Developing Distribution Chain Traceability in Continuous Processes
- Experiments in the Iron Ore Pellets Industry

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Category: Case Study

ABSTRACT

A traceability system simplifies investigation of causes of product failures and is therefore vital for many industries. Traceability systems are extensively used in manufacturing industries, but creating traceability in continuous processes implies great challenges. The aim of this paper is to illustrate how traceability can be achieved in the distribution chain for iron ore pellets. Radio frequency identification (RFID) was used as a technique to trace iron ore pellets. Experiments were performed to verify the suitability of the technique. The results indicate that RFID is an appropriate technique. With one stationary RFID reader, about 50 % of the tagged iron ore pellets were identified. Possibilities for higher read rates are discussed.

Keywords: *RFID tag, process industry, residence time, read rate, bulk product*

INTRODUCTION

A vital part when working with improvements is eliminating defects and their root cause (Duffin, 1995). Defects are often discovered late in the production chain, sometimes by the final customer. The traceability, i.e. the ability to trace a product backwards throughout the process to locate the cause of a defect, is therefore vital for any industry (ibid). Traceability is defined as: the ability to preserve and access the identity and attributes of a physical supply chain's objects (Töyrylä, 1999, page 38). Numerous benefits from using traceability systems have been identified, e.g. facilitating investigation of product failures, minimizing the extent of product recalls and assuring lot uniformity in products (Juran & Gryna, 1980). Furthermore, a traceability system can also be used to trace reasons for positive changes in the final product characteristics.

There are four elements connected to traceability; see Steele (1995), Töyrylä (1999) and Jansen-Vullers et al (2003):

1. *Physical lot integrity* - How large a batch of raw material is and how well the integrity of the batch is maintained determine the resolution or precision of the traceability system. The resolution of a system is the minimum number of units that cannot be individually separated from one another throughout the process, i.e. emanate from the same delivery batch.
2. *Data collection* - Two types of data are needed: process data that records process information, and lot-tracing data that keeps a record of movement and merging of batches.
3. *Product identification* - The linking of product and process data.
4. *Reporting* - Retrieval of data from the system, the actual use of the system.

Physical lot-integrity is the single most important factor when designing a traceability system, since it determines the maximal resolution of a traceability system. The physical lot-integrity for a process is affected by three elements: lot-mismatching, lot-end-mixing and lot-sequence mixing (Steele, 1995). Lot-mismatching occurs when a new batch is created and the size of the batch does not exactly match the original one. Lot-end-mixing arises if lots are processed in repetitive or continuous batches and the organization fails to retain clear separation between batches. Lot-sequence mixing takes place if the traceability system depends on the first-in first-out principle and the process fails to pursue this principle.

Earlier works on traceability are mainly focused on food and manufacturing industries. The focus on food industries in the literature is primarily due to the outbreak of BSE (mad cow disease) and the following customer and legislation demands on traceability and traceability systems. The solutions discussed in this literature are often branch specific and therefore unlikely to suit other branches. Traceability systems are extensively used in manufacturing industries and are often relatively easy to implement. The reasons for this are that different kinds of tags and readers can be attached to a unit and thereby follow it from raw material to end product. Creating traceability in continuous processes implies vast challenges: process flows can be parallel as well as serial; sub-processes can be continuous as well as batch-wise. These challenges make it impossible to trace a product throughout the system without special applications. It is neither possible to trace problems identified by customer complaints back to their sources upstream in the process, nor is it possible to determine if other customers are affected.

In a continuous process the raw material is gradually processed in an uninterruptedly material flow. Continuous processes are often found in process industries like pulp and papermaking, mining, metallurgy and the food industry. The input to a continuous process industry often consists of few raw materials that are divided into several products during the process; the opposite is typically true of the manufacturing industry (Fransoo & Rutten, 1994). The added value to products in continuous processes is often very small and the equipment is frequently single purpose specialized; high production speed is therefore important (ibid).

Existing traceability systems in continuous process environments are often based on calculation from models of residence time and dispersion in different process steps; see, for example, Lundqvist & Kubulnieks (1995). The flow schemes and dispersion are often different for the process steps and individual models therefore need to be identified by measurements or experiments. In spite of an extensive literature study, no models or guidelines for achieving traceability in a continuous process for unpacked bulk products, i.e. different types of pellets, was found. Hence, *the aim of this paper is to illustrate how traceability can be achieved in a distribution chain for an unpacked bulk product in a continuous process.*

DESCRIPTION OF STUDY OBJECT

Due to its continuous distribution chain for unpacked bulk products, Luossavaara-Kiirunavaara AB (LKAB) was selected as study object. LKAB is a Swedish mining company, specialized in extracting and processing iron ore from deposits in northern Sweden. The main product is different types of highly developed iron ore pellets that are shipped to customers all over the world. In this paper, the distribution chain of MPBO (iron ore pellets produced in Malmberget) was studied. MPBO are blast furnace pellets ranging in size from 9 to 12.5 millimetres in diameter. For a thorough description of pelletizing of iron ore, see Meyer (1980). A flowchart of the production process and the distribution chain is presented in Figure 1.

