PRODUCTION CAPACITY AND INVESTMENT POLICY FOR A MANUFACTURING COMPANY USING SIMULATION AND INTEGER PROGRAMMING

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ABSTRACT
In this paper we constructed a simulation model to determine production capacity in a manufacturing company. The main objective was to define a range of expected production for a particular footwear model. This information was necessary to ensure that the factory was able to meet the new costumers demand prior to set an agreement with bigger orders. The results confirmed that the factory did have sufficient capacity for these new orders; nonetheless the time dedicated to produce other orders was quite narrow. We also detected the need for increasing production capacity; therefore an integer program was constructed in order to explore two goals: 1) Maximize production given a fixed investment budget, and 2) Minimize the investment cost to obtain a certain production. The results of the integer program were tested in the simulation model to obtain new production capacity.

Keywords: production capacity, simulation, integer programming, investment policy

1. INTRODUCTION
Simulation has been used as a tool to explore complex systems due to its capacity to incorporate elements with stochastic behavior and logical interactions between them.

Production systems are exposed to many and different inputs, each of them have an impact in the overall outcome; therefore simulation technique may be useful to generate information that allows us to describe and predict the behavior of the production system, and moreover, generate insights for decision-making.

The company studied belongs to the leather and footwear sector. It had had a wide spectrum of product mix; nevertheless due to commercial reasons, the company decided to focus on footwear products.

Before addressing costumers with bigger orders, it decided to determine its production capacity if the whole factory were dedicated to shoe-manufacturing. Therefore, the research question was: How many shoes can be produced by the factory given current conditions?

Simulation was selected because of the reasons given above and because of the flexibility for adding relevant elements and for integrating or disintegrating objects attributes. In Figure 1 we show a picture of the footwear product.

Figure 1. Picture of One Product

2. LITERATURE REVIEW
There are analytical formulations for production process that optimize certain attributes of the system (e.g. maximize production, minimize total cost), these formulations give an optimal or almost optimal solution (Pinedo 2005); nonetheless they are very time-consuming and impractical for real world problems, therefore different approaches have been tried such as network modeling, simulation, and hybrid approaches.

Network formulations can easily grow fast with the addition of elements and become impractical (Argoneto 2008).

Carvalho et al. (2012) used simulation to analyze different scenarios for a three-echelon supply chain and improve the overall system. Heilala (2008) constructed a simulation model to design a sustainable manufacturing system while optimizing different subsystems.

Lee et al. (2002a) tried an analytical-simulation approach; the simulation model is used to deal with operation times. Lee et al. (2002b) also combined discrete and continuous simulation models to represent the supply chain.

