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Applications of RFID to Improve Traceability in Continuous Processes

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1. Introduction

To achieve traceability in discontinuous (discrete or batch) processes can be rather straightforward since identification markers, such as bar codes or serial numbers, can be attached to the product/batch or its package and be scanned at predetermined locations in the supply chain. However, continuous processes differ from discontinuous processes in a number of ways and these differences results in a number of difficulties concerning, for example, traceability. Traceability is important in continuous processes and the importance of traceability has been highlighted in, for example, the food and dairy industries due to food crises, such as, the BSE (mad-cow disease), foot-and-mouth disease, and the scandal of infant milk tainted with Melamine in China.

This chapter presents a number of traceability methods that can be used to improve traceability in continuous processes with a special focus on RFID (Radio Frequency IDentification). We then exemplify how RFID may be applied and combined with other methods to improve traceability in continuous processes with two examples from continuous processes. The first example demonstrates how RFID can be used to improve traceability in a continuous refinement process of iron ore by adding transponders with similar physical characteristics as the product to the product flow. The second example is taken from the forestry industry and gives an example of how RFID can be used to improve traceability through the wood refinement process by tagging individual logs with a transponder at the felling site.

In addition to the two examples additional RFID applications to improve traceability in continuous processes are described. Various benefits of using RFID to improve traceability in continuous processes are identified and discussed from the described RFID applications. Also, special challenges using RFID in continuous processes are identified and how to solve or avoid these challenges are discussed. Finally, we describe some ideas for future research projects and ongoing research projects.

2. Traceability in continuous processes

All production processes occasionally fail to produce products within specifications. Some defects will not be detected before the product is sold and a product recall may be

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necessary. A product recall results from an incident or an attempt to prevent an incident and the cost for a product recall can be astronomic and escalates dramatically, see, for example, Jacobs (1996). Traceability is an important tool to minimize the extent of product recalls, see, for example, Jacobs and Mundel (1975) and Fisk and Chandran (1975). Also, traceability is vital for continuous improvements (Mahoney and Thor, 1994), important for identification of root-causes and prevent their reoccurrence (Duffin, 1995), essential if effective methods of process control are to be applied (Oakland, 1995), et cetera. Hence, traceability is an important ability for all manufacturers (Fisk & Chandran, 1975).

In this chapter traceability is seen as the ability to "*preserve and access the identity and attributes of a physical supply chain's object*" (Töyrylä, 1999, p. 38). According to Moe (1998), traceability needs to be managed by traceability systems. A traceability system is the system that enables traceability in a process by combining process information with data covering the product flow throughout the supply chain. The product flow data can be continuously recorded or modelled with different traceability methods.

The research literature concerning traceability is dominated by applications in discontinuous processes, while descriptions of applications in continuous processes are scarce. Continuous processes can be described as production processes which primarily schedule long production runs where setups are fixed or seldom changed and the production systems are organized and sequenced according to a fixed production flow. Continuous processes are commonly found in process industries, and characterized by that the products are refined gradually and with minimal interruptions through a series of operations (Fransoo & Rutten, 1993; Dennis & Meredith, 2000). There are a number of characteristics in continuous processes that makes traceability complicated. For example, traceability systems normally rely on the definition of a batch, and the continuous flow in a continuous process implies that no batches exists (Skoglund & Dejmek, 2007). Also, the products in continuous processes are often in a non-discrete state and can undergo multiple changes of states prior to the delivery (Fransoo & Rutten, 1993; Dennis & Meredith, 2000). Another traceability concern is that the product flow in the sub-processes can be continuous as well as batch-wise (Lundqvist & Kubulnieks, 1995). Finally, the flow in continuous processes is not necessarily sequential, as the processes are typically designed to separate, mix, form or react (Hild et al., 2000). Yet, traceability is important in continuous processes and especially in the food and pharmaceutical industries, see Flapper et al. (2002). The special characteristics described imply that other types of traceability methods are needed for creating traceability in continuous processes compared to discontinuous processes.

3. Traceability methods for continuous processes

Kvarnström and Oghazi (2008) have identified five traceability methods that can be used in continuous processes to improve traceability as well as advantages and disadvantages with each method, see Table. 1. We will here give a brief description of each method with a focus on RFID, for further descriptions see Kvarnström and Oghazi (2008). However, it should be noted that the same traceability method is rarely suitable to use throughout the whole process, since, for example, the material often change state during the process. Hence, the suitability of a traceability method needs to be considered for each specific process stage.

Traceability method	Advantages	Disadvantages
Chemical tracer	- Flexible - Easy to use - Low-cost	- Dilutes - Needs sampling - Based on historical data
Radioactive tracer	- Flexible - No sampling needed - Interior flows can be measured	- Health hazards - Permits required - Based on historical data
Process data	- Easy to use - Low-cost - Based on real time data	- Hard to find - Low precision - Initial sampling needed
Material signature	- Flexible - Informative - High analysis precision	- Large amount of data handling - Time demanding - Costly
Traceable marker	- High precision - No sampling needed - Could be used in process sections with both batch and continuous flows	- Lower flexibility - Can not be used for fluids - Can only be used at shorter distance - Costly to implement

Table 1. Various traceability methods that can be used to improve traceability in continuous processes. Adapted from Kvarnström and Oghazi (2008, p. 729).

