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FOOD TECHNOLOGY

Increasing yoghurt daily production with modeling and simulation process

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ABSTRACT: *The objective of this research was to use the modeling and computer simulation to support decision makers, aiming to increase the productive capacity of the agro-industry of LaticínioFunarbe. Specifically, it has modeled the current yoghurt production sector for simulation that enables it to meet the new demand. The Arena 14.7 simulation software was used to conduct the modeling. To validate the model, the output of yoghurt production collected at the factory for three months was compared with the output from the simulated computational model. Two indicators were established to perform analyzes of four different scenarios. The implemented model resulted in an increase in the production capacity of 5,000L.d^{-1} of yoghurt, corresponding to a production of yoghurts processed daily three times higher than the current production.*
Key words: *modeling, computer simulation, cenario analysis, yoghurt, dairy industry.*

Aumento da produção diária de iogurte com modelagem e simulação de processos

RESUMO: *O objetivo deste trabalho foi usar a modelagem e a simulação computacional como ferramenta de suporte aos tomadores de decisão, visando a aumentar a produtividade da agroindústria Laticínio Funarbe. Especificamente, modelou o setor atual da produção de iogurte para elaboração de análises que possibilita atender à nova demanda. Para a modelagem utilizou-se o software de simulação Arena 14.7. Para a validação do modelo foram comparados os resultados de produção de iogurte coletados na fábrica durante três meses com os resultados simulados pelo modelo computacional. Foram estabelecidos dois indicadores para realizar análises de quatro cenários diferentes. Por meio do modelo implementado, obtivemos um aumento da capacidade produtiva de 5000L.d^{-1} de iogurte, que corresponde a uma produção de iogurtes processados, diariamente, três vezes maior do que a produção atual.*
Palavras-chave: *modelagem, simulação computacional, análise de cenários, iogurte, indústria de laticínios.*

INTRODUCTION

The production of milk in Brazil increased about 16% between 2010 and 2013 (IBGE, 2015). Minas Gerais is the state with the biggest annual production of milk in the country. It produced over 6 million liters of milk in 2016, from a total of 23 million in Brazil (IBGE, 2017). According to CARVALHO (2010), the dairy industry is the main responsible for the growth in milk production, because the dairy sector stands out as the second largest in gross revenue of food products. Dairy products participation in the total gross revenue of the Brazilian food industry is estimated to be 13.6% (ABIA, 2016). Therefore, the dairy industry sector has peculiar conditions that demand strategies to sustain growth.

Yoghurt is a product derived from milk, acidified and clotted, resulting from the lactic fermentation of the milk when a mixture of Lactobacillus bulgaricus and Streptococcus thermophilus is added (MOTA et al., 2015). The micronutrients reported in yoghurt are similar to those present in milk; however, they are available in a much higher concentration, which makes yoghurt a good source of proteins, vitamins B2 and B12, and minerals, such ascalcium, magnesium, potassium and zinc.(BUTTRISS, 1997; WANG et al., 2013). According to GARMUS et al. (2016), the annual per capita consumption of milk in Brazil is about 6kg, a low value compared to other countries. However, the value is high when you consider the total volume consumed in the country of over 1,200 million tons.

Improving the use of the available technological resources is an alternative to reduce production costs and improve productivity in a dairy factory (ANGEL et al., 2014). According to ALMEIDA

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JÚNIOR AND DA SILVA (2005) the agro-industries should develop production processes control systems, like expenses, supply, availability and restrictions in order to obtain efficiency in meeting market demand. To this end, it is essential that decision makers know the production processes and act preemptively regarding future scenarios(TURBAN et al, 2004).

Mathematical modeling and simulation technique is an alternative used to reduce obstacles found when the analysis of problems by direct observation is time-consuming or costly(SILVA NETO et al., 2006). According to AHUMADA AND VILLALOBOS (2009), computational modeling and simulation are used to simulate real data leading to an optimal solution. Modeling and simulation are focused in many applications in the process of decision-taking, making it possible to predict the behavior of the system facing different scenarios and allowing an analysis of the critical factors to increase productivity in the process (LAW; KELTON, 1991).

