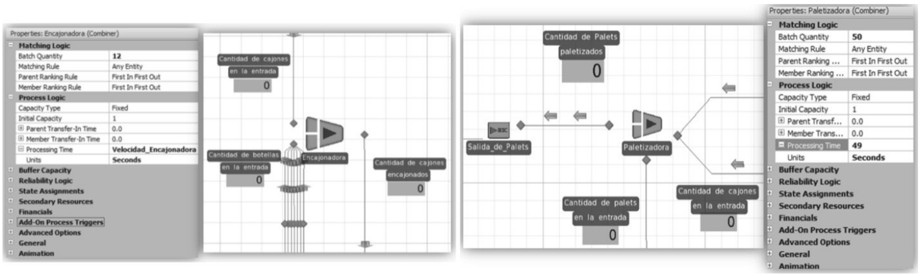
"Activar_Mesa" is triggered by the monitor. This process verifies that the conveyor capacity does not exceed 90% of its maximum capacity. If this happens, the accumulation table is activated.

In addition, a binary variable named Activar_Mesa_N determines the current state of accumulation table N. If such table is activated, Activar_Mesa_N values 1; otherwise, it is set to zero.

Transports: There are two transport lines, one for bottles and other for drawers. "Basic Node elements" and "Conveyor objects" have been used to model such lines. From Fig. 11, it follows that conveyor objects have important properties to be set by the user such as speed, traveler capacity, and the option for accumulating or non-accumulating paths.

The drawer line has single conveyors while the bottling line has variable width conveyors, which allow carrying from one to ten bottles in parallel (see Fig. 11).

Several SIMIO procedures, whose logic is embedded within "Basic Nodes elements", were defined into the simulation model to integrate conveyors with variable carry capacities (see Fig. 12). Each defined procedure uses a discrete distribution so that the bottles can be distributed on conveyors with available capacity. If one of



Properties: Encajonadora (Combiner)

Matching Logic

Batch Quantity	12
Matching Rule	Any Entity
Parent Ranking Rule	First In First Out
Member Ranking Rule	First In First Out

Process Logic

Capacity Type	Fixed
Initial Capacity	1
Parent Transfer-In Time	0.0
Member Transfer-In Time	0.0
Processing Time	Velocidad_Encajonadora
Units	Seconds

Properties: Paletizadora (Combiner)

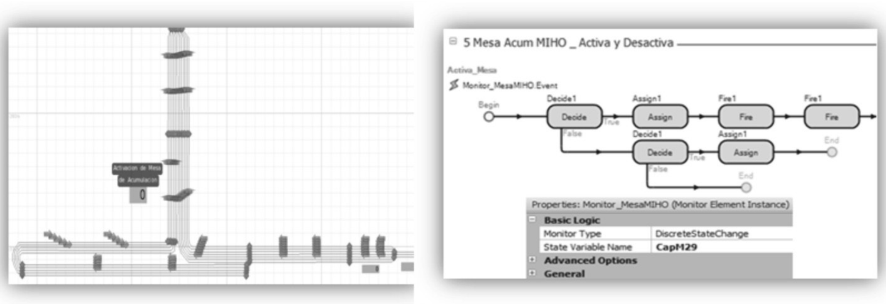
Matching Logic

Batch Quantity	50
Matching Rule	Any Entity
Parent Ranking ...	First In First Out
Member Ranking ...	First In First Out

Process Logic

Capacity Type	Fixed
Initial Capacity	1
Parent Transf...	0.0
Member Trans...	0.0
Processing Time	49
Units	Seconds

Fig. 9. 2D SIMIO model (packer process and palletizer process)

