DESIGN AND OPERATION OF A DAIRY PLANT BY MEANS OF A DECISION SUPPORT TOOL BASED ON THE PETRI NETS PARADIGM

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ABSTRACT
Despite a worldwide presence, the characteristics of dairy industry may vary largely from one country to another and also between the different regions of a country. Farmers can form co-operatives or operate individually, while processors may transform very different amounts of milk into a diversity of dairy products.
Moreover, the variety of dairy products that can be found in the market, the short-term expiry date of some of them, as well as the strong competition for a saturated market, lead to a complex environment, where the design and operation of the dairy factories require decision support tools for helping the decision makers.
In this paper, it is considered the development of a decision support system for improving the survival chances of dairy plants in a competitive worldwide market. This tool is based in the implementation of an optimisation process, where the performance evaluation of the feasible decisions is performed by means of simulation. The objective of the decision making covers the complete life cycle of the dairy plant, from its design to its operation (Jimenez et al. 2014).

Keywords: decision support system, dairy plant, Petri nets, discrete event systems, modeling and simulation, exclusive entities, alternatives aggregation Petri net.

1. INTRODUCTION

Despite a worldwide presence, dairy industry may vary largely from one country to another and also between the different regions of a country. Farmers can form co-operatives or operate individually, while processors may transform very different amounts of milk into dairy products.

Moreover, the variety of dairy products, the short-term expiry date of some of them, as well as the strong competition for a saturated market, lead to a complex environment, where the design and operation of the dairy factories require decision support tools for helping in the associated decision making.

In this paper, it is considered the development of a decision support system for improving the survival chances of dairy plants in a competitive worldwide market. A variety of decision support systems can be found in the scientific literature (Bruzzone and Longo, 2010), (Longo et al. 2013). This tool is based in the implementation of an optimization process, where the performance evaluation of the feasible decisions is performed by means of simulation, (Mújica et al. 2010). Several tools for decision support in the food industry have already been applied successfully (Latorre et al. 2014a), (Latorre et al. 2013b) (Jimenez et al., 2014).

Furthermore, the simulation model of the system is performed using the paradigm of the Petri nets (Piera et al. 2004), (Latorre et al. 2013a). So far, Petri nets have been applied to very different systems with success (Xiao and Ming, 2011), (Zaitsev and Shmeleva, 2011). In particular, considering a usual situation in the design of dairy plants, where the system presents a variety of alternative Petri nets or feasible structural configurations, the formalism used for developing the model of the system needs to include a set of exclusive entities (Latorre et al. 2010)(Jimenez et al, 2005).

The methodology proposed in this paper presents a model of a general middle-sized dairy factory in process of being designed (Macias and Parte, 2004). The freedom degrees in the model of the factory are associated to alternative structural configurations.

Moreover, the optimization process is based on the simulation of a set of selected feasible decisions, chosen from a solution pool. The choice of the most promising decisions is performed by means of a search methodology guided by means of a genetic algorithm (Latorre et al. 2014a).

As a result of the application of this methodology, a practical decision support tool for the design and operation of a medium-sized dairy factory is available for improving the chances of survival and success of such a facility in a competitive worldwide market.

The paper is organized as follows. Section 2 presents the main production activities developed in a dairy plant, the objective of the modeling and decision making considered in this paper.

Furthermore section 3 is devoted to the description of the modeling formalism, based on the formalism of the Petri nets. In particular, due to the fact that the discrete event system to be modeled includes several alternative structural configurations, it is convenient that the chosen formalism include a set of exclusive entities, such a compound Petri net, a set of alternative Petri net, an alternatives aggregation Petri net, or a disjunctive colored Petri net.

Section 4 will introduce the model of the dairy plant, discussing the freedom degrees, represented by undefined parameters in the Petri net model of the system.

The next section, will deal with the decision support tool based on the simulation of the model described in the previous section. In this section, it is discussed the statement of a simulation-based optimization problem, as well as its further solution, A heuristic will be used to search for the optimum in the pool of feasible solutions.

Last section refers the conclusions of the research described in this paper, where future research lines will be commented.

2. PRODUCTION IN A DAIRY PLANT

2.1. Importance of milk

Milk is one of the most complete foods that exist. Despite the fact that 90% of its composition is water, it contains many minerals and vitamins, in addition to fat, lactose and three proteins: casein, lactalbumin, and lactoglobulin. The latter compounds contain all the essential amino acids that are necessary for a balanced diet for human beings. These substances need to be supplied by the ingested food, since human body by itself cannot synthesize them.