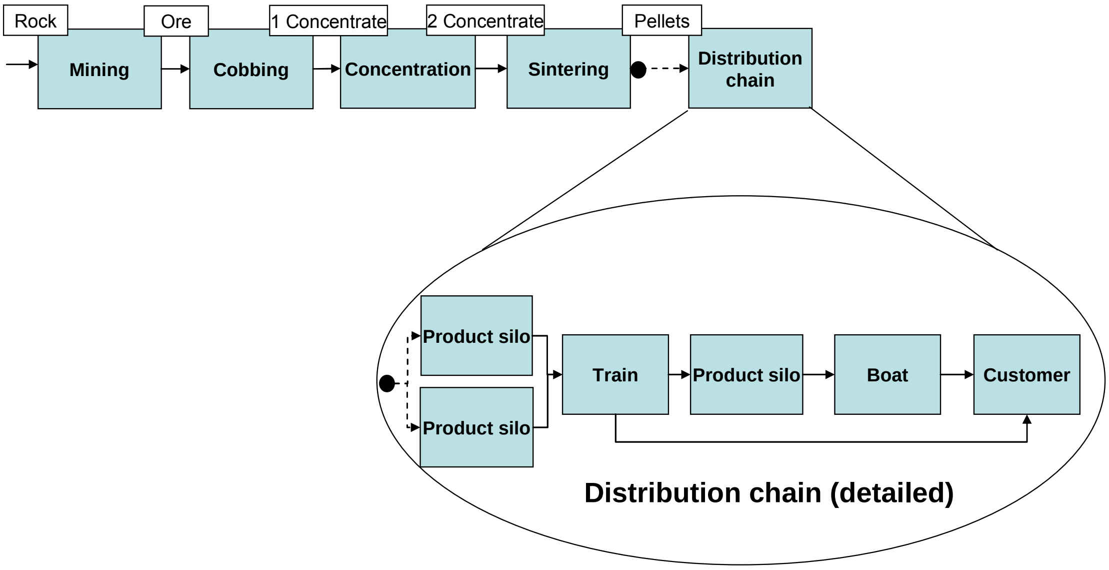

Figure 1. Flowchart for production of MPBO at LKAB. The white boxes, between the steps, in the flowchart describe the intermediate products in the process chain. The traceability system designed in this paper is supposed to achieve traceability for the detailed part (distribution chain) of the figure. Finally, the dots in the figure show how the detailed part is connected to the general process flow.

The traceability system designed in this study is supposed to solve traceability for the distributions chain[1], the detailed part in Figure 1. After sintering, the iron ore pellets are fed by a conveyor belt to one of two product silos, for later transportation by train to either the port of Luleå or the final customer in Luleå. On arrival to the port, the iron ore pellets are tipped into another product silo before loading and transport to the final customer. All three elements that may deteriorate the physical lot-integrity are represented in this distribution chain: the transport and storage rooms differ in size (lot-mismatching); there are two possible ways of transportation to customer (lot-sequence mixing); there is no clear separation between batches (lot-end-mixing). These characteristics make the distribution chain even more interesting as a case for developing a traceability system.

There is neither any existing continuous measurement in the distribution chain nor any regular change of product, so there is no available method for estimating residence time. Consequently, it may be concluded that an instrument must be implemented, temporarily or for long-term use, for estimation of residence time. It is important that the instrument gives accurate results.

USING RFID TECHNIQUE TO TRACE PELLETS

Radio frequency identification (RFID) has been used to trace goods in the manufacturing industry, and it was decided to try a similar approach for the iron ore pellets product. The RFID technique offers the possibility to create a small traceable unit that can be read at some distance. The RFID technique resembles the bar code, but has five primary abilities that make it different compared to the bar code (Wyld, 2006): it does not require line of sight to be read, it can have a unique code, it is more durable,

[1] The study presented here is part of an extensive research project that aims at developing the traceability from the mine to the final customer.

it can hold larger amount of data and it allows for almost simultaneous reading of multiple tags.