3.1 Off-line tracer methods

Off-line tracer methods imply that mathematical models are created for estimating the residence time of the products in a process section based on data from, for example, chemical or radioactive tracer experiment. Such experiments are usually performed the following way, a temporary modification is made to the input of a process section or stage and the effect of the modification are then studied in the output. For example, a chemical tracer can be added momentarily to the input section and the concentration of the tracer can then be measured at various times in the output to estimate the residence time of the tracer. Experiments to estimate the residence time distribution are often performed at various process settings to determine how the residence time distribution depend on different factors. A mathematical model can then be fitted to the estimated residence time distribution, assuming that the process conditions are known and can be quantified. The tracer method to estimate residence time distribution in a process section or stage has, for example, been used by Yianatos et al. (2001), Lelinski et al. (2002), Choi et al. (2004), and De Andrade Lima and Hodouin (2005). Also, data from product changes may be used to estimate the residence time distribution based on the transition time (the time it takes for a process to react on a change) in a process. Vanhatalo et al. (2009) describes and exemplifies a method were principal component analysis and time series analysis are combined to estimate the transition time in a continuous process based on data from the input and output of a process.

3.2 Process data

For some continuous processes there may exist known and repeatable changes in the raw material properties. These changes can often be seen at different positions in the process, and the residence time distribution may be estimated based on the propagation of the changes and then mathematically modelled or continuously monitored. Lundqvist and Kubulnieks (1995) have created traceability in a paper and pulp production industry by comparing the appearance time and forms of deviations in kappa number (a measure indicating the bleach ability of wood pulp) and brightness (a measure of how much light is reflected), two process parameters normally continuously measured at various positions in the process. Kvarnström and Bergquist (2009) describe a similar method using simulations based on ideal flows and existing process knowledge to improve traceability in a continuous process.

3.3 Material signature (fingerprint)

Instead of using knowledge of the process or process data, knowledge of the material may be used. Like all humans have unique DNA and fingerprints, similar unique signatures may be found in the structure of other materials, such as meat, grain, wood, and ore. For example, in a pork chop the exact amount and combination of chemical elements may depend on the origin, nourishment, soil, birth date and other variables. Oghazi et al. (2009) has suggested and exemplified how particle texture analysis and multivariate data analysis can be combined to identify and follow changes in particle morphology in the concentration process of iron ore. A similar approach for the sawmilling industry has been proposed by Flodin et al. (2008) using 3-D data, x-ray data, and discriminant analysis to match planks to logs based on, for example, knots.

3.4 Traceable marker (or unit)

Different types of markers are commonly used in discontinuous processes to mark either individual units or batches. The same approach may be used in continuous processes. Marking technique such as paint label, stamped codes, paper or plastic label, magnetic stripe card or smart card, RFID, microtaggant paint, and chemical tracer may for example be used, for an extensive list of marking techniques with descriptions of each technique see, for example, Dykstra et al. (2002). To mark all units may be too expensive or even impossible in continuous processes, and a batch approach may be a more appropriate solution. If the marking are to be based on a batch system, the flow needs to be divided into subgroups and, hence, the continuous process flow is problematic. A solution is to use the markers to divide the flow into batches, and the markers would then work as start- and endpoints of each batch. To do this the markers need to behave as the product in the process flow and to be identifiable within the product flow.

RFID transponders offer a possibility to mark a flow with markers that are automatically readable and the markers can be designed to have similar flow behaviour as the product. Also, it is possible to see exactly where each transponder is since the transponders has a unique identification number. Hence, RFID transponders can be used both to mark individual units and to create batches in continuous flows. Henceforth, the chapter will focus on the use of RFID to improve traceability in continuous processes. A number of examples describing the use of RFID in continuous processes are presented with a special focus on two examples, one in which RFID has been used to create batches and one in which RFID has been used to mark each unit.

4. Example 1 –Tracing iron ore pellets

The first example is taken from the refinement process of iron ore to iron ore pellets (henceforth pellets) and the distribution of the pellets from producer to customer. First, the studied process will be described as well as why it is important to achieve traceability in the process. Secondly, the design of the RFID application used to improve traceability in the process will be described and tested. Thirdly, results and experiences of various experiments investigating the possibility to use transponders to trace the movement of pellets in the distribution chain are described. Finally, on-going and future development of RFID for the pelletising process is described.

4.1 The production process of iron ore pellets

Luossavaara-Kiirunavaara AB (LKAB) is a Swedish iron ore mining company that extracts and refines iron ore from deposits in northern Sweden (Kiruna, Malmberget and Svappavaara). LKABs main product is various types of pellets used for iron making in blast furnaces and direct reduction furnaces. A pellet is a spherical particle created from iron ore concentrate with diameters ranging from 8-18 millimetres. The production process of pellets at LKAB is performed in four consecutive steps. First, crude iron ore is extracted from underground mines through blasting and drilling and hoisted to surface level. Secondly, the iron ore concentrate is separated from the tailing (gangue minerals) in the crude ore by crushing and magnetic separation. Thirdly, the iron ore concentrate is further refined by grinding and wet magnetic separation. Fourthly, the refined iron ore concentrate is transformed to pellets through agglomeration and thermal treatment. The pellets produced at LKAB are then shipped to the customers from two different harbours one in Luleå (pellets produced in Malmberget) and one in Narvik (pellets produced in Kiruna and Svappavaara). The distribution chain for the two harbours differs on a detailed level, but both distribution chains consists of a buffer system at the pelletizing plant where the pellets are stored before transportation, a train transport to the harbour, a buffer system at the harbour where the pellets are stored before shipment, and a shipment to the customers, see Figure 1. The RFID technique has been suggested to be used to improve traceability in the distribution chain, while other techniques has been suggested for the other parts in the production process, see Kvarnström and Oghazi (2008).

