

Discrete event simulation for resource programming: case of Ecuadorian textile industry

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Abstract

Much of the success of an organization is focused on making decisions in its operations function. Managing properly the men and machines that intervene in their transformation processes, becomes a real challenge in order to increase effectiveness. For this, the optimization based on discrete event simulation constitutes a tool of great potential by its capacity to minimize errors in decision making. The present work was proposed to demonstrate the strengths of these tools as support on decision making, for optimize the assignment of these resources in the productive processes with certain level of complexity and that guarantee a good performance of the system. For that, the Flexsim software was applied as discrete event simulator. The results are presented with the application to a case study related to a company producing socks and belonging to the textile sector of Imbabura province, Ecuador. The men and machines assignment is made by each of the sections and subsections that make up the limiting point of the production process, adjusted to the amounts determined in the Master Production Schedule for each type of socks, ensuring minimal total cost and good performance of the principal metrics in that operation.

Keywords

Optimization, discrete event simulation, resource assignment

1. Introduction

The advance of programming languages and commercial softwares have made simulation one of the most used techniques in Operations Research and Administration Sciences. Examples of this are its applications in inventory management (Goodsell & Kley, 2000), in the analysis and improvement of the supply chain (Chan, Tang, Lau, & Ip, 2002), in the analysis and validation of performance measures in manufacturing systems (O'Kane, 2004) and in applications of improvements through Six Sigma deployments (Mahanti & Antony, 2005), just to mention some of them. As a descriptive tool for Operations Research, it demonstrates its usefulness in the process of analyzing and designing complex systems in view of the need to study them to increase the understanding of the relationships between the various components, or to predict performance under new operating conditions (Law & Kelton, 2000). Another area of application is in production systems, among other reasons, because simulation proves to be useful in

estimating a new system design (Singh, 1991). In addition, it allows supporting the decisions of programming, sequencing, workloads, capacity planning and prediction of delivery times, and unlike many others, it does not consider cycle times as constants (Roy & Grinsted, 1986).

This case study belongs to the Ecuadorian productive sector, specifically, the textile sector of the Imbabura province. This factory produces socks for this market for more than 20 years and is considered the second largest in the country in terms of its production capacity. It is produced in batches, which vary between medium and large according to the product nomenclature. The orders of the clients are satisfied from the inventories, being a make to stock system (Schroeder, Meyer, & Rungtusanatham, 2011).

The process consists of five operations: forming, sewing, turning, ironing and labeling. Of these, the formed or weaving of the sock turned out to be the fundamental point operation and the bottleneck. It consists of 212 automated machines that add the greatest value to the product and work under conditions of high continuity, with a work regime of 24 hours a day, from Monday to Saturday and in two work shifts. The brands of these machines are Lonati, Sangiacomo and Conti and are grouped into five sections in correspondence with three compressed air generators. This layout allows, as the main objective, not to produce large variations in the power factor during the week, reducing the cost of production. The assignment of the amount of machines to be used during the week is done according to the amounts determined in the Master Production Schedules and according to the assortment of socks that will be produced. Human talent is assigned by subsections and consists of threaders and turners. The first are dedicated to address the breakdowns of the machines and the seconds to turn the stockings and manipulate them to the work in process area.

Some improvement opportunities were detected from interviews with experts and workers. It highlights the inefficient assignment of resources, both the quantities of machines to produce the different types of socks, and the number of workers to be assigned in the subsections; that they guarantee the quantities to produce according to those determined in the Master Production Schedules and at the minimum total cost. In addition, the lack of knowledge of the effective production capacity in the forming operation, both of the total operation, and by type of sock, which affects the elaboration of the Approximate Capacity Plan.

The modeling in Flexsim¹ of this operation was directed to the solution of these problems, with the purpose of adjusting the assignment of workers and machines to the quantities of socks to produce and determined in the Master Production Schedules, that guarantee the minimum total cost and a good performance of the system. For this purpose, this work is based on the model developed by Orozco Crespo & Hermoso Ayala (2017)².

2. Materials and methods

As a basis, the six-step methodology of Harrell (2011) was used, which led the development of the model from the definition of the objectives to the process of optimization and presentation of the results.

The objective of the simulation was aimed at optimization, fundamentally, for the model to identify possible alternatives for the assignment of workers and machines for the production of different types of socks, which satisfactorily comply with the Master Production Schedule (MPS) and which guarantees the minimum total cost.

The following decision variables were defined: number of threaders and turners to be used ($E_{i,j}$ and $V_{i,j}$); quantities of machines for the production of different types of socks ($M_{i,j,k}$). The combinations of these decision variables generated the possible scenarios in which the performance metrics of the model were measured from their dependent or response variables (table 1).

¹ Manufactured by Flexsim Software Products, Inc. and released in its version 1.0 in February 2003 (Flexsim Software Products, 2018). It was conceived to be the most sophisticated 3D package of discrete events. In this study version 7.7.4 of 2016 was used.

