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Chapter 15

Challenges and Possibilities of RFID in the Forest Industry

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Additional information is available at the end of the chapter

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1. Introduction

Considerable added value in wood and timber production can be achieved via higher yield and quality of the wood products deriving from improved control of the production processes. The key to improve the production is the identification of the individual wood items in order to utilise exact information of their properties. This can be realized by marking and tracking of tree trunks, logs and sawn wood products to allow the information associated with them to be collected and utilised in all stages of the value chain from forest to the wood product.

Marking and traceability technology for forest industry have been investigated for some time and several technologies have been considered. Recently, UHF RFID technology tailored for the needs of the forest industry has been developed. This Chapter will discuss the unique challenges that the forest industry sets for the radio frequency identification technology and will highlight the benefits and possibilities of the RFID use. Recently developed technical solutions and their trials in production conditions are described.

2. Traceability in the wood supply chain

Individual identification of the wood items (tree, trunk, board, pole, etc.) allows detailed information to be associated with them which can be used to optimise the production. The simplified basic wood supply chain is illustrated in Figure 1.

Figure 1. Simplified general wood supply chain.

First the trees are cut down and then they are transported for processing into products. The processed products are then transported to a secondary manufacturer or to an end-user. The supply chain varies in different countries and for different products as does the level of automation – for example the felling of trees can be done manually with a chain saw or by a forestry harvester. The felling is followed by removal of the branches and in some countries the trunks are cut into logs in the forest by the forestry harvester. The trunks or logs are transported to road side for storage and subsequent transportation to an intermediate storage or directly to a processing plant. The processing steps depend on the product in question – the most common ones being pulp for paper or cardboard making, boards, panels, veneer and poles. Each of these products uses different wood as their raw material and wood with different properties. The highest value round wood in the Nordic countries is used for the production of sawn timber such as boards. This supply chain is discussed in more detail in the following Section.

After processing into the primary product (e.g. boards) the wood products are transported via the associated logistics chain to a secondary manufacturer such as a building component manufacturer or a furniture manufacturer or the end-user (e.g. a consumer or a constructor).

If the wood material could be identified at individual level (trees, trunks, logs, boards, poles, etc.) information can be associated with it – and this information can be traced through the supply chain to optimise the production of wood products.

2.1. Nordic wood supply chain for sawn timber

The Nordic wood supply chain is illustrated in Figure 2.

The trees are felled and cut into logs by a harvester. The harvester also carries out a multitude of measurements on the logs such as measuring their dimensions to determine the volume of wood felled. Next the logs are transported to a pile in the road side by a forwarder. A harvester and a forwarder are shown in Figure 3.

The logs are collected from the road side by a timber truck which transports them either directly to a saw mill or to an intermediate storage. From this storage the logs are transported to a saw mill by truck, train or by floating. At the saw mill the logs are received and sorted into different classes – this sorting is usually based on dimensional measurements using a 3-D laser scanner. In addition to the laser scanner, X-rays may be used to characterise the internal properties of the log. After sorting, the logs of a suitable class are sawn into boards which are then sorted based on their dimensions and quality (e.g. number and size of the knots in them). The sawn boards are usually dried in a kiln and graded for quality after the drying. The graded boards are then stored and packaged for shipping to the end user or to a secondary manufacturer.

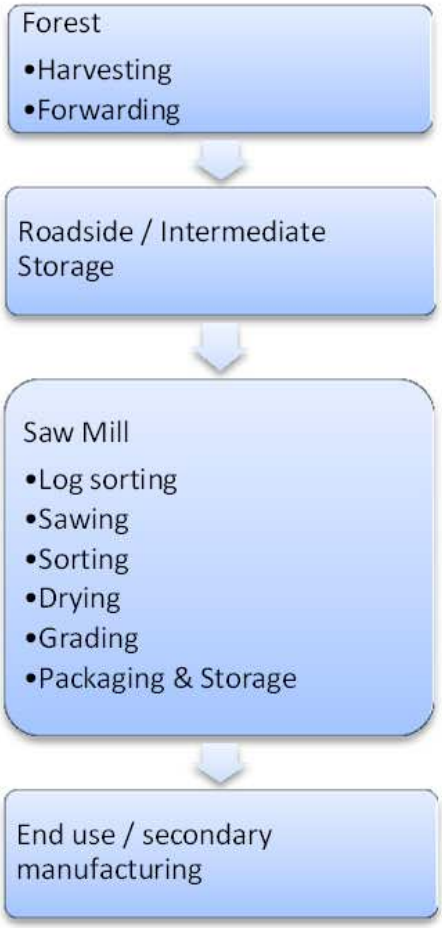

Figure 2. Nordic wood supply chain for sawn timber.

Figure 3. Examples of a harvester and a forwarder [1].

2.2. Possibilities and benefits with wood traceability

Currently, the wood material properties are measured when needed in the wood conversion chain and the gathered data is usually lost between the processing steps as illustrated in Figure 4.

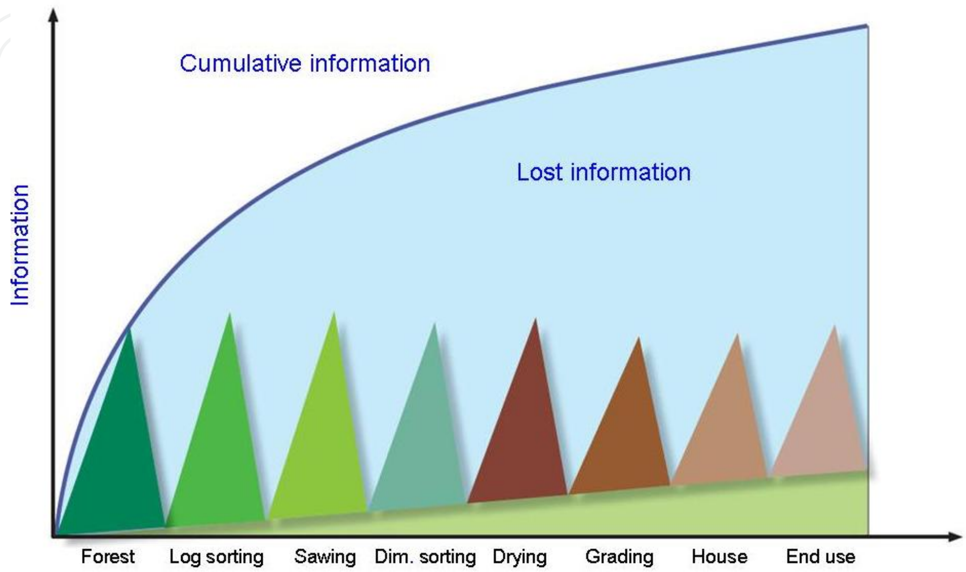

Figure 4. Collection and utilisation of information in the wood supply chain [2].