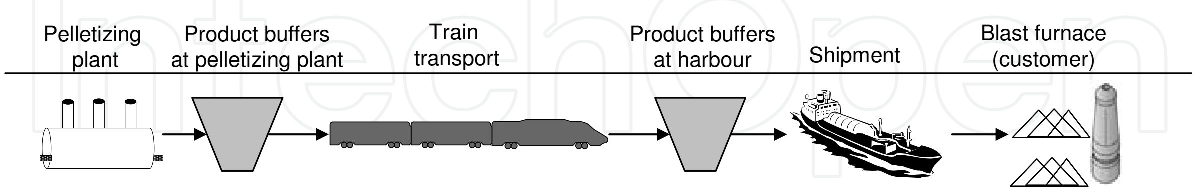

Fig. 1. The distribution chain of iron ore pellets at LKAB.

Improving the traceability in the distribution chain at LKAB would result in a number of benefits. For example, the knowledge of the flow mechanisms in the distribution chain would be improved and it would be possible to combine product analysis from different stages in the distribution chain. Also, traceability would make it easier to manufacture customer specific pellets. Perhaps most importantly, an improved traceability would make it easier to track customer complaints or praises back to the production process as well as trace pellets with quality deviations for disposal or downgrading.

4.2 Design of RFID application

In the pelletizing process the RFID application was intended to improve traceability in the distribution chain of iron ore pellets. To improve traceability, RFID transponders were to be added between the pelletizing plant and the product buffers at the pelletizing plant. The transponders were to be added directly into the product flow to create batches and indicate start and end point of each batch. The batch approach was selected because the individual pellet value is to low to motivate that each pellet was marked with a transponder. A transponder type with similar size as a pellet was necessary since the transponders need to behave as the pellet in the product flow. Also, passive transponders were to be used since no data except identification number needs to be transferred between the transponder and the reader. Furthermore, the transponders can not be removed from the product flow and, therefore, need to be harmless for later processes and approved by external customers.

The readers were decided to be placed at conveyors, used for transporting pellets, at different positions in the process, since the conveyors are the process section were the smallest read zones can be applied. The conveyors used in the process have a width between 1.2-2 meters and a height of approximately 0.5 meters. When lying on the conveyors the transponders moves with a speed of 3 meters/second and the orientation of the transponders and the distance between transponders are completely random on the conveyors. There was no water and metal within the read zone, but there was some metal in the proximity. Also, the reader needed to be designed to be insensitive to dust and large temperature shifts (between ±50 degrees of Celsius).

The prerequisites for the design of the RFID application imply that not all transponders were expected to be read. If a transponder is not read, data are lost and information about the change of batch is not received. To secure that information about the start and end point of each batch will be received several transponders are to be dropped simultaneously. Also, multiple RFID readers can be used at a single process stage to further reduce the risk of missing information about the passage of a batch. The readers would then be mounted with different orientation against the conveyor and with a distance large enough to avoid interference between readers but close enough to avoid that the transponder shift orientation. While moving through the distribution chain the pellets are extensively mixed during, for example, buffering and transports, and the batch boundaries will blur. Hence, in case of a disturbance within a batch resulting in that an action must be performed the action needs to be performed to the actual batch and the adjacent mixing zones, see Figure 2 for illustration. Furthermore, if the disturbance that needs an action occurs within a mixing

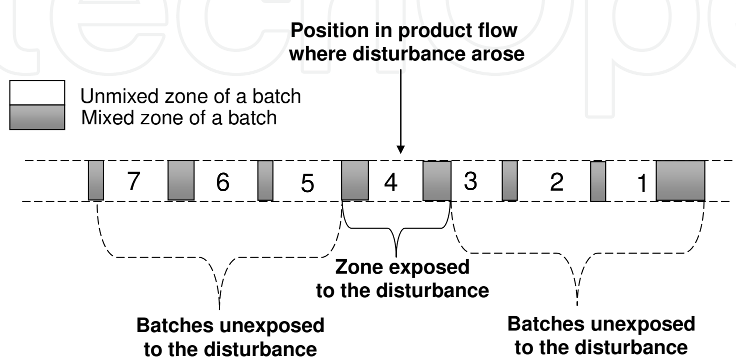

Fig. 2. Illustration of how a disturbance in the product flow within a batch affects other batches.

