Traceability system for capturing, processing and providing consumer-relevant information about wood products: system solution and its economic feasibility

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ABSTRACT

Current research and practice reports indicate the existence of purchase barriers concerning eco-friendly products, e.g. wood products. These can be ascribed to consumers' mistrust regarding the non-observable environmental impact of wood products. To counter the mistrust, wood products are commonly endowed with eco-labels, which may be perceived mostly as a marketing tool, therefore not fulfilling their intended purpose. Current studies have shown that providing consumers with wood product information based on traceability systems increases product trust and purchase intentions, with those information items most valued by consumers being identified as well. Based on this, the paper proposes a traceability information system for the capturing, processing, and provision of product in-formation using examples of wood furniture. Furthermore, a cost- benefit model for the proposed solution is developed. The calculations indicate the possibility of implementing traceability at the item level based on a four-layer system architecture enabling the capture and delivery of all information valued by consumers at acceptable costs. The proposed system helps to overcome purchase barriers of eco-friendly products, increasing consumers' product trust and purchase intentions.

Introduction

Traceability systems (TSs) provide accurate, timely, and consistent information about material flows and processes through the supply chain. The provision of the product history allows drawing consumers' attention to products made from renewable raw materials, thereby enhancing trust in these products as well as preferences for eco-friendly and abstinence from non-eco-friendly materials (Gleim et al., 2013). For example, furniture can be made from various materials such as wood, metal, plastic, or glass. While wood is a CO_2-neutral renewable raw material, the other commodities have significant environmental impacts. Furthermore, wood furniture can consist of solid wood (i.e. primary processing of forest wood) or wood-based materials (i.e. secondary processing of sawmill by-products, waste wood). This fosters cascading utilization which keeps the absorbed CO_2 continuously inside the wood products for a long period (Kim and Song, 2014). To increase loyalty to wood as an eco-friendly material, providing value added information about wood products such as furniture can also be used (GS1, 2009). Hence, TSs can support consumer acceptance of environmentally friendly goods by providing product information, therefore leading to a more sustainable consumption.

Current research shows consumers valuing detailed wood furniture information and their willingness to pay (WTP) a surcharge as a price premium for the information provision (Aguilar and Cai, 2010; Osburg et al., 2015; Teisl, 2003). Osburg et al. (2015) conducted a study about wood furniture and identified 10 information items (e.g. country, type of wood, carbon footprint, additives, health effects) increasing consumers' product trust and purchase intentions. According to Osburg et al. (2015) consumers should not only be provided with relevant product information but they must also perceive this information as trustworthy. They suggest that consumers ascribe higher trustworthiness to a traceability system-based information retrieval compared with product labelling. However, an appropriate TS is still required, satisfying consumers' demand for wood product information.

Several studies about TSs in the wood-based supply chains focus on the B2B area (Bajric, 2010; Holzmann, 2009; Kasturi, 2005; Timpe, 2006; Tribowski et al., 2009; Uusijärvi, 2010). It was found that TSs support decisions in production and logistics planning as well as the handling of distinctive features of the wood supply chain such as deviations in quantity, quality and harvest times of wood, high risks of illegal timber felling and timber theft during storage and transport. The contribution of TS data on wood quality and quantity to increasing resource efficiency is particularly relevant (Wilhelmsson, 2008). Accordingly, detailed and current TS data help to increase the wood yield and to reduce errors occurring in wood processing, such as during drying or boring (Uusijärvi, 2003 and 2010). However, to tap its full potential, wood product acceptance leading to a more sustainable consumption behavior has to be stimulated accordingly. Therefore, it is necessary to use the product information, in both the B2B and B2C areas, with the latter mostly neglected so far. The present work aims at conceiving a traceability information system capturing, processing and providing consumer-relevant wood product information by also considering the economic feasibility. Since traceability data can be used for different purposes, this analysis covers both direct effects in the B2C (e.g. WTP, purchase intention) and indirect effects in the B2B sector (e.g. improvement of production processes or inventory). As the effects occur in both areas, emerging costs can be compensated by consumers and supply chain members. Nevertheless, the cost distribution enhancing the economic feasibility has to be investigated. Hence, the following research questions are addressed:

> RQ1: How should a traceability information system be conceived that supports capturing wood product information and providing consumers with their valued items?

