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Potentials and limitations of RFID to reduce uncertainty in production planning with renewable resources

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Abstract: In this paper the benefits of RFID technology in the specific environment of the Supply Chain of renewable resources are examined. Due to their natural growth the production planning and the Supply Chain Management is faced with some uncertainties which differ from conventional Supply Chains. We will show how RFID can be applied to natural resources and how the whole Supply Chain can benefit from the implementation of RFID.

Keywords: Uncertainty, Supply Chain Risk Management, RFID, Renewable Resources, Production Planning

1. Introduction

Topics like Sustainability, Green IT and Greenhouse gasses are talk of the town. Most papers regarding these topics reduce their focus to emissions, energy consumption or carbon foot printing. Basically there are two research directions (Melville, 2010; Watson et al., 2010): IT is seen either as a polluter which should be operated more efficient (Green IT) or as an enabler of more sustainable processes by measuring, supporting and controlling them more efficient (Green IS). But IT could help to make products even more greener by supporting the use of renewable resources – which would be a new way of Green through IT. Due to their CO2 neutrality during the whole life cycle, these resources have a positive impact on the products carbon footprint and would make products more sustainable (Narodoslawsky, 2003; Berndes, 2006; Kaplan, 1998). But it is not just the environmental aspect which leads to increased use of renewable resources in the production process of goods. In contrast to other natural or synthetic raw materials they are available in the long run and can be produced according to plan – there is no exhaustion. We will show later, that these plans can be subject to uncertainties. The industry just started to use more renewable resources in their products: Mercedes-Benz uses up to 43 kilogram of natural fibers in their cars (DaimlerChrysler Communications, 2008), Toyota integrates bio-plastics made of soy or other starch in their seats and interiors (Connell, 2008) and BASF (2009) points out the resource change as one of their future markets. McCarthy and Bergman (1995) thought many more examples can be found in other industries and products. But the production planning of renewable resources is faced with more uncertainties compared to conventional resources; due to their natural growing and the dependency on environmental factors.

RFID has the potential to improve the visibility in logistics processes. The technology promises to closely interlink material and information flows, thus increasing efficiency and transparency in supply networks. But does RFID also have the potential to reduce the specific uncertainties in supply networks dealing with renewable resources?

In this paper we examine the general potential of RFID in the Supply Chains of renewable resources and furthermore the potential to handle the specific uncertainties, provide more and better data for the Supply Chain and thus enable a safer green production. The paper is organized as follows: First we review the relevant literature on the potentials of RFID and Supply Chain Risk Management. After that, we describe some basics of renewable resources in section 3 and the specific uncertainties in their Supply Chain in section 4. Section 5 discusses specific characteristics regarding the implementation of RFID in these Supply Chains. In section 6, we analyze to what extent the described uncertainties can be reduced with RFID tracking systems. The article ends with a conclusion in section 7.

2. RFID and Supply Chain Risk Management

The potential benefits of RFID in Supply Chains are well analyzed both from a theoretical point of view (Cannon et al., 2008; Dutta et al., 2007; Ivantysynova and Ziekow, 2008; Lee and Özer, 2007) and a practical view derived from case studies (Attaran, 2007; Sellitto et al., 2007; Kärkkäinen, 2003; Jones et al., 2005; Angeles, 2005). Summing these articles up, the advantage of RFID over other Auto-ID techniques from a technical and process-oriented perspective are a higher reading rate, bulk reading, more reliable scanning, non-contact communication with the reading device, no visual contact is needed and data collection processes can be automated which results in just-in-time information. Apart from sporadic reading errors there is no need for manual identification activities. This helps to avoid errors on the one hand, and on the other hand facilitates increased data entry without much effort. The use of RFID-transponders makes it possible to increase the quantity of information supply through an increased number of reading points compared to barcodes. A continuous tracking and tracing throughout the Supply Chain becomes thus possible, data can be retrieved in real time and stored for later information purposes. Real time integration thus leads to an increased integration of the real and the virtual world.