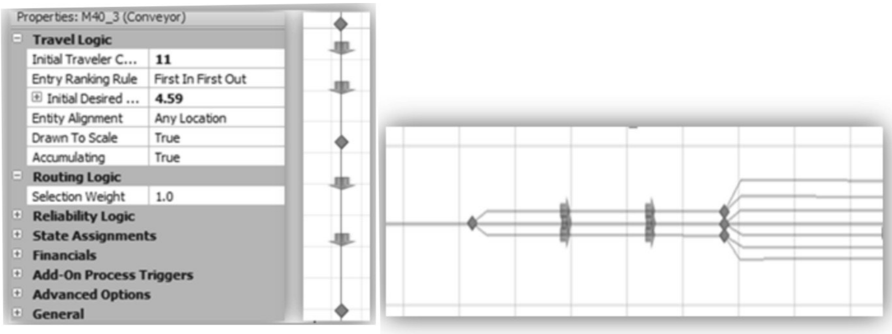


Properties: Monitor_MesaMIHO (Monitor Element Instance)

Basic Logic

Monitor Type	DiscreteStateChange
State Variable Name	CapM29

Fig. 10. 2D SIMIO model (accumulation table for bottles and monitor element)



Properties: M40_3 (Conveyor)

Travel Logic

Initial Traveler C...	11
Entry Ranking Rule	First In First Out
Initial Desired ...	4.59
Entity Alignment	Any Location
Drawn To Scale	True
Accumulating	True

Routing Logic

Selection Weight	1.0

Fig. 11. SIMIO simulation software (conveyor properties and bottle conveying line)

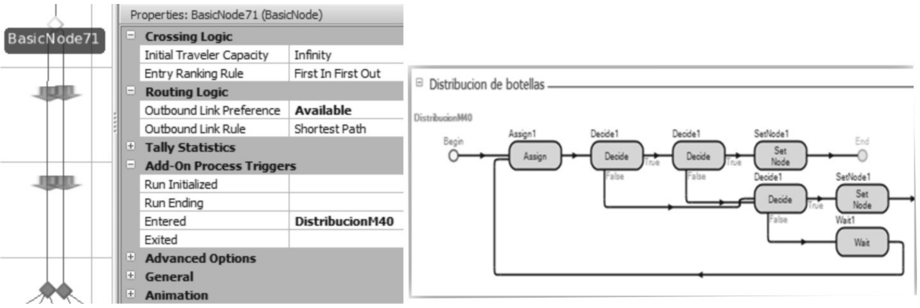
them is above the limit of its capacity, other one in parallel must be chosen.

Drawers Combiner: On the belt conveyor of drawers, there are two combiners which aim to join two lines into a single or reversely (see Fig. 13). The first combiner is located after the depalletizer machine, more precisely where Control 100% is performed. The second combiner is situated before palletizer machine and its function is to divide the belt conveyor from the packer machine in two lines.

A set of SIMIO procedures has been defined to explicitly represent the behavior of the two drawer combiners, as represented in Fig. 13. Since the capacities of the two conveyors involved in the combiners are different, more drawers are taken from the largest one in order to maintain a balance in the accumulation of the conveyors. It is worth to remark that when one conveyor is moving, the other stops running.

Sensors: Under normal operating conditions, machines on the packaging line work independently. It avoids that compatibility problems can appear when different equipments are put together on the same packaging line. However, some issues can emerge when operations are not properly coordinated. As a result, equipment should be monitored individually and a considerable time is spent in starting up and shutting down operations.

Several sensors control the number of bottles or drawers on the line. Such devices, located on strategic points of the belt conveyors, emit signals so that conveyors or machines can start or stop their activities. Sensors are switches that are activated or deactivated according to whether they are in contact with the object. To represent the above behavior, three monitors have been defined for incoming and outgoing conveyors of each machine (see Fig. 14). If a capacity change is detected in them, the monitors trigger a process determining the speed at which the equipment should operate. For example, if there is no accumulation in incoming conveyors and there are drawers on the outgoing line, the unpacker machine operates at low speed. Otherwise, if there is accumulation in the incoming conveyor, the machine is capable of running at a higher rate. In this way, three states are defined for each equipment: (i) stopped, (ii) low speed and (iii) high



Properties: BasicNode71 (BasicNode)

Crossing Logic	
Initial Traveler Capacity	Infinity
Entry Ranking Rule	First In First Out
Routing Logic	
Outbound Link Preference	**Available**
Outbound Link Rule	Shortest Path
Tally Statistics	
Add-On Process Triggers	
Run Initialized	
Run Ending	
Entered	**DistribucionM40**
Exited	
Advanced Options	
General	
Animation	

