

PLANT CAPACITY ANALYSIS IN A DAIRY COMPANY, APPLYING MONTECARLO SIMULATION

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ABSTRACT

In this paper, results of plant capacity analysis made to a dairy company are reported. This enterprise is one of the best-positioned companies in production and distribution of milk products in México. The enterprise has only one production plant and seven distribution centers. Because of the enterprise does not cover the client demand, the Planning Department planned to buy more equipment, in order to increase the production rate. This analysis was performed to determine the plant capacity, in order to know the quantity of additional equipment that production plant will need. An annual increasing rate was considered in the study, which was calculated with data of two years ago. In this work, the Monte Carlo method was applied to carry out the simulation of the production plant processes, and ProModel software was used to implement the simulation model.

Keywords: production plant, plant capacity analysis, Monte Carlo method, computer simulation

1. INTRODUCTION

Plant capacity means the maximum quantity that can be produced by time unit in the plant with the existing equipment. (Fare, Grosskopf, and Kokkelenberg 1989)

The knowledge about the production plant capacity is very important because it defines the competitive limits of the enterprise, i.e. the plant capacity sets the response rate, the costs structure, the composition of the personnel, and the general strategy for inventory. If the plant capacity is inadequate to satisfy the market demand, a company could lose its clients.

On the other hand, if the plant capacity is excessive, probably the company will reduce the prices of its products to stimulate the demand, underutilize personnel, keep overstocked, and produce other products, less profitable, in order to be in operation.

1.1. Company description

The plant capacity analysis reported in this paper was developed in a dairy company, which for confidentiality reasons the name of the company is omitted.

This company is one of the highest milk distributors in all the Mexican territory, it processes almost 3 million of milk liters every day, and more than 900 million per year. Furthermore, the company produces more than 100 milk products, which generates setup changes.

The company has a raw milk harvesting system, which is collected from ranches of associated ranchers, according to a morning schedule. The raw milk is transported in tankers from the ranches to the production plant, where the raw milk is pasteurized and ultra pasteurized.

The production plant has silos for the harvested milk, silos for the processed milk (pasteurized and ultra pasteurized), and equipment for bottling and packing.

Furthermore, according to client demand, ultra pasteurized milk is added with flavors, which needs silos for the bottling process, where the milk is mixed with the flavor required.

In addition to fluid milk products, the production plant processes products made from milk, such as yogurt, cream, butter, and cheeses.

1.2. Plant capacity concepts

The aim of this work is focused in the plant capacity analysis; hence, following paragraphs presents some plant capacity concepts. (Blackstone 1989)

1. Design Capacity (DC): Is the maximum possible production rate in a process, given the current designs of the product, mixing, operation policies, human resources, plant installations, and equipment.
2. Effective Capacity (EC): Is the maximum production rate that can be obtained in a reasonable way, taking into account preventive maintenance times, setup changes, and production system limitations.

3. Real Capacity (RC): Is the effective production rate achieved in the process. Normally, it is a time function and it changes constantly. RC is affected by the equipment wear, wastes and reworks, limited machinery assembly, employee's absenteeism, inadequate production master planning, and other similar factors that contribute to decrease the real capacity rates.

As a relationship among these concepts, it can be seen that $DC > EC > RC$.

Moreover, according to given concepts, some indicators can be obtained, such indicators are the utilization factor and the efficiency:

$$Utilization\ factor = \frac{Real\ Capacity}{Design\ Capacity} = \frac{RC}{DC} \quad (1)$$

$$Efficiency = \frac{Real\ Capacity}{Effective\ Capacity} = \frac{RC}{EC} \quad (2)$$

1.3. Monte Carlo method basis

Monte Carlo method is a generic form to call to mathematical procedures whose common feature is the use of random numbers and probability distributions, such as normal, exponential, uniform, beta, among others. It uses random variables defined in a finite dimensional space and the expectation value is calculated to find the approximated solution of a problem. (Kalos M.H., et al., 2008)

Monte Carlo method is widely used, because it can be applied to solve stochastic problems, or those that can be set out in a stochastic way.

2. DESCRIPTION OF PRODUCTION PLANT PROCESSES

The production plant is divided in three main areas: raw milk reception area, fluid milk processing area, and milk derivative processing area.