As the collected information is lost between the processing steps, measurements need to be repeated - such as the measurement of the log dimensions in the forest by the harvester during cutting and the re-measurement of the dimensions in log sorting in the saw mill to determine the volume of the wood for the second time. The lost information also naturally means reduced control over the wood conversion chain from forest to end product as the information related to the wood cannot be traced along the chain.

The traceability of the wood and the associated information can be achieved by identifying the individual wood items – logs and boards, instead of relying on classification of wood and processing in batches of the same class of wood. The benefits of the traceability include:

- Increased quality of the products
- Increased yields
- Reduced production costs.

The quality of the products can be increased with improved control of the production processes by effectively utilising the information collected in the previous stages of the conversion chain. The production process can be optimised based on the individual properties of the wood - processing parameters can be adjusted to better suit the material in question and the most suitable raw material can be used for the product in question.

The yield in the production can be also increased with improved information utilisation and control enabled by the traceability. Downgrading of the boards in the final grading can be reduced when the desired final quality is more consistently achieved. The yield can be also increased by using the right raw material for each product - each type of wood can be used for the most valuable product it is suitable for and less wood material of higher quality is wasted in the production of basic wood products. The production costs can be reduced with improved processing control as the need to 'over-process' the wood is reduced when the actual properties of the wood can be traced instead of relying only on the information on the batch. The improved control over the wood supply and conversion chain together with the more efficient and comprehensive utilisation of the information on the wood material allows also potential new and tailored wood products. Individual identification of the wood items can also be utilised in the logistics – transport planning and control, stock inventory and control in storage, etc.

The traceability in the wood supply chain can also be used to certify the origin of the wood to prevent illegal logging and log theft.

3. Challenges of traceability in the Nordic forest industry

The forest industry presents some unique challenges to the traceability – item marking and identification, and information storage, retrieval and exchange between the different actors in the supply chain. Different supply chains with somewhat different challenges exist for different wood products e.g. pulp and paper, sawn timber, other wood products and energy wood. For simplicity, the discussion is limited here on the sawn timber supply chain with the focus on the round wood.

The wood harvesting takes place in the forest outdoor conditions in rough terrain. The wood is stored outdoors where there is ice, snow, rain, water, dirt, mud, etc. The transportation is by trucks, train or by flotation in bunches from forest to the saw mills. The logs are subjected to impacts with machinery parts, other logs, rocks and the ground. At the saw mill the logs are handled with cranes and conveyors. These conditions are challenging for the log markings and their identification, and for the electronic hardware to be used.

The logs are sawn into boards, which usually destroys the physical markings in the wood and the boards have to be re-marked if full traceability over the chain is targeted. Board marking represents a different challenge from the log marking – the boards are handled in a more controlled industrial environment mostly indoors but the number of boards is larger than that of the logs as each log is sawn in to several boards and the value of each board is lower. Thus the board marking and identification needs to be very inexpensive to be feasible.

In the following Sections, the approaches considered for log marking and identification are discussed together with the specific challenges and limitations related to the use of UHF RFID technology in the forest industry.

3.1. Wood traceability techniques

The traceability can be based on marking and identifying the wood items such as logs and boards. Several methods have been considered for marking tree trunks and logs including painted markings, engraved markings, attached labels with a printed serial number (or other alphanumerical data) or a bar code, fingerprinting techniques based on physical, chemical and/or genetic properties of the wood, and RFID [3]. Markings can be painted or printed on the wood surface and they can be read either by personnel or automatically using machine vision technology (cameras and software). Different coding schemes from simple colour codes to serial numbers and to more advanced codes such as 2D matrix codes have been used. A medium-sized saw mill in Nordic countries typically processes a few million logs per year and thus individual identification of the logs requires a large number of unique codes to be available as the harvested logs may be also transported to several saw mills. Therefore, for unique identification only the more complex codes such as long serial numbers, barcodes or data matrices are feasible. Figure 5 shows examples of a bar code and a matrix code.

(00) 0 0123456 123456789 6

Figure 5. Examples of a GS1-128 code and GS1 DataMatrix [4].

The code markings can be painted, printed, engraved, punched or otherwise imprinted on wood. The main attraction of this kind of markings is the low cost of the marking as each individual marking is inexpensive to make. The most common application of these visual marking codes is printing them onto the boards as the large number of the items and their relatively low value emphasizes the need for low cost marking. The main weakness of the visual markings is their readability – the codes can be obscured by dirt, snow and moisture. A line-of-sight is needed for the camera and optical equipment may need frequent maintenance in dusty industrial environments. Printing of the codes on the surface of wood is also challenging; the surface of wood varies and clear markings are difficult to achieve consistently. For example, markings printed accidentally on dirt or other material on the wood come of when this material comes of the wood. The drying of the wood may distort the shape of the marking and the wood may crack under it.

Multiple techniques have been developed to overcome the problems with visible markings on wood surfaces. One can use attachable labels for smooth printing surface but these labels may also be detached from the wood during the processing steps and the labels can also be covered by dirt, saw dust or other opaque material preventing their reading. Special luminescent inks have been used to improve the readability of the visual markings by increasing

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the contrast between the markings and the wood surface [5]. Matrix codes allow also for error correction algorithms for improved readability. The achievable identification rate in the board marking with visual codes seems to be in the range of 90-95 % [6].

The use of visual markings on round wood, such as logs and tree trunks, is more complicated than on boards. Logs have to be marked and identified outdoors where the environment is more challenging due to the more frequent occurrence of dirt, water, snow, ice and other materials obscuring the marking. The wood surface also varies more on logs than on sawn boards. In the Indisputable Key –project two log marking methods based on visual markings were tested: luminescent nanoparticle (LNP) ink codes with a handheld marking device and harvester saw integrated printer that sprayed a matrix code or a custom bar code consisting of ink dots or stripes onto the log end [6]. The LNP ink dot or the line markings were read using an infrared camera. The trial achieved 75 % readability of the log markings. The harvester saw integrated marker was tested in marking logs in the forest that we identified using a camera at the log sorting station in a saw mill. Automatic detection rate of the correct identity of the marked logs was nearly 40 % and by eye 74 % of the markings were readable [7].

To overcome the readability problems with visual marking techniques radio frequency identification (RFID) has been tested for log identification. The main advantage of RFID technology is the capability for very high readability – radio waves do not require a line-of-sight and they propagate through most materials excluding highly conductive materials. Thus RFID technology is insensitive to the commonly found dirt, snow, ice and other opaque materials on wood. In the past, RFID trials have used commercial transponders – mainly low frequency (LF, 125 kHz) and high frequency (HF, 13.56 MHz) tags. LF and HF tags have been available much longer and were considered to be better suited for wood marking than UHF (ultra high frequency, ~860-960 MHz) transponders with known problems on moist surfaces e.g. on wet wood and near metal.