> RQ2: How can a model be designed estimating the economic feasibility of TS implementation and how do different parameters affect the feasibility in a use case?

This article is structured as follows. The theoretical background refers to TSs and the wood furniture supply chain. Section 3 outlines the results of the empirical study (Osburg et al., 2015) and the requirements of the proposed TS. Section 4 presents the four-layer system architecture of a traceability system for capturing wood product information and providing consumers with their valued items (TSfWPI). A cost-benefit model is developed, and an exemplary calculation is given in Section 5. While Section 6 documents the results, Section 7 closes with a brief conclusion and outlook.

2. Theoretical background

2.1. Description of traceability systems

Traceability is the ability “to trace the history, application or location of an entity by means of that which is under consideration” (ISO 9000, 2005). According to Moe (1998), traceability has to be managed by setting up a TS, capturing, archiving, and communicating the history of product routes and selected data.

TSs consist of four key elements (Nguyen, 2011). The starting points are clearly marked objects, called traceable units (TRU; identification) which are unique units, i.e. no other unit has exactly the same or comparable characteristics from traceability's point of view (Moe, 1998). They are detectable at specified points of the supply chain (data acquisition and recording). Collected data can be linked with other information such as bills of materials, purchase orders or process data (data linking). The enriched data is communicated internally and externally for further processing (communication).

TSs can be implemented paper-based (paper traceability), IT-supported (electronic traceability), or combined (Magera and Beaton, 2009). A paper-based TS is cheap, but manually intensive, leading to errors, delays due to tracing information, and media breaks if data processing occurs IT-supported (Petersen and Green, 2006). Electronic traceability enables automatic data import, simple data accumulation, and information provision to internal and external data processing. This reduces manual data entry resulting in decreased error rates and staff time costs. However, introducing electronic TSs requires: definition of TRU with associated identification (ID) methods; set of data standards; definition of the system architecture; willingness and ability to invest in TS and IT skills.

Electronic systems can use a central or multiple distributed databases. As central databases rely on a uniform standard, the information provision in the supply chain is simplified (Petersen and Green, 2006). A central database is operated by a dominant enterprise of the supply chain or an information intermediary who assigns reading and writing permissions to a database part to each participant. Outsourcing a complex system architecture and data management to the operator is particularly advantageous for small and medium-sized enterprises (SMEs) with low financial resources and IT skills. Contrarily, the decentralized approach allows each supply chain participant to maintain full control over its own company's information (Melski et al., 2007). Information of distributed databases is accessible via the internet, therefore requiring a network connection.

Database solutions support the concept of “Data-on-network” with all TRU-relevant data being stored in databases. Only the ID number is placed on a tag and detected at different points of the supply chain so that all participants have the same information level. In contrast, “Data-on-tag” refers to all information being physically present at the place of action. The presence of TRU is a prerequisite for information access, representing an information-accumulating system, so that the last supply chain stage receives the complete product history. Fig. 1 illustrates these concepts that are also combinable.

2.2. Description of the wood furniture supply chain

The wood supply chain is a facility network procuring forest raw materials (round wood), transforming them into intermediate goods (lumber, veneer, particleboard) and final wood products (furniture) which are delivered to end customers through a distribution system (Lee and Billington, 1993). Fig. 2 gives the example of a supply chain for wood furniture, while Table 1 presents its main steps with associated processes and wood-based flows.

The wood furniture supply chain has specific characteristics:

- It combines continuous (sawing, particleboard pressing) and discontinuous processes (drying, joining) that take place partly in harsh conditions like dirt, chemicals, temperature (Capron, 1963; Murphey and Jorgensen, 1974; Tsoumis, 2009). Additionally, the cascading utilization implies that many different