2.1. Raw milk reception area

This area receives raw milk from dairy farms that belongs to shareholders of the company. Raw milk is transported in tankers with capacity of 25,000 liters. Before the raw milk is received, it is analyzed by the Quality Control Department in order to determine the quality of the product.

There are six reception lines, where each line pumps milk to 40,000 liters per hour, toward one of the four reception silos, with capacity of 150,000 liters each one. One of them stores milk used to produce milk derivatives. In the pumping process, the milk passes through deareators, filters, and coolers. The capacity of these equipments is 40,000 liters per hour.

Moreover, there is one reception line for cream, which pumps cream to 15,000 liters per hour. The cream is pumped into two tanks, with a capacity of 40,000 liters each one.

2.2. Fluid milk processing area

The processing area has two silos with a capacity of 100,000 liters each one, ten silos with a capacity of 150,000 liters each one and one silo with a capacity of 30,000 liters. The last one is only used to process cream.

Before the milk is pumped to process silos, it passes for a clarification process. There are four clarifiers, two of them have a capacity of 25,000 liters per hour, and the other two have a capacity of 30,000 liters per hour.

Fluid milk processing area is divided in two production lines: pasteurized milk line, and ultra pasteurized milk line.

2.2.1. Pasteurized milk lines

In order to produce pasteurized milk, these production lines take fluid milk from process silos; the milk is pumped to a homogenizer, and then, the milk is sent to two pasteurizers, each one with a tank with a capacity of 18,000 liters.

After that, pasteurized milk is bottled by three bottle filling machines with a capacity of 18,000 liters per hour. Sometimes, another machine with a capacity of 9,000 liters is used in this process; this machine is shared with other production lines.

2.2.2. Ultra pasteurized milk lines

The production of ultra pasteurized milk uses seven lines. Five lines are used to process milk in presentation of one liter, and the other two are used to process in presentation of 250 ml. The use of the production line depends on the type of product demanded. These lines produce whole milk, lacto free milk, light milk, cholesterol free milk, and flavored milk, among others.

Each line has between two or four bottle filling machines, with their respective capacities. Table 1 shows the capacities of ultra pasteurized milk lines.

Table 1: Ultra Pasteurized Lines Capacities.

Line	Cap (*)	Product presentation	Bottle filling machine	Cap (*)
I	24	1 liter	b ₁	12
			b ₂	12
II	24	1 liter	b ₃	6
			b ₄	6
			b ₅	6
			b ₆	6
III	24	1 liter	b ₇	6
			b ₈	6
			b ₉	6
			b ₁₀	6
IV	16	1 liter	b ₁₁	6
			b ₁₂	6
V	30	1 liter	b ₁₃	12
			b ₁₄	12
			b ₁₅	6

Table 1: Ultra Pasteurized Lines Capacities. (Cont.)

Line	Cap (*)	Product presentation	Bottle filling machine	Cap (*)
VI	7	250 ml	b ₁₆	1.5
			b ₁₇	1.5
			b ₁₈	1.875
			b ₁₉	1.5
VII	10	250 ml	b ₂₀	5
			b ₂₁	5

*: in thousands of liters per hour.

2.3. Milk derivative processing area

This area is divided in two subareas: cream area and yogurt area.

2.3.1. Cream area

Cream stored in the two cream reception tanks is pumped toward to three tanks used for a standardization process; these tanks have a capacity of 9,000, 9,000, and 14,000 liters per hour, respectively. Then, the cream is pumped to pasteurization and homogenization process.

There are three pasteurizers, with a capacity of 7,000, 4,000, and 7,000 liters per hour, respectively. Every pasteurizer is connected to its homogenizer, where homogenizer speed is synchronized with the pasteurizer speed.

After that, the cream is pumped into four tanks, with a capacity of 5,000 liters each one. The first tank is used to bottle cream manually in a presentation of four liters.

The second, third, and fourth tank, are alternatively used to bottle cream in three bottled lines. Table 2 shows the characteristics of these lines.