Ideally, from the nutritional point of view, the healthiest approach consists in serving consumers milk so little modified as possible, i.e. raw milk. This is possible in the places close to those where production is performed. However, appropriate processes are necessary for guarantee the conservation when the period between production and consumption may be large.

2.2. Types of milk to be produced

There are several kinds of milk that might be found in the market, according to the industrial process developed for obtaining them:

1) Whole milk:

This product contains all the properties of cow's milk. The main treatment it receives is sterilization.

2) Semi-skimmed and skimmed milk:

From whole milk, by removing a certain percentage of fat, the different types of semi-skimmed and skimmed milk are produced. These products are suitable for those needed of a diet low in lipids.

3) Concentrated milk:

This type of milk is prepared by evaporating nearly 65% of the water contained in its composition. The concentration of the milk is performed in vacuum. Adding the same amount of extracted liquid, the original product can be reconstituted.

4) Condensed milk:

Adding a significant proportion of sugar (17 to 18 %) to a quantity of milk already concentrated it is possible to obtain sweetened condensed milk. The sweetened condensed milk is not subjected to a heat treatment after the filling and sealing of packaging. Their conservation properties are attributed to its content of lactose and other soluble sugars capable of preventing the growth of the populations of the main types of bacteria.

5) Powdered milk:

This product is obtained after a similar phase of concentration in vacuum to the concentrated milk. However, to obtain powdered milk, the first stage is followed by a process of drying in cameras. The overall process consists in the evaporation of the water at low pressure and temperature of less than 50 ºC. At the end of the process, a powder is obtained that retains all the nutritious elements of the original fluid and most of its vitamins.

6) Fermented milk:

In fermented milk, germs are eliminated by the action of heat. After this process, the product is inoculated with ferments, mainly lactic, in order to obtain the resulting dairy product.

2.3. Industrial processes applied to milk.

There are different types of industrial processes for the treatment of the milk in order to extend its shelf life once packed for its consumption:

A) Processes based on the application of cold:

The implementation of a temperature of approximately 4 °C prevents microbial blooms. However, the cold does not improve the bacteriological quality of the milk, because the germs are not usually destroyed.

B) Processes based on the application of heat:

To date, different conservation treatments for milk based on heat transfer have been applied:

B.1) Pasteurization at low temperature:

This technique consists in the application of a temperature of approximately 63 ºC in the milk for a period of half an hour. The main drawback is the alteration of the properties of the product that represents a time interval so long.

B.2) Pasteurization at high-temperature, short-time (HTST):

In this case the temperature applied to the flow of milk is about 72ºC. This process lasts from 15 to 20 seconds. The pasteurization provides protection for about 3 days to the product.

B.3) Pasteurization for extended shelf life (ESL):

The sterilization of the milk is achieved in this case, by applying a temperature of 90 to 95 ºC for a few seconds.

B.4) Sterilization:

While pasteurization aims at reducing the number of pathogens in the milk so they are unlikely to cause disease, sterilization is intended for the elimination of all the microorganisms present in the milk. This result is achieved by the application of a temperature around

115ºC during a time that varies between 15 and 20 minutes.

B.5) UHT:

In this case, the milk is processes by a ultra high temperature. This process raises the temperature of the milk to over 130 ºC or more, during one or more second.

2.4. Essencial stages in the production of milk.

The production of the milk passes through several essential stages. The first of these stages is milking. At this step the harvested milk should be kept in refrigerated tanks at 3ºC of temperature, preventing the proliferation of microorganisms in the product.

The next stage is described below:

A) Transport:

To keep the milk in perfect conditions, this process must be performed at a constant temperature, equal to the storage temperature of the product in the previous stage. The shipping of the milk from the milking facilities to the processing and packing plant is performed on a daily basis.

B) Pretreatment of milk:

This second stage prepares the product for sterilization. It consists of the following phases:

B.1) Checking the acidity:

This parameter should be known since if the acidity of the milk is very high, the subsequent processing will be defective. This is due to the fact that the following stage of heat treatment of acid milk would cause precipitation of certain substances on the inner walls of the ducts of the heat exchangers. For this reason it is not convenient to use milk with a high acidity.