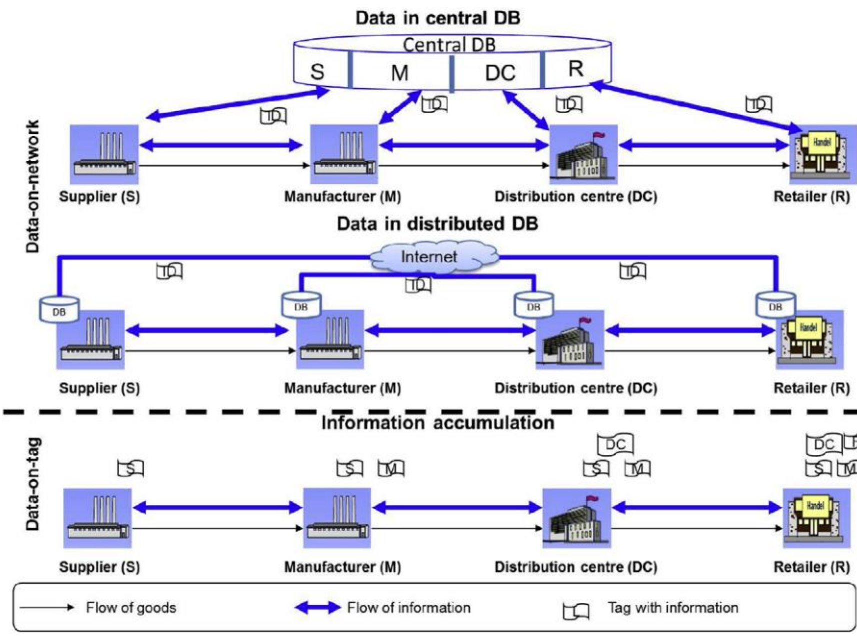

Fig. 1. Concepts of data organization in TS (according to Melski et al., 2007).

input materials are processed (e.g. used wood, by-products of wood handling). All input materials and processes need to be considered in the traceability process.

- It encompasses many small- and medium-sized participants who often refuse cross-organizational IT systems (Friedemann et al., 2011), due to poor IT experience. They are increasingly focusing on the cost-benefit ratios of a TS introduction because of their limited investment capacity.
- Its power distribution, trust level, cooperation, and legal aspects influence the willingness to distribute information and introduce new information systems. Nonetheless, there still are no studies reviewing the organizational specifics and their influence in the selected area.

2.3. Traceability systems in the wood furniture supply chain

Several studies about the supply chain of wood furniture consider the new hardware and appropriate procedures for auto-ID. Dykstra et al. (2003) and Murphy et al. (2012) provide an overview of technologies that are robust against harsh environmental conditions, wood moisture and suitable for industrial use.

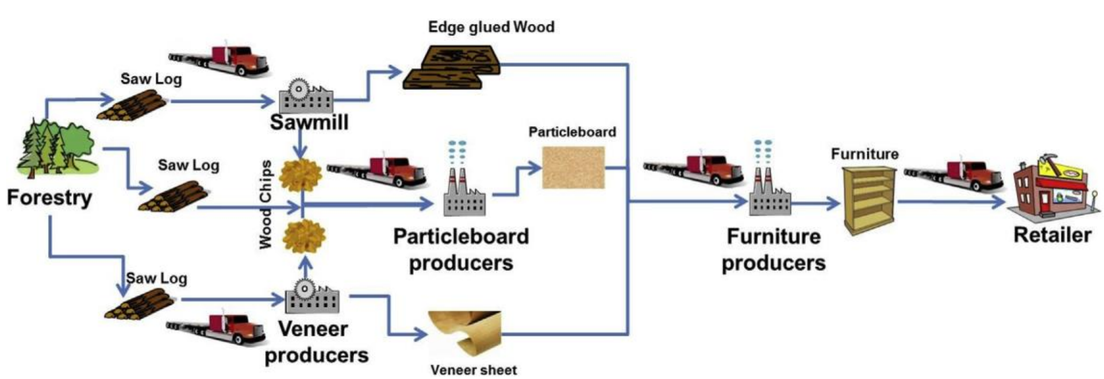

Fig. 2. Wood furniture supply chain (according to daSilva, 2010).

Table 1
Steps of the wood furniture supply chain with associated processes and material flows (Capron, 1963; Murphey and Jorgensen, 1974; Tsoumis, 2009; VHI, 2014).