Table 2: Cream Bottled Lines

Line	Source tank	Capacity (*)	Presentation
c ₁	2, 3, 4	10	450 ml 900 ml
c ₂	2, 3, 4	10	450 ml
c ₃	2, 3, 4	10	200 ml

*: in thousands of liters per hour.

2.3.2. Yogurt area

Yogurt process is divided according to product presentation. There are four lines in this area: Plant I, Plant II, Plant III, and Plant III-A.

Raw milk stored in one of the four reception silos is used to process milk derivatives. Milk is pumped from this silo to three standardization tanks, then, milk is pumped to one of the four plants depending on the product presentation:

Plant I: Processes drinking yogurt and fruit yogurt.

Plant II: Processes yogurt with cereal, creamy yogurt, and whipped yogurt.

Plant III: Processes whipped yogurt, drinking yogurt and fruit yogurt.

Plant III-A: Processes a type of yogurt mixed with fruits. Moreover, this plant is shared with pasteurized milk line.

3. PROBABILITY DISTRIBUTIONS

In order to take into account the seasonality of the system, the data provide by the company were analyzed for every month. The company had a set of data from three years.

The modeling of real system started from the arrivals of tankers to reception area. Inter arrival times were analyzed, and the probability distributions are shown in table 3.

Table 3: Probability Distributions for Inter Arrival times of tankers.

Month	Probability distribution (in minutes)
January	E(18.4805)
February	E(18.46)
March	E(18.4804)
April	E(19.39)
May	E(18.7)
June	E(18.15)
July	E(18.49)
August	E(18.49)
September	E(18.4)
October	E(18.2)
November	E(18.52)
December	E(19.476)

The next variable to analyze was the milk contents of tankers, although the capacity of tankers is 25,000 liters, its real content is different. Table 4 shows the obtained results.

Table 4: Probability Distributions for Milk Contents of Tankers.

Month	Probability distribution (in thousands of liters)
January	Normal(22.7500, 3.0000)
February	Normal(22.2500, 2.6800)
March	Normal(22.2500, 2.5000)
April	Normal(22.5710, 2.5000)
May	Normal(22.1140, 2.5000)
June	Normal(22.6630, 2.7000)
July	Normal(22.3120, 2.3000)
August	Normal(22.9000, 2.2500)
September	Normal(22.7500, 2.8000)
October	Normal(22.3500, 2.7990)
November	Normal(22.4190, 2.9250)
December	Normal(22.7500, 2.4000)

Production Master Planner provided us data about weekly production for every product. We obtained the corresponding probability distribution for every product in every month of the year. Fitted distributions for some products in January month are shown in table 5.

Table 5: Probability distributions for product depending on client demand.

Product	Probability distribution (in thousands of liters)
Whole milk 1 liter	LogNormal(229537.93, 69776.62)
Light milk 1 liter	Weibull(10.119, 36666.36)
Strawberry flavored milk 1 liter	Normal(63342.21, 16008)
Drinking yogurt 250 ml strawberry-coconut	Triangular(25967.76, 40661.22, 221153)
Drinking yogurt 250 ml pineapple-coconut	LogNormal(130621.49, 47559.78)
Ultra pasteurized milk with fruits 250 ml strawberry	Triangular(0.65235, 0.65235, 35401.05)
Ultra pasteurized milk with fruits 250 ml mango	Triangular(0.00276, 0.00276, 24286.53)
Yogurt with cereal 150 ml strawberry-nut	Uniform(1775.45, 3791.46)
Yogurt with cereal 150 ml peach-nut	Triangular(0.02711, 0.02717, 11662.38278)
Cream 200 ml	Weibull(32.022, 1467150.23)
Cream 450 ml	Weibull(7.0071, 858032.40)
Yogurt 150 g strawberry	Weibull(9.970, 201340)
Yogurt 150 g peach	Normal(831686, 182164.92)

Figure 1 shows the graphic for the probabilistic distribution fitted for the data corresponding to whole milk in presentation of 1 liter.