² In this model, the optimal combination of resources was determined to reach the maximum effective production capacity.

Table 1. Response variables

Specific objectives	Dependent variable	Denomination	UM
Determine the use of resources (workers and machines)	Average percentage utilization of the threaders	$UE_{i,j}$	(%)
	Average percentage utilization of the turners	$UV_{i,j}$	(%)
	Average percentage of processing of the machines	P_k	(%)
Analyze the causes that affect the performance in the operation, both those related to the machinery, as well as the continuity of displacement of the items.	General average percentage of breakdowns of the machines	B	(%)
	General average of the percentage of waits of the machines by the threaders to attend the breakdowns	WOM	(%)
	General average of the percentage of waits to the turners for the transport of the socks	WO	(%)
	General average of the percentage of waits to the turners for the transport to the production area in process	WT	(%)
Determine the total units produced according to their type	Total of dozens produced in a week	T_k	(doz/sem)
	Performance of the operation according to the type of sock	R_k	(doz/min)

Where:

i : work sections (a, b, c, d and e)

j : work subsections in which some of the work sections are divided (1 and 2)

k : type of sock (1, 2, 3, ... and 21)

The model follows the logic shown in Figure 1, which is related to its programming. The first phase was aimed at analyzing the feasibility of the MPS, to determine if there is sufficient capacity to face the volume of production proposed by the plan for each of the items in the week planned (I). This process follows a similar logic to that proposed in Krajewski, Ritzman, & Malhotra (2008) for the preparing this plan and has as main inputs the Aggregate Production Plan and the MPS. If resources are not available to face the volume of production that is planned, adjustments must be made to the Production Aggregate Plan, after consulting the rest of the factory areas or, as a last alternative, reprogramming machines for those items with capacity deficit, which is not part of the model since it was assumed excess capacity of the factory given the sales of recent years. Otherwise, the authorized MPS is obtained on which the model will work and which constitutes the fundamental input for the next phase.

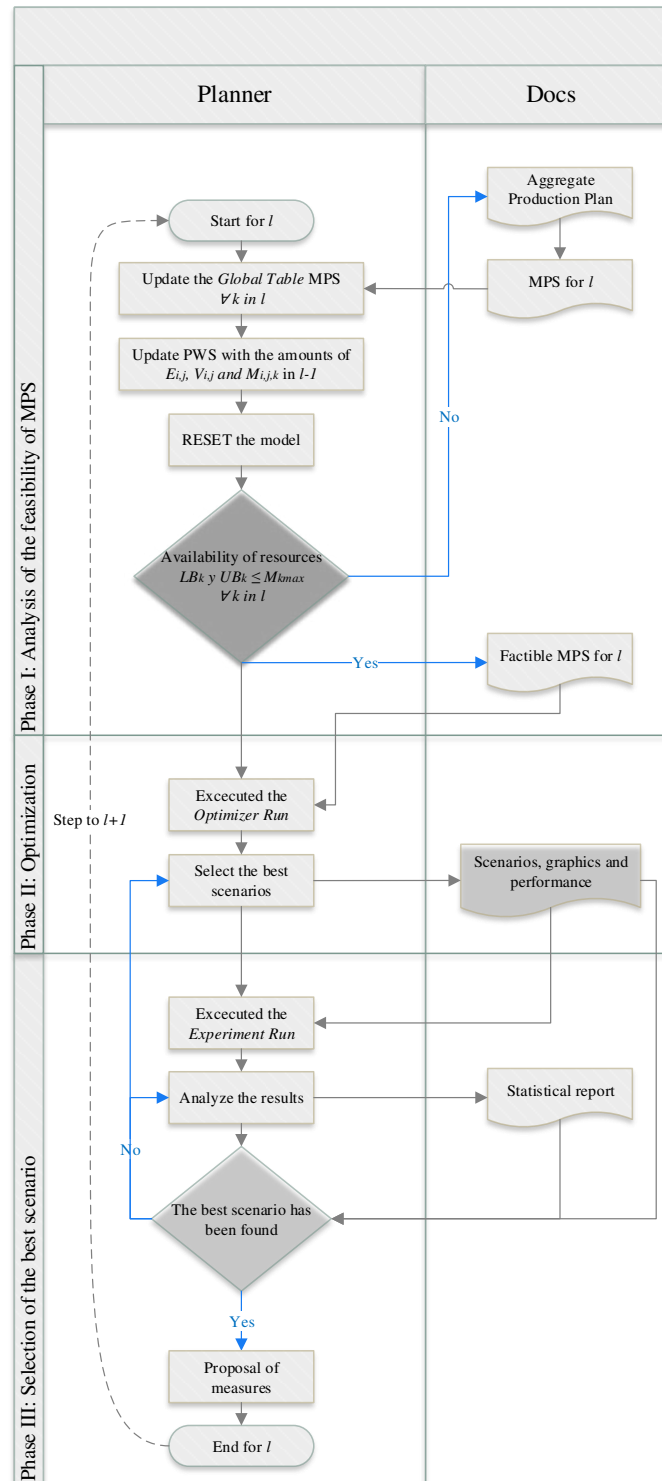


Figure 1. Model logic

In the optimization phase, the solutions obtained through the Optimizer Run are analyzed and feasible solutions are selected that minimize the total costs and that have high levels of compliance with the production plan. After this analysis, the graphical and numerical results of all the response variables and the objective function were exported. All with the options Export Selected Scenarios, Export Screenshot and Export as CSV of the Optimizer Run.