Therefore, a higher availability of information concerning the processes, promoted by the evolution of information technology has made studies in the food sector by using modeling and simulation tools (PIZZUTI; MIRABELLI, 2015). Many papers reported in the literature have used modeling and simulation to assess the performance of different processes like traffic (KAMRANI et al., 2014), food production in small and medium industries(LIONG et al., 2016; RANI et al., 2014) and restaurants (GHALEB et al. 2015).

However, there are not many studies available that use computational modeling and simulation to the optimize processes in the dairy industry without the need to intervene in the real productive process. That is to say with the computational model it is possible to implement changes and predict consequences.

Based on the considerations above, this study's main objective was to apply computational modeling and simulation in a dairy factory. The goal was to provide support to decision makers, aiming to improve productivity with the use of a simulation software.

MATERIALS AND METHODS

This study took place in the Laticínio Funarbe unit, at the Universidade Federal de Viçosa (UFV), Minas Gerais, Brasil. This factory manufactures products such as milk jam, mozzarella cheese, butter, milk, cream cheese and yoghurt. According to the factory managers themselves, there is a need to expand the yoghurt production sector. The current system capacity was limited to 3,000L.d^{-1} of yoghurt, but executives ascertained that in 2018 the required productive capacity to meet the projected demand should be of approximately 8,000L.d^{-1} of yoghurt.

This study was developed using the research-action method. This method consists of a research with an empirical basis, in which researchers and workers of the studied sector act in a participatory and cooperative way (CARR, 2006). The work group acted with the objective of expanding the yoghurt production sector, seeking ways of improving the system performance. The research action method was applied by planning the research, the implementation of the computational model, description and evaluation of the suggested scenarios.

Data collection

To carry out the study, the first step was to collect data in the shop floor between January and March 2017, focusing on the yoghurt production process. The process is divided in the following sub processes: homogenization; mixing milk with sugar; pasteurization; fermentation; chemical analysis; cooling; addition of fruit bases; setup of the dosing equipment for the 185g and 860g packages; bottling of the 120g, 185g, 860g and 10kg and stocking. The factory uses two tanks in the yoghurt production; one has a capacity of 1,000L and the other of 2,000L. A digital chronometer was used to collect the duration of each activity in the sub processes. The percentage of units produced in each package size was defined with values based on the first seven months of 2017. Then, data regarding the quantity of packages was obtained, used and forecast based on information collected with the production planning and control department.

Sub processes time

According to CHWIF E MEDINA(2014), the number of samples collected should be between 100 and 200, because samples with less than 100 observations could compromise the identification of the best probabilistic model, whereas samples with over 200 observations do not provide important improvements to the study. The time necessary to execute each sub process was determined while the unit was operating. The initial and final time of each sub process was marked in a spreadsheet. To complete the study, 120 observations were collected.

Data analysis

The software used to provide an analysis of the descriptive statistics of the data was the Minitab version 17. All data regarding time of every sub process that makes up the yoghurt production were analyzed. Descriptive statistics made possible to summarize, describe and comprehend the data of a distribution, using central tendency measures (mean and median), measures of dispersion (minimum and maximum values, standard deviation and coefficient of variation) and quartiles. Then, the outliers were defined. Outliers are observation potentially discrepant from the population. The use of this approach allowed summarizing the values of each sub process in relation to the total distribution of the data. Then, it was possible to conclude if the data was in accordance with the real system.

Adherence testes

The objective of these tests was to choose the distribution that best represents the population. After the conclusion of the descriptive analysis of the data, the next step was to use the Input Analyzer of the Arena version 14.7 software (developed by Rockwell Automation Inc., Milwaukee, Wisconsin), to determine the nature of the distribution of frequencies and the expression that best describes the collected data. Thus, the hypothesis tests to assess the best distribution were conducted, with a significance level, α=0.05:

H0: the distribution selected properly represents the collected data.

Test p-value (0.0<p-value<1).

The density function was represented in a histogram for the different durations of the sub processes to provide an exact expression of the simulation model. The criteria used to carry out the adherence test were:

Chi-square tests;

p-value, always between 0 and 1;

small p-value (<0.05): poor adherence;

Choose the distribution with the smallest square error value;

Square error=sum of the square of the differences between the histogram frequencies and the adjusted distribution.