Examples of the LF and HF transponder trials are described in [8,9]. In [8] logs were marked by inserting 23 mm long LF tags by Texas Instruments into logs in the forest using a prototype applicator in the harvester. The reading range is reported to have been up to 0.5 m and reading accuracies in the range of 80-90 % were reported at the saw mill. Korten et al [9] report trials with HF transponder cards that were stapled on the logs and read using loop antennas in the forwarder, in a timber truck and at the saw mill. The reported reading range was 0.5-1 m depending on the reading location. Reading is reported to have been reliable.

Reliable automatic log identification is the basis for the traceability in the wood supply chain. UHF RFID technology offers the potential for high readability as the reading range is typically much longer than at LF and HF. Also, a few years ago GS1 introduced standardisation for UHF RFID which facilitates the implementation of the RFID systems. The challenges related to the use of UHF RFID technology in wood supply chain are discussed in the next Section.

3.2. Challenges of UHF RFID technology in wood traceability

Economically viable utilisation of the traceability requires that the wood items can be automatically identified. The item marking should not reduce their value or limit their use as a high quality raw material. The identification of wood items, the marking and reading, should be done without reducing the production efficiency e.g. by slowing it down and the costs related to the traceability should be reasonable to allow the benefits of the traceability to be utilised. The most significant part of the RFID system is the transponder as they are the most numerous component in the system and their performance is the basis of the overall system performance.

Wood is a natural material with varying properties between the trees, logs and boards – and within them. The density of the wood, the grain orientation and the moisture content vary and thus the electromagnetic properties (the complex permittivity) also vary. The varying moisture content has the greatest effect on the permittivity and loss in the wood. The permittivity variation can lead to transponder antenna detuning and the high loss due to the high moisture content attenuates the radio signal. These effects have to be taken into account in the design of the UHF RFID transponder to guarantee a sufficient reading range in all conditions in the wood supply chain. UHF label tags are therefore not suitable for marking fresh wood with high moisture content. In practice, the reading of the tags at saw mills has to be done at distances up to 1 m. The reading range depends mostly on the transponder as the reader operation is governed by the radio regulations defining for example the maximum allowed radiated power.

Reliable identification of the wood items requires that the tags have a high survival rate in the wood processing steps as transponders that have been destroyed or have been detached from the logs or boards cannot be read. In the RFID trials it has been frequently found out that tags glued, stapled or otherwise attached on the logs may be lost in the wood processing – especially during transportation, on conveyors and in debarking. In [9] it is reported that some 75 % of tags attached to the front-end of the log were lost in debarking at the saw mill. In trials carried out by the authors with tags attached onto the surface of the log ends typically up to a few per cent of the transponders were lost in each processing step which results in a significant loss of tags over the supply chain. Therefore, in order to ensure the transponder survival through the whole supply chain the tags has to be inserted inside the wood. Inside the wood the tag is protected from impacts which will improve the transponder survival rate considerable.

The transponder has to be attached on or preferably inserted into the wood by an applicator tool or machine and the tag has to be suitable for reliable and quick application. The application of the transponder should not reduce the production efficiency i.e. the application should not introduce significant delays. The application has to be done automatically where the wood processing is automatic and manual application is possible only if the wood is handled manually, e.g. felled with a chain saw or a reasonably small number of logs are marked. The transponder has to withstand the application to be readable.

In paper making certain materials even in small concentrations are banned from the wood used as the raw material in pulping as they may cause problems in the quality of the paper produced. These materials include most plastics, coal and metal. This represents a challenge in the manufacturing of the transponders as the commonly used materials cannot be used. When round logs are sawn into rectangular boards some of the wood is left over and this wood is commonly chipped and sold to pulp mills. These wood chippings are a high quality raw material for paper making and a valuable by-product for saw mills. As transponders and their pieces may end up into these chippings, the same restrictions on the tag materials apply also to their use in the sawn timber supply. Thus conventional plastics cannot be used in the tags to avoid possible plastics contamination of the wood. The transponder design and materials have to be suitable for inexpensive mass production of the tags as the costs of the transponders typically forms the largest part of a RFID based traceability system.

4. RFID implementation for forest industry

The past RFID trials have focused on using available commercial RFID transponders to mark logs or other wood items. The results of these trials have varied, but in general the transponders intended for other applications have not been optimal for the needs of the forest industry. Therefore, a custom made RFID solution was considered advantageous and was developed in an EU FP6 funded project called Indisputable Key [10]. The following Sections describe the passive UHF RFID solution developed for the supply chain of the forest industry.

4.1. RFID transponder for log marking in sawn timber supply chain

The basis of the traceability utilising RFID is the transponder used to mark the wood items. The requirements for the transponder to be used in log marking in the Nordic sawn timber wood supply chain can be summarised as follows:

- High readability
- Easy attachment into a log
- Harmlessness in pulp and paper making
- Suitability for inexpensive mass production.

These requirements are discussed in Section 3. The required compatibility of the material used with the pulp and paper making processes is perhaps the most constricting requirement for the transponder. Typically a UHF RFID transponder consists of a thin plastic inlay with a metal foil for the antenna to which the microchip is connected and of a hard plastic casing. As common plastics are not accepted in the wood used for pulping, alternative materials were considered. Biopolymers offer an interesting alternative to conventional plastics.

In addition to the chemical compatibility with the paper making processes, the transponder material has to be suitable for insertion into the wood to ensure tag survival in the logs in the wood processing steps in the supply chain. The material has to be mechanically durable; sufficiently hard but not brittle and it may not absorb water. The transponders have to survive several months in the logs. The material should have suitable electromagnetic properties at UHF frequencies – ideally low loss and stable properties. In addition to the suitable chemical, mechanical and electrical properties the material has to be applicable for mass production of the transponders using common plastic fabrication techniques e.g. injection moulding. A suitable bio-composite material meeting these requirements is ARBOFORM® by Tecnaro GmbH [11] and it was selected as the transponder casing material. The ARBOFORM® -material consists of lignin, natural fibres and processing aids. To facilitate the mass production, conventional plastic inlay with aluminium as the antenna pattern material was selected, as the amount of plastic in the inlays ending up into the pulping from the saw mill is negligible. Currently, paper inlays are also available for a non-plastic alternative. The transponder is EPC Class 1 Generation 2 compatible.

The desired high reliability in the wood tracing requires a good survivability of the transponders, which can be only achieved by inserting the tags inside the log. For high readability in the different steps of the supply chain the best location for the tags is in the log end. The transponder size and shape have to be optimised for insertion into the log – several approaches were investigated in the Indisputable Key –project [12] but a wedge-shaped transponder that is punched into the wood was selected [13]. This transponder has the additional advantage of being difficult to remove from the log or to tamper with. The shape of the casing with the inlay inside and the application method are illustrated in Figure 6.