B.2) Filtering:

The milk is subjected to a filtration or to centrifuge purification in order to remove macroscopic impurities that could eventually be contained. This clarification responds to a double purpose: the first is a commercial one, while the second is more technical. The first is obvious, because this process improves the quality of the product under the eyes of the consumer. The second objective of this phase consists of minimizing the macroscopic impurities on the internal surfaces of the ducts of the heaters.

B.3) Standardize:

The percentage of fat content of the milk received in dairy plants may vary in significant proportions. For this reason, the milk is subjected to a process of standardization by special separators after heating the product to 30 or 35 °C. The quantities of cream (fat) recovered in this way are delivered for consumption or used for the manufacture of butter.

B.4) Creaming:

This process is an alternative to the previous one because that consists of a implementation of the a similar but more intense process. It is performed on centrifugal separators producing milk with a low fat content (skimmed or semi skimmed) and fat. This second product is used for the production of butter.

The last of the stages of processing milk consists of sterilization and packaging:

C) Treatment:

The packaging of milk requires a prior stage of sterilization to minimize the risk of subsequent microbial proliferation. Milk is one of the foods that best responds to the treatment known by the name of high temperature – short time (HTST). In the particular case of the milk, this process is called UHT treatment. It consists of a sterilization by continuous flow in which the product reaches a temperature over 135 ºC for a few seconds. This method consists of the following phases:

C.1) Warming up:

During this stage the temperature of the milk is increased as quickly as possible until the value required by the sterilization of the product is reached.

C.2) Sterilization:

The high temperature of the food is kept for a minimum period of time that ensures the total destruction of the microorganisms present in the milk. Their duration should be the minimum possible to preserve as much as possible the properties of the milk.

C.3) Cooling:

To proceed to the packaging, the flow of warm milk should be cooled to a temperature under 35 ºC. In particular an appropriate value is about 4 °C. In the same way as the previous stage of warming up, this step should be done as quick as possible. The goal of this process is to minimize the time at which the milk is exposed to high temperatures, preserving, in this way, the product from nutritional and organoleptic alterations by effect of the temperature.

D) Sterilization of the packaging:

This step differs from the sterilization of the milk on the technology used in its development. In this case, a chemical sterilization is applied. The bactericidal agent should be easy to apply and to remove as well as fast and efficient in its operation. The substance most commonly used for sterilizing the packages is the oxygenated water (hydrogen peroxide). The bactericidal action of this substance is effective at high temperatures.

E) Packaging:

The flow of sterilized milk can be packed in accordance with the rate of sterilization. Another possibility consists of the storage in aseptic conditions of the sterilized milk, before packing. This latter technique allows greater freedom in the choice of the filling speed. The process of filling and sealing should be performed in completely aseptic conditions, in order to not neglect the sterilization process of the milk and its container previously made.

F) Distribution:

This phase consists of the storage of packaged milk, its transport, and subsequent distribution to the points of sale.