From the business perspective most authors point out the labor cost reduction in comparison to barcodes, improved tracking and tracing along the Supply Chain or in warehouses, improved inventory control and availability, reduced inventory holding and thus less capital commitment. These aspects can result in improved information visibility and improved cooperation along the Supply Chain. RFID is seen as the “enabler of information” (Smith, 2005). While the case studies range from automotive, retailing, fast moving consumer goods or health-care to logistics, the research concerning the use of RFID in Supply Chains with renewable resources is still lacking. Some research about the application, robustness and reading ranges of RFID-Transponders in the field of renewable resources like wood and crops was done (Dykstra et al.,2003; Korten and Kaul, 2008; Sirkka, 2008; Beplate-Haarstrich, 2007), but the potential benefits and the usefulness for the whole Supply Chain is not examined yet.

The risk and uncertainty in conventional Supply Chains and its corresponding risk management is analyzed in several case studies (Jüttner, 2005; Johnson, 2001; Norrman and Jansson, 2004). Scholars defined some risk frameworks for understanding and handling risk in Supply Chains (Zsidisin, 2003; Svensson, 2000). According to these authors risk is defined as every non-influence-able, unplanned and external event – where external could mean the Supply Chain itself or just one partner, depending on the perception of the cooperation level in Supply Chain Management. Most literature available defines risks or uncertainties in an abstract manner: Supply risks, environmental risks, demand risks. Individual risk assessments with more concrete sources of uncertainty for Supply Chains are – if any – just done in case studies. To our best knowledge, such studies from a business perspective for the entire Supply Chain of renewable resources were not conducted yet.

3. Basics of Renewable Resources

Renewable resources are naturally occurring resources which are either auto-generated within a natural system or grown by agriculture and silviculture. They are different from natural resources as they are renewable and not depleted. The industrial use of renewable resources distinguishes between energetic and recycling use. In energetic use the raw material is used to produce energy or heat. In recycling use the raw material or some of its components are used to produce other material products.

Wood, cereals and plant fibers are frequently used renewable resources which are also grown for industrial production. In forestry, preferably willows and poplars are grown in short-rotation plantations to be used as energy crops. Sugar cane, maize, wheat, sugar beets and rapeseed are also cultivated for bio-fuel production; due to subventions and support for instance by the European Union their cultivation is steadily increasing. Another thriving area for renewable resources is the so-called bio-synthetics or bio-polymers (Kaplan, 1998; Mohanty et al., 2002), for the production of which mainly chitin, keratin, lignin, casein, gelatine and sugar are used. These synthetics have the advantage of being bio-degradable and CO2-neutral throughout their entire life-cycle (Mohanty et al., 2002; Minol and Sinemus, 2004). Besides these three main development trends, there are many more possible applications of renewable resources, all of them leading to the increased industrial use.

The Supply Chain of agricultural and forestry products usually consists of the small-sized original producers, regional sales intermediaries and the processing industries. There is a mixing of different charges at all stages where bulk goods such as grains or fibers are concerned. Even during the first step of transporting the grain to the storage facility harvests of different origin are mixed. The same is true for storage in silos, transport by lorry or train and finally the production of a certain good, where raw materials of different origin may be included. An exemplary supply chain of renewable resources is shown in Figure 1.

This specific process, the mixing of deliveries and the dependency on natural growth leads to some new uncertainties in the Supply Chain, which will be explained in more detail in the following section. The special requirements regarding tracking and tracing will be described in chapter 5.

4. Specific Uncertainties and Requirements

The “5Rs“ of logistics (right product, right place, right time, right quality, right quantity) play a key role in the goal achievement of Supply Chains, because these are increasingly globally interconnected nowadays, involving a great number of players in transport, production and supply of goods. Producers and suppliers today are largely able to provide conventional raw materials in the required quantities and at the required time through scheduled production or mining and well-established supply-chains. In the case of renewable resources, goals like production and supply just-in-time cannot be granted. Natural growth processes make it difficult to ensure exact times, quantities and qualities of harvests (Narodoslawsky, 2003; McCarthy and Burgman, 1995; Dennis et al., 1985). The dependency on variables that cannot be influenced, such as precipitation, solar radiation or infestation by pests creates new uncertainties in the supply of raw material, which are not or not.