Step of the supply chain	Processes	Input	Output
Forestry	Felling and crosscutting		Logs
Sawmill	Sawing and drying	Logs	Lumber; by-products
	Cutting, planning, sorting, joining, gluing, and shortening	Lamellae	Edge-glued wood
Veneer producers	Sawing, slicing, or peeling	Logs	Veneer sheets
Particleboard producers	Chipping and sorting	Logs and waste wood	Wood chips
	Sorting, gluing, pressing, cutting	Wood chips, sawing by-products	Particleboards
Furniture manufacturers	Separating, coating, and joining	Edge-glued wood	Furniture made from solid wood
		Veneer sheets and particleboards	Furniture made form veneered particleboards

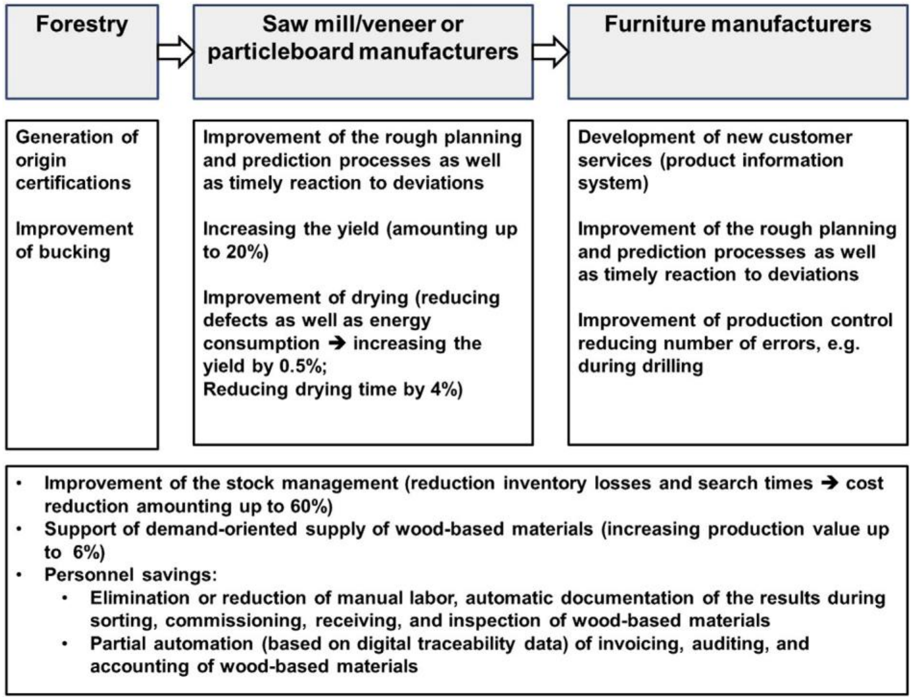

Fig. 3. Benefits of electronic TS in the wood furniture supply chain.

The research streams of identification technologies are twofold: Firstly, several studies focus on marking technologies such as ink-printing and especially radio frequency identification (RFID; e.g. Erhardt et al., 2010; Korten and Kaul, 2008; Virtanen et al., 2013). Secondly, many studies investigate material signatures such as anatomical, genetic, and chemical wood fingerprints (e.g. Charpentier and Choffel, 2003; Chiorescu and Grönlund, 2004; Flodin et al., 2008). Additionally, the role of TSs in the respective supply chain is often considered (Kasturi, 2005; Timpe, 2006; Uusijärvi, 2010), examining benefits of the traceability in B2B relationships. In addition to improving the product quality as well as the reliability, responsiveness, and flexibility in the supply chain, cost reductions can be generated during production, inventory holding, and forestry operations (Bajric, 2010; Uusijärvi, 2010; Lundahl, 2007; Timpe, 2006). Holzmann (2009) highlights personnel savings resulting from the use of electronic TSs. Otherwise staff overhead (attachment and reading of marking especially by mobile readers) is necessary as the electronic TS introduction requires process restructuring. Nonetheless, Uusujärvi (2003) and Holzmann (2009) show a positive difference between personnel savings and higher staff costs. Fig. 3 summarizes the effects of using electronic TSs indicated by current literature.

Table 2
Wood product information items valued by different consumer segments (Osburg et al., 2015).