An RFID system requires three parts: a tag, a reader, and software forwarding the information from the reader. The tag is attached to the object that is to be identified, and consists of three essential components; the chip, the antenna and the shell that encloses and protects the other parts. The chip holds the unique identification code, and is attached to the antenna. One of the largest advantages of the RFID technique is that it is relatively cheap, i.e. the basic types of RFID tags cost less than one dollar.

The reader assembles information from the tags. To detect the tags the reader generates an electromagnetic field, which the tags in the field respond to by sending a signal. The signal from the tag is received and decoded by the reader and transmitted to the software.

Read rate (percentage of RFID tags that can be read) and the working distance between tag and reader (read range) are vital factors in an RFID system. Porter et al. (2004) tested what environmental features influence the read rate of a RFID-system. They found that the read rate is affected by the orientation of the tag, direct contact with metals or liquids, and the number of tags inside the capture zone. The read range is determined by the frequency of reader and tag, the power of the reader and the tag (for the tags used here, only the power of the reader is of interest), the size of the reader and the tag antenna, as well as environmental conditions (Wyld, 2006).

In a continuous process, the RFID technique could be used to create virtual batches; the RFID tags would then be imaginary start and end points of a batch. These batches would make it possible to trace a certain product back to an approximate production time. The interval between the tags determines the precision with which a product can be traced. Hence, by using the RFID technique, it should be possible to achieve traceability in the distribution chain, and it would also be possible to estimate residence time and residence time dispersion continually. As far as I know, the RFID technique has never been used in this way before, and therefore needs to be tested prior to implementation.

EXPERIMENTS

To explore the suitability of the RFID technique, experiments were conducted. For the experiments, twelve millimetres long glass tags, see Figure 2, were inserted into iron ore pellets. During the experiments, a fixed reader manufactured by a local company was used. The reader was 1.35 metres wide and 0.50 metres high. Experiments were performed in a laboratory environment and in the actual distribution chain.

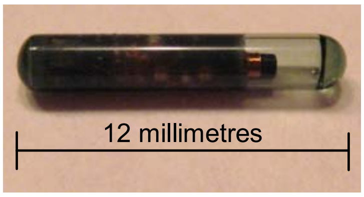

Figure 2. RFID-tag used for the experiment.

In the laboratory experiment, the tag reading ability in the centre of the reader antenna, the orientation in the x-y plane, and speeds up to two metres/second were examined. To perform the tests, a small model of a conveyor belt with adjustable speed was constructed. How the different planes relate to the reader antenna is described in Figure 3.

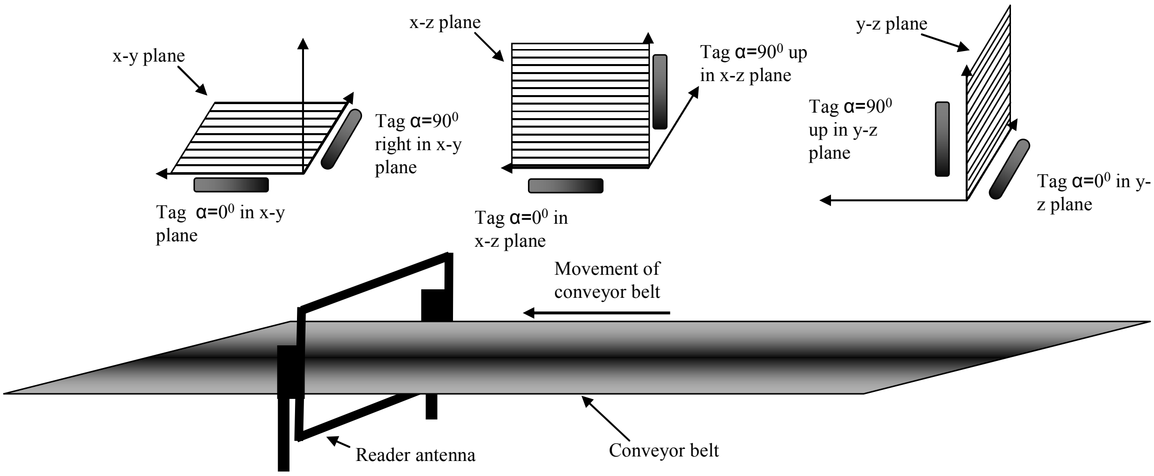

Figure 3. The figure demonstrates how the three different planes are related to the conveyor belt and the reader. It also illustrates how the different angles (α) of the planes are defined.