Construction of the computational model

The input variables used were the gap between each sub process and the productive capacity of the analyzed sector to construct the computational model of the yoghurt productive system sub processes. The production system was modeled discretely using the software Arena version 14.7. The simulation model was created from a series of objects from Arena.

Validation of the computational model

The validation of the model is one of the most important stages in the development of the simulation model. If there is not a strong correlation between the data generated by the model and the data from the real system, it is not possible to obtain quality in decision-taking (CHWIF; MEDINA, 2014). Before starting the validation processes, the model was verified, with the objective of identifying possible implementation mistakes regarding the functioning logic of the model. Validation guarantees the precision of the model in relation to the real system. The criteria used in this process was based on historical output data and in the experience from the expert operators of the production line.

To validate the model, a pilot sample with thirty replicas was built. Thereby, the results of the yoghurt production collected in the factory were compared with those simulated by the computational model. With the results from the pilot sample the precision (size of the confidence interval) and the 95% confidence interval (interval of values that contain the mean of the population, with 95% statistical confidence) were obtained. Precision and the confidence interval were defined by Equations 1 and 2, respectively (CHWIF; MEDINA, 2014).

Whereby:

x=mean; h=precision;

=Student’s distribution t with n-1 degrees of freedom and bilateral significance level 0.05/2;s=standart deviation;

n=replication number.

To achieve optimal precision, the size of the confidence interval must be equal or less than 10% of the population mean. In the case that the precision is bigger than 10% of the population mean, it is necessary to determine the number of necessary replications needed to find the new precision. Using Equation 3 it is possible to estimate the number of necessary equations(CHWIF; MEDINA, 2014).

Whereby:

n^*=number of necessary replications.

h^*=optimal precision.

Relative error is defined by the module of the difference between the collected values minus the simulated one, divided by the collected value.

Scenario analysis for decision taking

The next step consisted in proposing alterations in the current production process, seeking to identify the ones that could improve more the factory performance. Two performance indexes were proposed:

a- Quantity of products manufactured daily (Q);

b- Time of the setup of the dosing device sub process and

$$h = t_{n-1;0.05/2}\, x \frac{s}{\sqrt{n}} \quad (1)$$

$$\bar{x} - h \leq \bar{x} \leq \bar{x} + h \quad (2)$$

$$n^* = \left\lceil n \left(\frac{h}{h^*}\right)^2 \right\rceil \qquad (3)$$

time of the bottling sub process for each type of package.

The indexes analyzed in four different scenarios enabled the observation of the effect of the adding of new equipment, as well as the replacing existing equipment, in order to achieve the results needed to attend the projected demand.

RESULTS AND DISCUSSION

Construction of the computational model

Table 1 contains the adherence test included

Table 1 - Measures of probability distribution of sub processes times.

----------------------------Homogenization-----------------------------				--------------------------------Pasteurization---------------------------			
-----------1,000L Tank---------		-----------2,000L Tank---------		-----------1,000L Tank----------		----------2,000L Tank--------	
Dist=	Normal (NORM)	Dist=	Weibull (WEIB)	Dist=	Weibull (WEIB)	Dist=	Normal (NORM)
Exp=	NORM(41.4, 5.22)	Exp=	67.5 + WEIB(21.2, 2.62)	Exp=	13.5 + WEIB(12.7, 2.72)	Exp=	NORM(41.4, 5.42)
Test	Chi-square	Test	Chi-square	Test	Chi-square	Test	Chi-square
p-value	0.607	P-value	0.206	p-value	0.596	p-value	0.589
Sq	0.009	Sq	0.013	Sq	0.005	Sq	0.007
-----------------------------Fermentation------------------------------				-----------------------------------Cooling--------------------------------			
----------1,000L Tank----------		----------2,000L Tank---------		-----------1,000L Tank----------		----------2,000L Tank---------	
Dist=	Beta (BETA)	Dist=	Normal (NORM)	Dist=	Normal (NORM)	Dist=	Normal (NORM)
Exp=	435 + 69 * BETA(1.82, 1.62)	Exp=	NORM(413, 20)	Exp=	NORM(24.7, 4.75)	Exp=	NORM(43.3, 5.96)
Test	Chi-square	Test	Chi-square	Test	Chi-square	Test	Chi-square
p-value	0.496	P-value	0.75	p-value	0.404	p-value	0.488
Sq	0.015	Sq	0.02	Sq	0.004	Sq	0.005
----------Packing 860g---------		-----------Packing 185g--------		-----------Packing 120g---------		----------Packing 10Kg--------	
Dist=	Normal (NORM)	Dist=	Erlang (ERLA)	Dist=	Triangular (TRIA)	Dist=	Gamma (GAMM)
Exp=	NORM(98.4, 9.45)	Exp=	19.5 + ERLA(3.01, 6)	Exp=	TRIA(90.5, 101, 135)	Exp=	1.5 + GAMM(1.3, 5.1)
Test	Chi-square	Test	Chi-square	Test	Chi-square	Test	Chi-square
p-value	0.353	p-value	0.191	p-value	0.477	p-value	0.156
Sq	0.008	Sq	0.008	Sq	0.009	Sq	0.004
------------------------------Device Setup---------------------------				-----------------------------------Stock-----------------------------------			
Dist=		Normal (NORM)		Dist=		Normal (NORM)	
Exp=		NORM(34, 5.56)		Exp=		NORM(43.1, 6.37)	
Test		Chi-square		Test		Chi-square	
p-value		0.228		p-value		0.308	
Sq		0.007		Sq		0,010	