In the third phase, the Experiment Run was executed for the Previous Week Scenario (PWS) and those selected in Phase II for the current week. Subsequently, the response variables were analyzed from their mean values, standard deviations and confidence intervals for a 95% confidence level. The scenarios were compared with each other and with respect to PWS, until finding the best scenario for the week that is planned. After which, the pertinent measures are taken referring to the adjustments of machines, the relocations of the workers in the work subsections or other productive areas within the factory. As another result of this phase, the statistical report that was generated in the Experiment Run/View Results was obtained.

2.1 Brief description of the model's programming

The data collection was divided into two categories: numerical and structural. The first ones were related to the data collection and statistical analysis through the use of the Experfit tool. The seconds defined the elements of the system, such as: machines, boxes for production in process, workers and the layout of the operation.

The following were considered as input variables: four different types of breakdowns for the machines, the sock forming time according to the model of the machine, the turning times of the dozens, the speed of movement of the workers, the times of loads and discharges of workers in the internal manipulation of the dozens of socks and the times associated with the work regime. The defectiveness percentages were added according to the type of machine. Sources, processors, queues, combiners, sinks, task executors and dispatchers were added, which resulted in the top view of the operation (figure 2); as well as, functionalities for breakdowns, task sequences, routings and the labor regime through time tables.

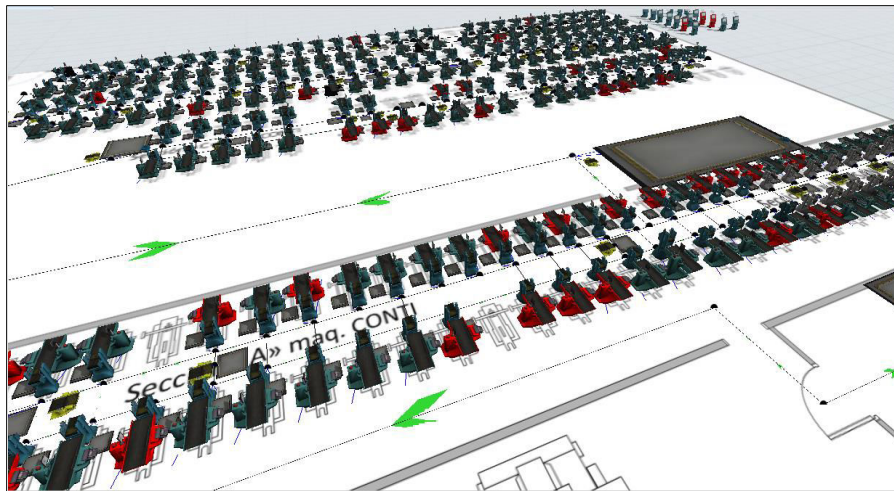


Figure 2. Top view of the model

To follow the logic of the flow diagram of Figure 1, the global table called MPS was designed, which decreases the search range of solutions for the number of total machines to be assigned for the production of the different types of socks and to contribute to the speed in obtaining the results in the optimization (figure 3).

MPS	Start MPS	Maximum production capacity	LB	UB	Max Machines
COL1012	676.00	1887.00	8.00	11.00	27.00
COL0810	1040.00	2383.00	11.00	14.00	30.00
COL0608	443.00	1148.00	4.00	5.00	12.00
COL0406	552.00	1264.00	4.00	6.00	12.00
COL0204	61.00	146.00	1.00	1.00	1.00
COR1012	396.00	870.00	5.00	7.00	11.00
COR0810	146.00	360.00	1.00	2.00	4.00
COR0608	211.00	510.00	2.00	3.00	6.00
COR0204	224.00	540.00	1.00	2.00	4.00
COR0002	98.00	180.00	1.00	1.00	1.00
LAR1012	75.00	316.00	1.00	2.00	5.00
ZAP1012	367.00	846.00	3.00	5.00	14.00
CORPO1012	864.00	2265.00	3.00	4.00	10.00
CORPO0608	387.00	1075.00	1.00	2.00	4.00
MED TEC	8.00	40.00	1.00	1.00	1.00
CORALG1012	3115.00	6944.00	10.00	13.00	35.00
CORALG0810	319.00	666.00	1.00	2.00	3.00
LARPO1012	551.00	1407.00	2.00	4.00	8.00
ZAPPO1012	386.00	960.00	1.00	2.00	4.00
ZAPPO0608	356.00	977.00	1.00	2.00	4.00
MED HOM	419.00	1036.00	5.00	7.00	16.00

