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Tracking and Tracing Products in Continuous Processes

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Summary

Traceability is important for quality control and process improvements, but it is often difficult to track or trace products in continuous process production, since products and product lots are difficult to separate. In the past, engineers have had to rely on coarse calculations for tracing products, but new possibilities emerge as new technology and models are being used. In this paper, we present experiences from applying chemical and RFID tracers to achieve traceability in continuous flows, with examples taken from the minerals processing sector.

Keywords

RFID, Experiments , Tracers, Logistic regression, Process industry, Time series analysis

The Importance of Traceability for Improving and Controlling Quality

Failing equipment, human errors and variation of raw material properties often lead to product defects that may be harmful for customers and customer feedback is thus one important source of information that may guide improvement work. When customers complain, we need to understand why the customers were unsatisfied and what the defects were. When we know what caused the complaints, regular methodology includes tracing a defective product to where the defect had its origins. This could for instance include investigating from what raw material batch the product was produced, when it was produced and if the production process' control system did indicate that something was unusual during production.

In processes where it is possible to mark individual products in early process steps, creating traceability may be uncomplicated, which for instance is the case for many types of parts production. The possibility to easily mark products is, however, much more difficult in continuous production. Here we will discuss some difficulties and possible solutions to obtaining good traceability for such products and processes. The paper starts by discussing traceability from a continuous process perspective, and then the paper focus on two approaches for improving continuous process traceability, simulations based on liquid tracers and modeling based on radio frequency identification (RFID).

The Difficulty of Maintaining Traceability in Continuous Processes

Many products are not by themselves valuable enough to bear the cost of an individually based marking system, other products cannot be marked in any physical way. With current technology, it is for instance not feasible to mark every little rock in a shipment of gravel or even the grains in a shipment of industrial diamonds or gold powder. When products are in granular, liquid or slurry states, we may also find that product mixing will occur when the product is handled, within the production process or when the product is transported. When the product uninterruptedly passes through different process steps, such as often is the case in the process industry, we thus face both the difficulty of having products continuously mixing and individual particles being too inexpensive to be marked. Furthermore, the product may be subjected to hostile environments such as high temperatures or pressures, and the product may change physical states. Any methods to mark products in such environment must be able to cope with such stresses.

Towards Continuous Process Traceability

Usually, we cannot recall and recollect the processing history of every particle or atom in a continuous process, and traceability thus becomes a statistical property rather than a deterministic. Customer complaints may, at best, be traced to an interval where it is likely that most of the product passed different process sections. To obtain proper interval estimates, we need data from which we may obtain the statistical distributions of the property in question. Instead of marking all individuals, we may mark a selection of individuals that has properties we would like to detect. We may for instance charge some grains of sand with radioactive elements so that these grains can be detected through the process and thereby generate data for estimation of the residence time distribution. The knowledge of how the residence time distributions changes may then be used for modeling purposes. Observe, however, that the use of tracers for modeling purposes relies on the assumption that the tracer particles behaves as the product it is supposed to model.

Here it is convenient to change from discussing individual particles or infinitesimal volumes of liquids into product lots. A lot is a collection of material which can be seen as a unit, and we may use the lot description for tracking purposes, whether or not the process is subdivided into such physical lots. In a continuous process, we will experience mixing of the lot, so the content of the lot entering a process section will seldom match what is in the lot when it leaves the section [1].

Process Modeling Approach

Often, real-time process data are not available or cannot for other reasons be used for tracking and tracing products within processes. For these cases, process modeling may aid process control when products with known disturbance features are tracked through the processes, or for tracing products to where and when a process disturbance must have been initiated. The modeling step needs to be based on the prevailing conditions of the modeled processes such as, for instance, temperature, reaction speeds, flows, volumes, concentrations et cetera. In simple cases, it may be possible to connect process events to product properties and create models from regular process data. Time series analysis may be used in slightly more difficult cases [2].