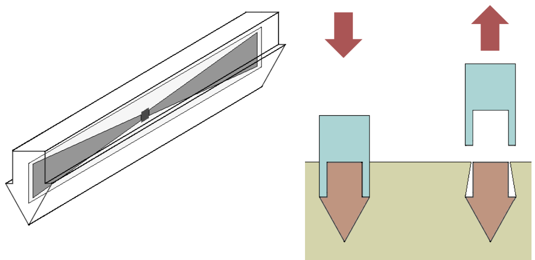

Figure 6. Wedge-shaped transponder and its insertion into the wood.

To achieve good readability in the production conditions on the conveyors, a long reading range is needed. The transponder casing material is somewhat lossy (measured electrical loss tangent is ~0.03 at UHF) which limits the choice of possible transponder antennas to dipole antennas. Wood is a natural material which is not isotropic or homogenous, and the moisture content varies greatly as the wood dries or gets soaked in rain after the tree is felled. The moisture content affects greatly the permittivity and losses of the wood and thus the transponder antenna has to be designed to operate in the wood with varying electromagnetic properties. The moisture content may exceed 100 % of the dry material weight in fresh wood.

The design of the transponder antenna was developed using electromagnetic simulations, laboratory tests and tests in production conditions in saw mills [14]. For electromagnetic simulations, Ansoft HFSS was used. The transponder readability is best when the tag is in the end of the log, as this part is usually exposed in the piles and on conveyor. If the transponder is in the side of the log it may be left under the log or covered by other logs and reading would have to be done through considerable thickness of wood and with the possibility of the tag being pressed against a metal surface. Figure 7 shows the simulator model of the transponder inside the log and the basic layout of the planar dipole antenna inlay.

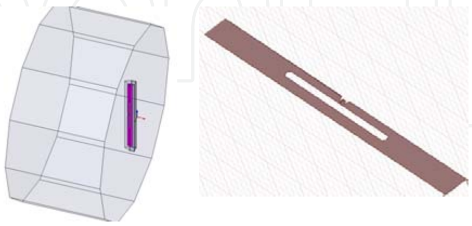

Figure 7. Simulation model of the transponder inside a log and the planar dipole antenna layout.

The planar dipole antenna was optimised for operation inside wet wood with tolerance for varying permittivity caused by varying moisture content in the wood. The electrical properties of wood were measured at UHF and the relative permittivity of the spruce was found to be of the order of 2.3 when fresh and 1.8 after kiln drying. Correspondingly, the loss tangent was 0.08 and 0.03 for fresh and dry spruce. When soaking wet, the relative permittivity of the wood may be even in the magnitude of 10. The final antenna design has the dimensions of 74 mm x 5 mm. Figure 8 shows the reading range measurement in the laboratory together with the measured reading range using TagFormance™ measurement device.

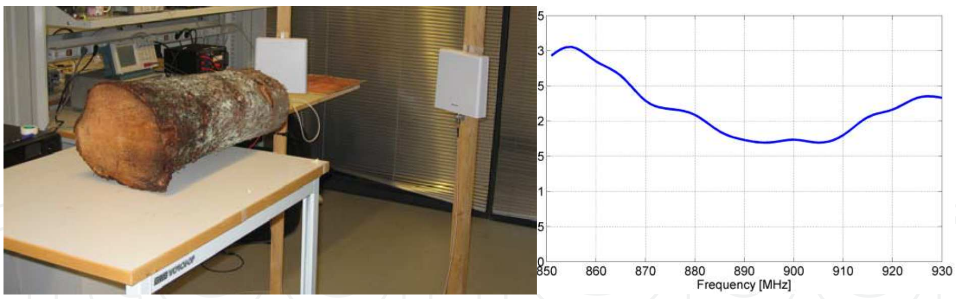

Figure 8. The reading range measurement in the laboratory and the measured reading range.

The reading range from freshly cut wood is approximately 2.5 m at the European UHF RFID frequencies (865.6 - 867.6 MHz) in the laboratory measurements. For inserting the transponder into the log, a simple tool or a manual applicator was developed. The applicator is made from an axe by replacing the blade with a holder for the transponder. Using this applicator, the tag is hit into the end of the log as shown in Figure 9. After some practice an operator may mark up to 100 logs / hour with the first strike success rate of approximately 95 %. In addition to this manual application tool, a prototype for an automatic applicator for a forestry harvester was developed [15].

Figure 9. Application of the tag and the tag inserted into the end of the log.

4.2. RFID readers

Ideally, the traceability in the wood supply chain would reach from the forest all the way to the end user of the wood products - for full coverage of the supply chain RFID transponders would have to be read with RFID readers in every processing step shown in Figure 2. In the Indisputable Key project, the RFID based traceability was used in the round wood supply chain from harvesting in the forest to sawing at the saw mill. RFID readers were used in three processing steps: in the harvesting, at the log sorting and at the sawing where most of the information on the logs is collected and needed – hand-held readers can be used in other processing steps to supplement the fixed readers in the harvester and on the conveyor in the saw mills. The transponders and readers were compatible with the EPC Class 1 Gen 2 air interface standard.

Each reader installation site represents some unique challenges for the RFID reader and for its antennas. The RFID reader has to be able to read the transponders reliably from a practical distance that depends on the location; for example on the conveyor in a saw mill the practical minimum distance from the reader antenna(s) to the transponder in the log is about 1 m as the thickness of the logs varies and sufficient space has to be left to accommodate this variation. The forestry harvester represents the most challenging environment for the RFID readers in the wood supply chain; the reader is subjected to difficult electromagnetic and physical environment in outdoor conditions with rain, snow and ice, vibration, shocks, Nordic four season temperatures and also to occasional impacts. The developed prototype of a vibration and shock resistant RFID reader is described in [14, 15]. The RFID reader features a robust impact resistant IP67 casing, adaptive RF front end for cancellation of reflections from large metal surface in the harvester head and EPC Global Reader Protocol v. 1.1 compatible interface over a CAN-bus to the harvester.

The reader installations at the saw mill were placed in the log sorting where the logs are first received and in the sawing. In these locations the RFID readers are subjected to industrial

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production conditions – particularly to saw dust and wood splinters, and to the risk of impacts. To protect the readers and to facilitate their installation over the conveyor the commercial readers were enclosed into a robust aluminium casing with the antennas on the outside. The reader used was Sirit Infinity 510 with circularly polarised antennas. Figure 10 shows the reader installations in a saw mill in Sweden in the log sorting station and in the sawing. In the log sorting it was found that antennas in a frame around the conveyor gave more reliable reading of the tags than over the conveyor assembly.

Figure 10. RFID readers in the log sorting and sawing in a saw mill.