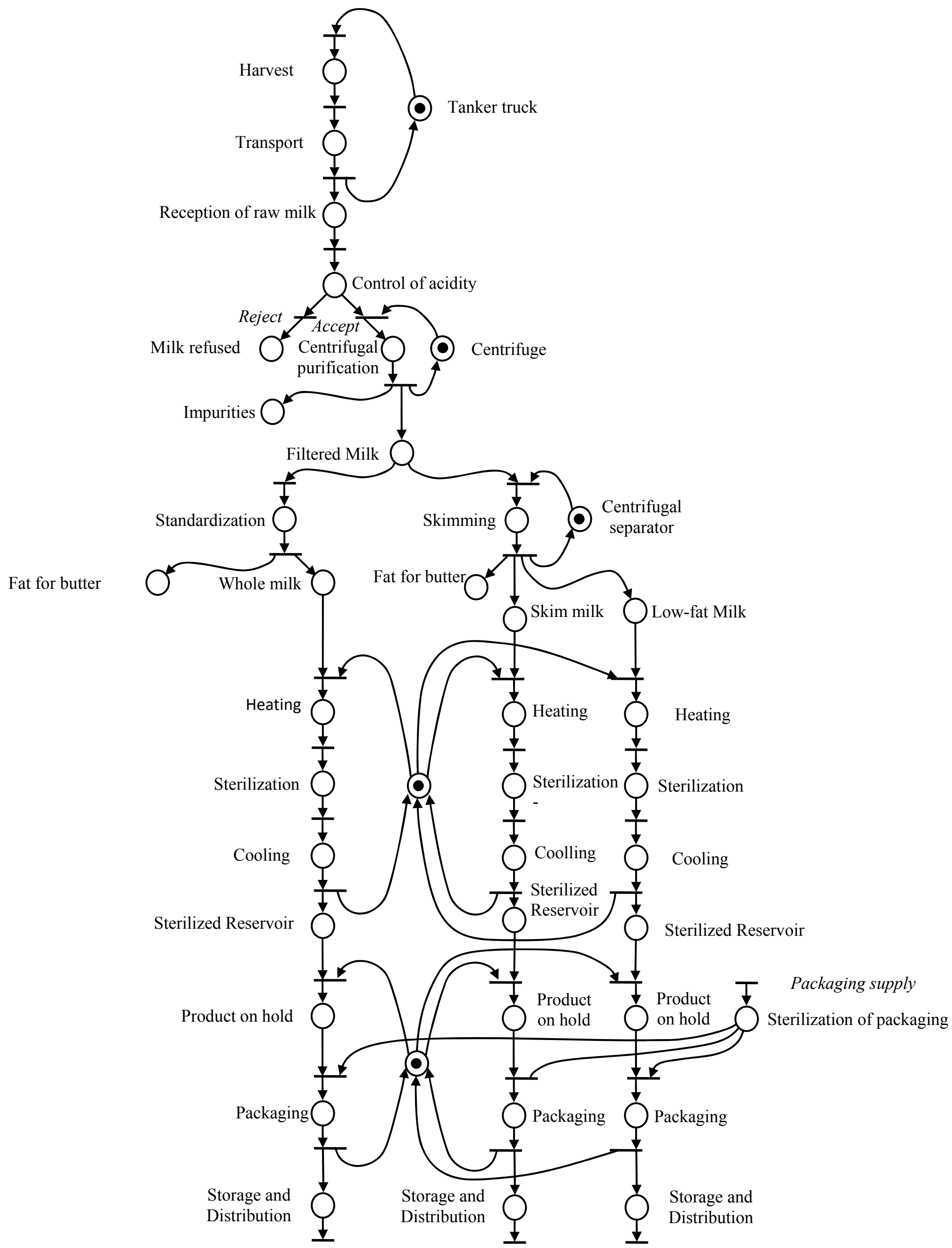

Figure 1. Petri net model of a dairy plant.

3. MODELING FORMALISM

In order to develop a model suitable for a decision support system based on simulation, an appropriate formal language has to be chosen.

The formalism chosen in this paper is based in the paradigm of the Petri nets, due to its proven suitability for the analysis, simulation, and optimization of discrete event systems (Silva 1993), (David and Alla 2005), (Jensen and Kristensen 2009).

Definition 1. A Petri net system is a 5-tuple $R = (P, T, \text{pre}, \text{post}, \mathbf{m}_0)$ such that:

i) P is a non-empty set of places.

ii) T is a non-empty set of transitions and $P \cap T = \emptyset$.

iii) pre and post are functions that associate a weight to the directed arcs between the elements of the sets P and T, in the following way:

iv) pre: $P \times T \rightarrow \mathbb{N}^*$ and post: $T \times P \rightarrow \mathbb{N}^*$, where $\mathbb{N}^*$

is the set of natural numbers, excluding zero.

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v) $\mathbf{m}_0$ is the initial marking, such that $\mathbf{m}_0$: $P \rightarrow \mathbb{N}^*$.

□

A discrete event system in process of being designed may contain a set of freedom degrees, some of them corresponding to the structure of the system. The model of such a system should be able to describe with the alternative structural configurations of the discrete event system.

An intuitive approach for modelling a discrete event system with alternative structural configurations may be to develop so many models as structural configurations (Latorre *et al* 2012).

Nevertheless, this approach uses to be ineffective, since the whole set of alternative Petri nets usually shows large amounts of redundant information among the models (Latorre *et al* 2014b).

A more appropriate formalism for developing efficient simulations is the alternatives aggregation Petri nets. The mechanism for the decision making associated to the choice of one of these alternative structural configurations is represented explicitly by means of the so called choice variables (Latorre et al. 2013c).