		Consumer segments (and their size)			
		Environmentally oriented (29%)	Environmentally and quality oriented (22%)	Quality oriented (17%)	Unmotivated (32%)
Origin					
1	Country of wood	X			
Environmental impact					
2	Sustainable forest/ management	X X plantation			
3	Carbon footprint	X			
4	Portion of recycling	X	X		
Material					
5	Type of wood		X X		
6	Material composition		X X		
7	Additives		X X		
8	Health effects of additives	X	X	X	
9	Comments of the producers			X	
10	Composition of the veneer			X	

X – preferred wood product information.

Since the characteristics of the furniture supply chain represent the greatest challenges to the TS establishment, only few TSs have already been developed and empirically tested (Häkli et al., 2013; Korten and Kaul, 2008; Timpe, 2006; Wessel, 2006). RFID solutions are used, e.g. at the German forestry company Cambium, reducing the wood shrinkage rate from the forest to the sawmill (Kasturi, 2005), or in the Swedish wood supply chain (Sveaskog – harvester, Malå saw mill and Norsjö Trä – window manufacturer), increasing the yield of wood and boards (Lycken, 2010). Many furniture manufacturers (Victory Land Group, Inc.; Knoll Mf., QuanU Furniture Co., Ltd.; Ploß & Co. GmbH; Wellmann GmbH & Co. KG) support their internal processes with RFID-based traceability using the concept "data-on-tag" to control the production, reduce the error rate, and handle a diversity of product variants (Tribowski et al., 2009).

Available TS solutions focus on improving internal processes or B2B relationships, without considering their role in B2C relationships. A system concept supporting the information capturing and provision to consumers is still missing. Therefore, this work proposes a corresponding system and analyses its economic feasibility.

3. Requirements of the proposed traceability system

Analysing customer requirements of the information provision at the point of sale (POS) (functional requirements) is the starting

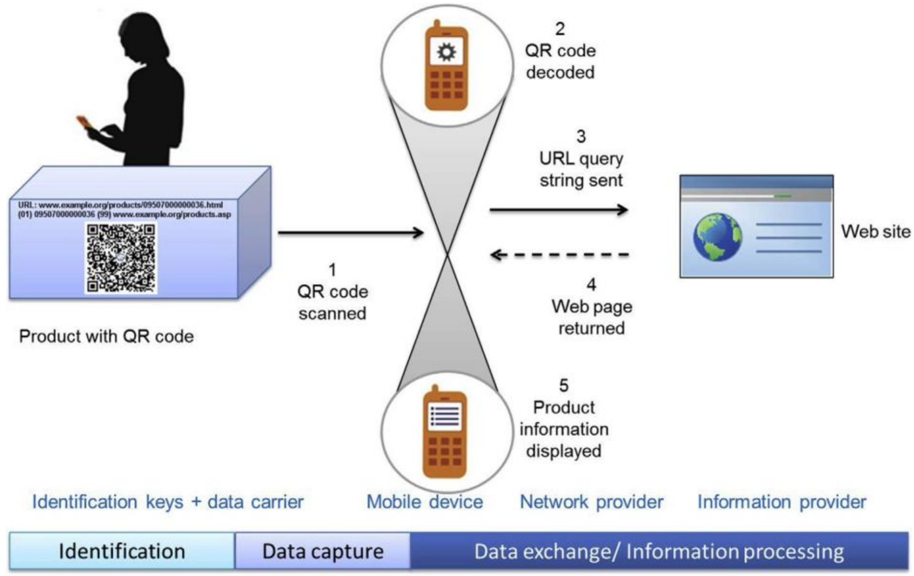

Fig. 4. Information access process using QR code with encoded HTTP URL to the website with specific product information (according to GS1, 2009).

point for the further work (Hevner et al., 2004) and has been conducted by Osburg et al. (2015) using the example of bookshelves made from solid wood and veneered particleboards. The authors investigated this issue using an online survey on which wood product information items consumers view as increasing product trust and purchase intention. Specifically, young consumers (age range 18e30) were examined since they might value product information in particular as they spend more time looking for information and use this information accurately (Kanchanapibul et al., 2014; Klein and Ford, 2003). Thereby, four consumer segments have been identified of which three value the information provision. Which items are evaluated as important differs among the identified segments (cf. Table 2). Nevertheless, respondents indicated that most items require further explanation and/or reference values to facilitate intelligibility. As a high amount of information items bears the risk of consumers' information overload, the information should be accessible at the POS by addressing the segments only with their specific information preference. Osburg et al. (2015) suggest that three information packages should be created containing the items valued by the segments. Hence, consumers can assign themselves to one of the three segments at the POS.