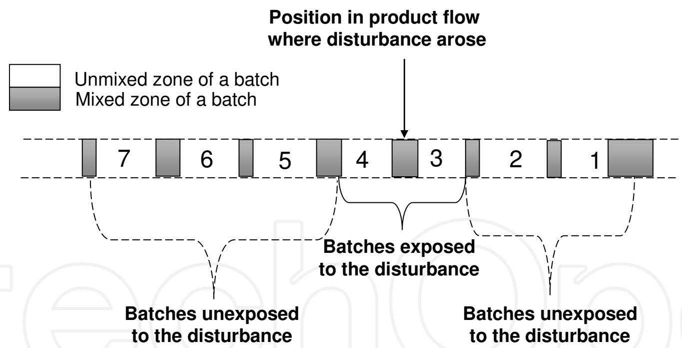

Fig. 3. Illustration of how a disturbance in the product flow within the mixed zone of a batch affects other batches.

zone the preceding and the following batch may be exposed to the same disturbance, see Figure 3 for illustration. When deciding the batch size for a traceability system the mixing zone must be known, since the selected batch size must exceed the size of the mixing zone. The mixing zone can be estimated by studying the residence time distribution for transponders added simultaneously.

4.3 Results from tests with the RFID application

To identify suitable antenna designs and transponder types for a traceability system in the distribution chain of pellets, laboratory tests were performed. The laboratory tests showed that RFID may be possible to use and that a low frequency (125 kilo Hertz) 12 millimetres long glass transponder with a 2.12 millimetres in diameter, see Figure 4, could be used, but the read rate was low (around 50 %) with the established read zone. Based on the results of the laboratory tests it was decided that initial tests in the distribution chain should be performed. For the tests in the distribution chain a longer glass transponders (22 millimetres long and 4 millimetres in diameter), with higher read rates anticipated, were decided to be tested in addition to the 12 millimetres transponders. Furthermore, the temporary reader antenna was to be mounted wrapped around the conveyor. The tests in the distribution chain indicated a decrease in read rate compared to the laboratory tests. Also, the tests showed that the 22 millimetres transponders had a better read rate than the 12 millimetres transponders and that it could not be rejected that the 22 millimetres transponders behaved as the 12 millimetres transponders in the product flow. For a closer description of these tests see Kvarnström and Vanhatalo (2010).

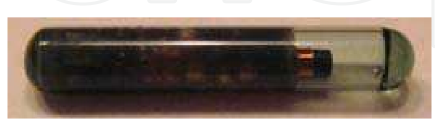

Fig. 4. The smallest glass transponder, 12 millimetres long and 2.12 millimetres in diameter, used for the tests.

After the initial tests a second set of tests were performed in the distribution chain with two readers, see Figure 5, and the same two types of transponders. The read rate for the tests is summarized in Figure 6. For the 12 millimetres transponders Reader 2 had a higher read rate, but for the 22 millimetres transponders no clear difference could be seen between the two readers. The read rate for the 22 millimetres transponders were higher than the read rate for the 12 millimetres transponders, which was expected. By using two readers with different antenna orientation against the conveyor the overall read rate was improved from 60 % to 80 % for the 22 millimetres transponders.

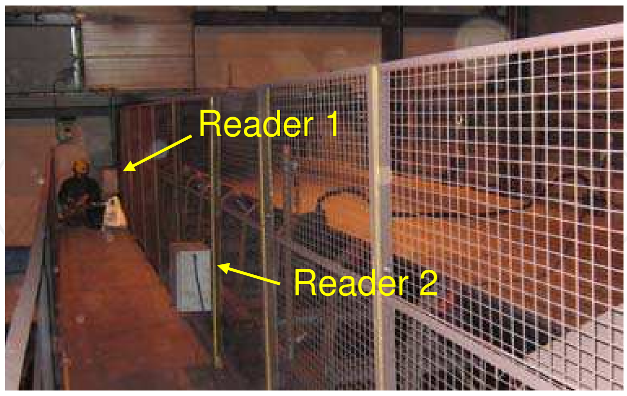

Fig. 5. The position of the two RFID readers used for the second set of tests. Reader ones antenna is mounted under the conveyor but bend slightly as a saddle so the distance between the conveyor and the antenna was minimized. Reader twos antenna is mounted around the conveyor.