Where process knowledge is lacking, the model needs to be calibrated experimentally. Kvarnström and Bergquist[3,4] investigated a pelletizing plant where a product with special properties were to be produced in a production process that were not intended to produce different products, but to continuously produce one product only. Moreover, since the process was optimized for producing only one product, it lacked special arrangements for monitoring large shifts such as when products would change, and different storage facilities for different product types between the different process sections. The engineers therefore needed to know when the product entered different sections, and they also needed better knowledge of how the special product could be produced with as little interference with the production of the regular product. The engineers therefore decided that a simulation model was an appropriate measure to gain the needed knowledge. The simulation model was to be based on a combination of qualitative process knowledge and quantitative empiric data obtained from tracer experiments, regular process measurements and blueprints.

The flow characteristics of are important from traceability and prediction perspectives. If we assume that there are no means for active, regulatory control, flow induced mixing will reduce the amplitude of product disturbances such as chemical variations. On the other hand, such mixing will also prolong the time these disturbances are acting on the output.

On the other extreme, we may have flow where there is no mixing, commonly referred to as *plug flow*. Any disturbance entering a section without mixing and control will be present to the same amplitude and duration in the exhaust, only delayed by the time it takes for the product to pass the section. Process sections with high degree of mixing containing large volumes will therefore greatly reduce the amplitude of the disturbance. However, the disturbance will remain in the process much longer which may be troublesome if the product is sensitive to that disturbance. A water plant taking fresh water from a large lake infected with some bacteria may for instance be worse off if the water of the lake is continuously mixed rather than a plug flow between the fresh water inlet and exhaust.

Storage volumes are also important for the propagation of disturbances. However, it is not certain that the volumes taken from the blueprint, together with readings of the surface level of a container are enough for modeling purposes. Pockets of stagnant flow will reduce the active volume of storages regardless of media but certain media such as slurries are known to deposit powder in sections where the flow is stagnant The active volume content of a container for slurries may thus be a function of both the flow system of the process setting as well as the time since the container was cleaned.

Process Modeling Approach: Building the Flow Simulation Model

To accurately estimate the flow behavior of the various process sections are thus important for the performance of any flow simulation model. However, initial analyzes of the studied process showed that most of the residence time could be attributed to two storages where flow properties were unknown. By adding a tracer to the largest of these storages, we saw that the flow could be approximated as a perfectly mixed flow with a stagnant pocket. These results were implemented in the simulation model and then the two extremes, completely mixed or plug flow, were both used to check if also the second-largest container needed tracer experiments. The flow behaviors of the remaining containers were based on engineering estimates of flow behavior. The overview of the research process is given in Figure 1.

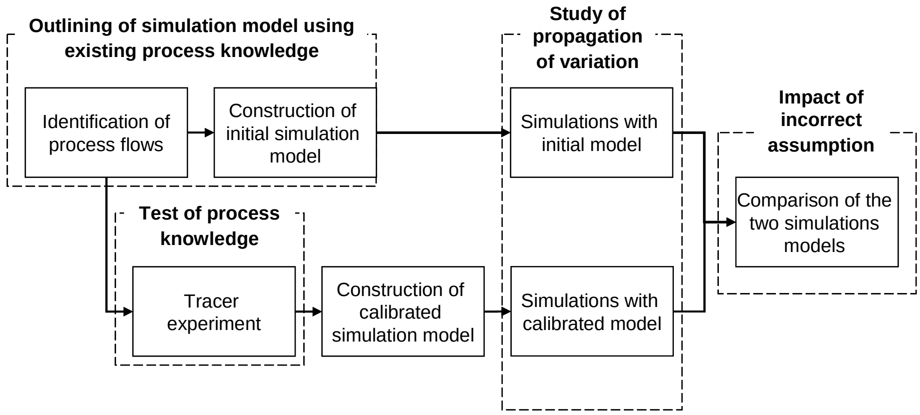

Figure 1: The research activities for the simulation modelling, from [4].