Figure 3. Global table MPS

The first column is entered manually by the production planner on the basis of the MPS and before the start of the work week, measured in a dozen/week. The second corresponds to the maximum effective production capacity of the operation, measured in a dozen/week. The third and fourth columns are limits within which the software will search for the optimal number of machines to be assigned (Lower Bound and Upper Bound). The Lower Bound and Upper Bound are determined for efficiencies of 100% and 85%, respectively, given the characteristics of high continuity of the operation. The fifth column is the number of machines that, at most, can be used for the production of one type of sock and corresponds to those that are currently programmed for such purposes according to the Production Aggregate Plan. When RESET the model, the Lower Bound and Upper Bound values of the third and fourth columns are automatically updated.

Next, the amounts of resources that were actually used in PWS are updated, that is, the values that the decision variables took in the previous week and that could have resulted from previous optimization processes or adjusted decisions by operations. This is executed in the Experimenter / Scenarios in the PWS column (figure 4).

Simulation Experiment Control		
Scenarios Performance Measures Experiment Run Optimizer Design Optimizer Run Optimizer Results Advanced ?		
Variables	Scenarios	None
Variable	PWS	
SCL THREADERS	Nr TEs in Team /D Enebrador CL	1.00
SC TURNER	Nr TEs in Team /D Virador C	2.00
SA THREADERS	Nr TEs in Team /D Enebrador A	3.00
SA TURNER	Nr TEs in Team /D Virador A	2.00
SB THREADERS	Nr TEs in Team /D Enebrador B	2.00
SB1 TURNER	Nr TEs in Team /D Virador B1	1.00
SB2 TURNER	Nr TEs in Team /D Virador B2	1.00
MACH COL 1012 E1	Nr Objects in COL_1012_E1	3.00
MACH COL 1012 E2	Nr Objects in COL_1012_E2	11.00
MACH COL 1012 D2	Nr Objects in COL_1012_D2	3.00
MACH COL 0810 E1	Nr Objects in COL_0810_E1	10.00
MACH COL 0810 E2	Nr Objects in COL_0810_E2	6.00
MACH COL 0810 D1	Nr Objects in COL_0810_D1	1.00
MACH COL 0810 D2	Nr Objects in COL_0810_D2	1.00

Figure 4. Previous Week Scenario (summarized)

This allowed comparing the new scenarios with each other and in turn comparing them with PWS when running the Experiment Run. In addition, to detect the machines adjustments that are needed, as well as, the relocations of the workers in other subsections of work or other productive areas within the factory. The Optimizer Design was developed as shown in figure 5.

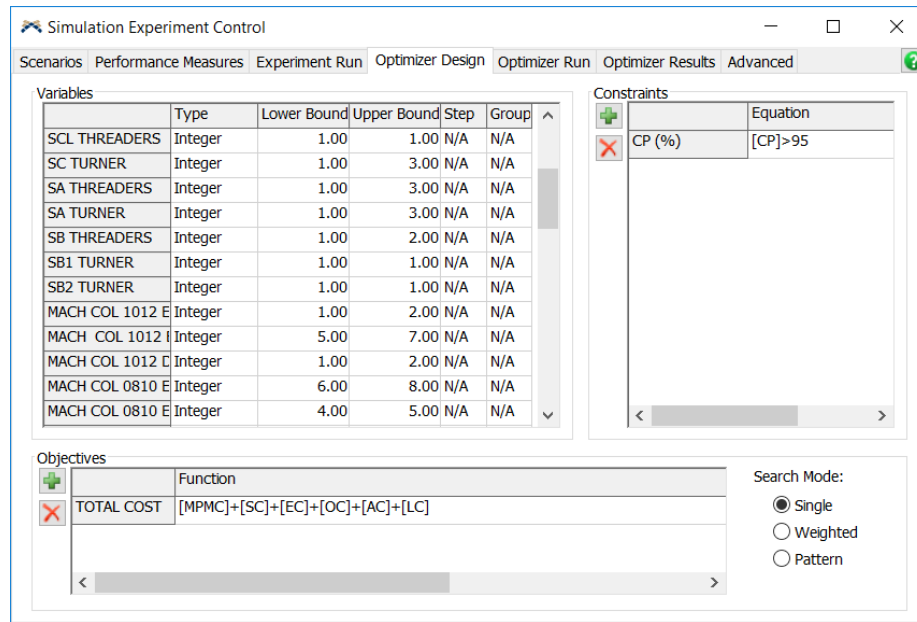


Figure 5. Design of the optimization model (summarized)

It was proposed as a restriction to the model that the fulfillment of the production plan was always above 95% (CP), according to the objectives of the factory. This value gave the possibility of visualizing as feasible solutions all those that complied with this restriction. The objective function was aimed at minimizing the total costs (\$/week).