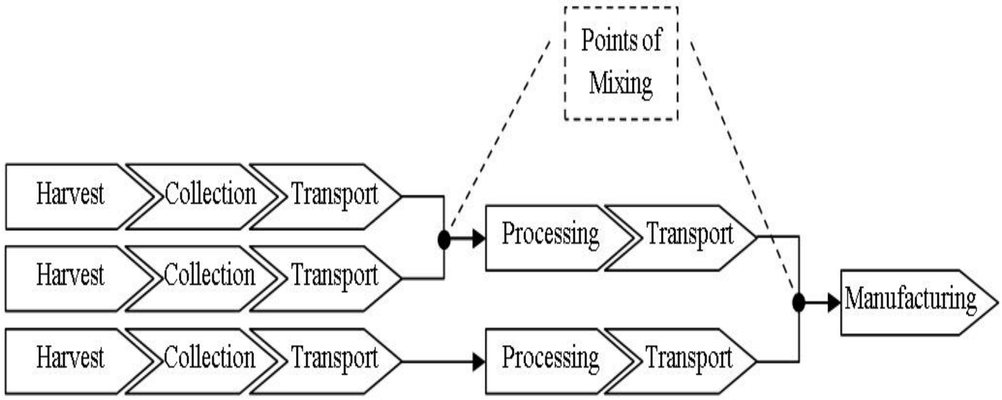


Figure 1: Exemplary supply chain of renewable resources

Sufficiently taken care of in conventional Supply Chains and in production planning (Krupinsky et al., 2002): This problem, which occurs at the beginning of the Supply Chain, influences all stations up to the final consumer and is therefore often referred to as “system nervousness” (Ho, 1989).

There are three problem areas: qualitative, quantitative and time-related uncertainties. Table 1 shows them with some exemplary influencing factors (McCarthy and Burgman, 1995; Dennis et al., 1985; Krupinsky et al., 2002). Complete losses of harvests, e.g. through natural disasters, droughts or pest infestations will certainly be a rare occurrence. However, a deviation from a planned target is the more probable the more precisely the target was stipulated. If there is a time window of only a few days during which resources have to be supplied in an agreed quality, target achievement is much less probable than it would be if the time window lasted a couple of weeks. This leads to a discrepancy between production planning and uncertainties in the time of availability of renewable resources. In the case of quality, uncertainties result from differences in size, material defects or damages and divergences from the defined requirements towards raw materials as required by the production process. Similar reasons lead to fluctuations of the harvested quantities. Furthermore, qualitatively inadequate raw materials cause more quantitative uncertainties as low-grade raw materials cannot be used for production.

Weather impacts on the characteristics of raw materials can be monitored throughout the growth process and are therefore well predictable. However, climate change makes weather forecasts more unreliable, and the occurrence of sudden climate events such as floods and storms will increase. This does not only influence the availability of resources, but also transport routes and infrastructures, e.g. forest roads (Nöthinger and Caluori, 2009). This creates a new monitoring requirement in the Supply Chain (including harvest) of renewable resources, the requirements of which are quite different from those in conventional raw materials.

Quality	Infestation by pests of fungi
	Damage by severe weather events, natural disasters
	Changed characteristics due to weather conditions (e.g. level of maturity)
	Material defects (e.g. in leather)
	Natural loss of quality (drying or shrinking) during transport and storage
Quantity	Loss through severe weather events, natural disasters
	Loss through pests or fungi
	Growth fluctuations due to weather conditions
	Differences in size
	Natural loss through deterioration or evaporation
Time-related	Changed characteristics due to weather conditions (e.g. level of maturity)
	Any disturbance in the Supply Chain which causes discontinuity
	Long transport and/or storage times
	Manual application of identification numbers
	Manual identification of resources while loading, transport or goods receipt

Besides the need of production planning to receive data on the resources at an early point in time, the qualitative fluctuations also require a retrospect monitoring of the Supply Chain. If the resources delivered differ from the data agreed in the contract, a demand for adequate compensation has to be made towards the supplier. Legal requirements on traceability and product liability lead to new information demands in the Supply Chains of renewable resources. It must also be borne in mind that the unequivocal identification of the supplier is very helpful when it comes to call-backs. Regulation (EC) No. 178/2002 requires all traders in foods and animal feeds to know all suppliers and recipients and to be able to reconstruct the flow of goods across all stages (European Union, 2002; Theuvsen and Hollmann-Hespos, 2004). The EU also recommends systems for internal traceability (European Union, 2002; Waldner, 2006). Besides supporting legal requirements, traceability systems also support the credible communication with the end-user as they enable the use of certification standards (Theuvsen and Hollmann-Hespos, 2004; Pawelzik and Theuvsen, 2008). The following section shows how identification using radio frequency technology can meet the uncertainties in the Supply Chains of renewable resources and grant their traceability.