Fig. 12. 2D SIMIO model (distribution processes and bottles distribution)

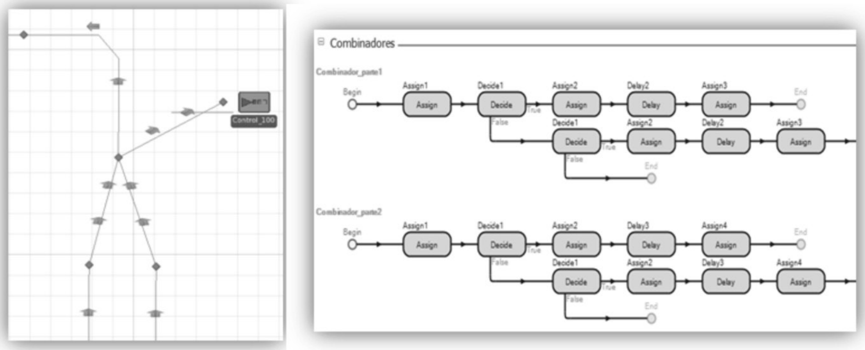
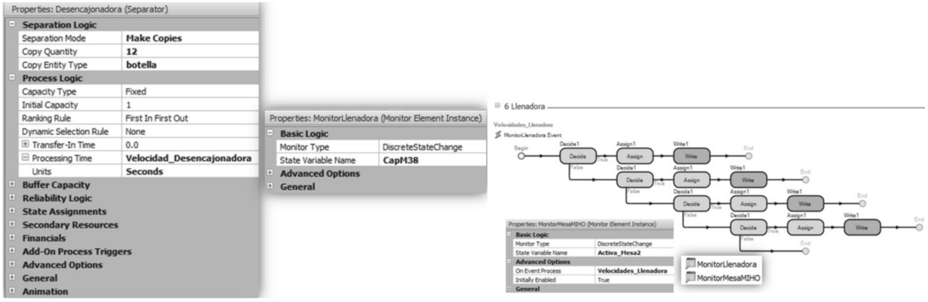


Fig. 13. 2D SIMIO model (Drawers combiner) and SIMIO processes



Properties: Desencajonadora (Separator)

Separation Logic	
Separation Mode	**Make Copies**
Copy Quantity	**12**
Copy Entity Type	**botella**
Process Logic	
Capacity Type	Fixed
Initial Capacity	1
Ranking Rule	First In First Out
Dynamic Selection Rule	None
Transfer-In Time	0.0
Processing Time	**Velocidad_Desencajonadora**
Units	**Seconds**
Buffer Capacity	
Reliability Logic	
State Assignments	
Secondary Resources	
Financials	
Add-On Process Triggers	
Advanced Options	
General	
Animation	

Properties: MonitorLlenadora (Monitor Element Instance)

Basic Logic	
Monitor Type	DiscreteStateChange
State Variable Name	**CapM38**
Advanced Options	
General	

Properties: MonitorMesaMIHO (Monitor Element Instance)

Basic Logic	
Monitor Type	DiscreteStateChange
State Variable Name	**Activa_Mesa2**
Advanced Options	
On Event Process	**Velocidades_Llenadora**
Initially Enabled	True
General	

Fig. 14. 2D SIMIO model (Unpacker machine properties and Accumulation monitor features) and speed changes for filling and capping machine

speed. A variable is used to determine the machine state at a given time. The alternative values of this variable are: 0 (if the machine is stopped), 1 (if the equipment is operated at low speed) or 2 (if the machine is running at high speed).

For filling and capping machines, sensors are used to monitor their incoming conveyors (see Fig. 14). If such lines are not full of bottles, both machines stop working. In turn, if the accumulation table, located after the bottle inspector machine, is activated, the filling equipment will run at a greater rate. The normal filling speed is of 550 bottles per minute while 600 bottles per minute are filled when the machine operates at high speed.