RFID readers are used to read the transponders inside the log so that the logs can be identified and information such as measurement data can be associated to the log or the associated data can be retrieved. To identify the individual logs in addition to the reading of the transponder IDs, the ID-code has to be associated with the correct log on the conveyor. In the case of logs in the sawing this is relatively straight-forward as the logs are sawn top first so that the tags in the butt end of the log are always separated by at least the log length. This is based on the automatic applicator always inserting the transponder into the butt end of the log. The speed of the conveyor in sawing is reasonably low as well. In the log sorting the case is more challenging as in some saw mills the logs are not turned before the sorting and the transponders in the log ends can be very close to each other in adjacent log ends on the conveyor. To correctly identify the logs on the conveyor RFID positioning methods such as [16] could be used. In the Indisputable Key projects a simple method based on using the average reading time stamps from several antennas was used to determine the order of the transponders (and logs) on the moving conveyor). When the log separation was larger than about 1 m the logs could be identified reliably but some ambiguity in the log identification remained when the log separation was well below 1 m. The main reason for this was the difficult reading environment in the log sorting shown in Figure 9. There was a flat metal floor under the conveyor that causes reflections; the rapidly changing radio channel causes strong variation in the signal strength and variation of the position where the transponder is read on the conveyor. In the tests in other locations the log identification was significantly more reliable.

4.3. RFID system performance

The RFID system performance in the traceability of round wood in the Nordic wood supply chain was tested in several trials in a saw mill in Sweden and in another saw mill in Finland [15]. In the tests the number of repeated transponder ID readings by the reader was found to be a good indicator of the reading reliability and means to compare reader set-ups. When the tag stays in the field of the reader, the reader keeps reading the ID of the tag repeatedly. With each reading event lasting about one milliseconds, the number of repeated readings indicates how long time the tag has been in the field of the reader. Table 1 shows an example of the observed average number of repeated readings in three tests – in Sweden 164 transponders in 82 logs were run through the log sorting twice, and in a Finnish saw mill 143 test logs with transponders were sawn.

Test	Number of transponders	Reading rate	Number of repeated readings per tag	Standard deviation of the repeats
Log sorting test 1	164	100 %	190	120
Log sorting test 2	164	99.4 %	180	120
Sawing test	143	99.3 %	390	150

Table 1. Reading tests with logs marked with UHF transponders.

Typically the obtained transponder reading rates exceeded 99 % in tests with some 200 logs. In practice, the maximum read rate is 300…600 times per second. As can be seen in Table 4.1 the deviation in the number of repeated ID readings (~120) is rather large compared to the average number of the repeats (180-190) in the log sorting at the saw mill in Sweden, whereas in the other reader location the deviation is smaller in relation to the average number of repeats (150 vs. 390) indicating a more reliable and consistent reading of the transponders. These results also show that for intact normally operating transponders the reading rate can be close to 100 %.

Tests with RFID marked logs were also carried out to determine the log identification rate in the log sorting station in the Swedish saw mill shown in Figure 9 (left-hand side). In this location, reflections from the metal floor caused ambiguity in the reading position on the conveyor and the correct order of logs was unusually difficult to determine. Table 2 summarises the results from three tests where the log marking with RFID tags was carried out both in the forest and in the log yard at the saw mill using the manual applicator or the prototype of an automatic applicator in a forestry harvester.

Log marking	Reader location	Number of read tags in the test	Unique measurement results for the readings	Log identification rate
Automatic in the forest	Log sorting	285	268	94.0 %
Manual in the log yard	Log sorting	218	207	95.0 %
Automatic & manual, all logs for 26 Jan 2010	Log sorting	812	754	92.9 %

Table 2. Examples of identification rates obtained in RFID tests in a Swedish saw mill.

The log identification rate was determined by synchronising the measuring time of the logs by 3D scanner in the log sorting and the RFID tag reading time. Due to the variation in the position of the transponder in the conveyor when it was read by the RFID reader located on the conveyor slightly after the 3D scanner, there was a time window for the time difference the reading timestamp and the 3D scanning timestamp. In the tests, there were also unmarked logs mixed with the RFID marked logs. When there was only one log inside this time window when the RFID tag was read, the log identification was considered successful. The achieved log identification rate was on average about 93 % in the log sorting at this saw mill and in other reading locations the log identification rate was practically the same as the transponder reading rate.

4.4. RFID use in other wood supply chains and processing steps

The promising results in the log identification using UHF RFID in the Nordic round wood supply chain created interest to test the capabilities of the RFID technology in tracing wood in other wood supply chains in the Indisputable Key project. Two other cases were investigated: wooden impregnated poles and sawn timber (boards). Impregnated poles are a product that has a supply chain similar to the round wood supply chain for sawn timber except that the wood used for poles has more stringent requirements and thus a higher value. Additionally, the impregnated wood is not used as a raw material for paper or any other product so there is no limitation for the materials to be used in the RFID transponders. The main challenge in the pole RFID marking is the impregnation process: the poles are impregnated with creosote in high temperatures exceeding +100°C and creosote is a powerful solvent of plastics. The tags are exposed to creosote for an extended time in these high temperatures. The impregnation of the poles destroys most commercial tags as well as the developed biodegradable transponder. After some trials some special materials and high-temperature tolerant commercial tags where found but their high prices made them not feasible for production use. Excluding the destruction of tags in the impregnation, the readability of the UHF transponders in poles was excellent.

The high readability of the RFID tags approaching 100 % caused the desire to try UHF RFID marking of sawn timber, i.e. boards, as the optical marking techniques can typically only reach at best up to 90-95 % readability of the markings in production conditions. The large volumes of the boards sawn and the relative low value of the softwood boards excluded the use of cased transponders (hard tags) due to their price. Thus the only option was to experiment with label tags attached to the boards. The best readability with a label tag on the surface of fresh moist board immediately after sawing was achieved using an inlay indented for near metal applications with good performance in close proximity of detuning materials such as wood – e.g. UPM Raflatac Hammer. The achieved reading range was sufficient for board conveyors to ensure nearly 100 % readability where the reader antenna can be placed approximately 0.4 m away from the boards. However, the application of the label tags on the boards proved to be problematic. Different glues and stapling with plastic staples were tested but the transponder survival on boards in the saw mill in the processing steps from sawing to packing of the dried boards proved to be low - up to 30-40 % of the label tags attached to the boards after the sawing were lost before the packing. Thus the resulting traceability of the boards would be too low for useful applications in the range of some 60 %.

4.5. ICT solution

In the Indisputable Key project an ICT system solution was developed to handle the data storage and transfer to enable efficient utilisation of the collected information by different actors in the value chain.

The ICT System Architecture connects the enterprise business processes to the actual flow of objects. The architecture consist of tags to mark the individual objects, readers to observe the movements of tagged objects, reader data processor to interpret the raw RFID reads to basic observation events and an adapter to create the meaningful business events from the RFID events. The Traceability Services that provides the services to analyse and use the information and the Local ONS that provides the way of publishing the services to the other business partners and the users. Figure 11 presents the overall data flow of the architecture.

The ICT system architecture follows the guidelines set by the EPCGlobal architecture. The EPCglobal Network Architecture Framework is a collection of interrelated standards for hardware, software, and data interfaces, together with core services that are operated by EPCglobal and its delegates, all in service of a common goal of enhancing the supply chain through the use of Electronic Product Codes (EPCs).