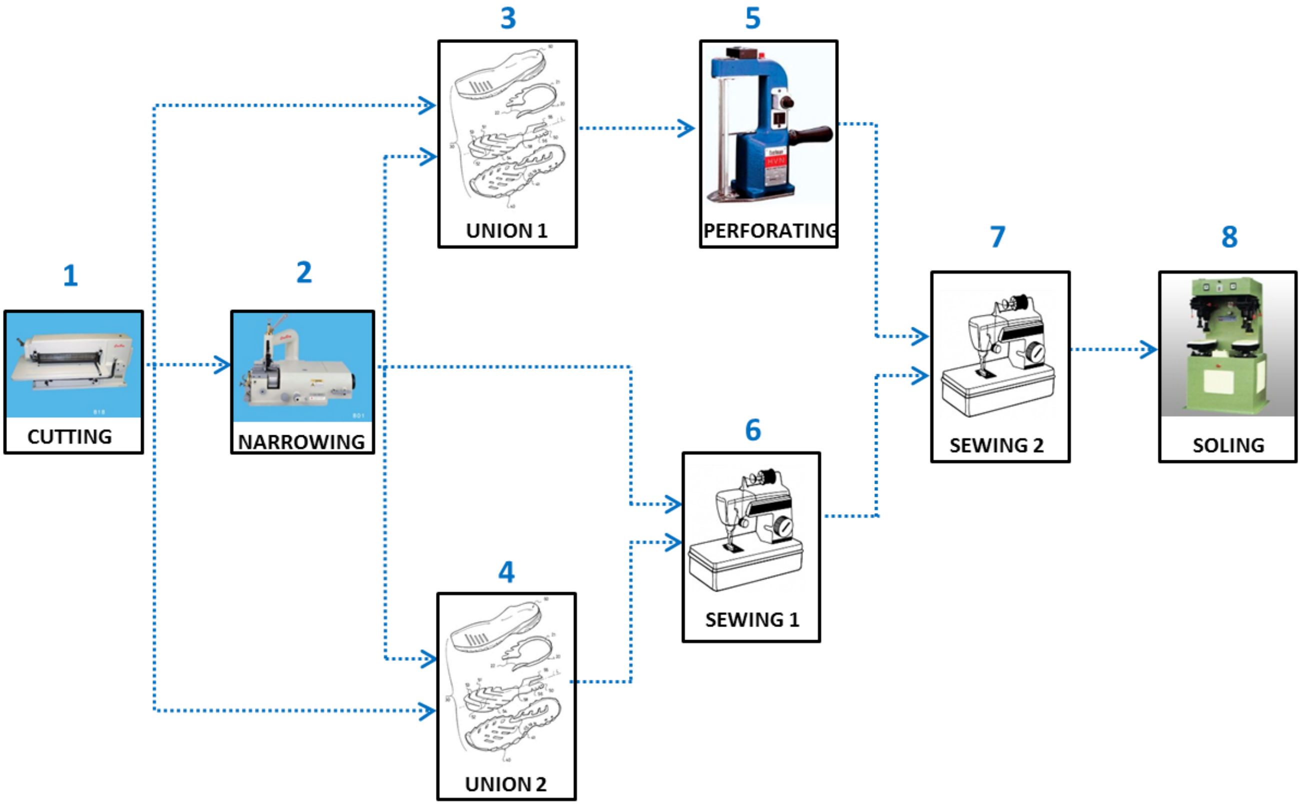


Figure 2. Shoe-Manufacturing Process

3. MANUFACTURING PROCESS

The shoe-manufacturing process is shown in Figure 2.

3.1 Cutting (Op. 1)

Raw material consists of three different kinds of leather: lamb, pork, and veal. All of them pass through the cutter machine where standard molds produce pieces of different sizes and colors.

3.2 Narrowing (Op. 2)

Pieces from lamb leather must have the same thickness; therefore they are process by the narrower machine.

3.3 Union 1 (Op. 3)

Here the insole pieces from different leathers are attached into one.

3.4 Union 2 (Op. 4)

In this operation an attachment is performed between pieces that will be located in the upper part of the shoe.

3.5 Perforating (Op. 5)

The pieces from operation 3 are perforated along the edge to guide the next sewing operation. This is made by a hammer machine.

3.6 Sewing 1 (Op. 6)

A first sewing is performed by a sewing machine to keep the pieces all together.

3.7 Sewing 2 (Op. 7)

The second sewing is performed to give the shoe a hand-made artistic appearance.

3.8 Shoe soling (Op. 8)

Finally plastic or leather soling sheets are attached to the piece from operation 7. This machine processes groups of exactly three shoes; once it finishes with one group then receives another. So the production is always a multiple of 3.

3.9 Times

Times associated with operations are shown in Table 1; they depend on the size of the shoe and the skills of the worker. The table shows the minimum, mode and maximum of the data.

The first operation has different times depending on the raw material type. Pieces *b*, *c*, *d* are from the lamb leather, and *a*, *d* are from pork and veal respectively.

Table 1. Operation Times

Operation	Name	Time (minutes)		
		Min	Mode	Max
1.*a*	Cutting *a*	2	2.5	4
1.*b*	Cutting *b*	2	2.5	4
1.*c*	Cutting *c*	1	1	1
1.*d*	Cutting *d*	2	3	4
1.*e*	Cutting *e*	2.5	3	4.5
2	Narrowing	1	1.5	2
3	Union 1	4	5.5	7
4	Union 2	2.5	3.5	6
5	Perforating	4	5	6
6	Sewing 1	3	3.5	4
7	Sewing 2	6	7	9
8	Shoe soling	20	20	20

4. SIMULATION MODEL

4.1 Data collecting

Operation and transport times were taken. Triangular distributions were selected to model operation times; Kolmogorov-Smirnov and Anderson-Darling tests were applied to ensure its vality. We consider transport times as negligible.