4. Model Verification and Validation

One of the most important stages of a simulation project is the verification and validation of the model. In this work, the verification process was carefully performed first in order to assure that the computational model was adequately codified. Then, the validation process was accomplished. According to [7], the goal of validation is twofold: (i) to produce a model that represents true system behavior and (ii) to increase to an acceptable level the credibility of the model, so that the model will be used by managers and others decision markers. The results obtained from the validation procedure allowed to determine that the model behavior and the simulated output data resemble the real system.

4.1. Sensitivity Analysis

Once validation step was completed, alternatives scenarios were evaluated by experimenting with the simulation model. The goal was to determine the potential changes for performance improvement in existing facilities. In this way, the simulation model developed with SIMIO was run in an experimentation mode. One or more key properties of the model were modified to evaluate the impact on the whole system performance, mainly on the number of processed bottles in the filling machine, which is the bottleneck asset in the packaging line. The scenarios analyzed were as follows:

- Scenario 1 considering current system configuration.
- Scenario 2 establishing theoretical speeds of the machines with regards to line design ("V Line"). It is assured that the bottleneck asset is neither starved of material nor blocked due to any issues upstream and downstream respectively.
- Scenario 3 combining the features present in Scenario 2 with the option of using a drawer collector between packer and unpacker machine.
- Scenario 4 modifying Scenario 2 by changing the logic of drawer combiner located after the depalletizing machine.
- Scenario 5 modifying Scenario 2 by increasing conveyor speeds operating in the clean room.

Previous scenarios were defined in order to evaluate the following performance indicators:

- Filling machine efficiency: Taking into account the speed of filling machine, this parameter is determined by dividing the real amount of bottles that were filled during the simulation time by the number of bottles that should have been processed during the same time.
- Effective efficiency global indicator: Taking into account the speed of palletizer machine, this indicator is computed by dividing the amount of bottles processed during the simulation time by the theoretical number of bottles that should have been processed during the same time.
- Occupancy rate of belt conveyors: It allows analyzing and modifying the operation of conveyors that have a high occupancy.

- Number of pallets full of empty bottles entered to the bottling line vs. Number of pallets full of filled bottles produced: It indicates the productivity level achieved by the bottling line in a work shift of 8 hours.
- Changes in the speed and stability of the machines: The goal is to reduce machine downtime.

4.2. Results

The design of packaging line is based on the concept of "V Line". The filling machine speed, which is the bottleneck asset, is taken as reference to define the speed of machines located upstream and downstream. Their speeds are increased from 10% to 15% according to distance from filling machine. It is assured that the bottleneck asset is neither starved of material nor blocked due to any issues upstream and downstream, respectively. Table I shows the theoretical speeds at which machines should run according to a filling machine speed of 550 bpm while Table II gives a detailed of which are the current machine speeds on the line. Data in Table I and II is graphically shown in Fig. 15.

In addition, the productivity of packaging line is determined taking into account the equipment efficiency. This performance indicator is calculated as shown in Eq. (1). The theoretical number of bottles produced is derived from the filling machine speed, which is the bottleneck stage of the packaging line.

Table I. Analysis of theoretical speeds

	Machine Speeds (bph)	% Capacity of bottleneck asset
Depalletizer	43260	40
Unpacker	40170	30
Washer	35535	15
Filling	30900	0
Labeler	35535	15
Packer	40170	30
Palletizer	43260	40

$$\text{Efficiency} = \frac{\text{Actual number of hottles produced}}{\text{Theoretical Number of bottles produced}} \quad (1)$$

Taking into account the production data of 3 consecutive months, Eq. (1) has been used in order to determine of productivity efficiency of each month analyzed. The results are presented in Table III. From this table, it follows that the packaging line has an average efficiency of 66.77%.

It is worth to remark that when the computational model was run to quantify the performance of packaging line, the simulation output reported a line efficiency of 66.8%. Other performance indicators, such as the number of pallet produced by work shift and the production rate in each machine, were considered to validate the model too. A comparison between the historical company data and the performance measures quantified by simulation is given in Table IV.

The inherent advantages of the simulation study are highlighted by evaluating the alternative scenarios specified above [8]. The results obtained in each of them are described below.