Traceability Services Architecture extends the EPCglobal scope by offering the way to use other codes than EPCs and by providing Traceability Services. Traceability Services offers methods to monitor and optimize of the forestry wood supply chain, to research wood property correlations, and of course to trace the wood material throughout the supply chain. By tracing the wood object and processes used to manufacture the wood product the Traceability Services offers the chain-of-custody and environmental product declaration for wood products.

The architecture comprises three modules: Adapter, Collaborative Messaging System and Traceability Services. Adapters are used to acquire traceability information from the processes. The Adapters connect the observations of objects to the process data, generate events and send the events to the Messaging System. The Collaborative Messaging System is responsible for sending the event messages to the right subscribers. The Collaborative Messaging System is also responsible for authentication and authorization. The Traceability Services is responsible for storing the Traceability Data and presenting it to the users in correct format.

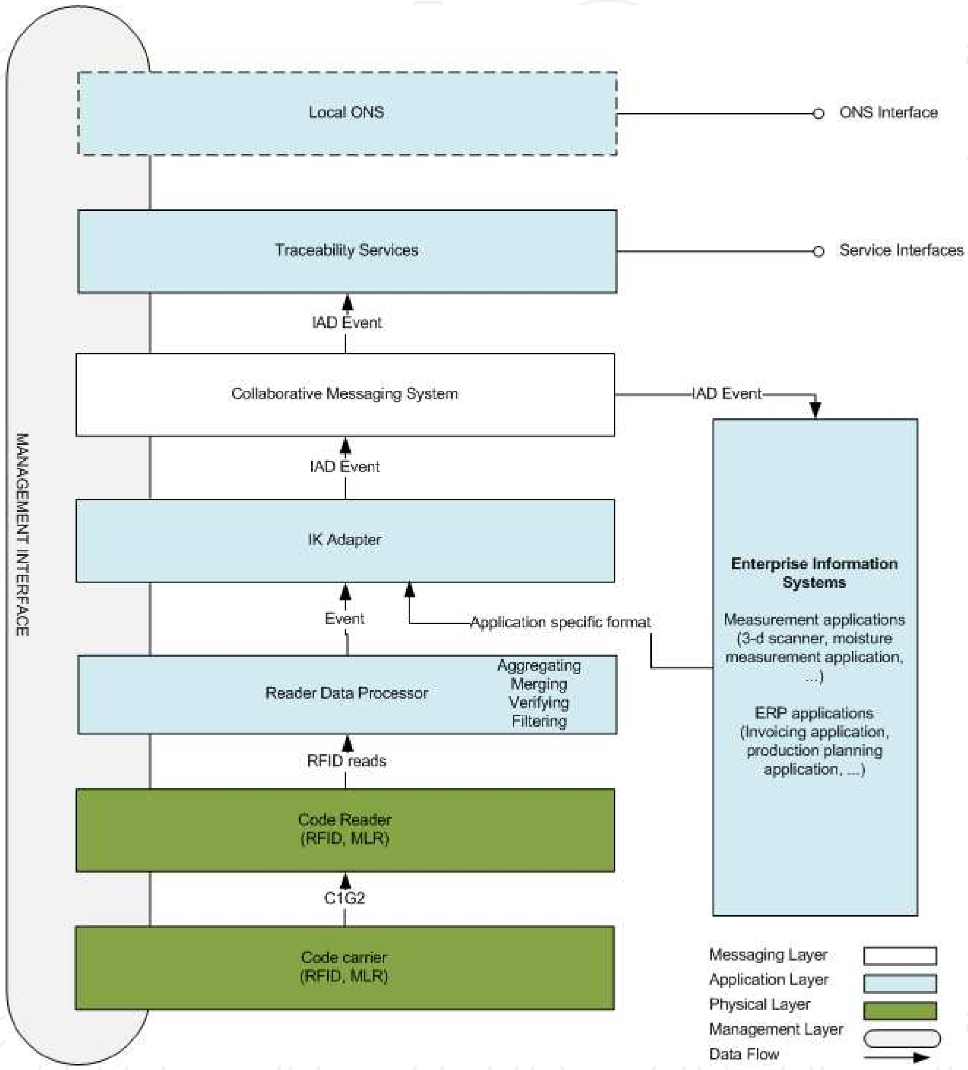

Figure 11. ICT System Architecture.

The interfaces between architecture modules are specified to each message format:

- C1G2, UHF Class 1 Generation 2 Tag Interface standard specifies the interface between RFID readers and RFID tags. The specification describes the interactions between readers and tags and tag operating procedures and commands. The full specification can be found from [18].

- RFID reads are individual reads of a RFID tag. The specification of the protocol used when tag readers interact with upper levels is specified in [19].

- Event is specified to be one observation concerning an individual object. The interface used to transmit the event to the Adapter is EPC global's Filtering & Collection (ALE) Interface, that specifies the delivery of event data to the upper roles. The event in this level could be "At location X in time Y the object with EPC was observed".
- Application specific format is used to connect the business data to the object observations. For example IK Adapter receives a measurements made by 3-D scanner are received as flat-file. The IK Adapter then connects the measurement information to the event information it received from the RFID-reader.
- IAD Event is specified to be one event concerning an individual object.

The Figure 12 presents the architecture when used across enterprises that do not use the same Collaborative Messaging Service. The data flow between enterprises can be realized by using the IAD events. Some application in Enterprise B can subscribe to the events produced in company A. Another connection point is ONS, for example end customers or parties not included into the production chain is to use ONS to look up for the service and use Services provided by the Traceability services to fetch the needed information. For example - customer can fetch a Chain-Of-Custody document or Environmental Product Declaration for object.