Dist – distribution; Exp – expression; Sq – squareerror; NORM – Normal; WEIB – Weibull; BETA – Beta; ERLA – Erlang; TRIA – Triangular; GAMM – Gamma.

in the computational model. The test was vital in order to find the probability lines, which can range from Normal, Beta, Weinbull, Erlang, Triangular and Gamma distributions. In addition, the adherence test has shown the expression with the best adjustment of the sub processes times, in accordance with the lowest square error and an acceptable adherence of the p-value used in the simulation model.

Validation of the computational model

According to the current production schedule, the productive capacity is 3,000L.d^{-1}, which correspond to approximately 8,000 unitsof120g, 185g, 860g and10kg, per day. The implemented model represents the current state of the productive system. Table 2 shows the pilot sample of the simulation of yoghurt units processed daily and the confidence interval of the computational model. The simulation was repeated thirty times in order to achieve a more accurate representation of reality.

As the confidence interval increased, so did the table value. Therefore, the precision h should also be bigger, increasing the size of the confidence interval. The work group opted to choose a confidence level of 95% (significance level of 5%), as this is used recurrently in statistics studies and because it represents an acceptable percentage for type I error. The obtained precision related to the quantity of yoghurt units processed daily was of 89 units.

The obtained precision value was approximately 1.1% of the average of yoghurts processed daily. The obtained precision value was inferior to 10% of the mean simulated quantity of yoghurts processed daily, showing that the implemented model obtained optimal precision.

Thereby, the following results were obtained:
Simulated quantity of yoghurts processed with 30 repetitions: 8.041units per day;
Yoghurts manufactured according to the collected data: 8.000units per day;
Relative error obtained by comparing real and simulated data was low: 0.5%.

The results obtained in the model indicate that it represents well the current process of Laticínio Funarbe. The simulated quantity of yoghurts processed daily obtained in the implemented model

Table 2 – Simulation of the quantity of yoghurt processed daily and trust interval of the computational model.

---Pilot Sample---			
Repetition (n)	Predicted value of yoghurt (units.d^{-1})	Repetition (n)	Predicted value of yoghurt (units.d^{-1})
1	8,080	17	8,069
2	7,850	18	7,562
3	8,342	19	8,066
4	8,140	20	8,089
5	7,680	21	8,070
6	8,225	22	8,076
7	8,433	23	8,063
8	7,829	24	8,083
9	8,377	25	8,087
10	8,037	26	7,690
11	8,068	27	8,394
12	8,032	28	8,097
13	8,145	29	7,324
14	8,125	30	8,121
15	8,022	Total Mean	8,041
16	8.051	Standard deviation	238
Trust % (100-α)	t-Student	Precision(h)	Mean Trust Interval (IC)
95%	2.045	89	7,952 $<\bar{x}<$ 8,130

was in accordance with the quantity of products used in the factory production schedule. Therefore, the computational model of the yoghurt production system was considered validated.