4.2 Assumptions

1. Shoe manufacturing was the only type of production consider. Other products were discarded.
2. Different sizes and colors were modeled by the probability distribution functions of each machine.
3. Transport times between operations were negligible.
4. There were always sufficient raw materials for production.
5. Machines are always operational.

4.3 Software

Simio Simulation Software was selected to carry out the simulation due to its robustness and the flexibility to represent industrial environment.

4.4 Model

Operations were represented with objects from Simio library, and data tables and add-in processes were used.

Simulation runs started with no semi-finished product. We show a schematic procedure of the simulation in Figure 3, operations are shown with rectangles.

4.5 Results

A total of 2500 replications were made, the results of the model allowed us to calculate the Expected Weekly Production and a Confidence Interval of size 96%. This is shown in table 2.

Table 2. Simulation Weekly Production

Mean	Standard deviation	Min	Max	Confidence interval 96%
124	15.75	102	147	[111, 135]

The distribution of the production is shown in figure 4. The results are multiple of 3 because of the last machine constraint commented above.

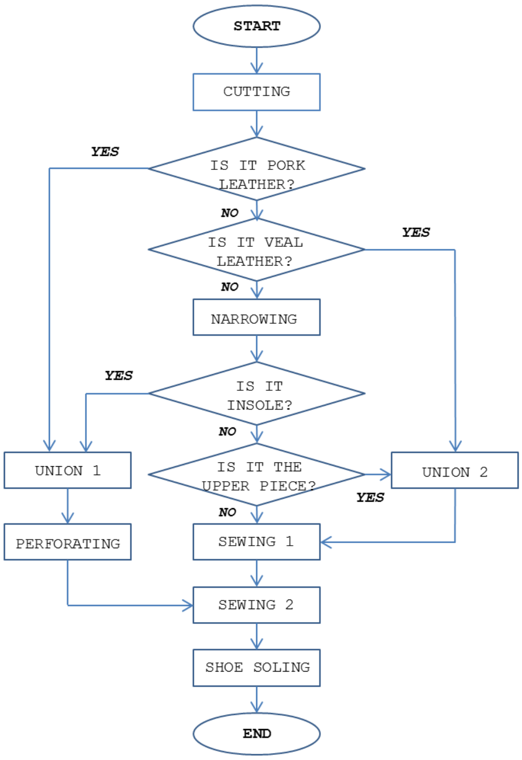


Figure 3. General Simulation Diagram

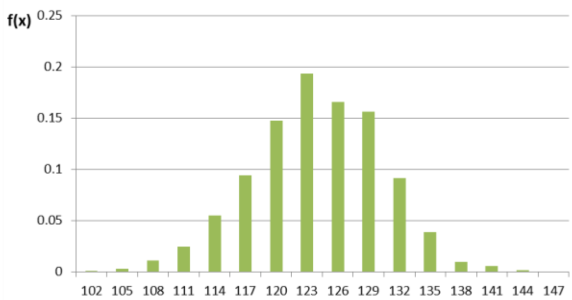


Figure 4. Weekly Production Distribution

To ensure the validity of the model and the results, we took the daily production of one month and tested a statistical hypothesis to determine whether population mean was different from the one obtained from simulation. We concluded that the data analyzed did not provide any information for supporting the statement that they were different.

5. INTEGER PROGRAM

We constructed an integer program to study two goals: 1) Maximize production given a fixed investment budget, and 2) Minimize the investment cost to obtain a certain production. Moreover, the integer program also balances the production line, so a measure of efficiency can be decided.

We only used one model to explore both goals, by setting the objective function in the first as a constraint in the second and conversely.

5.1 Data Collecting

The output of the simulation model was used to determine production parameters. Machine prices, investment budget and minimal expected production were provided by the company.