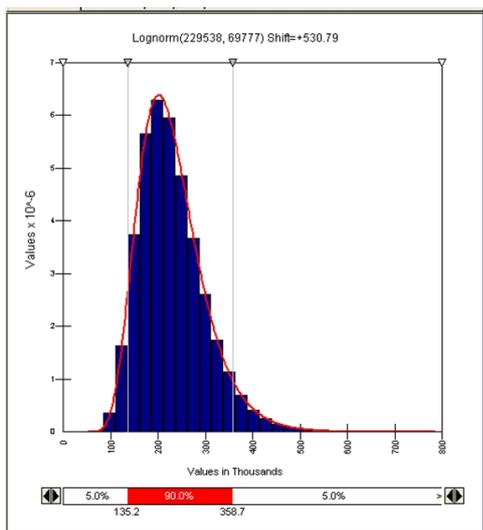


Figure 1: Probabilistic distribution fitted for whole milk of 1 liter.

With the statistical analysis, we found an annual growth rate of 6.16%.

4. COMPUTER SIMULATION

The simulation software used to carry out the simulation model was ProModel.

ProModel Simulation Software provides tools to model and simulate manufacturing process. It has a graphical interface, where the modeler can define entities, locations, processing, arrivals, resources, etc. (Harrel, Ghosh, and Bowden 2003; García, García, and Cárdenas 2006).

The items listed below must be identified from the real system:

Locations: are places used as servers, where entities are processed.

Entities: are dynamic objects that are served by locations.

Processing: model policies are defined in this part.

Resources: used to transport entities among locations, like forklifts, workers, etc.

Arrivals: used to define inter arrival time, it could be a constant value or a probabilistic distribution.

Attributes: used to add values to entities.

Variables: used to save data computed during simulation execution.

Subroutines: used to define procedures in order to improve the software functionality.

In the following subsections the simulation model is described.

4.1. Construction of the simulation model

In this phase of the project, all the elements of the real system that are involved in the product processing were identified, since raw milk arrivals until the bottling filling machines.

Because of fluid milk and cream flows are continuous variables, we considered one entity of milk or cream as 1000 liters of milk or cream, respectively.

4.1.1. Raw milk reception area

Arrival times for tanker were shown in table 3, and the tanker contents in table 4.

Tankers were defined as resources, and the reception silos, valves, and pipes were defined as locations. See figure 2.

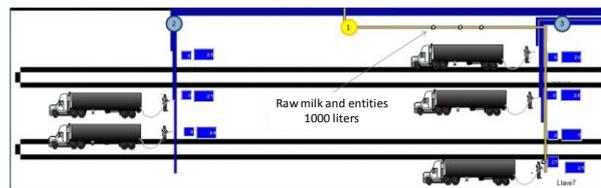


Figure 2: Tankers downloading raw milk.

Raw milk is pumped to reception silos, numbered as 29, 30, 31 and 40. The flow of the raw milk is shown in figure 3; it follows the description given in subsection 2.1.

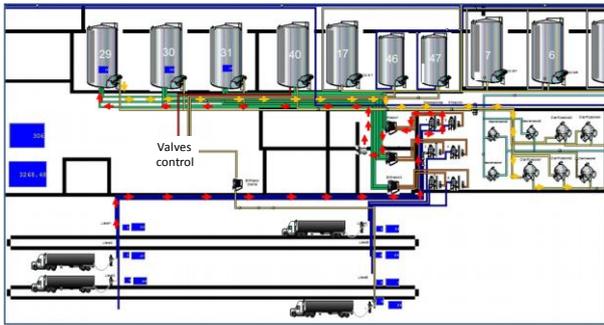


Figure 3: Raw milk pumped toward reception silos (29, 30, 31, and 40).

4.1.2. Fluid milk processing area

Silos, clarifiers, pumps, pipes, homogenizers, pasteurizers, ultra pasteurizers, and bottle filling machines were defined as locations, with their respective processing time.

Figure 4 shows a part of the pasteurized milk area.