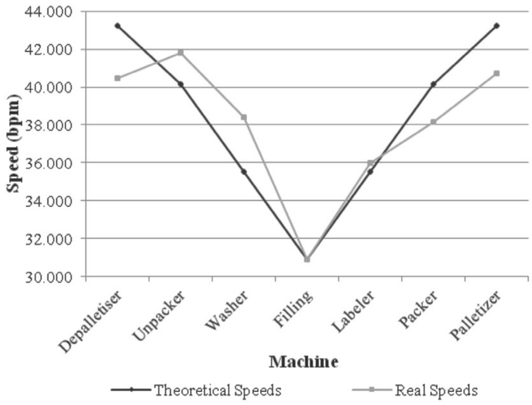


Fig. 15. "V" line with ideal and actual speeds

Table II. Analysis of current speeds

	Machines Speeds (bph)	% Capacity of previous machine	% Capacity of bottleneck asset
Depalletizer	40440	-9.7	30.9
Unpacker	41820	8.9	35.3
Washer	38400	24.3	24.3
Filling	30900	0.0	0.0
Labeler	36000	16.5	16.5
Packer	38160	6.0	23.5
Palletizer	40740	6.8	31.8

Table III. Productivity Data

Month	Week	Amount of Bottles Produced Current	 Theoretical	Average Efficiency (%)
1	1	3187638	4752000	67.58
	2	3079862	4752000	
	3	3269809	4752000	
	4	2985746	4752000	
2	1	3082036	4752000	66.55
	2	3041290	4752000	
	3	3424400	4752000	
	4	3054792	4752000	
3	1	3155279	4752000	66.17
	2	3069707	4752000	
	3	3245196	4752000	
	4	3108242	4752000	

Table IV. A comparison between the performance of the real system and the simulation model

	Pallets produced per shift Real System	 Simulation Model
Despalletizer	283	282
Empty bottle inspector	280	278
Filling	277	275
Labeler	272	268
Packer	278	274
Palletizer	271	270

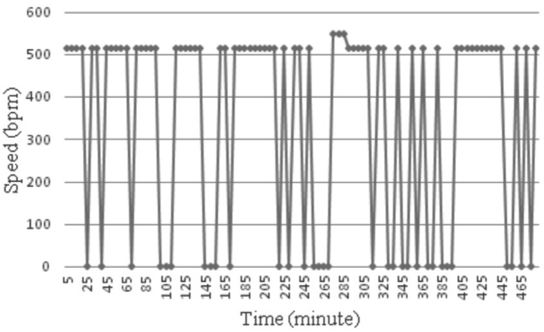


Fig. 16. Filling machine speed for Scenario 1

4.2.1. Results for Scenario 1

The use of simulation modeling to evaluate the current system configuration has returned as major result that the filling machine do not maintain a continuous operation and its speed changes over time. This is because downstream and upstream machines stops several times during production process. Fig. 16 shows the sequence of filling machine shutdown.

Besides, the use of simulation allowed to determine the level of accumulation of drawers and bottles between each machine. For scenario 1, results show an imbalance in two sectors of packaging line. On the one hand, there is an accumulation of bottles in the feeding-area, more precisely in one of conveyors located between the palletizer machine and the drawer combiner. On the other hand, a high accumulation of bottles takes place in the belt conveyor of the clean room, located between the bottle washing machine and the empty bottle inspector (see Fig. 17).

It is important to remark that the conveyors located between the washing equipment and the inspector machinery should maintain a correct profile of accumulation so that the number of shutdowns of washing machine can be reduced. However, the operation of packaging line shows that there is a high level of accumulation of bottles in those conveyors actually.

Besides, a high accumulation in conveyors situated before depalletizing machine may cause that this equipment stops. Consequently, all operations upstream will be affected too. The sequences of shutdowns for depalletizer and unpacker machines are given in Fig. 18.