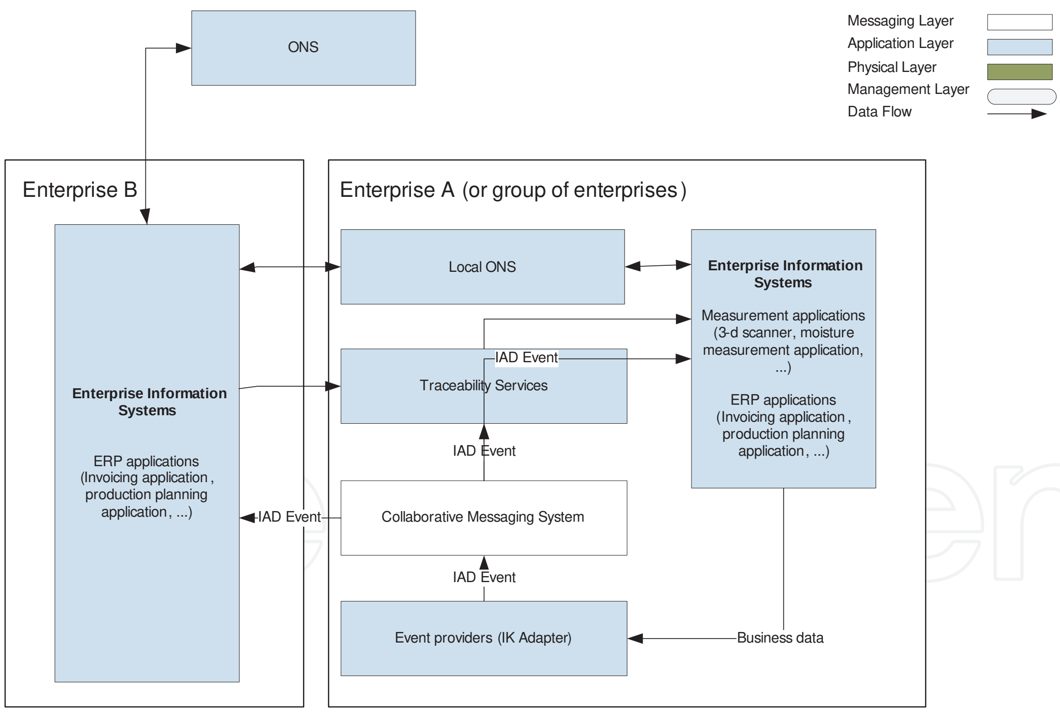

Figure 12. ICT system architecture across enterprises.

The centre of the ICT system architecture is a Collaborative Messaging System that is responsible of transmitting the messages from publishers to correct subscribers. The Publishers are not aware of Subscribers and all the authorization and authentication is performed by the Messaging System.

The Collaborative Messaging System is realized using publish-subscribe pattern. Publish-subscribe is an asynchronous pattern where publishers of events are not sending the events to predefined subscribers. Instead of sending the message to predefined subscriber, message is published with some topic and content. In forestry-wood production system each event must contain event providers ID, detected object ID and a time stamp. Event can also contain some measurement information. For example in log sorting the event can contain measurements that 3-D scanner read from an object.

Any defined Event provider is an event provider in traceability system. IAD event messages are published about events concerning IAD objects and process information events are published about information concerning processes that can't be focused to an individual object. Each IAD event message must contain id of an event provider, id of an object and an observation time, which is the instant of time when the observation took place. An IAD event message can also contain measurement information about an observed object. For example in log reception station a log is measured with a 3-D scanner. These measurements are included into an IAD event message.

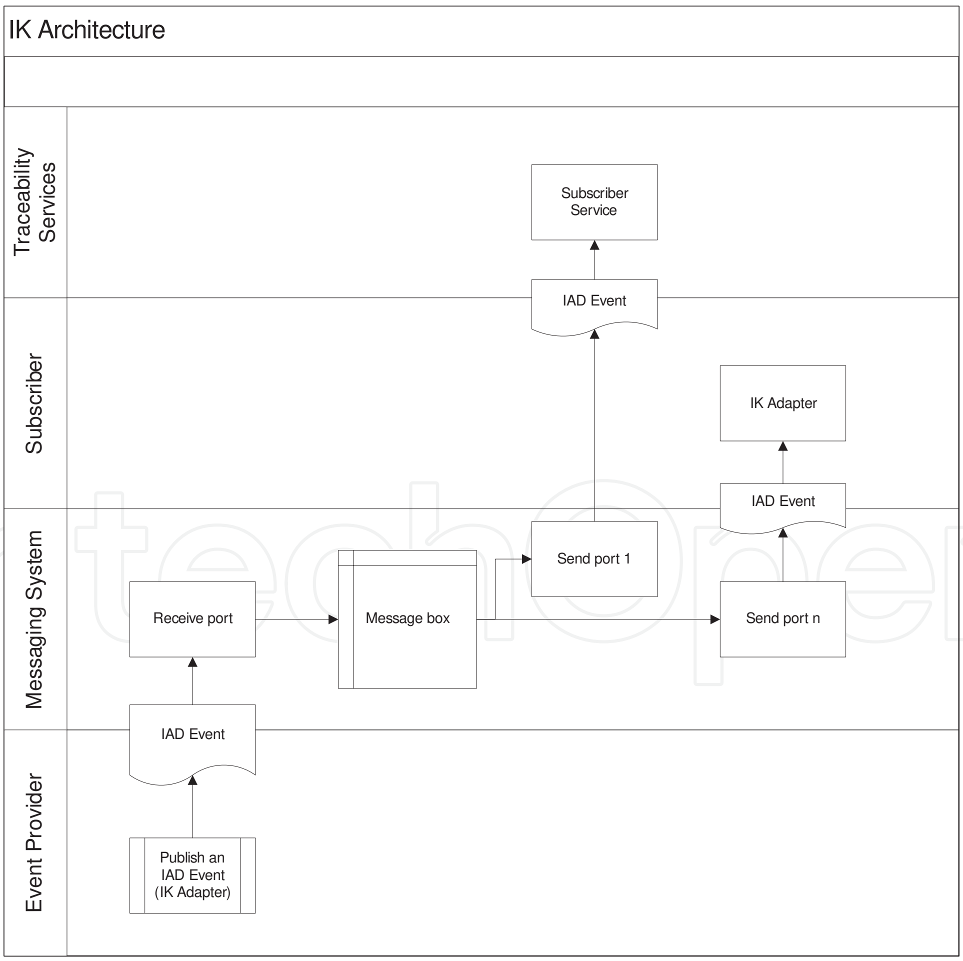

Figure 13. Collaborative Messaging System Data Flow.

Subscription could be topic-based, content-based or a hybrid of these two. In a topic-based subscription a subscriber subscribes for an events published with some topic. In a content based subscription, subscriber receives an event if a content of the event matches to the constraints defined by subscriber. Traceability architecture support hybrid of these two. IAD event providers publish events of a topic and subscribers can define content based subscriptions to one or more topics. For example - as illustrated in Figure 14Example IAD event data flow.