Process Modeling Approach: Simulation Results

The simulation results are presented in Figure 2. Originally, the model was designed to simulate the process with all variables being constant, but this induced unnecessary error. The model was therefore altered to also include current updates of measured field data which improved the fit between the simulation output and the analysis data, see Figure 2.

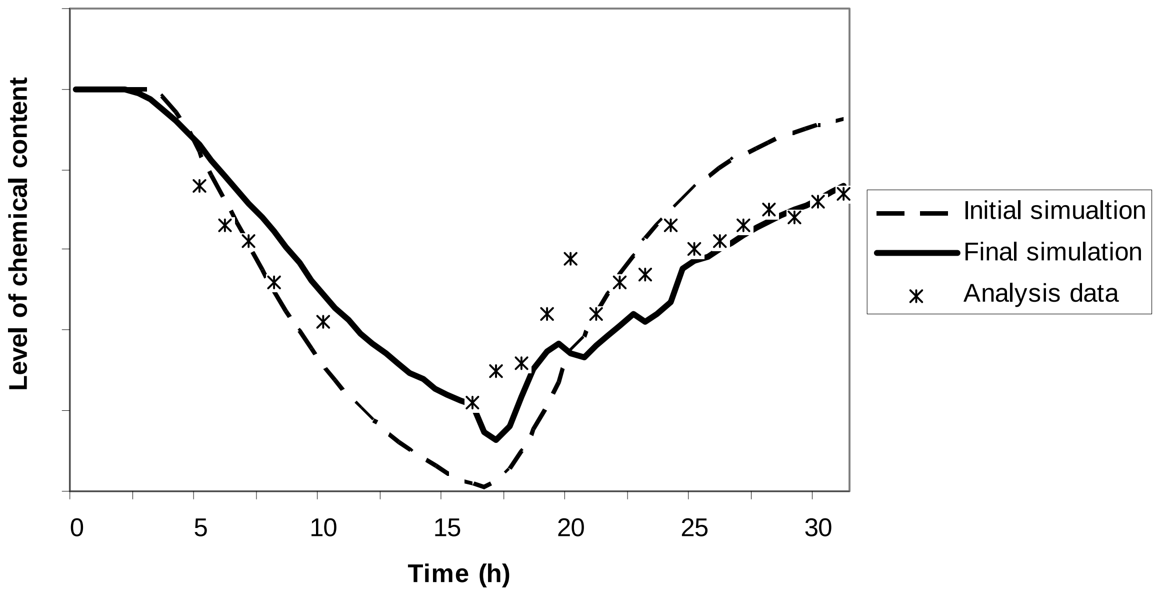

Figure 2. Model predictions and lab results of chemical content. From [4]

Process Modeling Approach: Discussion

The two flow alternatives used in the second largest container gave only small changes in total residence time of the products flowing through the section, and the model was considered useful without further calibration. The laboratory results seen in Figure 2 were also used to fine-tune the model. However, the adjustments due to laboratory calibrations were small and the improvement of the simulation results was considered marginal.

RFID Markers Approach

Simulation models are not always possible means to create traceability, for instance where storage volume measurements or estimations have large errors, or where information of product transports is not recorded on an accessible format. The distribution chain of iron ore pellets from the Swedish mining company LKAB to their customers around the world was an example of such a chain. The distribution chain included two longer transports by boat and train, three large intermediate storages, and many conveyor transports in-between. The process contained a mixture of continuous and batch flows, and was thus semi-continuous. At the plant, the inflow of pellets to the first silos was continuous, but after that, flows were batch-wise. However, these batch sizes varied depending on arrival or departures of trains and boats. Traceability in the distribution chain was further complicated by the design of some process steps, where the flow includes mixing. Process steps with intermittent flow induce residence time variation.