5.2 Assumptions

1. The investment policy considered machines and tools; the cost of hiring and training workers was excluded.
2. Machines had the same capacity than the current ones in each operation.

5.3 Software

Lingo 13 was selected because it provides easiness to introduce short instructions and the capacity to link with *.txt*, *.xls*, *.dll*, and other data files.

5.4 Model

The integer program is the following:

$$Max\ z = x_N \tag{1}$$

$$\sum_{i=1}^{N} c_i w_i \leq b \tag{2}$$

$$x_i \leq a_i(1 + w_i) \quad \forall i \tag{3}$$

$$(1-d) f_i x_N \leq x_i \quad \forall i \neq N \tag{4}$$

$$x_i \leq (1+d) f_i x_N \quad \forall i \neq N \tag{5}$$

$$x_i \geq 0 \quad \forall i \tag{6}$$

$$w_i \in \mathbb{Z}^+ \ \forall i \tag{7}$$

x_N represents the rate of production of the last operation (Op. 8). c_i is the cost to buy and to install a machine in operation i. b is the total investment money. a_i is the rate of production of the machine i, this was obtained from the simulation model. d is the allowed proportion deviation (% of efficiency), f_i is a coefficient that represents the number of units from operation i needed to produce one final product. x_i and w_i are decisional variables.

In order to explore the second goal we changed equation (1) to (1.a) and equation (2) to (2.a) as follows:

$$Min\ z = \sum_{i=1}^{N} c_i w_i \tag{1.a}$$

$$p \leq x_N \tag{2.a}$$

The rest of the equations remained the same. p is the minimal desired production.

5.5 Results

First we will review the results associated with the first model (maximize production) and then those associated with the second model (minimize investment cost).

In the first model we tried with several values of d, finally we decided along with the manager, to set $d=0.10$, which implies 90% of efficiency.

Table 3. Optimal Solution of the First Model with $d=0.10$

Op.	RP (current)	New mach.	RP (new)	Balanced RP
1	50.69	1	101.38	88.20
2	28.23	2	84.69	72.17
3	29.00	2	87	87.00
4	28.36	2	85.08	85.08
5	24.05	2	72.16	72.16
6	28.80	2	86.41	86.41
7	22.80	3	91.20	88.20
8	20.66	3	82.64	80.18

In table 3, *Op.* is the operation; *RP (current)* is the maximal rate of production in current conditions; *New mach.* is the number of new machines to buy according to the optimal solution; *RP (new)* the maximal rate of production considering new machines; *Balanced RP* is the optimal balanced rate of production considering new machines.

This solution consumes the entire investment budget and the production goes from 124 to 480 shoes weekly, this represent an increase of 287%.

For the second model (or goal), we decided to explore a set of minimal weekly productions p in order to associate production to different investment levels. Again 90% of efficiency was selected, i.e. $d=0.10$.

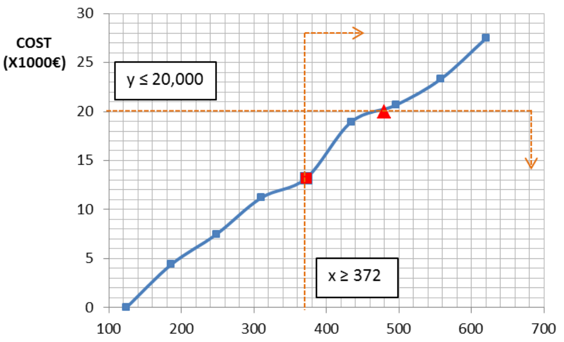


Figure 5. Weekly Production Associated with Investment Levels.

In figure 5 we can see that the investment cost function is approximately linear. The distance between blue dots is constant in x-axis. The production and financial constraints are shown with dotted lines.

The red triangle shows the optimal solution found for the first integer model, the red square shows the optimal for the second.

The solutions selected to be tested in the simulation model are the following:

Table 4. Optimal Solutions Selected

	Op.	Solution A	Solution B
Investment policy (new machines)	1	1	1
	2	2	1
	3	2	1
	4	2	1
	5	2	2
	6	2	1
	7	3	2
	8	3	2
Weekly production		480	372
Investment cost (€)		20,000	13,200

Solution A is the optimal obtained from the first integer program, solution B was selected because it provides the higher ratio (production/investment cost), it is above the weekly production objective set by the manager, and below the investment budget.