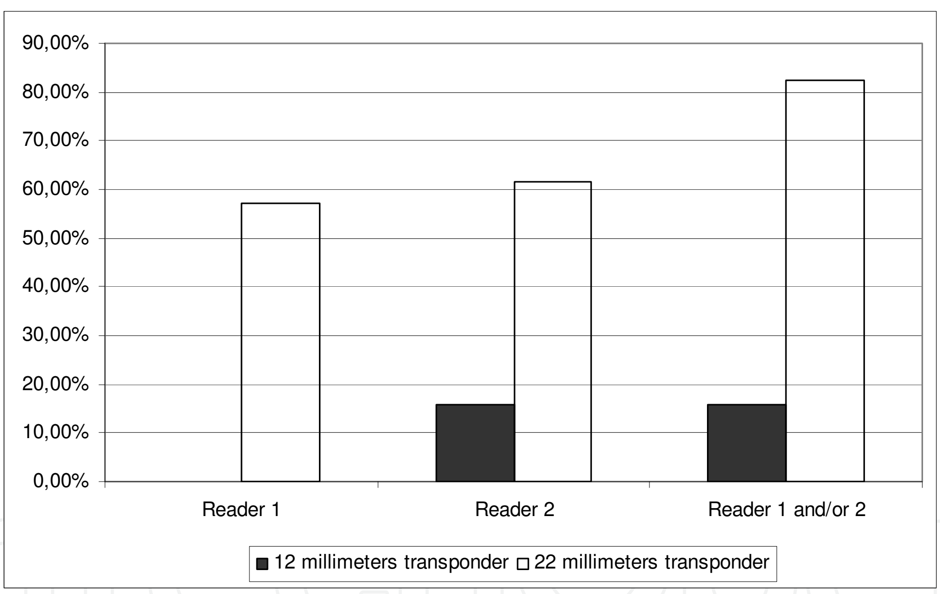

Fig. 6. The observed read rate for the two types of transponders tested at reader 1, reader 2 and reader 1 and/or reader 2.

4.4 On-going and future development of RFID technology for the pelletising process

The tests made within the distribution chain of iron ore pellets have shown promising results. However, there are still a number of questions that needs to be answered and solved before a final judgment about the suitability to use RFID to improve traceability can be made. A research project, within the Mining Research Programme at VINNOVA, aiming to further investigate the possibility to use RFID to trace granular products has been granted. The research project will, for example, address the possibility to develop RFID transponders that behave as a specific granular product.

5. Example 2

The second example is taken from the sawmill industry, following the chain from felling of trees in the forest until the sawn wood (boards) arrives at the secondary manufacturer (Figure 7). The structure of the chapter follows the same structure as Example 1. First a description of the sawmill process and the potential of using traceability technology, secondly a description of the RFID-application followed by some results, experiences and descriptions of future work and development.

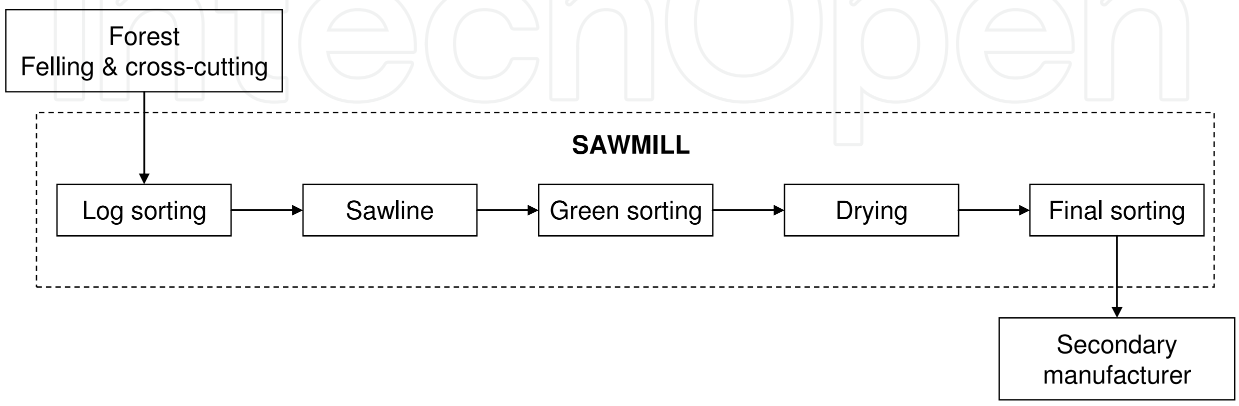

Fig. 7. A schematic description of the production of sawn wood.

5.1 The sawmill process

Wood is a biological material. Every stem, log and board has its unique individual properties. One effect of this is that while most industrial processes have a convergent flow, the sawmill industry has a divergent flow.

The production of sawn wood starts in the forest (Figure 7). In the Nordic forest industry an important decision is made already in the forest when the harvester cuts the stem to logs with different length. The cross-cutting of a stem results in a number of logs, each with individual properties and consequently best suited for different products. The individual logs are transported to different sawmills, and after arriving at the sawmill the logs are sorted and allocated to different groups of logs. The sorting of the logs improve the efficiency of the production since it allows sawing of log batches with similar properties such as dimension and knotstructure. In the sawline, each log is sawn into several boards, each with different dimension and properties. In the green sorting the boards are sorted based on customer demands. In this way the drying can be optimized for a specific dimension and product. The pre-drying sorting is important, for instance because that different products are dried to different moisture content and with varying demands on variation in moisture content. After drying, the boards are graded and sorted in the final sorting and then shipped to the customers, i.e. the secondary manufacturers.

The fact that the sawmill industry is based on a continuous flow of individual logs and boards, and that it is a divergent flow in several steps, makes it very interesting to apply traceability technology to the production of sawn wood (Chiorescu, 2003; Uusijärvi, 2003). There are three main benefits with tracing logs and boards through the process:

1. *Follow-up of decisions in the production process*, i.e. to create a system where it is possible to get feedback from stages later in the chain. Without traceability it is not possible to know for instance what happened when a specific log was sawn. With a traceability

system it would be possible to verify whether a log was sorted to the correct batch of logs, or if it was better suited for other products. In this way it becomes possible to improve and fine-tune the production process based on the feedback from previous production.
2. *To certify the origin of the products*. Traceability would make it feasible to prove, for instance, that a product is based on wood from a specific area that has been managed in a sustainable way.
3. *To base process control decisions on information from previous production steps*. With a real-time traceability system it would for instance be possible to base the decision in the log sorting also on information from the harvester.

