FUZZY TRACEABILITY: A PROCESS SIMULATION DERIVED EXTENSION OF THE TRACEABILITY CONCEPT IN CONTINUOUS FOOD PROCESSING

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Abstract: Liquid food production often involves continuous processing. This leads to problems in traceability systems due to mixing zones and therefore indistinct batch identities causing difficulties with regard to withdrawals or recalls. This article outlines the possible use of the concept of dynamic simulation to improve the handling of batch identities in continuous production of liquid food, a concept we call *fuzzy traceability*. The concept is illustrated with a realistic example from a real dairy process line.

Keywords: traceability; internal traceability; fuzzy traceability; dynamic simulation; dispersed flow; continuous production; virtual batch; food safety.

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DOI: 10.1205/fbp07044

0960–3085/07/
$30.00 + 0.00

Food and Bioproducts Processing

Trans IChemE,
Part C, December 2007

INTRODUCTION

Large-scale food production in a global market poses a potential threat to society due to the potential large-scale public health consequences of unsafe food reaching retailers and consumers. This health and safety aspect is the foundation of legislation concerning traceability in the food industry, where the aim is to establish means of limiting the consequences of food of unacceptable quality. The need for the development of food traceability is clearly demonstrated by the outbreak of bovine spongiform encephalitis (BSE, 'mad cow disease') leading to New Variant Creutzfeld-Jakob Disease in humans (Loader and Hobbs, 1996; Palmer, 1996).

In 2002, European Union enacted Regulation 178 which is primarily concerned with this public health aspect of traceability. It requires all food businesses to be able to identify for each of their products the immediate business supplier and the immediate business customer. The legislation thus covers only one aspect of traceability, chain traceability in the terminology of Moe (1998). This is a well studied subject.

The other aspect, *internal traceability*, concerns the the ability to trace a batch within the business. Moe (1998) provides a list of seven advantages of internal traceability. One of them is the possibility of avoiding uneconomic mixing of high and low-quality raw materials. Another is that it provides better grounds for implementing IT solutions to control and management systems. This is important for the market communication by the ability to respond quickly and transparently to the public in case of food with unacceptable quality.

The advantages of internal traceability are not confined to food and related areas, for example Peyret and Tasky (2004) demonstrate the feasibility of a traceability system for asphalt quality parameters from the plant to the asphalt-pavement site.

One cornerstone in all current traceability systems is the definition of a *batch*. Kim *et al*. (1999) define a traceable resource unit (TRU) as a unit with unique characteristics that no other unit can have, from a traceability point of view, in a batch process. However, as Moe (1998) states, when dealing with continuous processing, defining a TRU is difficult. This applies to both processing conditions and material TRUs.

For example, in continuous processing of liquid food, e.g., milk production in a dairy, it is difficult to claim that two final products, based on different raw materials (source TRUs, e.g., silo tanks with milk from different farms), should be considered as two separate batches (TRUs) when they are produced sequentially by *change on the fly*.[1] It would be even more difficult to claim that only a minor part of the final product is a separate TRU due to different processing conditions during a period of production (e.g., unintentional temperature variations during pasteurization or intentionally adjusted set-point of fat content in milk). In case of withdrawal or recall the two original batches would most certainly have to be considered a single batch after packaging due to the uncertainty in mixing in the production system. This problem will remain even if an IT solution (enterprise quality management, EQM) is implemented in accordance with Deasy (2002) to monitor the integrity data.

Depuy *et al*. (2005) are discussing intentional dispersion in a sausage production, whereas we address *unintentional dispersion* in mixing zones in connection with continuous liquid food production. For example, one silo tank of milk, intended for one batch of consumption milk, may unintentionally appear in three batches of consumption milk due to mixing at the interfaces of the preceding and succeeding batches when the milk is pumped through the system of pipes, valves and other processing equipment. With the terminology of Depuy *et al*. (2005), the intended *downward dispersion* is 1, but unintentionally it becomes 3 even though the level of cross contamination is very low.