5. RFID in the Supply Chain of Renewable Resources

As the characteristics of renewable resources due to their nature differ from conventional resources, the application of RFID-transponders also differs. In this section we describe the first step, the integration into the Supply Chain, taking into account the specific characteristics of renewable resources, the place of application and possible automation of this process. The following utilization in the Supply Chain is described afterwards. The section ends with the process of the transponders' removal from the resources.

5.1 Integration into the Supply Chain

As already mentioned, most of the uncertainties in the Supply Chains of renewable resources arise at the level of forestry and agricultural producers. In addition, legal frameworks require the traceability down to this level. In order to facilitate support through RFID technology, transponders have to be integrated into the Supply Chain at the earliest possible point. First of all it has to be clarified how the attachment of the RFID transponders to the raw materials can be organized. When selecting a type of transponder and the frequency to be used later on, the specific characteristics of the resource have to be taken into account. As these often contain water, low frequency transponders should be preferred due to their insensitivity towards liquids. Some alternatives to common smart labels have been developed: tags in the form of nails, coins, number plates, ISO cards and special adhesive labels are available from different manufacturers (Korten and Kaul, 2008).

There are experiments to measure the quality parameters of raw materials during the growth phase, for example by implanting transponders into tree trunks. Given that the transponders can be read during the growth phase, they can also be read after harvesting and act as identifier in the further supply chain. This is the earliest possible form of integrating RFID transponders into the Supply Chain. The implementation or fix connection during the growth period is not practicable with other resources like grains, mainly due to their size, making it necessary to implement them at the time of harvest.

Whether the transponders are attached to the individual product or to batches depend on the value of the product and the related ratio between transponder price and profit as well as on the physical opportunities to implement them on individual products. In small scale raw materials like grain or fibers the identification of individual products becomes impossible, not only due to the lack of options to attach a transponder, but also because it would simply be uneconomical. If the raw materials are transported in batches of identifiable vessels such as drums, bags, packets or containers, these transport units can be marked. However, this method of identification cannot be used for bulk commodities like grain, because these undergo numerous processes of mixing with raw materials of different origins during transport and storage. This may happen immediately after harvesting in the transport trailer, during the filling into silos or during storage in cooperatives which collect and market the products of several farmers. For this scenario, experiments with grain dummies were carried out which were mixed with the grain and were similar in their external characteristics and their specific density in order to prevent the de-mixing of the transponders from the grain, e.g. during pouring processes (Beplate-Haarstrich, 2007; Beplate-Haarstrich et al., 2008). These transponders are mixed with the grain in the combined harvester during the harvesting process and contain relevant data such as the GPS-coordinates and the name of the producer. During the mixing processes the ratio of grain and transponders remains the same, making it possible to identify at least the origin of the raw materials and their shares within the mixed quantities. Similar dummies can be developed for other bulk commodities; an application with other renewable resources is thinkable. More research is needed with respect to the coverage of the responders in their specific environments and their physical durability in a rough environment. The mixing quantities of transponders and raw materials have to be analyzed in order to ensure the identification at defined probability levels.

When talking about item-level tagging, raw materials of higher value of single pieces such as timber do not only provide opportunities for the implementation of transponders, but also render their use economically viable, given that transponder prices are less than about 0.20 USD per piece (Dykstra et al., 2003). Experiments have shown that RFID transponders have a great potential for rendering the timber logistics chain more efficient (Korten and Kaul, 2008). Comparing it to other ways of identifying log timber, Dykstra et al. come to the conclusion that RFID is the most promising identification technology within future forestry logistics chains (2003). Relating to Table 1 Dykstra points out particularly the time-related effects.

The application of the transponder is done directly during harvesting. In the motor-manual timber Supply Chain, the transponder in the form of nails or (already widely used) wooden numbering plates must be implemented by the lumbermen (Korten and Kaul, 2008; Stiebitz et al., 2009; Kaul and Korten, 2007). Using a mobile data collection unit, the unique number is then entered together with further data such as length, diameter, place of harvest and kind of tree. These data can be forwarded immediately to data base systems through a mobile network connection. In the case of highly mechanized timber harvesting, the harvesting machine attaches a tag to each of the segments of a felled and cut tree. Pilot experiments have shown that the implementation of an application unit on the harvesting head of the vehicle as well as the application of the tags do not pose any problem and do not consume additional time during the harvesting process. Other than in manual application, the transponder number can be connected fully automatically to the operating data of the harvester. This operating system measures the trunks and is able to establish the exact place of harvesting via GPS systems.