The study also reveals that consumers prefer an information access through Quick Response (QR) code scanning. The use of QR codes allows encoding the Uniform Resource Locator (URL) pointing directly to the website with valued product information. The access to information consists of five steps, which are shown in Fig. 4. Firstly, the consumer scans the QR code on the packaging with a mobile device. The reader application decodes the HTTP URL from the scanned codes and subsequently opens the URL in the mobile device's web browser. Based on this, the webpage at the URL operated by the information provider returns information packages from a central database (e.g. from the association of the furniture industry). Finally, the mobile device displays the received information on the screen. For consumers' access to additional information through QR code scanning with a smartphone, the following components are necessary: identification keys for object identification; data carriers physically representing the identification key (QR code); mobile devices capturing data from the data carrier; network providers and technologies for the data exchange across a network; information providers for information processing and transactional functionality (GS1, 2008). The furniture manufacturer as an information provider will share valued product information with consumers leading to better customer service, differentiation from competitors, increased brand trust through transparency, assists in on-the-spot purchase decision and a wider audience (GS1, 2008). Even though trust between members of the supply chain is a prerequisite, the relationships along the supply chain can be improved as the presence of digital data helps to reduce the information asymmetry and uncertainty between the different supply chain participants (Yu et al., 2001). Furthermore, the TS can create access barriers to supply chains, thereby protecting the market share or pool of suppliers.

Thereby, the information access process requires the following:

1. A call-out logo/service mark on the packaging informing consumers about the availability of additional information;
2. A suitable mobile device offered at the POS for consumers without smartphones and internet connection;
3. Human-readable interpretation of QR codes (in particular HTTP URL) on the packaging if problems and errors emerge during the scanning process;
4. Consumers' valued information (cf. Table 2) must be available at the information provider;
5. Emerging costs must be economically viable for both consumers and manufacturers.

The last two requirements are the most significant challenges. Firstly, the valued information has to be collected, linked and enriched with additional data, exchanged along the supply chain and provided to the applications processing this information (such as the product information system). The material flows and processes should be represented digitally, taking into account the supply chain characteristics (cf. Section 2.2). Additionally, the furniture manufacturer must also aggregate data from different trusted sources to provide reference values, benchmarking, and explanations for the individual information items. To implement these requirements, a four-layer system architecture is considered (according to Häkli et al., 2013; Lee and Park, 2010; Thoroe et al., 2011). Fig. 5 shows the model that describes the layers and key questions which should be clarified during the TS conception. Secondly, the costs incurred by introducing and operating the

Application layer
carries out data usage and processing (the product information system (PIS) allows consumers to be provided with relevant product information via QR code scanning)

Questions:
- Which functionalities does the PIS have to provide?
- Which actor/s is/are responsible for the operation?

Network layer
allows data exchange along the furniture supply chain and provides information to consumers

Questions:
- Which IT components shall be used for the exchange of TRU-relevant data?
- Which standards for data exchange have to be established?

Integration layer
involves collecting, compressing, analyzing, and linking data as well as their integration into existing systems

Questions:
- Which data has to be linked and how?
- Which storage approach (central vs. distributed databases) has to be selected?
- Which actor/s is/are responsible for the operation?

Infrastructure layer
includes hardware components and infrastructure for data identification, collection, and pre-processing

Questions:
- Which TRUs have to be identified with which technology?
- Which data organization concept has to be set?
- Which data standards, regarding the storage and collection of data on tags, have to be chosen?

Fig. 5. Four-layer system architecture.

system architecture and by meeting the first three requirements must be divided between actors. The cost distribution between the supply chain members is highly important, as most actors are SMEs with limited investment capacity.