Thus we propose that for not critical use, the traditional deterministic approach be complemented with *fuzzy traceability*. By *fuzzy traceability* we mean recognition of the fact that there is a certain probability that an unintended source material may be present in a product, and we must learn to live with the consequences. This means we should concentrate on quantifying the probability of finding an intended or unintended component in a product. A more straightforward interpretation of this is to calculate the unintended dispersion-caused composition of finished product.

Below it is shown how dynamic simulation can be used to predict and analyse system behaviour, particularly concerning mixing zones, and thus provide the necessary information for the *fuzzy traceability* concept. The dynamic simulation can be used as an integral part of traceability systems with the aim of optimizing the management of batch separation concerning the size of TRUs, costs, market communication and health aspects.

BATCH IDENTITY

Processing of food involves equipment cleaning in order to maintain a high hygienic standard. In the case of liquid food, cleaning is normally performed by pumping water and detergent through the production equipment, i.e., cleaning-in-place (CIP). Cleaning between two product batches is taken to mean that the batches cannot contaminate each other. Therefore, in batch tracing systems, cleaning is used as a distinct separator between batch identities, which according to Cocucci *et al*. (2002), is 'of primary importance'.

This means that if/when food of an unacceptable quality has been discovered, its corresponding batch identity, or TRU, can be established by means of the traceability system, leading to reprocessing, withdrawal or recall of all the items belonging to that batch. In the simplest kind of traceability system, each individual consumer package in a batch need only have one common batch identifier, and information about *when* in the batch it was packed, early, late or by ordinal number, is not available. However, in reality each consumer package is, or can fairly easily be made, identifiable by for example a time stamp.

Production parameters such as silo changes, temperatures, pressures and compositions can be logged, and if a way can be found to correlate the production parameters as a function of time along the processing line to the product in the package, variations in the quality of food from the same batch can be traced and related to variations in the production parameters. A traceability system capable of this could be used to minimize rejects or withdrawals from *the same batch*. Thus, using the terminology of Kim *et al*. (1999), the batch will consist of many TRUs.

A special case of this is the variation of composition due to mixing between two batches or products that are produced in sequence without being separated by cleaning or water flush. For example, the production of a certain amount of consumption milk may require that two or more silo tanks (source TRUs), containing milk with different origin, are run through the process line sequentially, without any interrupt for intermediate cleaning or water flush. Then a system that can predict the actual composition in each consumer package would be valuable from a traceability point of view.

Cleaning is costly since it occupies the production equipment and requires cleaning agents, energy and manpower. Hence, there is an incentive to clean as seldom as possible. However, this implies that withdrawals or recalls will be large due to large production batches (produced from many source TRUs) between cleanings. Therefore, if batch sizes—with cross-contamination criteria defined in the traceability system—could be kept small and well controlled, from a traceability point of view, even without cleaning between production batches, this would be a great advantage. Thus we introduce the conception *virtual batch* [see Figure 1(a)–(c)]. For example, the cross-contamination criterion for a *virtual batch* X of consumption milk could be defined as the collection of all packages that contain pasteurized milk with a composition of $\geq$99.0% of not pasteurized milk from silo tank Y. Thus, a system that can predict the composition during batch changes would help the traceability system to keep track of such virtual batches when no physical batch separation (cleaning or water flush) has taken place.

In contrast to 'guaranteeing product identity' as stated by Cocucci *et al*. (2002), this is an alternative where more flexible criteria are used in order to maintain high production efficiency while still having a good control of the traceability.

`FUZZY´ BATCH SEPARATION BY SIMULATION

Beside the characteristics of continuous food processes described in the introduction above, such processing of liquid food, e.g., milk and juice, often leads to problems with indistinct batch separation. In many of these processes, the food from different batches undergoes final processing just before it is packed, e.g., UHT[1] pasteurization of milk without an aseptic buffer before packaging. Changing batch means that the source (a tank) is changed by activation

[1]With *change on the fly* we mean that a product (source TRU) is changed to another directly without any flush or cleaning between. In other words, the succeeding product chases the preceding product out of the system.

[1]Ultra-high temperature.