Definition 2. Given a discrete event system with n alternative structural configurations, a set of choice variables can be defined as $S_A = \{ a_i$ Boolean $| \exists! \ k \in \mathbb{N}^*, k \leq n$, such that $a_k = 1 \wedge \forall j \in \mathbb{N}^*, j \leq n, j \neq k$ it is verified $a_j = 0 \}$, where $|S_A| = n$, and the assignment $a_k = 1$ is the result of a decision.

□

Once the concept of choice variable has been introduced as a way to represent in a Petri net model of a discrete event system a set of alternative structural configurations, it will be defined the formalism called alternatives aggregation Petri nets.

Definition 3. An alternatives aggregation Petri net can be defined as a 10 tuple $R^A = (P, T,$ pre, post, $\mathbf{m}_0$, S_α, $S_{valnstr\alpha}$, S_A , f_A, $R_{val\gamma}$), where

i) S_α is a set of undefined parameters.

ii) $S_{valnstr\alpha}$ is the set of feasible combination of values for the undefined parameters in S_α.

iii) S_A is a set of choice variables, $S_A \neq \emptyset$ and $|S_A| = n$.

iv) f_A: $T \rightarrow f(a_1, \ldots, a_n)$ is a function that assigns a function of the choice variables to each transition t such that type[$f_A(t)$] = boolean.

v) $R_{val\gamma}$ is a binary relation between $S_{val\gamma}$ and R_A.

On the other hand, f_A: $S_A \rightarrow T$, assigns a choice variable to a single or several transitions of the Petri net, and if $S_A' = \{ a_1 , a_2 , \ldots , a_k \}$ is the set of every choice variables associated to the transition t, then the guard function of the mentioned transition is $g_A(t) = a_1 + a_2 + \ldots + a_k$.

□

4. MODEL OF A DAIRY PLANT

In order to develop an appropriate model for a general purpose dairy plant, the different subsystems that can be implemented in such a facility will be overviewed in the following paragraphs.

1) Milking facilities:

The facilities in which the animals are kept and/or milked present a degree of automation that increases with time. It is necessary to count on refrigerated tanks with controlled temperature to store the harvested milk up to the time of their transport.

B) Trucks:

Isotherm tankers carry the milk to the dairy facilities.

C) Cooled tank:

Until the time of its processing, the milk is kept in conditioned deposits that optimize the preservation of the product. A temperature of 3 ºC prevents the growth of the microbial content of the product.

D) Centrifugal separator:

This equipment allows removing from the product a desired amount of fat, as well as developing the stages of filtration and standardization. For decreasing the viscosity of the milk and to increase the efficiency of the process of separation, this system is usually operated at a temperature around 35 ºC.

E) Heat exchanger:

A treatment received by the milk before its packaging consists of a thermal sterilization in a heat exchanger. Another heat exchanger cools the output milk under 35 ºC.

F) Sterile Reservoir:

It consists of a reservoir that adapts the rates of sterilization of the milk and its packaging. This stages provides flexibility to the production process.

G) Sterilization equipment for the packaging:

The implementation of the chemical agent bactericidal, usually hydrogen peroxide, is carried out in different forms, depending on the circumstances of the manufacturing process:

H) Aseptic filler:

This equipment must operate under aseptic conditions. Performs the filling and subsequent closure of the sterile packing.

A graphical representation of the Petri net model of a general dairy plant can be seen in figure 1.

5. DECISION MAKING

This paper has the purpose of describing the construction of a decision support system for a dairy plant, from its design process to its operation.

In the previous section, a model of the system has been described. In the following section, the rest of the elements that constitute a decision support tool will be overviewed.

The decision support system will be based on the statement of an optimization problem, where the objectives of the optimization will be quantified in the so called cost or objective function.

A heuristic search, such as the genetic algorithms, or the ant colony, will be used for finding the most promising solutions in the solution space. Simulating the behavior of the model under the scenario imposed by the selected solutions it is possible to compare the relative quality of them and, so, to choose the best one.

6. CONCLUSIONS

As it has been seen in this paper, a model of a dairy plant can be developed, using the paradigm of the Petri nets, with the purpose of developing a decision support system for the design and operation of such a facility.

As open research lines, it can be considered the application of this methodology to a variety of dairy plants, as well as to improve the described model by including other uses of the milk harvested, such as yoghurt, cheese, cream, or butter manufacturing.

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