Minimize

$$TC_e = FC_e + AC_e + LC_e$$

$$TC_e = MPMC_e + SC_e + EC_e + OC_e + AC_e + LC_e$$

Where:

TC_e : total cost of the alternative or scenario e

FC_e : costs associated with manufacturing and which included expenses for raw materials and materials ($MPMC_e$), workers' salaries (SC_e), energy consumption of machines (EC_e) and other fixed costs such as were the depreciation of the machinery (OC_e)

AC_e : approximate costs for production in process

LC_e : adjustment cost of the machines

The Optimizer Run was run for a week of work (442 800 seconds) and for a maximum of 100 solutions to be evaluated.

3. Results

Results of the feasibility analysis of the MPS

For the presentation of the results were selected the last week of the month of May and the next first of the month of June of 2017, which were considered as PWS ($I-1$) and as the week that is planned (I), respectively. The amounts corresponding to the MPS for both weeks are shown in table 2.

Table 2. Amounts planned in MPS

<i>k</i>	Start of MPS (dozens)	
	<i>l-1</i> (PWS)	<i>l</i>
1	1089	676
2	1352	1040
3	483	443
4	721	552
5	100	61
6	566	396
7	194	146
8	259	211
9	327	224
10	96	98
11	198	75
12	514	367
13	1095	864
14	684	387
15	21	8
16	4164	3115
17	393	319
18	997	551
19	620	386
20	587	356
21	453	419

This selection responded, on the one hand, to the fact that both weeks belong to different months planned in the Aggregate Production Plan, and on the other hand, to the decrease of the dozens to were produced for all the items. This last reason inferred from the beginning the decrease in total resources to be used for compliance with the plan. From this analysis it was obtained that the quantities to be produced in *l* are less than the maximum effective capacity of the operation for each of the types of items (figure 3). To this was added that the quantities of machines determined in the Lower and Upper Bound were less than or equal to the maximum number of machines that are programmed according to the Aggregate Production Plan. Given these results, feasible master plans were obtained, validated by their approximate capacity plans.

Results of optimization

The behavior of costs, compliance with the plan and performance of the scenarios that were evaluated by the Experimenter are described in figure 6. Solutions 92, 90, 99, 100 and 63 were selected because they minimized the CT and keep CP values above 95% (table 3).