Providing product information to consumers diminishes purchase barriers by enhancing product trust and increases the purchase intentions (Gleim et al., 2013; Osburg et al., 2015). As a result, furniture manufacturers can acquire new customers and thus increase demand by providing a product information system (PIS). The increased demand is distributed across the supply chain stages according to the transformation coefficients with which their products are turned into end products. To make the cost-benefit ratios attractive for SMEs, it is necessary to consider indirect effects in the B2B area (cf. Fig. 3) and to keep costs low. This requires a simple architecture: One central hub of the system operates integration and networking layers and the distributed nodes access information in central databases via web services and complement the information manually or automatically through appropriate readers. An independent organization formed by the associations of the furniture industry could act as a central hub of the system controlling multilateral relationships along the wood furniture supply chains. The gradual development of a quasi-standard for traceability can also help to increase consumer protection, fulfill the obligations concerning consumer information, act quickly and effectively in recalls and simplify the certification process (e.g. Chain of Custody or ISO norm 9000ff.) leading to increased trust in wood furniture and more sustainable consumption. The presence of the independent organization can support participants' willingness to provide the data and participate in the standardization processes. As a possible starting point for such a structure, COMPETENCE CENTER DATA E.V. may be considered. It is an independent, non-profit organization within the associations of the woodworking and furniture industry, involved in the area of data communication for planning-intensive furniture. For communication between furniture manufacturers and distributors, a master data server is already available. The manufacturer can input the product data, which are then retrieved by distributors. The communication between all participants in the supply chain and the storage of the product histories about TRUs have to extend the available solution. Subsequently, the operation of integration and communication layers by an independent organization is assumed. The thus centrally held data can be used by PIS (application level) providing consumers with the information on mobile devices. It is proposed that PIS should be developed and operated by furniture manufacturers. This solution enables manufacturers to control the sensitive product information, provide information in brand layout and keep a competitive advantage.

4. Elements of the proposed traceability system

4.1. Infrastructure layer

The lowest layer is the interface to the real world with unique TRUs. Three methods allow keeping track of a TRU's supply chain location and the correct linkage between associated data (Appelhanz and Schumann, 2013; Kvarnström, 2008). Process data combined with tracers are required for creating virtual TRUs from endless flows in continuous processes. Marker technology and material signature are used to identify physical TRUs (details: Appelhanz and Schumann, 2013). ID methods at the item level allow the highest supply chain transparency (Melski et al., 2007). Receiving not only relevant but also unique product information might enhance consumers' product confidence. Considering the specifics of supply chain processes, two ID methods are used: the marker technology for discontinuous and process data for continuous processes. As the characteristics of material flows vary, different marker technologies are combined.

Thereby, selected markers should be suitable for attachment to a wood surface and industrial use. Dykstra et al. (2002) considered several marker technologies in the wood supply chain and identified various benefits of using RFID as traceable markers (e.g. robustness against environmental influences, bulk and fast reading, without visual contact), though being an expensive solution (about 0.35 V per transponder). Because of the high costs, Erhardt et al.

Table 3
TRUs with associated traceability methods.

TRU	Method
High grade timber log	RFID
Industrial wood log	Ink-printing
Shipment of industrial wood logs	RFID
Lumber, lamellae	Ink-printing
Edge-glued panel	RFID
Silo cell with by-products or chips	RFID
Shipment of by-products	RFID
Waste wood	Not traceable, wood type determination at particleboard manufacturers is handled through optical spectroscopy
Particleboard fleece	Process data
Particleboard	Ink-printing
Trading unit of particleboards	RFID
Veneer sheet	Ink-printing
Trading unit of veneer sheets	RFID
Furniture part in the company	RFID
Packing of wood furniture	QR-Code

(2010) suggest the utilization of RFID tags equipment at the level of a shipment or a commercial unit, items with high monetary value and items in closed loop systems, with multiple-use rewritable RFID tags.

For full traceability at the item level, this paper also considers the ink-printing solution being developed for the wood supply chain as a marker technology: A prototype ink-printer device can be integrated into the harvesting/sawing blade and print two-dimensional (2D) barcodes or data matrices into the log/board/veneer (for only 0.002 V per board) (Uusijärvi, 2010), as used for items with low monetary value.