5.2 Utilization in the Supply Chain

The raw materials can now be read-out and monitored throughout the entire Supply Chain. To ascertain tracking (the exact localization of the present whereabouts) and tracing (backtracking in order to fulfill qualitative and legal requirements), the read-out should be done whenever there is a change in position or in status. In order to record all possible influences on the quality of the raw material, the transponder should be read-out for each means of transport (tractor trailer, truck-trailer), for each process (harvesting/felling, pouring, moving/skidding, rumbling, transporting, measuring) and for each storage location (silo etc& cooperative store, factory store). For raw materials that need, for example, cooling or dry storage to protect them from environmental influences during transport, a connection of sensor data, vehicle data and unique serial numbers of the transponders is thinkable in order to determine the correctness of transport conditions or to identify the origin of problems. Data may either be stored on a chip or forwarded to a central data base in order to ensure permanent storage and provision of data for all sides involved. However, as desirable and efficient this procedure might be, there are still some things lacking at present: Especially during the initial stations and processes within the Supply Chain there is presently no technical infrastructure to write on the transponders or to read them. Harvesting machines are not equipped with the devices to store, write and attach the transponders. Until now, there are only prototypes which are far from being ready for serial production. Transport units and storage stations do not have reading devices. If the Supply Chain were to be fully equipped with the required reading and writing units, the question arises what would be the advantage for all sides involved and how it should be financed. Should the financing be shared by all users as in a cooperating Supply Chain or should each party finance the equipment they require? In this context, the dynamics of supplier-customer relations have to be taken into account.

5.3 Removal from the Supply Chain

Tracking and tracing usually comes to an end when the raw materials are processed or the batches dissolved. While the removal of transponders from batches and bulk commodities is not especially complicated and can be done without difficulties, this is not always easy to manage in the case of individually marked products. If attached directly to the raw material, as described above for the case of timber, the transponder has to be removed manually, leading to additional work loads and delays in the fully automated processes at the saw mill. If possible, the removal should be done by machines, either in an additional step or integrated into an already existing processing step. The transponder can, for example, be cut off during the decorticating process if it was fixed at the side of the trunk, or when sawing off the head piece if it was attached there. If these loges are submitted to energetic use, the transponders can be separated from the rest of the wood or the resulting waste by ash sifters. In the case of bulk commodities, the transponders have to be removed in the last step before processing, e.g. before grinding. Magnetic or opto-electronic sorters, which are used in many other processes and are well proved and tested, ensure fast and safe sorting.

6. Potential of RFID for Reducing Uncertainties

Having described the uncertainties in the Supply Chain of renewable resources in chapter 4, we will now examine the potentials of using RFID technology to reduce these uncertainties. As transponders can only be adequately attached from the point of harvest onwards, any uncertainties that lie before the point of introducing the transponders into the Supply Chain cannot be covered. These data can only be collected through other sensor networks, e.g. on tractors during seeding and cultivation or via satellite observation. Only some of the sources of uncertainties listed in table 1 can therefore be covered by RFID technology and made transparent.

6.1 Quality

At the point of attaching the individual transponders that is at the point of harvest, typically no qualitative product characteristics are known. In some cases, data concerning qualities are obtained by the farmer before harvesting the resources and are signaled to the producers. Certain characteristics will be collected and stored even without the use of transponders, e.g. length, humidity or condition. These data may then be connected to the transponder data, making the original individual quality data retrievable throughout the lifetime of the raw material. Previously signaled quality data can now be connected to single-item data. Furthermore, the quality data are available in real time thanks to automated data processing; they can therefore, together with the data regarding their location, be used by the producing companies for disposition and production planning of these raw materials, as it is exactly known, which quantities of which quality are available at certain stations within the Supply Chain. Repeated measuring of the quality characteristics along the Supply Chain, either manually or using sensors or other automated methods (optical or laser measurement), can monitor the condition of the raw materials and the planning of the raw material available for production becomes more exact. These measurements can also ensure quality assurance throughout and facilitate the fulfillment of legal requirements or the conditions set by normative authorities. The origin of later deviations from initially measured data can be traced along the Supply Chain and the actors involved. Indirectly, the increase in quality leads to the faster delivery of the consignments. The raw materials reach the consumer in a fresher condition and therefore in better quality (Korten and Kaul, 2008).