To achieve benefit 2 and 3 requires traceability for every individual log and board. Hence, if benefits 2 and 3 are to be achieved the traceability system has to be based on a technology that provides a low cost for marking each log or board. The first benefit can on the other hand, be based either on a system where all logs and boards are traced, or a system where only a random sub-sample is traced.

For a sawmill, the raw material, i.e. the logs, represents more than 70 % of the total production cost. Because of this, there is a great need to optimize the utilization of the raw material. An accurate and efficient optimization of the production requires feedback from the process. Consequently, the first benefit has the highest economical potential and therefore also the highest priority.

For boards, there are solutions that make it possible to trace individual boards by printing a matrix code on the board and then read it later in the process. For logs, it is possible to print a code on the end-surface of the log, but snow and dirt make the identification unreliable. RFID has therefore been suggested as a suitable technology for tracing logs from forest to sawline (Uusijärvi, 2003).

5.2 RFID application

In 2006, Träcentrum Norr[1] initiated a project where the aim was to show how a traceability system can make it possible to get feedback from the production and use this information for optimization of production. Based on the suggestion by Uusijärvi (2003) it was decided to use RFID for tracing logs from log sorting (or forest) to sawline. All installations, tests and verifications of how to utilize the system were done at a large sawmill in northern Sweden. The sawmill has an annual production of 390 000 m^3 sawn wood and has high technology level with X-ray and 3D-scanning of logs, automatic grading of boards in both green and final sorting and a printer/reader system for tracing individual boards from green to final sorting.

When deciding on how to design a RFID system for the sawmill industry, there are a number of factors to take into account:

1. *The cost for the transponders*. The sawmill where the system was installed consumes approximately 5 million logs per year. Therefore, the application is very sensitive to the transponder cost if all logs are to be marked.
2. *The cost for applying the transponders*. Automatic application can be done by the harvester, but the application is not allowed to delay the harvesting operation.

[1] A competence centre for applied wood technology research, see www.ltu.se/ske/tcn.

3. *No plastic is allowed in the transponders*. Sawmills sell the wood chips to pulpmills, and the pulpmills do not accept any plastic material in the wood chips.
4. *Small amount of metal*. Only a small amount of metal is allowed in the tranponders. One reason is that hard materials in the logs will damage the tools when sawing the logs. The other reason is that because of this problem, logs with metal are automatically put aside in the log sorting.
5. *Harsh conditions*. The transponders have to be applied into the log for protection and must also tolerate damp and cold conditions (-30°C).

The aim of the project was, as mentioned above, to make it possible to obtain feedback for optimization of the production. Based on the limitations due to cost, it was decided to aim initially at a system that makes it possible to trace a sub-sample of logs, around 0.1-0.5 % of all logs that are sawn. A sub-sample traceability system solution is less sensitive to the cost of the transponders and allows manual transponder application either in the forest or in the log sorting. The manual application is possible since the operators already today has to handle a small number of logs manually (around 0.3-0.7 %) for quality control purposes. Hence, the manually handled logs could easily be manually marked with a RFID transponder at the same time.

Due to the material limitations (no plastics), it was decided to use low-frequency (125 kilo Hertz) glass transponders of the same type as in Figure 4. A special tool was developed for manual application of this type of transponders, see Figure 8.

Fig. 8. Left: Tool for manual application of transponders. Right: Manual application of transponder to log.

In the sawmill, the transponders are to be read in the log sorting and in the sawline. Different antennas were designed specifically for these two positions, see Figure 9 and 10. When a transponder is read, the transponder id is sent to the process control system. In the log sorting, the log is then scanned by both X-ray and 3D scanners. Based on the scanner information the logs are sorted into different bins, each bin corresponds to logs aimed for specific products. A crucial step is to match the log transponder id to the scanner data for the same log. To match the correct id and scanner data is difficult, since the logs travel with 2.5 meters/second and the distance between logs can be down to 30 centimetres even during normal conditions. The correct transponder id also needs to be matched to the correct data in the sawline, but in the sawline the speed is lower and the distance between logs is longer.

Fig. 9. Antenna for RFID reading in the log sorting.

Fig. 10. Antenna for RFID reading in the sawline. The arrow is indicating the position of the antenna.

After sawing, the order of the boards is changed randomly before going through the green sorting. However, to get feedback from the result after sawing, i.e. the boards, traceability need to be obtained through the sawing. To obtain traceability the boards were colour marked and then the marked boards were identified in the green sorting before printing the matrix code. Hence, by combining the transponder id, colour marking id and the matrix id, traceability may be created from the forest to the secondary manufacturer.