Radio frequency identification (RFID) have been suggested to be used for tracing granular material flows [5-7], where a fraction of the granules are marked with RFID transponders. Here, we have performed two experiments to study if RFID markers could be used for creating virtual batches in the described distribution chain.

To avoid risking transponders to segregate, and thus have other residence times, the transponders should have similar properties as the granular products they are to measure the residence time of. The sizes and densities, shapes and other properties of the granular media thus limit the RFID transponder types that are useful for the specific application. The pellets for this application are spherical and have a diameter that range from 9 to 15 mm.

RFID Markers Approach: Antenna Selection and Design

Another limitation was the possible positions of the RFID reader antennas. As the readability for a given system is improved if the reading ranges are small, the readers should be mounted closely to where the transponders will enter the reading field. The sizes of the antennas in this application were governed by the conveyor belt dimensions which meant that reading distances were large. The angle between the reader and transponder antennas also influences the reading range, but note that the transponders may lie in any direction and that this angle cannot be controlled. Two different orientations of the reader antennas were therefore used to increase the probability of detection of the transponder pellets, see Figure 3.

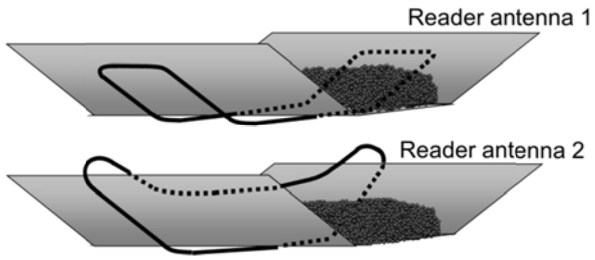

Figure 3. The two reader-antenna shapes. The antenna of reader 1 is mounted under the conveyor and the antenna of reader 2 is mounted around it.

RFID Markers Approach: Transponder Selection and Encapsulation Design

It was assumed that transponders encapsulated in a container that gave the transponders the same density and size of a pellet and with similar surface properties would behave as the pellets in the product flow. However, earlier experiments had shown that only few of the transponders small enough to fit within casings the size of a pellet (Ø 15 mm) was detected by the readers, whereas larger transponders were easier to detect. Unfortunately, it was uncertain whether the residence times of the larger transponders measured the pellets' residence time, since size is a determinant for particle segregation. Another property that may influence segregation is particle density, so an experiment was set up to see if density could be used to compensate for the larger sizes of the transponders that were easier to find.

The tested transponders are seen in Figure 4. The control treatment Type A had similar size, shape, density, and surface structure as a regular pellet, and it was used to emulate the pellet's flow behavior. The pellets are normally spherical, and the density of a pellet is approximately 4.3 g/cm3. Type A contained a 12 mm passive transponder with a 14 mm casing and a density of 4.3 g/cm3. The other two types, B and C, both contained a 22 mm long transponder and their casings were larger than a pellet, with a spherical 24 mm casing. Earlier experiments had showed that lighter, larger pellet transponders also had a larger residence time. In this case, the densities for larger transponders were therefore equal (Type B) or higher (Type C, 6.1 g/cm^3) than the regular pellets

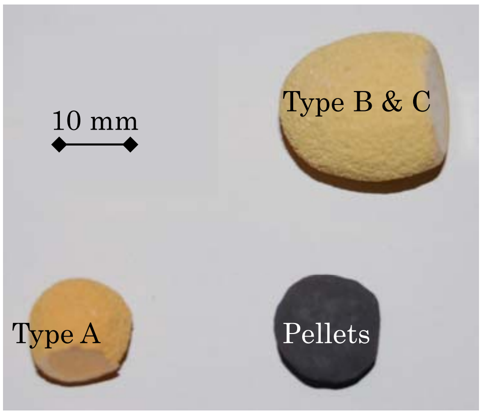

Figure 4. The two transponder casing types and a pellet.