6.2 Quantity

The advantages of establishing the exact quantities of the raw materials harvested stretch throughout all stations of the Supply Chain. Individual marking of the raw materials and connecting it to the location of harvesting facilitates the more efficient planning and implementation of the subsequent processes. As the transport company knows the exact location and amount of the resources, it can plan its routes better and achieve a higher degree of capacity utilization. During the loading process of piece goods it can be exactly established whether all relevant raw materials have been loaded.

Losses through theft pose a great problem particularly in the logistics of timber trade. As ideally the location and the quantities of certain loads are known all along the further Supply Chain, theft may be prevented or at least reconstructed. Losses due to other reasons are also traceable.

Reduced quantities due to environmental impacts, e.g. evaporation or deterioration, may not be prevented by RFID technology, but they can be noticed. If sensors measure the relevant characteristics of a raw material during transport or at the time of arrival at a station, deviations can be established by comparison with earlier measured data. The exact relationship of effects and causes can be established. The combination of transponders and sensors is able to monitor that cooling chains are unbroken and other prescribed storage and transport conditions observed (Kern, 2006).

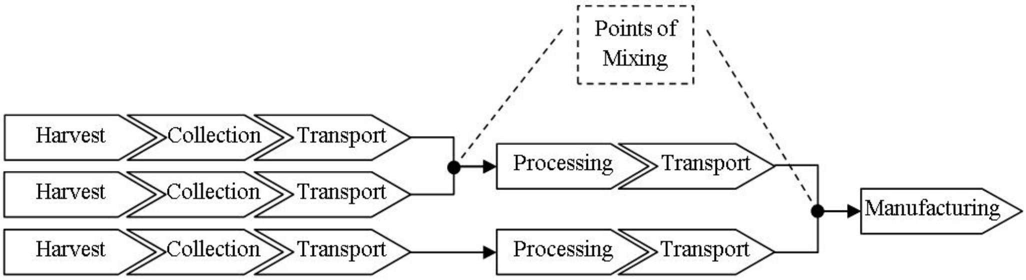
Another advantage results from the transparency of the Supply Chain. A common attempt to hedge against uncertainties is simple keep more resources than needed in storage – especially in fixed production plans that need a continuous input of resources, the lack of which leads to the downtime of the entire production process (Cannon et al& 2008; Milgrom and Roberts, 1988). Here increased storage creates a kind of artificial certainty. A rise in visibility and transparency for all partners involved is one of the typical effects of the introduction of RFID into Supply Chains (Melski et al., 2008; Delen et al., 2009). In the case analyzed here this may mean that production planning can use more detailed and reliable data, leading to a decrease in stocks to be maintained (Angeles, 2005). As this advantage becomes noticeable throughout the Supply Chain, it has a high potential for decreasing the capital commitment.

6.3 Time

The positive effects of RFID on the factor time have been widely described in the literature. The automation potential leads to a faster and more efficient execution of all steps within the Supply Chain. These advantages can also be identified in the Supply Chain of renewable resources. The unique identification, sometimes even of individual instances, makes locating easier and facilitates planning and on-the-spot control of transportation. The identification of the raw materials at all subsequent stations can be fully automated, so there is no more need for the manual read-out of previously attached numbers. The receiver can control delivery and check against dispatch notifications much faster; if RFID technology is used in production, it even becomes possible to steer processes automatically or to use the transponders for the identification and connection of other data in the further processing.

		Harvest	Collection	Transport	Processing	Manufacturing
Quality	Infestation by pests of fungi	R	R			
	Damage by severe weather events, natural disasters	R	R			
	Changed characteristics due to weather conditions	R	R			
	Material defects	R	R			
	Natural loss of quality (drying or shrinking)	R	R, I	R, I	R, I	R, I
Quantity	Loss through severe weather events, natural disasters	R	R			
	Loss through pests or fungi	R	R			
	Growth fluctuations due to weather conditions					
	Differences in size	R	R			
	Natural loss through deterioration or evaporation	R	R, I	R, I	R, I	R, I
Time	Changed characteristics due to weather conditions					
	Any disturbance which causes discontinuity	R	R	R, I	R, I	R, I
	Long transport and/or storage times		R, I	R, I	R, I	R, I
	Manual application of identification numbers	I			I	I
	Manual identification of resources	I	I	I	I	I
R: Problem can be recognized through the data I: Situation can be improved by RFID directly						

The tracking of resources requires less time for supplying the data needed for logistics, disposition and production planning. In the case of complete integration it even becomes possible to do this without any manual interference. Data provision can therefore become more efficient and the execution of the related processes be increased.