6. SIMULATION OF OPTIMAL SOLUTIONS

We made a simulation experiment of 2500 replicates for both solutions and obtained weekly productions about five percent higher than predicted from the integer program, this was because the simulation model considered several other but it was still a good prediction.

Table 5. Statistic Measures of the Optimal Solutions.

	Solution A	Solution B
Mean	501.7	390.4
Range	87	33
SD	12.5	5.7
CV	2%	1%
Average Efficiency	90.6%	93%

The range of results of B solution was narrower than A's and its standard deviation was smaller, but both solutions had a low coefficient of variation. Average efficiency was higher in B solution, which means that the rate of production implies a better use of resources.

Both solutions represent an intended full capacity of the system useful for providing insights for decision-making. With any of these levels of production the company is capable to meet the new customers demand.

Also, the production obtained can be used as an objective production considering that the assumptions of the model did not involve any production line stopping.

The decision between the optimal solutions has to consider the preference of the manager about installed capacity.

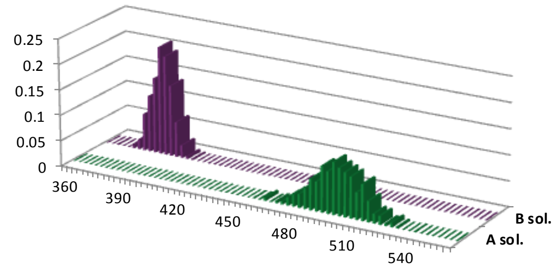
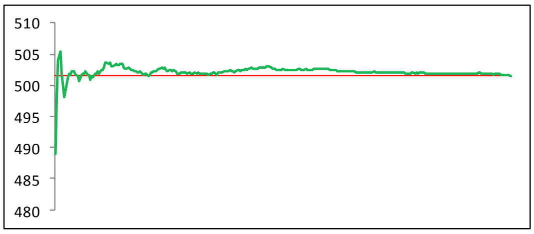


Figure 6. Weekly Production Distribution for A (green) and B (purple) solutions.

In Figure 7 we show how the mean production was approaching to its statistic regularity value as more replicates were made.

(a)



(b)

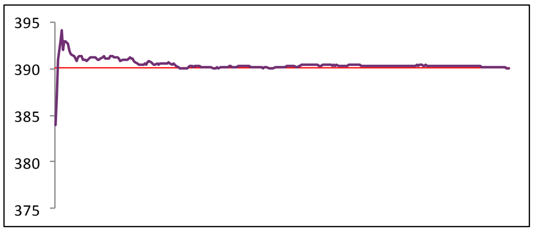


Figure 7. Mean´s Statistic Regularity for A *(a)*, and B *(b)* solutions.

7. CONCLUSIONS

With the conditions the company had, it would be completely dedicated to shoe-manufacturing if it wanted to meet new customers demand. It would not be capable to meet other orders.

We recommended increasing the capacity of the factory according to A solution only if the company is capable to sell such levels of production; otherwise it is advisable to increase the capacity according to B solution.

We used the integer program to find 'promissory solutions', then we used simulation for a deeper research in those solutions. We believe this is a good approach to face situations in which time and resources are scarce. Trying to explore through simulation every possible investment configuration would lead to a combinatory problem that would be very expensive and time-consuming.

Also we must say that the simulation model was a good fund-finding tool for the company. It generated tangible information about levels of production associated with investment budgets that the investors can rely on.

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ACKNOWLEDGEMENTS

The author would like to thank Dr. Idalia Flores for her support and Pablo I. Alcántara for the facilities provided by the company.

AUTHOR´S BIOGRAFY

Jorge Andrés García studied Industrial Administration at the National Polytechnic Institute (IPN) and then a Master in Operations Research at the National Autonomous University of Mexico (UNAM). His research lines are Optimization in Production Planning and Simulation.