For the experiments in the distribution chain, the reader device in Figure 4 was used. At first the sensitivity in orientation for stationary tags and tags under slow motion in all dimensions was examined. This was done by pushing tags in different angles through the antenna on the conveyor belt and observing which angles were detected.

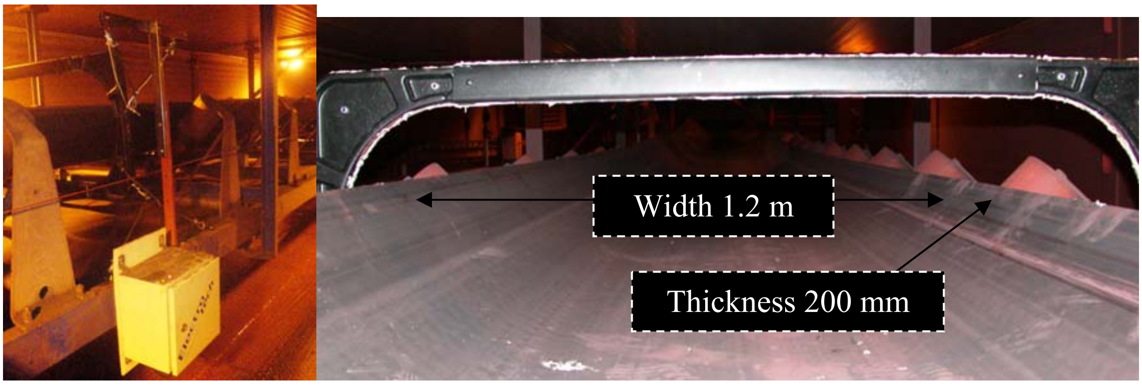

Figure 4. The figure to the left shows the conveyor belt with the mounted reader device. The figure to the right shows the antenna of the reader and the dimensions of the conveyor belt.

After the tests conducted on stationary tags, tests were made of how the read rate and accuracy were affected by the movement of the conveyor belt. A wooden lath with pre-drilled holes, angled from 10^0 to 90^0 with intervals of 10^0, was used for this. To test if the reader could detect several tags simultaneously, the lath also had pre-drilled holes closely angled to 45^0 with 50 mm intervals. The speed of the conveyor belt was 1 m/s during these experiments.

Finally, tests were made of what read rates could be expected during loading. Throughout the loading, the conveyor belt ran at a speed of 1 m/s and the iron ore pellets bed was between 0.15 and 0.2 m thick. Twelve tags were tossed onto the conveyor belt during loading to examine what read rates could be expected.

RESULTS

The results from the experiments are described in Table I. To calculate the read rate for the conveyor belt without load, the values in Table I were used. The direction of a RFID tagged unit cannot be influenced, so the angle of a tag passing through the reader antenna is therefore completely random. The possible angles for the RFID tags passing through the antenna can subsequently be seen as equivalent to the surface area of a sphere with a radius corresponding to the length of the tag. Thus, the fraction of RFID tags that can be detected are identified, by calculating the surface area that can be detected by the reader and dividing it by the surface area of an equivalent sphere. Since all the intervals in which a tag can be detected are equilateral in a specific plane, the formula can be simplified by calculating one section and then multiplying it by a constant equal to the number of sections. The read rate was calculated at 62.6 percent; see Formula (1) for calculations.

Fraction of surface area that can be detected by the reader =

$$\frac{A}{A_{tot}} = \frac{8\int_{0}^{\pi/3}\int_{\pi/9}^{\pi/2} r^2 \sin\theta \, d\theta \, d\rho}{4\pi r^2} = \text{equation solving} = \frac{2}{3}\cos\left(\frac{\pi}{9}\right) \approx 0{,}626 \qquad (1)$$

Table I. The table shows the results from the experiments with the RFID technique. Here α indicates the angle of the tag in the specific plane; see Figure 3 for illustration of different values of α.