5.3 Results from tests with RFID

The initial plan was to use 13.3 millimetres long transponders with 3.15 millimetres in diameter for the RFID application. However, the signal to noise ratio for the 13.3 millimetres transponder was to low. The low ratio was mainly caused by disturbances due to moving metal parts in the conveyor. A sufficient ratio was not possible to reach using the 13.3 millimetres transponder, so it was decided to use 22 millimetres long glass transponders with 4 millimetres in diameter. The 22 millimetres transponders are more expensive, but the main reason for wanting to avoid the longer transponders was that these were causing problems with the metal detection equipment used in the log sorting. To ensure that logs with metal do not reach the sawline the metal detection equipment sort out logs containing more metal than a certain value. The problem was that the 22 millimetres transponders contained to much metal and was sorted out by the metal detection equipment. To avoid that logs marked with the longer transponder were sorted out two different threshold levels

for the metal detector were created, one level for logs with RFID transponders and a lower level for all other logs.
The read rate for the RFID application was tested by applying the longer transponders to 49 logs in a batch of totally 85 logs. The logs were run through the log sorting and then sawn during normal conditions. In the log sorting 49 transponders (100 %) were read and matched to the correct data, while 45 transponders (92 %) were read and matched to the correct data in the sawline. The 49 logs resulted in 196 centreboards and for 150 of these boards (77 %) the colour marking could be read and matched to the properties of the log.
The results from the read rate tests are promising. If 10 000 logs are marked with RFID transponders, this results in a database with connected log and board data for 7 700 logs, based on a 77 % read rate for both the RFID transponder and the colour marking. The RFID transponders costs around 1.5 EURO, resulting in 15 000 EURO for 7 700 traced logs, i.e. 1.9 EURO/traced log. For a comparison, the estimated cost for a test sawing where 150 logs were traced manually was 4 500 EURO, i.e. 30 EURO/traced log.
The traceability data received from the application could, for example, be used to identify the relation between relative knottiness in boards and knottiness in logs, see Figure 11. Hence, if a customer wants boards with a relative knottiness less than 0.3, Figure 11 shows that logs with a relative knottiness less than 45 produce boards that are suitable for that customer. By using traceability data, like the data in Figure 11, it is easier to optimize the production process, since the connection between process data and product data is available.

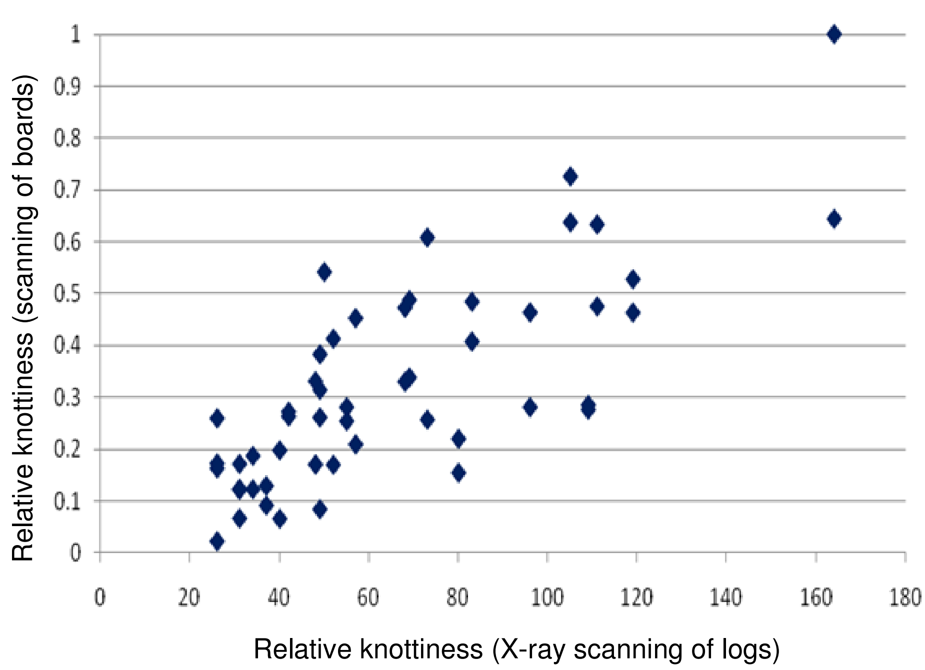

Fig. 11. Relative knottiness in boards as a function of relative knottiness in logs.

5.4 On-going and future development of RFID technology for the sawmill industry

The example shows a successful application of RFID for a sawmill industry. However, a wider use in the forest industry will require RFID transponders that are specifically developed for this application. That means a low cost transponder that can be automatically applied and that does not cause problems for neither pulp mills nor sawmills, i.e. such a transponder can not consist of plastic and can only contain a minimum amount of metal. Research work aiming at such a transponder is being done and a first prototype have been developed within the EU-project Indisputable key, for more information see Anonymous (2009).

6. An outlook on other RFID applications

There have been other ideas and uses of RFID to improve traceability in continuous process except from the two examples described. We here briefly describe some of these applications found in the literature.