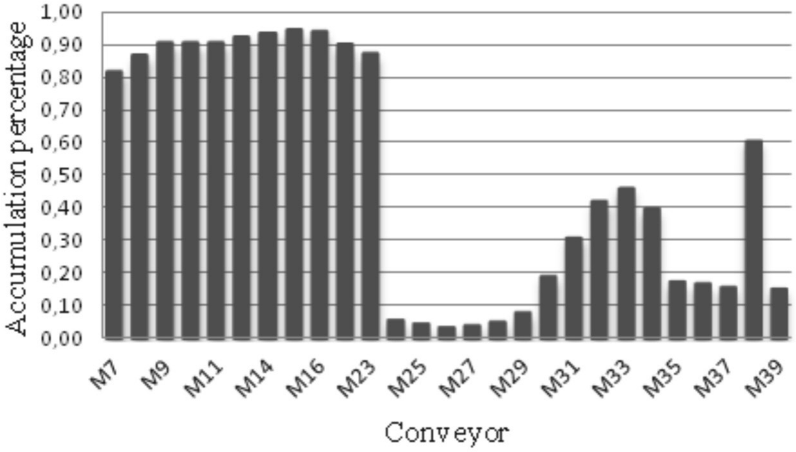


Fig. 17. Bottles accumulation in clean room conveyor for Scenario 1

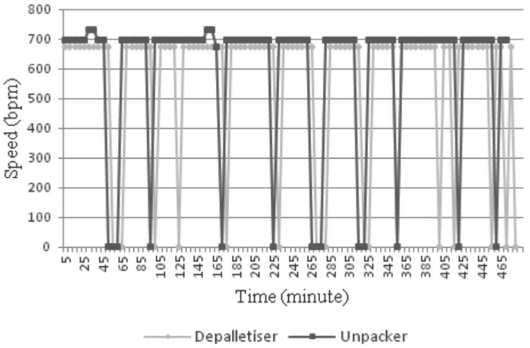


Fig. 18. Stoppages of depalletizer and unpacker machines for Scenario 1

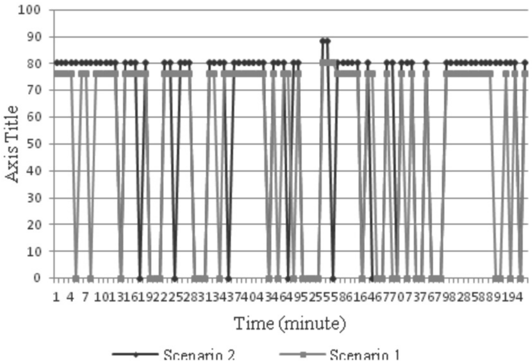


Fig. 19. Gearshifts in filling machine

4.2.2. Results for Scenario 2

The sequence of gearshifts in filling machine is shown in Fig. 19. From the comparison between the original and proposed speed variations, a higher number of shutdowns were observed in the bottleneck equipment. Hence, scenario 2 results in a lower stability of the line, a lower efficiency level of the filling machine (61.1%) and a lower global effective efficiency (58.4%). In turn, results show an imbalance accumulation in the conveyors of both the clean room and the feeding area, similar to previous scenario.

In order to increase throughput and efficiency of the packaging line without having to modify machine speeds, new alternatives from scenario 2 were proposed and their results are detailed below.

4.2.3. Results for Scenario 3

In this case, the options of incorporating a drawer accumulator and an operator were considered in order to improvement the results of previous scenario. Three alternatives were proposed: (i) it includes a drawer accumulator, (ii) it includes an operator, and (iii) it considers both a drawer accumulator and an operator. For each of proposed alternatives, simulation results were analyzed in order to determine performance improvements. If a drawer accumulator is used, an efficiency of 61.2 is achieved. However, no significant changes were detected in the other cases with respect to the Global Effective Efficiency Indicator.

For a work shift, the operation speeds of unpacker and packer machines are shown in Fig. 20. From this picture, it follows that a significant reduction in the number of machine stops is achieved by using the drawer accumulator. However, the usage of critical equipment, the filling machine, was not upset and the amount of product palletized is maintained in 115400 bottles. This is so because the stoppage of machine is minimized by the design of packaging line, in which there are conveyors that acts as buffer between machines. Consequently, an investment from company is not justified because there is no impact on the performance of the line.