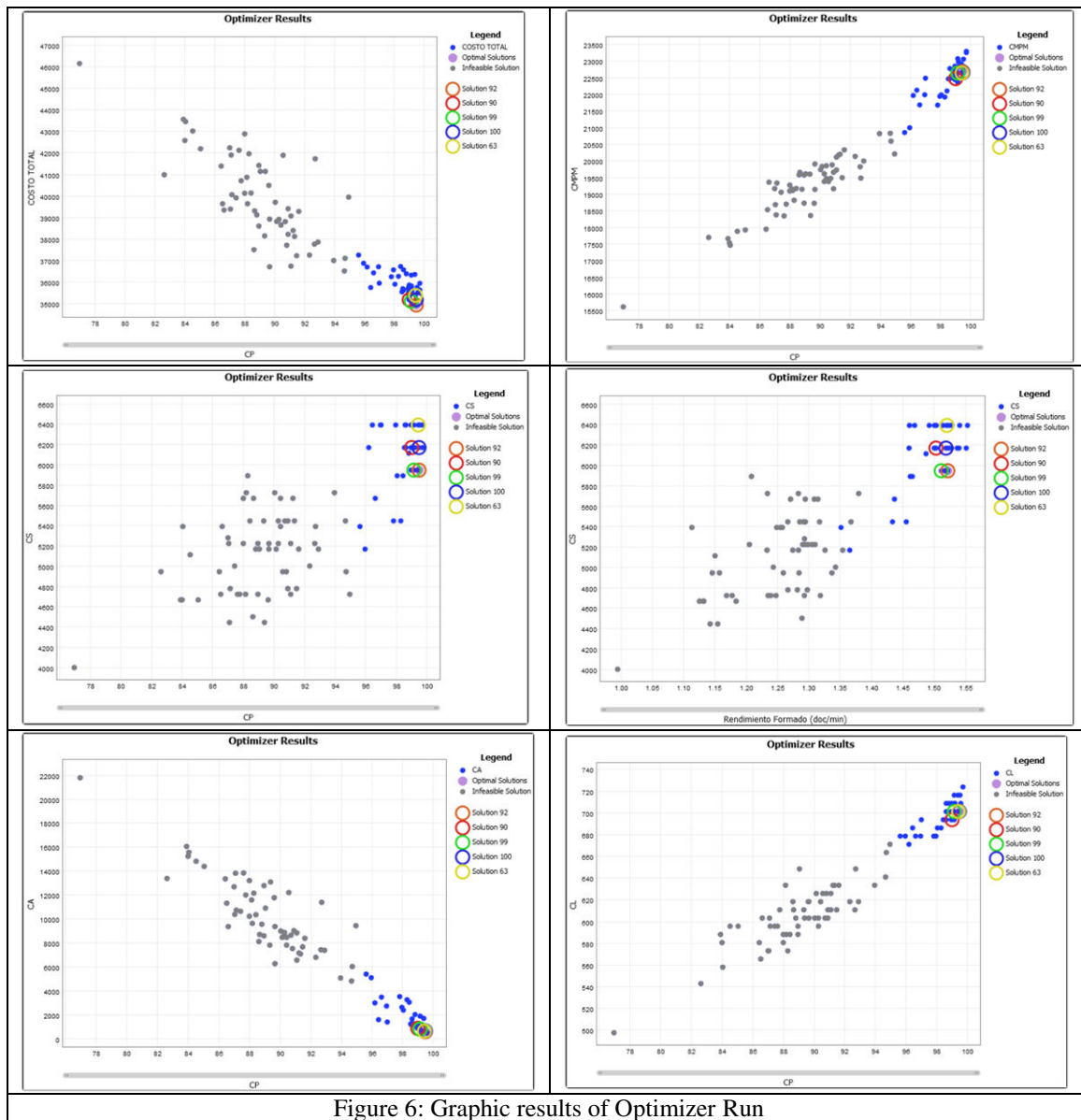


Figure 6: Graphic results of Optimizer Run

Table 3. Summary of cost results for the selected scenarios

Solution	TC (\$/week)	CP (%)	MPMC	SC	EC	OC	AC	LC	R (doz/min)
PWS	44372.54	98.76	29949.96	5946.58	3738.66	2330.5	1434.184	972.66	2.00
92	34941.52	99.48	22680.56	5946.58	2689.98	2330.50	592.68	701.22	1.52
99	35114.73	99.14	22636.64	5946.58	2689.98	2330.50	809.81	701.22	1.51
90	35192.44	99.00	22471.44	6168.88	2659.94	2330.50	868.00	693.68	1.50
100	35192.55	99.48	22642.92	6168.88	2689.98	2330.50	659.05	701.22	1.52
63	35394.92	99.43	22640.54	6391.18	2689.98	2330.50	641.50	701.22	1.52

These solutions decreased their costs with respect to PWS, due to the decrease in the quantities to were produced to a week to another. Among them they obtained similar results in terms of MPMC, EC and OC, since they produced similar quantities of dozens, so they spent similarly on raw materials and materials, used approximately the same amount of equipments and depreciated equal. In addition, they obtained CP levels above 99% and similar levels of performance.

The costs that determined the difference were the SC and the AC. Solutions 92 and 99 employed fewer workers to be able to comply with the plan, while solution 63 required the largest number of workers. These differences did not have a significant impact on the performance of the operation. Solution 92 turned out to be the one with the lowest storage cost since it managed to better balance inventory costs and lost sales due to excess or deficit, respectively; not the case of solutions 90 and 99 that obtained the worst results in this regard due to their lower levels of compliance with the production plan. The following solutions stood out as the best candidates, in order of priority according to the TC:

- Solution 92 with a minimum TC of \$ 34941.52 and with the highest CP level of 99.48%.
- Solution 90. Even though this solution obtained the lowest CP value with 99%, it turned out to be the lowest LC of all the solutions; and, therefore, it was the one that guaranteed fewer machines adjustments with respect to PWS.
- Solution 100 as the fourth best regarding TC and with the same CP level as solution 92.

The solutions 99 and 63 were discarded. The first one because it was similar to solution 92 but with a lower CP value. The second because it was the worst result in terms of TC.

The selected solutions indicated the same number of total workers with respect to PWS, from which a decrease in the use of these resources was inferred if it takes into account that the amounts declared in the MPS from one week to the next decreased. The number of threaders was the same for all combinations of (i,j) , whereas the turners varied for (d,l) and (c,l) (table 4).