Use of RFID	Application, Writing	Reading, Writing	Reading, Writing	Reading, due to mixing possible application of new transponders	Reading, Writing	Reading, due to mixing possible application of new transponders
Collected Data	Place of origin, Owner, Quality, Quantity	Quality, Quantity	Sensor data, Position, Carrier, Transport route (tracking)	Combination of deliveries, Processing steps, Sensor data	Sensor data, Position, Carrier, Transport route (tracking)	Combination of deliveries, Processing steps, Sensor data

Figure 1: Overview of RFID in an exemplary supply chain of renewable resources

Overall it can be stated that the general potential of RFID technology becomes especially clear when looking at time-related advantages. Given a supply chain equipped with RFID-readers to identify the attached transponders reliable, automation and elimination of manual identification processes lead to the accelerated processing of all sub-processes. This may also have an impact on the quality of the raw materials, as longer storage, transport or processing times lead to a decrease in quality – the same is true for processes of dehydration or deterioration as described above. On the other side read errors can result in longer process interruptions than in the manual process, because it is more complicated to reintegrate manual operations in automated processes. When no visual identification is given, for example in the case of a simple transponder without a printed number, the manual identification can even become impossible.

6.4 Other issues

Besides the potentials already mentioned there are some more areas that could benefit from the introduction of RFID into the Supply Chain of renewable resources. First of all, reading out the transponders along the entire Supply Chain ensures constant tracing. This may contribute to the fulfillment of legal requirements and be helpful when applying for the certification of companies or certain products. Many certification offices require proof of the "custody of chain" when issuing seals of quality (Korten and Kaul, 2008; ISSC, 2010). The seal of the Forest Stewardship Council, for instance, is only awarded if the origin of the timber can be clearly shown (FSC, 2006). RFID technology helps to fulfill these requirements.

Overexploitation and theft are frequent problems when dealing with renewable resources. The timber logistics chain shows particularly high loss rates (Dykstra et al., 2003). The prevention of illegal logging of tropical wood and its export is another goal to be achieved. The clear and individual traceability of each raw material through RFID transponders makes it possible to prove its origin and check the legitimacy of sale. Although the transponders can be easily removed, it is imaginable that there could be an import ban on raw materials without identification marks or that buyer refuse to purchase such goods. The concepts for using RFID against product piracy (Staake et al., 2005) could also be applied in this context.

7. Conclusion

The Supply Chain of renewable resources and their specific environmental factors differ from the conventional Supply Chain. The same also applies for the application of RFID in this context. As shown above, most uncertain factors have their origin before the harvest of the resources; thus RFID cannot be applied and improve visibility of information along the Supply Chain before harvesting. Nevertheless RFID technology seems to have a great potential in improving the Supply Chain performance from the time point of harvest by increasing information and thus reduce the special risks. The exemplary Supply Chain from chapter 3 is supplemented with the potentials of RFID and the data which are collected at each stage in Figure 2. Table 2 lists up the effects of these collected data along the Supply Chain on the uncertainties mentioned above (see Table 1). Most of the problems arising from the uncertainties can be recognized through the data generated by RFID-systems; this can be seen as an indirect improvement by RFID for production planning. Six aspects can even be improved directly by using RFID technology. Nevertheless it must be pointed out that the application of new transponders and the transfer of object-related data due to the mixing of resources increase the complexity of processes, which would lead to a more laborious Supply Chain.

Well known benefits like visibility, automatic identification and accelerated processing of resources go along with specific benefits like proving the chain of custody, the possibility of connecting sensor-data to individual items and improved operational procedures while harvesting and processing the resources. As a next step the gathered data should be linked to ERP systems and used in production planning software to improve the stability of planning.

When the resources are equipped with transponders, it is also possible to handle another specific given factor in the Supply Chain of renewable resources: the raw material is often subdivided into several components or some by-products can be used in other industries, e.g. logs are processed to boards for industrial use and sawdust for energetic use. The further monitoring in terms of tracking and tracing is enabled by RFID technology. Methods for connecting the original data with the new increased amount of raw materials and linking the data flows across production networks are a new topic in research.

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