4.2.4. Results for Scenario 4

In this scenario, two operation alternatives for the drawer combiner situated after the depalletizing machine were evaluated. The waiting time of combiner is changed in the first alternative while the number of drawers to be transported by each conveyor is modified in the second one.

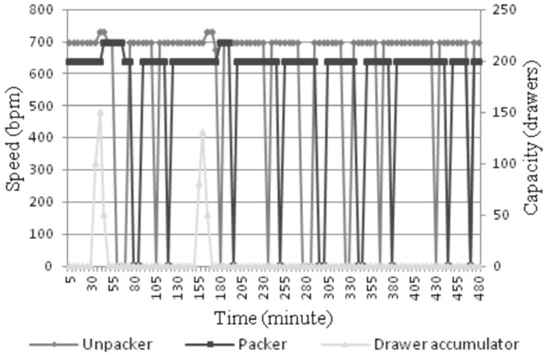


Fig. 20. Machine speeds for Scenario 3

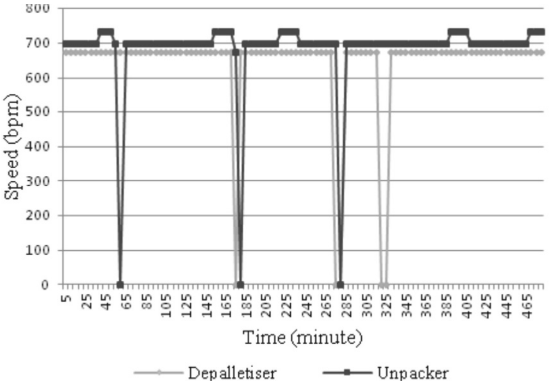


Fig. 21. Stops of depalletizer and unpacker machines for Scenario 4

Simulation results show that a reduction in the idle time was achieved for depalletizer machine and upstream equipments (see Fig. 21). Thus, a greater stability in the first equipment of the line is reached when some change is introduced in the feeding sector.

Moreover, an efficiency of 67.2 % (177462 bottles filled) was reported by the simulation runs. Thus, scenario 4 represents the best alternative to improve the efficiency of filling machine by reducing the idle time of this bottleneck equipment. In addition, a reduction in the number of equipment stops is observed with respect to scenario 2 (see Fig. 21).

4.2.5. Results for Scenario 5

This scenario evaluates the efficiency of the packaging line when the speed of conveyors located in the clean room is increased from 5% to 50%. Simulation results show that an important improvement in production level can be achieved when the conveyor speeds are increased by 25%. The performance of the bottleneck machine is shown in Fig. 22. From this picture, it follows that a growth in the stability of filling machines is achieved with regards to scenario 2 because the number of stops of this equipment is reduced. In addition, a high balance of bottles accumulated on the conveyor is observed (see Fig. 23). Consequently, the utilization rate of conveyors located between the inspector and filling machine is increased.

4.2.6. Evaluation of Results

Having analyzed the most relevant scenarios, the major performance indicators reported in each of them are summarized in Table V and Table VI. Therefore, it is possible concluding that

