Journal of Food Engineering 98 (2010) 1–12

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Transient analysis to design buffer capacity in dairy filling and packing production lines

Junwen Wang, Yao Hu, Jingshan Li *

Dept. of Electrical and Computer Eng. and Center for Manufacturing, University of Kentucky, Lexington, KY 40506, United States

ARTICLE INFO

Article history:
Received 24 August 2009
Received in revised form 28 October 2009
Accepted 15 November 2009
Available online 20 November 2009

Keywords:
Transient analysis
Dairy production line
Buffer capacity
Filling and packing

ABSTRACT

In dairy filling and packing lines, due to line unbalance, extra time is required for the upstream filling station with lower production rate to work in advance to build work-in-process so that the downstream packing station can operate at a higher productivity during a shift to achieve the desired production volume. In this paper, we present a study to determine the buffer capacity in such lines through transient analysis. We evaluate the system production rate and work-in-process during transients, the necessary extra time of the filling station, the system operating time, and the blockage and starvation of the filling and packing stations, respectively, for different buffer capacities. In addition, we investigate the impacts of filling station efficiency and initial inventory on system performance.

1. Introduction

Food production is an essential part affecting our daily life and overall economy. In particular, dairy products play a critical role. In 2006, milk and other dairy products valued $20 billion (USA Economy in Brief, 2006). Therefore, to design and operate highly efficient dairy production systems is necessary and important.

Substantial amount of research effort has been devoted to analysis of production systems (Li et al., 2009; Li and Meerkov, 2009). However, less study is focused on food or dairy productions. In addition to the typical problems encountered in many production systems, dairy production lines have some specific issues to deal with, such as unpredictable demand and perishable nature of the products. For instance, extra long failure may cause the in-process materials to be scraped due to quality deterioration during the stoppage. Tardiness and earliness of production are both unfavorable, and exact production volume to meet the demand is typically required. These have proposed challenges for design and operation of dairy production systems. Devoting research effort to improve the efficiency of dairy and other perishable food productions is important.

In addition, most of the manufacturing system research emphasizes on steady state analysis, while transient behavior is less studied. But in a manufacturing environment, production transients, i.e., the process to reach steady state, are of significant practical importance. It has been shown that the production losses during transients can be as much as 12% (Meerkov and Zhang, 2008). In some production lines, production has to start with zero inventory. For example, in automotive paint shops, vehicles have to be cleared from the buffers after electrocoating process at the end of the shift to prevent additional chemical reactions. In dairy production lines, no products can be left in the buffers at the end of the shift to avoid perishing. Thus, such systems will begin with empty buffers in next shift, which will lead to production loss due to transients. On the other hand, some systems operate at a "float" regime, where the slower upstream department will work overtime to accumulate inventories after the shift ends (or before the shift starts) so that the faster downstream department can work at full speed in subsequent shift without starvation. Such system can be observed in automotive assembly lines where buffers between sections are pushed to be full by the end of the shift. In yogurt production lines, since no dairy products can stay in the buffer at the end of the shift, the upstream department may need to work extra time before the shift starts (if it is slow) to build up inventories, which is another kind of "float". These examples show that transients play an important role in production system operations. Such a role becomes more critical in dairy production lines. For example, due to demand variation, the operating time of a dairy production line may vary everyday. Then, questions on how to operate such systems during transients, how to select appropriate buffer capacity or "float" and, how to schedule extra operating time to meet demand everyday in order to reduce production losses and to reach steady state quickly, are of significant importance.

Although transient analysis is important, it is almost unexplored. Only a few papers are discovered to address the transients

* Corresponding author. Tel.: +1 859 257 6262x450; fax: +1 859 257 1071.
E-mail address: jingshan@engr.uky.edu (J. Li).

0260-8774/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jfoodeng.2009.11.009

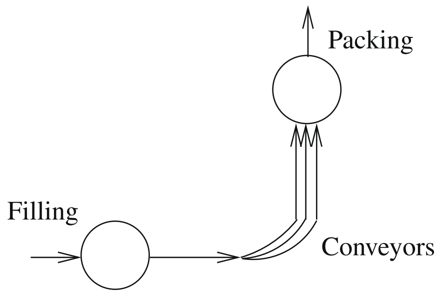

Fig. 1. Filling and packing dairy production line.

for simple systems, and no research has been found in the current literature study transients in dairy production systems. The goal of this paper is to contribute to this end. Specifically, we investigate the transients in a filling and packing dairy production system, and design the buffer capacity to ensure satisfaction of demands.