RFID Markers Approach: Experimental Results

The two transponder types B and C behaved similarly within the experiment and are only discussed as the large transponder types. As seen in Figure 5, none of the two transponder types had a 100% read rate, and especially the small transponder (type A) were often missed when passing the readers. The use of two reader antennas with different orientation did increase the number of read transponders, but the best placement differed for the two transponder types. The reader below the belt was the best for reading the larger transponders, but worse for detecting the smaller transponder type.

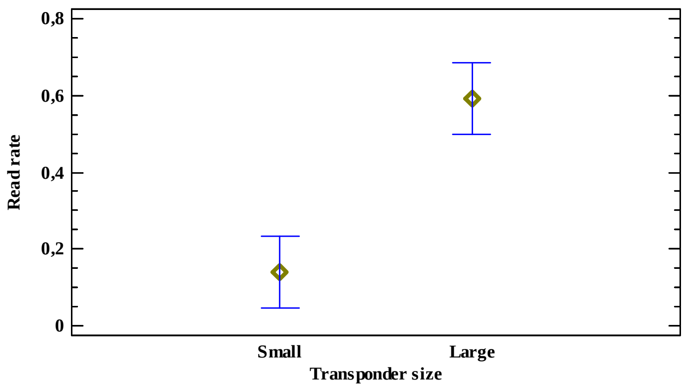

Figure 5. 95 % confidence intervals for the expected read rate for transponder size combinations.

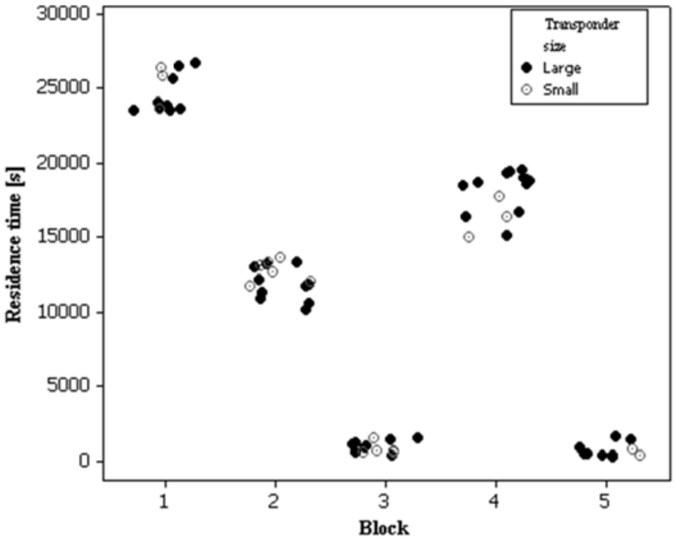

Figure 6. Transponder residence times for the experiment. The difference in mean residence time depends on intermittent loading of trains.

Comparing the residence times for the transponder sizes in Figure 6, we see that they are grouped into five distinctive groups, or blocks, related to five occasions when transponders were dropped into the process. The mean difference between the blocks is due to differences in silo levels and train loading schemes. More important is that we cannot spot any regularly appearing differences between the behavior of small and large transponders and an ANOVA test did not suggest a statistical difference between the means when the block effect was subtracted.

RFID Markers Approach: Discussion

We did not find evidence that the larger transponders encapsulated in a casing with similar or higher density had different residence times, and thus segregated during these experiments. These larger transponders were therefore better suited for use as product batch delimiters since their read rate was significantly higher than that of the small transponders. However, the RFID results in this paper are based on a relatively few transponder trials, and the whole transportation process was not included in the experiment. The results should thus be considered with caution. These results are to be validated by additional experiments that cover a longer part of the distribution chain.

Conclusion and Findings

It is more difficult to create traceability in continuous processes, and traceability changes to a statistical property rather than a deterministic one. In this paper we have shown how tracers and modeling efforts may be used to improve the ability to track and trace products in continuous processes, which ultimately will improve quality control, product quality and reduce waste.

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