Table 4. Results of the decision variables

Decision variables	PWS	Sol. 92	Sol. 90	Sol. 100	Decision variables	PWS	Sol. 92	Sol. 90	Sol. 100
$E_{e,1}$	1	1	1	1	$M_{d,1,4}$	7	5	5	5
$E_{e,2}$	1	1	1	1	$M_{d,1,5}$	1	1	1	1
$E_{d,1}$	1	1	1	1	$M_{d,1,6}$	2	2	2	2
$E_{d,2}$	1	1	1	1	$M_{c,2,6}$	1	1	1	1
$E_{cc,1}$	1	1	1	1	$M_{d,2,6}$	6	4	4	4
$E_{cl,1}$	1	1	1	1	$M_{vi,vj,6}$	9	7	7	7
$E_{a,1}$	3	3	3	3	$M_{d,1,7}$	3	2	2	2
$E_{b,1}$	2	2	2	2	$M_{d,2,8}$	1	1	1	1
Total E	11	11	11	11	$M_{c,2,8}$	3	2	2	2
$V_{e,1}$	2	2	2	2	$M_{vi,vj,8}$	4	3	3	3
$V_{e,2}$	1	1	1	1	$M_{c,2,9}$	3	2	2	2
$V_{d,1}$	3	2	3	3	$M_{c,2,10}$	1	1	1	1
$V_{d,2}$	1	1	1	1	$M_{d,2,11}$	4	2	2	2
$V_{c,1}$	2	3	3	3	$M_{c,2,12}$	7	5	5	5
$V_{a,1}$	2	2	2	2	$M_{c,1,13}$	5	4	4	4
$V_{b,1}$	1	1	1	1	$M_{b,1,14}$	2	2	2	2
$V_{b,2}$	1	1	1	1	$M_{c,2,15}$	1	1	1	1
Total V	13	13	14	14	$M_{a,1,16}$	8	6	6	6
Total	24	24	25	25	$M_{a,2,16}$	10	7	7	7
$M_{e,1,1}$	3	2	2	2	$M_{vi,vj,16}$	18	13	13	13
$M_{e,2,1}$	11	6	6	6	$M_{a,1,17}$	2	2	2	2
$M_{d,2,1}$	3	2	2	2	$M_{b,1,18}$	6	4	3	4
$M_{vi,vj,1}$	17	10	10	10	$M_{b,1,19}$	2	1	1	1
$M_{e,1,2}$	10	7	7	7	$M_{b,2,19}$	2	1	1	1
$M_{e,2,2}$	6	5	5	5	$M_{vi,vj,19}$	4	2	2	2
$M_{d,1,2}$	1	1	1	1	$M_{b,1,20}$	2	2	2	2
$M_{d,2,2}$	1	0	0	0	$M_{d,1,21}$	5	4	4	4
$M_{vi,vj,2}$	18	13	13	13	$M_{d,2,21}$	3	3	3	3
$M_{e,1,3}$	4	3	3	3	$M_{vi,vj,21}$	8	7	7	7
$M_{d,1,3}$	3	2	2	2	Total M	129	93	92	93

$M_{\forall i, \forall j, 3}$	7	5	5	5
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The total quantities of equipment to were used decreased with respect to PWS, which is logical by decreasing the quantities were planned. In this sense, $M_{e,2,1}$, $M_{c,2,12}$, $M_{a,2,16}$ and $M_{b,1,18}$ were the most significance.

Description of response variables

The results of the response variables are shown in tables 5 and 6. With respect to PWS, the use of workers decreased, except for $(d,1)$ in the solution 92. Among them, the solutions behaved similarly in average values and showed good stability by having standard deviations that did not exceed 2% of variability. The utilization of the threaders in $(e, 2)$ and $(c, 1)$ and of the turners in $(e, 1)$ and in $(d, 1)$ stood out with worse results. Sections a and b were those that best employed their workers with values close to or greater than 80% utilization. The use of the machines improved with respect to PWS and among them they behaved similarly with values above 85%.

Table 5. Numerical results of the use of threaders and turners

Var.	UM	PWS		Sol. 92		Sol. 90		Sol. 100	
		\bar{X}	s	\bar{X}	s	\bar{X}	s	\bar{X}	s
UE_{e1}	%	83.16	0.87	68.41	0.52	68.60	0.77	68.68	0.47
UE_{e2}	%	78.45	0.79	63.46	0.53	62.96	0.66	62.57	0.70
UE_{d1}	%	85.89	0.50	74.68	0.35	74.65	0.88	74.29	0.61
UE_{d2}	%	89.94	0.99	78.23	0.53	78.54	0.96	78.52	0.96
UE_{c1}	%	65.82	0.57	59.40	0.66	59.68	0.63	59.14	0.57
UE_{c2}	%	87.01	0.55	71.83	1.27	71.91	0.55	71.73	0.63
UE_a	%	98.53	0.54	88.95	0.44	89.08	0.56	88.83	0.70
UE_b	%	93.20	0.55	81.03	1.02	77.85	0.57	81.19	0.47
UE	%	85.25	1.96	73.25	2.06	72.91	2.02	73.12	1.85
UV_{e1}	%	69.05	0.98	63.30	0.84	63.39	0.53	63.54	0.77
UV_{e2}	%	86.61	0.17	72.96	0.15	73.07	0.10	73.06	0.10
UV_{d1}	%	62.10	0.54	65.72	0.49	58.33	0.99	58.58	1.17
UV_{d2}	%	83.67	0.22	76.26	0.11	76.27	0.18	76.29	0.19
UV_{c1}	%	95.11	0.42	69.20	0.49	69.44	0.72	68.95	0.69
UV_a	%	93.02	0.27	81.74	0.48	81.75	0.23	81.78	0.21
UV_{b1}	%	94.10	0.40	87.64	0.21	87.85	0.29	87.56	0.30
UV_{b2}	%	86.72	0.32	70.78	0.22	66.26	0.14	70.66	0.22
UV	%	83.80	1.36	73.45	1.24	72.05	1.41	72.55	1.63