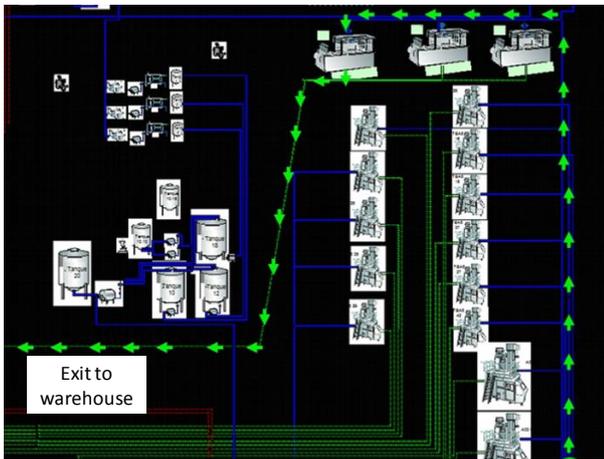


Figure 4: Pasteurized milk process.

4.1.3. Milk derivative processing area

Equipment installed in Cream area and Yogurt area were defined as locations, taking into account their respective processing time.

Figure 5 shows the cream homogenization process, and the four storage tanks.

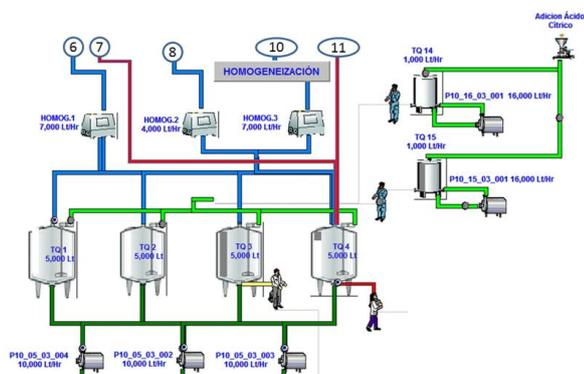


Figure 4: Cream homogenization process.

5. RESULTS AND CONCLUSIONS

The simulation scenarios were executed 100 times and the gathered statistics are summarized in the following tables.

Table 6 shows comparative data about the reception area. In order to get the Efficiency Capacity, time for clean the silos and maintenance time are considered. The table includes Design Capacity (*DC*), Effective Capacity (*EC*), Real Capacity (*RC*), Utilization factor (*UF*), and Efficiency (*Ef*). *DC*, *EC*, and *RC* are denoted in thousands of liters.

Table 6: Raw Milk Reception Statistics

	<i>DC</i>	<i>EC</i>	<i>RC</i>	<i>UF</i>	<i>Ef</i>
Valve 1	6,720	5,586	1,803	26.84%	32.28%
Valve 2	6,720	5,586	2,195	32.68%	39.30%
Valve 3	6,720	5,586	2,777	41.34%	49.72%
Valve 4	6,720	5,586	2,027	30.18%	36.30%
Valve 5	6,720	5,586	1,874	27.90%	33.56%
Valve 6	6,720	5,586	1,384	20.60%	24.78%
Silo 29	150	150	56.68	37.79%	37.79%
Silo 30	150	150	57.85	38.57%	38.57%
Silo 31	150	150	63.48	42.32%	42.32%
Silo 40	150	150	73.44	48.96%	48.96%

Data gathered from fluid milk pasteurization area are shown in table 7.

Table 7: Fluid Milk Processing Statistics

	<i>DC</i>	<i>EC</i>	<i>RC</i>	<i>UF</i>	<i>Ef</i>
Pasteurized milk	7,560	6,331	2,545	33.68%	40.21%
Ultra pasteurized milk	21,903	18,343	11,048	50.44%	60.23%

Finally, data obtained from milk derivative processing area are shown in table 8.

Table 8: Milk Derivative Processing Statistics

	<i>DC</i>	<i>EC</i>	<i>RC</i>	<i>UF</i>	<i>Ef</i>
Cream	1,860	1,626	973	57.95%	59.86%
Yogurt	6,762	6,191	2,481	36.70%	40.08%

Tables 6, 7, and 8 denote the behavior of the real system, and the capacity that the production plant

provides. Nevertheless, it can be seen that the installed equipment is not used at all.

The main obstacle to improve the usage of production lines is the harvesting system, because it is only performed in the morning. Veterinarians of the company declare that it is possible to set a new raw milk harvesting system, where the tankers go to dairy farms twice a day.

On the other hand, a good strategy in the elaboration of the Production Master Planning can reduce time wasted in setup changes, and, in consequence, to improve the efficiency of production lines.

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