Scenario analysis for decision taking

Changes to the current simulated process were suggested in an attempt to obtain improvement in yoghurt manufacturing performance and achieve a productive capacity of 8,000L.d^{-1} of yoghurt, which account for approximately 24,000 units of yoghurt in total, considering the different types of package, of 120g, 185g, 860g and 10kg, per day.

Scenario 01: Addition of an exclusive machine for the bottling of the 860g package.

Scenario 02: Replacement of the current bottling machine for the 120g package, for an automatic bottling machine, built in stainless steel 304 and with last generation technology, with national programmable controls (CLP), allowing precise doses and high productivity.

Scenario 03: Combination of scenario 01 and scenario 02.

Scenario 04: Acquisition of two new tanks with 5,000L capacity, one for fermentation and the other for the finished product. Moreover, the changes described in scenario 03.

The tests were repeated in the four different scenarios thirty times. Table 3 presents the comparative results of the assessed parameters for the simulated quantity of yoghurt processed daily and the operation time for scenarios 01, 02, 03 and 04.

Table 3 – Comparison of the predicted values of quantity of yoghurt processed daily and operation time.

	-------------------Current scenario------------------		--------------------------------Scenario 01-----------------------------	
Packages	TS (min)	Q (units.d^{-1})	TS (min)	Q (units.d^{-1})
120g	114.37	4,989	115.4	5,196
185g	38.55	988	22.03	1,029
860g	99.17	2,054	48.7	2,140
10kg	8.4	10	7.8	10
Total		8,041		8,375
	--------------------Current scenario------------------		--------------------------------Scenario 02------------------------------	
Packages	TS (min)	Q (units.d^{-1})	TS (min)	Q (units.d^{-1})
120g	114.37	4,989	56.36	5,329
185g	38.55	988	33.7	1,055
860g	99.17	2,054	97.1	2,194
10kg	8.4	10	8.5	10
Total		8,041		8,588
	--------------------Current scenario-----------------		--------------------------------Scenario 03------------------------------	
Packages	TS (min)	Q (units.d^{-1})	TS (min)	Q (units.d^{-1})
120g	114.37	4,989	57.5	5,741
185g	38.55	988	20.3	1,137
860g	99.17	2,054	46.02	2,364
10kg	8.4	10	7.8	11
Total		8,041		9,253
	--------------------Current scenario-----------------		--------------------------------Scenario 04------------------------------	
Packages	TS (min)	Q (units.d^{-1})	TS (min)	Q (units.d^{-1})
120g	114.37	4,989	98.25	15,282
185g	38.55	988	46.97	3,027
860g	99.17	2,054	84.18	6,294
10kg	8.4	10	16.9	30
Total		8,041		24,633

TS – Time in minutes of the setup of dosing equipment sub process and sub process time for each type of package; Q – quantity of yoghurt manufactured daily.

According to the results of the simulations, scenarios 01, 02 and 03 present an increase in the quantity of yoghurt manufactured daily. However, they would have a limited productive capacity of 3,000L.d^{-1}, which would not meet the projected demand. Scenario 04 would meet the projected demand with an increase of 5,000L.d^{-1} of yoghurt, without compromising the operation time of the yoghurt manufacture.

CONCLUSION

In conclusion, this is a low-cost study, considering that all the labor regarding the implementation is tested in a computer. This allows for simulation of numerous scenarios and alternative solutions for the systems analyzed. Computational modeling and simulation were fundamental to the decision-taking process concerning the changes in Laticínio Funarbe. The implemented model provided an increase of 5,000L.d^{-1} of yoghurt in the productive capacity, which corresponds to a production of processed yoghurts three times higher than the current production. Browsing inside the productive process was essential in identifying the main issues that a company faces, as well as assessing the positive and negative impacts on the business in the event of these difficulties being overcome. It can also be noted that there are difficulties in implementing the changes and improvements in the real process, so that the viability and applicability of studies involving computer modeling and simulation can be evaluated.

However, the management started to implement the changes proposed in the yoghurt productive system in the factory in order to verify and prove these analyses. Thus, this study generated reference material on the use of computational modeling and simulation, which can be used as basis for the modeling of other production lines in the analyzed company or also as reference for other studies.

DECLARATION OF CONFLICTING INTERESTS

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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AUTHORS' CONTRIBUTIONS

The authors contributed equally to the manuscript.

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