Table 6. Numerical results of the use of machines

Var.	UM	PWS		Sol. 92		Sol. 90		Sol. 100	
		\bar{X}	s	\bar{X}	s	\bar{X}	s	\bar{X}	s
P_1	%	84.33	0.36	87.60	0.29	87.59	0.53	87.67	0.34
P_2	%	84.32	0.30	87.46	0.30	87.53	0.38	87.66	0.34
P_3	%	84.45	0.54	87.47	0.31	87.30	0.41	87.76	0.53
P_4	%	84.10	0.37	86.94	0.31	86.94	0.25	87.13	0.32
P_5	%	84.07	0.58	86.94	0.62	87.02	0.66	86.88	0.64
P_6	%	84.55	0.49	87.34	0.24	87.49	0.32	87.53	0.46
P_7	%	84.05	0.52	86.81	0.48	86.95	0.30	87.14	0.57
P_8	%	85.01	0.24	88.00	0.42	87.89	0.32	87.87	0.46
P_9	%	87.09	0.38	89.57	0.33	89.86	0.28	89.64	0.37
P_{10}	%	87.17	0.66	89.67	0.39	89.70	0.35	89.81	0.56
P_{11}	%	82.59	0.58	85.92	0.44	86.06	0.33	86.37	0.49
P_{12}	%	87.23	0.34	89.94	0.39	89.90	0.21	89.97	0.20
P_{13}	%	81.52	0.47	83.36	0.52	83.06	0.43	83.46	0.26
P_{14}	%	82.02	0.58	84.80	0.45	85.41	0.46	84.79	0.43
P_{15}	%	87.01	0.66	89.54	0.32	89.66	0.43	89.85	0.53
P_{16}	%	84.13	0.51	85.78	0.39	85.96	0.24	85.85	0.32
P_{17}	%	84.10	0.33	85.93	0.23	85.98	0.39	85.93	0.28
P_{18}	%	82.17	0.45	85.00	0.31	85.37	0.32	84.84	0.27
P_{19}	%	82.17	0.43	84.84	0.27	85.40	0.30	84.75	0.32
P_{20}	%	81.85	0.64	84.59	0.31	85.17	0.43	84.54	0.43
P_{21}	%	82.85	0.57	86.11	0.30	86.12	0.56	86.29	0.52
P	%	84.13	2.25	86.84	1.72	86.97	1.80	86.94	1.96

Of the solutions analyzed, solution 92 stood out with relative better results, with an average utilization of 73.25% and 73.45% for threaders and turners, respectively. In addition, with a machines utilization of 86.84%, determined by a 4.70% (5.78 hours) of breakdowns (B variable) and an 8.46% (10.41 hours) of waiting for the threaders to attend said breakdowns (WOM variable).

Other causes that affected performance; and therefore, the movement continuity of the items, were the waits for the turners, whether for the hauling of the stockings (WO variable), or for the transportation of the dozens throughout the entire operation (WT variable), with 5.42% (6.67 hours) and 5.94% (7.31 hours), respectively. In addition, for this solution, the production plan was met above 95% and 100% was reached in most cases.

4. Discussion

The decrease in the quantities to be produced from one week to another conditioned the measures to be taken in the assignment of resources. The following measures were suggested to move from to week PWS ($l-1$) to the week analyzed (l):

- Implement solution 92 for having achieved lower total cost and higher compliance of the plan and throughput. In addition, it achieved better results in the use of human resources and machines.
- Maintain the same number of workers with respect to PWS, both for threaders and for turners, with the exception of relocating a turner from ($d,1$) to ($c,1$).
- Control the use of the workers in those subsections with the worst results (threaders in ($e, 2$) and ($c, 1$) and turners in ($e, 1$) and ($d, 1$)), which can collaborate in the work with the subsections a and b or with other areas of the factory.
- Decrease the quantities of machines destined to the productions of the different types of items, that is, preserve them transiently and according to the results obtained in table 4.

5. Conclusions

In this work, the optimization, based on the simulation of discrete events, is integrated with the assignment of human resources and machines in the productive systems, which demonstrates the potential of these tool in decision making. When applying the logic of the model, together with its programmed functionalities, it is evident the obtain of a feasible Production Master Plan and adjusted to the existing resources in the operation of bottleneck, which is executed at a minimum total cost, with high levels of compliance with the plan and with a good use of the production factors available. In addition, this logic allows identifying the best scenarios in which workers must be assigned to each of the sections and subsections of work, as well as, the machines assignment for each type of sock to produce.

The solution 92 is selected as the best alternative for the planned week with a minimum total cost of \$ 34941.52, a plan compliance of 99.48% and a throughput of 1.52 dozen/minute; accompanied by uses of 73.25%, 73.45% and 86.84% for threaders, turners and machines, respectively.

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