Experiment	Angles in which tags were not detected			Minimum distance between tags to be read, by the reader in the x-axis direction.	Read rate
	x-y plane	x-z plane	y-z plane		
Laboratory (speed 2 m/s)	$80^0 < \alpha < 100^0$ right and left	Not tested	Not tested	Not tested	Not tested
Static conveyor belt	$70^0 < \alpha < 110^0$ right and left	$70^0 < \alpha < 110^0$ up and down	All	Not tested	Not tested
Moving unloaded conveyor belt (speed 1 m/s)	$60^0 < \alpha < 120^0$ right and left	$70^0 < \alpha < 110^0$ up and down	All	≥ 150 millimetres	63 % (calculated)
Moving loaded conveyor belt (speed 1 m/s)	Not tested	Not tested	Not tested	Not tested	50 %

CONCLUSIONS AND DISCUSSION

By comparing the results in Table I, it can be concluded that the speed of the conveyor belt seems to affect the read rate. This is in conflict with the result from Porter's et al. (2004) study. A reason for this disagreement might be that the RFID tags, in the experiment presented here, are on the verge of the read range, and that the read range is affected by the time in the capture zone. Furthermore, the results from the experiments show that the orientation of the RFID-tag affects the read rate, which Porter et al. (2004) also concluded. The difference in orientation sensitivity between the x-y plane and the x-z plane is explained by the rectangular form of the reader antenna.

The read rate with load was 50 percent, which indicates a small reduction compared to the read rate without load, which was calculated at 63 percent. This difference is insignificant, because of the small number of measurements performed and the large uncertainty due to apparatus problems during the test. In the experiments it was not possible to test if the read rate was affected by the position in the iron ore pellets layer. However, the initial test with stationary tags did not show any dependency between the read rate and the position in the bed.

According to Porter et al. (2004), three features affect the read rate. Two of these, direct contact with metal or liquids and the number of tags in the capture zone, are not possible to control in this application. The orientation of an RFID tag cannot be directly controlled, but the sensitiveness can instead be reduced by using several RFID readers in series. The RFID readers should then be serially mounted at different angles in relation to the conveyor belt, which should result in significantly higher read rates due to reduced sensitiveness for orientation. How much the read rate will increase depends on how much the angles can be altered and the additional numbers of RFID readers. Nonetheless, the largest improvement in the read rate, with just one more RFID reader, will arise if the readers are revolved 45^0 in all planes in relation to one another.

Tags used in the manufacturing industry are usually attached to the single unit or package. This is not possible in the iron ore pellets distribution chain, since there is no package that can be tagged, and attaching tags to every iron ore pellet is not possible from an economic and process point of view. Tags dropped onto the conveyor belt with regular intervals could instead be used to create approximate, but immensely better traceability models for the iron ore pellets. At least three parameters should be considered prior to deciding on which interval tags should be added to the product flow: the residence time dispersion (amount of mixing) in the distribution chain, the gain of a traceability system (how much the cost for defects are reduced), and the cost for the traceability system. The residence time dispersion in the distribution chain is fixed, while the other two parameters are affected by the interval of tag drops and how the organization estimates the lack of quality costs. Residence time dispersion can be approximated by dropping several tags momentarily and then observing entry times at the reader and repeating this at different production states. Minimum distance between tags to be read in series, by the reader, is consequently of interest. The minimum reading distance for the system tested here was 150 millimetres.

The experiments indicate that the RFID technique could be used to trace products, through a distribution chain in a continuous process. Furthermore, the customers may also wish to install readers to keep track of the tags throughout their processes. The customer may e.g. use this information to attach tag numbers to complaints. For the iron ore pellets production process, the RFID technique makes it possible to achieve traceability from the sintering of the iron ore pellets to the blast furnaces of the customers. Hence, the root cause of problems/temporarily product improvements becomes easier to trace for problems and improvements detected both internally and externally.

During the experiments, numerous unexpected difficulties occurred. For example, the first RFID reader did not stand the environment due to vibration and dust coming into contact with sensitive parts during the assembling. The next RFID reader was therefore provided with a suspension and a great deal of the assembly was also made in advance in a dust-free environment to eliminate the risk of failures caused by dust and vibrations.

The results from the experiments indicate that the suggested application could be used for achieving traceability in the distribution chain. However, the technique has not been fully implemented in the process. Hence, it is necessary to further implement the technique before its suitability can be finally evaluated.

Moreover, iron ore pellets are a special type of product, even though other industries have similar products, and hence some of the findings in this paper may consequently not be valid for those.

Finally the RFID-technique is still under intense development. It is therefore the present author's belief that the RFID technique can be applicable in a variety of new fields, if not today, then at least in the future. For example, the application used here has shown considerably better results, in the experiment, compared to prior expectations.

FURTHER RESEARCH

First of all, if the RFID technique is to be used for achieving traceability in distribution chains, is it necessary that the tag behave like the medium supposed to be traced. Different ways of altering tag characteristics should therefore be examined, i.e. different methods of casting RFID tags. In addition, it would be of interest to study methodically how the read rate is affected by mounting several antennas in series at different angles in relation to the conveyor belt.

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