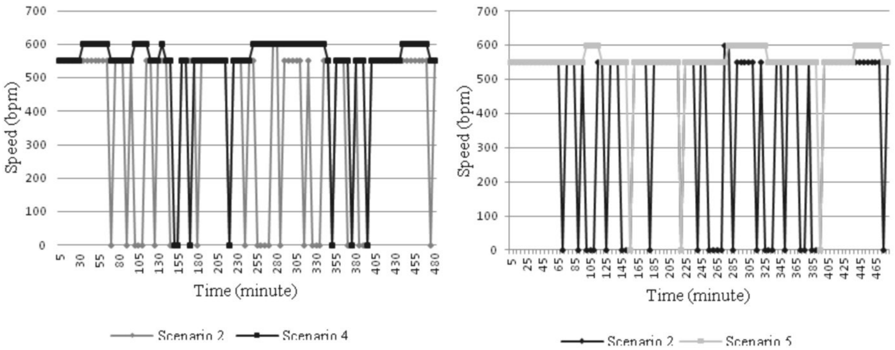


Fig. 22. Filling machine speeds for Scenario 5

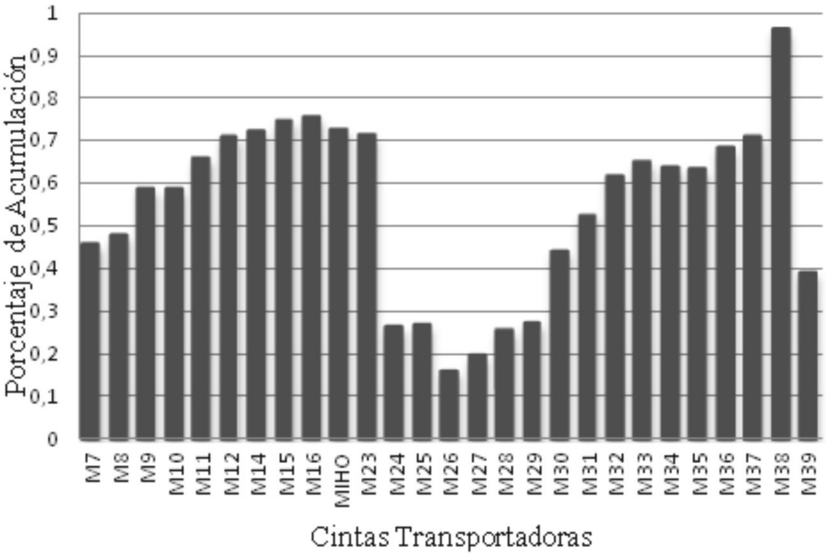


Fig. 23. Bottles accumulation on conveyors located in the clean room

Table V. Summary of scenario results

Scenario	Processed in filling bottles	Processed in bottles depalletizer	Processed in bottles Palletizer
1	165059	157200	151800
2	161375	160200	154200
3	161512	162000	155400
4	177462	178800	175200
5	206200	211200	204000

Table VI. Summary of efficiency indicators

Scenario	% Efficiency	% Effective Global Efficiency
1	66,8	61,4
2	61,1	58,4
3	61,2	58,9
4	67,2	66,4
5	78,1	77,3

scenario 5 achieves the highest level of efficiency in terms of the bottleneck resource and also the highest level of overall effective efficiency. This results in a remarkable increase in the production of a rolling line and the use of machines and transports.

From Table VI, it follows that the efficiency can be increased at least 11.3% by introducing the proposed changes in scenario 5 to the actual configuration of the packaging line. Such changes can be realized with minimum cost and the improvements in the operation of the line will provide the required return on investment.

5. Conclusions

In this paper, an innovative discrete event simulation modeling tool has been used to quantify the performance of the main packaging line of an international beer company located in Argentina. The work aims to evaluate alternative scenarios in order to determine potential changes in the line configuration to maximize production and efficiency.

As main results, it has been possible to determine that the efficiency of bottleneck asset, in this case the filling machine, and the holistic performance of the line can be improved by optimizing machine speeds and the use of accumulators. In addition, short stops primarily derived from simple causes can be reduced drastically by avoiding complex operations on the machines, although there are also small stalls that can only be removed using sophisticated methods of analysis and operations with high technical content.

According to simulation results, the productivity of the packaging line is affected mainly by modifying the logic of conveyors belts located in the feeding area and clean room. Moreover, the line is sensitive to changes in machine speeds, which are operating at a speed below the nominal speed.

It is worth to remark that for fixed values of speed and transport machines, no investment is needed by the company, because they have the materials and labor necessary for the modification of the same drivers. Moreover, the study remarks that not always increasing the efficiency ratio on a particular machine line, from the reduction of a kind of loss, produces an increased rate of holistic efficiency of the line. This is because the relationships and interactions in the real system are complex or some degree of uncertainty is present. The proposed model can be easily utilized and adapted to evaluate future changes in the operation and design of the main beer packaging line of the company. This work can also be modified to evaluate and improve the performance of beer packaging lines of other companies.

Acknowledments

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