The layout of a filling and packaging dairy production line is shown in Fig. 1. Empty cups are filled with yogurt or cream at the filling station. Through two sections of conveyors, those cups are transported to the packing station. After packing, the dairy products are prepared for shipping.

Although the system structure seems simple, the problem is not easy to solve. Since the filling station typically has much more complex operations, thus, it has lower throughput compared with the packing station. In this case, the packing station may be starved so that the system operates at lower production rate. To alleviate this, the filling station can start the work earlier than packing station, i.e., the filling station will work extra time (before the shift starts) to build up inventories. When a new shift starts, the packing station can work at full capacity without starvations. However, the question is how large the buffer (referred to as "surge" in the dairy farms where the study was carried out) capacity should be and how earlier the filling station should begin work so that the starvation of packing station will be minimum? This paper intends to address such questions.

The remainder of the paper is structured as follows: a brief literature review is presented in Section 2. Section 3 describes the model of the line under consideration and introduces the analysis. Finally, conclusions are given in Section 4.

2. Literature review

Unpredictable demand and perishable nature of the products are important features in dairy production. To account for this, research effort has been devoted to develop optimal scheduling and planning methods. For example, Entrup et al. (2005) develop mixed integer linear programming (MILP) models that integrate shelf life issues into production planning and scheduling. Three different MILP models for weekly production planning are presented. A case study in yogurt production line is introduced. Similarly, Doganis and Sarimveis (2007) also use MILP approach to develop optimal scheduling policy in yogurt production lines. Some special features that characterize yogurt production are considered, such as different fat contents and flavors of various products, sequence dependent setup times and costs, etc. Soman et al. (2004) introduce combined make-to-order (MTO) and make-to-stock (MTS) strategies in food production system to counter an increasing variety of products with varying logistical demands. A comprehensive hierarchical planning framework is proposed for MTO–MTS situations. A hybrid two-stage planning technique for the reduction of food overproduction waste (OPW) and improved utilization of resources is introduced by Darlington and Rahimifard (2007). In addition to addressing the supply chain issues in food production, the reliability of food processing equipment is also analyzed to achieve high productivity. Liberopoulos and Tsarouhas (2005) present a statistical analysis of failure data of an automated pizza production line to guide food product machinery manufacturers to improve design and operations of the production lines. Tsarouhas et al. (2009a,b) also carry out case studies on the reliability and maintainability of strudel and cheese production lines. To improve the performance of food production lines, Liberopoulos and Tsarouhas (2002) present a cost-effective way of speeding up a croissant-processing line by inserting an in-process buffer-refrigerator in the middle of the line. Somsen et al. (2004) intorduce a case study at a poultry-slaughtering line. A production yield analysis (PYA) method is proposed to improve the raw material yield.

As mentioned before, only limited publications address the transient behavior in production systems. Narahari and Viswanadham (1994) investigate situations where transient analysis may be needed. Two specific examples are introduced where transient analysis is needed, the computation of distribution of time to absorption in manufacturing systems with deadlocks of failures, and the analysis in multiclass manufacturing systems with significant setup times. Mocanu (2005) considers the transient behavior of the buffer between input and output flows. A partial differential equation describing the evolution of probability density function of a buffer is used to derive a numerical solution. However, no system-theoretic properties have been analyzed. Meerkov and Zhang (2008) investigate properties of transients of production rate and work-in-process for Bernoulli machine lines. It is shown that the transients of production rate and work-in-process are determined by the second largest eigenvalue of the transition matrix of the associate Markov chain and the pre-exponential factor. The settling time and production losses due to transients are also analyzed. To avoid the production losses during transients, it is suggested that all buffers are initially at least half full. In addition, Meerkov and Zhang (in press) study the smallest float necessary and sufficient to obtain the system throughput equal to that of the department with highest throughput in isolation. The design of a lean float is proposed and a practical recommendation to select float capacity is presented.

As one can see, the analyses of transients and food production lines are limited, and no results have been discovered in the current literature addressing the transients in dairy production systems. This paper is intended to contribute to this end.

3. Modeling and analysis

3.1. Model

To analyze the performance of the filling and packing system, a Bernoulli two-machine model is developed (Fig. 2). The following assumptions define the machines, buffer and their interactions.

(i) The system consists of two stations and a buffer separating them.
(ii) Both stations have identical processing times. The time is slotted as cycle time.

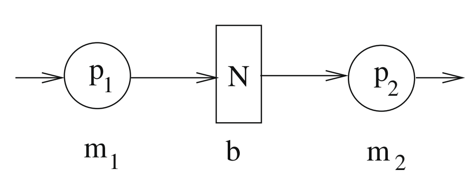

Fig. 2. Bernoulli model of filling and packing line.