RFID has been used in a number of mine to mill traceability projects around the world. La Rosa et al. (2007), for example, describes an application were hardened transponders and readers was used to track ore from the blast to the concentrator. The transponders were inserted in the blast holes or/and on the surface of the resulting muckpile. For each transponder the x-y-z position and identification number were linked. Tracking the transponder the source and properties of the ore being treated in a process step was accurately known at all times Also, tracking the ore with transponders made it possible to relate the metallurgical performance to original location in the mine and geometallurgical conditions. In the application, the measured survival rate for the hardened transponders after operations, such as blasting and crushing, was around 80 %. (La Rosa et al., 2007)

Lauf (2008) describes another application were RFID have been used in a coal fired power plant to track the quality of the input coal. Knowing the coal quality used in a power plant is important, since the process settings may then be optimized to the current coal quality and power plant efficiency can be improved. On-line analysis instruments for coal quality are very expensive, but analysis from the equipment is available in real time. Therefore, transponders with the same size as the average sized piece of coal were dropped into the product flow in connection to the analysis equipment of coal quality and the quality of the product was then linked to the transponder identification number and stored in a database. The movement of the transponders could then be tracked by a set of readers which forwarded the transponder identification number and time for detection to a database. The information in the database was used by the operators to continuously monitor the coal quality and optimize the plant settings. (Lauf, 2008)

Chen et al. (2005) have used RFID to collect data for modelling the flow pattern of pellets in a full scale test silo. Transponders were placed in the silo at different x-y-z positions and the position was linked to the identification number of the transponder. The transponders residence time were measured at the exit during discharge. To deduce the discharge flow pattern the residence times for the transponders at various positions was studied. The results from the tests showed that using RFID to study flow pattern is a reliable and cost effective technique that does not interfere with the silo's structure or operation. (Chen et al., 2005)

Moussavi et al (2005) present a novel traceability solution for meat products in an abattoir and boning hall. The solution comprise of a smart conveyor system integrating mechanical design, electronic architecture and RFID equipment. Besides improved traceability the solution resulted in better yield, less waste, and improvement in labour assignment. (Mousavi et al., 2005)

A more remote application is presented by Allan et al. (2006), they used RFID to trace the transport of pebbles in a mixed sand-and-gravel beach. To trace the movement of pebbles various transponders with similar characteristics as the pebbles were placed at five different locations. How the transponders had moved was then examined at various times by scanning the bottom with hand readers to see the new positions of the reader. The investigation demonstrated that RFID can yield important insights into the transport of gravel.

7. Conclusions, discussion and future research

The fragility of the transponders was beforehand thought as a limitation when considering various RFID applications. However, the described applications in continuous processes have shown that transponders can be designed to survive blasting, crushing, extreme temperatures and large shear forces. Therefore, we argue that the transponder fragility should not be seen as a limitation for most uses. However, designing transponders that survive in high temperature processes are still thought to be problematic or even impossible. In some continuous processes, for example the paper industry, the transponder may be a contaminating factor in subsequent process stages. However, if the whole process is kept in mind when choosing and developing the transponder the contamination can be avoided like in, for example, the sawmill process. The selection and development of a suitable transponder may be expensive and time consuming.

When transponders are dropped directly in the product flow the orientation between the reader antenna and the transponder antenna cannot be controlled. For some application all orientation may not be readable and some transponders may pass the reader without being read. By serially mount readers at different orientations in relation to the passage of the product flow, like in the pellets distribution chain, a higher fraction of transponders can be read. A low read rate implies more costs either in an increased demand of transponders or number of readers to be mounted. However, a low read rate does not imply that RFID has to be abandon as an application.

Installing a reader in some continuous process may demand that the process is stopped during the installation or that the installation must be done during a maintenance stop. Therefore, the installation may be costly or limited to a specific time and making changes to an installed reader may be both difficult and costly. Simulations may provide information that can be used to reduce the risk for the need to modify an installation and thereby the cost of an installation.

The production process in continuous processes is often highly automated and richly instrumented. An RFID application may affect or be affected by an existing instrument, and unexpected problems may occur similar to the problems with the metal detection equipment in the sawmill process. Hence, before an RFID application is installed it is recommended to perform a risk evaluation in an attempt to identify potential risks with the installation. To predict all potential risks for problems connected to an RFID application is complicated. Therefore, it could be wise to be cautious and initiate the application stepwise in an attempt to minimize the consequences of unexpected problems.

One factor limiting the use of RFID is the physical size of the transponders. Today the size of the transponders may limit the use of RFID to trace the movement to particles ≥ 10 millimetres. Another factor limiting the use is the read range, with longer read range the transponder position could be more thoroughly followed and new applications would be available. The third factor limiting the use of RFID is the transponder price. However, new transponders with longer read range, lower price and smaller sizes are continuously developed.

Even though we have found several RFID applications in continuous process to improve traceability we still think that this is a field that should receive more attention in contemporary research. The presented applications have resulted in a number of benefits beyond an improved traceability and the benefits have outweighed the costs for the described applications.

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Sustainable Radio Frequency Identification Solutions

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Radio frequency identification (RFID) is a fascinating, fast developing and multidisciplinary domain with emerging technologies and applications. It is characterized by a variety of research topics, analytical methods, models, protocols, design principles and processing software. With a relatively large range of applications, RFID enjoys extensive investor confidence and is poised for growth. A number of RFID applications proposed or already used in technical and scientific fields are described in this book. Sustainable Radio Frequency Identification Solutions comprises 19 chapters written by RFID experts from all over the world. In investigating RFID solutions experts reveal some of the real-life issues and challenges in implementing RFID.

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