A harvester publishes two events with different topic:

- A LogHarvested event which contains the exact volume, quality and price information about log harvested
- A HarvesterState event which contains information about harvester state (battery, fuel, position, etc…)

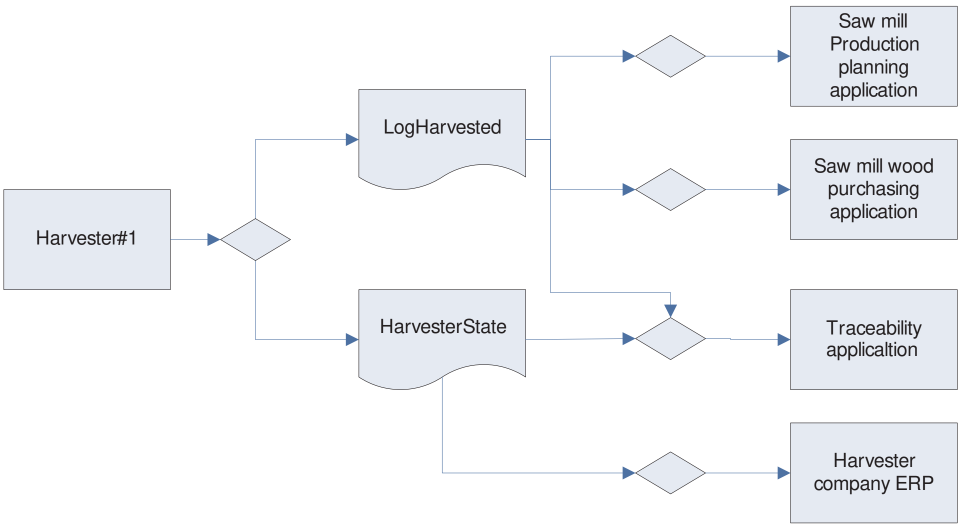

Figure 14. Example IAD event data flow.

There are three different subscribers for the event LogHarvested. Saw mill production planner wants to preplan the production beforehand by knowing the quality and amount of logs that are about to arrive to the saw mill. Saw mill purchaser makes payment based on the log volumes harvested and Traceability application gathers the information for research. For the event HarvesterState there are two subscribers. Traceability application gathers data for research and Harvester company can monitor its harvester status.

By combining information throughout the supply chain the Traceability Services enables new methods of analyzing the wood material. The properties of wood object can be compared between different steps, see Figure 15 Supply chain steps with properties.

For example length in harvesting vs. length in log sorting. Another possibility is to analyze how some property affects some other property. For example, how an area of origin affects the board quality.

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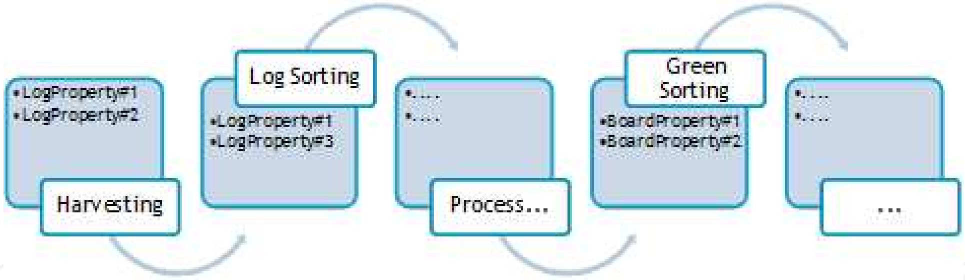

Figure 15. Supply chain steps with properties.

The purpose of Traceability Services is to act as a repository for item level traceability data and process level data and to provide services based on this information. The solution connects the steps of supply chain together and provides a common data model for the whole supply chain. The solution offers services for calculating of Environmental, Economical and Quality KPIs and analysis for the process data that are the basis for the KPI calculations.

5. Discussion

The forest industry represents some unique challenges to the traceability solutions – the data is utilised by different actors in the value chain so that typically the information is produced by one party and the information needs to be utilised by another party that may be outside the supply chain. The basis for the traceability and information utilisation is reliable and affordable identification of the wood. By identifying the wood material and items in the supply chain the associated information can be utilised by different parties. This enables new level of control of the wood conversion chain, tailored and specialised products, and new business models.

The main challenge in enabling the possibilities of the traceability in the forest industry has been the lack of a reliable and inexpensive means to identify automatically the logs and boards in various processing steps along the wood supply chain. The optical marking techniques such as printed markings offer the potential for very low costs but these methods struggle to reach better than 90-95 % success rate in the automatic identification of the wood items in industrial production conditions. The required identification success rate has to significantly exceed 99 % so that the information retrieval becomes a viable option for reacquiring the needed information, e.g. log dimensions. With 90-95 % identification success rate the risk for not being able to retrieve the needed data is some 10 times larger than what is generally considered acceptable – the benefits of the traceability are quickly lost if the information cannot be retrieved for a significant percentage of the wood items.

RFID technology offers the potential for near 100 % success rate in the identification of logs. The main challenge is the cost of the transponders – the acceptable cost for a transponder depends on the value of the wood material in question and on the expected savings and benefits to be obtained through the use of RFID. Currently the acceptable price for RFID varies case by case and there are different opinions on the price level. The price of the tags depends greatly on volumes – large scale mass production lowers the unit price considerably. For a hard tag the price may go as low as a few cents if there is market for sufficiently large volumes – large numbers of tags are needed to push the price down but before the prices are affordable there is not much demand for the tags.

The main challenge in achieving near 100 % identification success rate in RFID based log marking is the application of the tag – the insertion of the transponder into the wood. This has to be done automatically so that the log production efficiency is not significantly reduced by the log marking. Several prototypes of automatic applicators for forestry harvesters have been developed in different research projects but so far no device suitable for long term production use has been successfully built. This is the main technical challenge to be solved before the RFID based log marking can be adopted in large scale in the forest industry. Current solution allows manual tag application for small scale (up to a few thousand logs) log marking, e.g. for marking log batches and piles, or test logs for research and testing purposes, or marking tree trunks or logs when trees are felled manually using chain saws.

6. Conclusion

There are three main types of situations where traceability can be utilized to gain production improvements in forest industry: trouble-shooting, production optimisation and data mining. Trouble-shooting occurs when some end-product or batch deviates from the target quality. With traceability it is possible to trace the defect of quality to its root cause. For example it could be connected to the specific kiln in the saw mill or to a wood batch and its processing history.

Optimisation can be achieved using the traceability information. For example if the spiral grain angle of a log that has been used to produce a board is known, the twist of the board can be estimated. Using this information the board can be placed as a bottom of the drying patch. This can reduce the final twist of these boards by 50%. Traceability information can be used to mine the different correlations between wood properties. For example a window frame producer needs boards with long average distance between knots and wood with this property can be assigned for production of boards for this end product.

The basis of the traceability is reliable identification of wood items to associate and retrieve information on them. To identify the logs in the Nordic round wood supply chain a novel UHF transponder was developed together with robust RFID reader solutions. The novel wedge-shaped transponder is made from pulping compatible materials and it is inserted into the log end. In trials in saw mills the transponder readability was close to 100 % for intact functional tags. An ICT system solution was also developed for the data storage and transfer to utilise the collected information by different actors in the value chain.

The future development of the RFID based traceability should focus on further improving the reliability of the tracing close to 100 % for all logs. The main technical development needed is an automatic applicator suitable for production use in forestry harvesters to achieve high success rate in fast application of tags into logs. For marking high volume lower value items such as boards an inexpensive but sufficiently reliable identification method is needed – currently used printed markings are inexpensive but not highly readable in production conditions. UHF RFID technology has high readability but there are some technical challenges such as the application to the boards to solve – it is also difficult to achieve very low prices for tags if compared to printed markings.

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