Combining both technologies is supported as RFID readers are more often equipped with the 2D imager, whereby a parallel operation can run smoothly at acceptable costs (e.g. Reader Nordic ID, M3 orange or LogiScan). This allows implementing the backup system e.g. if ink-printing is unreadable. The use of RFID tags at the level of deliveries or sales units enables automating the TRU receipt, control, or commissioning, thereby leading to personnel savings. The full traceability at the item level also permits achieving several benefits along the entire supply chain (cf. Fig. 3).

Considering customer needs, the third type of marker technology is used by furniture manufacturers as the QR code is placed on the packaging. Therefore, each product carries the product's ID and the URL referring to the location of the required product information (Meyer et al., 2009).

Existing process data can be used to ensure the relationship between incoming and outgoing units in the continuous process steps during particleboard manufacture or sawmill, e.g. data collected online on the ratio of the wood types in fleece (optical spectroscopy) or moisture content (online microwave moisture analysers). Table 3 summarizes all TRUs with the associated identification methods.

Decisions on standards have to be made before defining the hardware components. The EPCglobal approach of storing only an identifier on the tag (Electronic Product Code (EPC)) and all related data in the supply chain participant's information systems is the predominant practice in using RFID tags (Tribowski et al., 2009). The reasons are: use of cheap tags; backwards-compatibility with other very commonly used standards managed by GS1; no necessity for cryptography, as the respective data are stored on the network. Additionally, EPCglobal network regulates not only the data standard but also the necessary IT infrastructure and standards for the storage and communication of EPC-related data (GS1, 2014a). The selected infrastructure also supports data-on-network storage. Thus, two types of EPC are crucial: The Serial Global Trade Item Number (SGTIN) identifies an individual product unit, the Serial Shipping Container Code (SSCC) a logistics handling unit. Additional information can be stored in the internal traceability on the tag (data-on-tag) and set individually by each company.

The hardware level includes the RFID tags and read/write units. The RFID tag (WORM and rewritable) use corresponds to the EPC Class 1 Gen 2 standard included in the ISO standard 18000-6c. Read/write units include the RFID devices on the harvester, mobile devices at forestry enterprises and furniture manufacturers, RFID gates or bulk-capable mobile RFID readers at the input and output of goods at each supply chain stage and ink-printing equipment at forestry, sawmills, and plywood manufacturers. Retailers should provide QR code readers to customers who cannot rely on smartphones. The hardware level can be supplemented by the edge level based on device controllers connecting the hardware with the software world. Appendix A provides a detailed description of the technical solution for each stage of the wood furniture supply chain.

4.2. Integration and networking layers

Information is collected by the specified hardware components at the infrastructure level. According to the concept of “data-on-network”, the reader captures the EPC of a TRU. Each acquisition receives a time stamp and reader data, which allow determining the place of action by the specification of the EPC Company Prefix of the enterprise responsible for operating the reader. The described attributes (movement data) are not sufficient for the transformations as input and output data must be linked, e.g. some product information (e.g. country or type of wood) is recorded at the forestry and inherited by subsequent intermediates and finished products. Product information such as material composition, additives, or portion of recycling only arises during transformations which describe form changes of TRUs during conversion processes, e.g. production processes transforming raw materials, parts, and intermediaries into one end product (Jansen-Vullers et al., 2003). Thereby, integration, division, and alteration have to be differentiated as transformation (details: Bechini et al., 2008; Lee and Park, 2010):

- Integration: A number of input materials are integrated into a single end product, e.g. production of furniture or particleboard
- Division: An input material is divided into several products, e.g. production of sawn wood and veneers
- Alteration: A new product is generated from another product by an alteration activity, e.g. refinement of sawn wood.

Integration and division are particularly relevant, as they determine the objects' hierarchy based on parts lists/recipes for the integration and sawing patterns for divisions. The transformation actor is responsible for preparing and illustrating these relationships in a TS. It is important to uniquely identify the basic document (e.g. bills of materials/recipes) listing the inputs or outputs with their transformation coefficients and to link it to the resulting unit. For unique identification of documents, a GS1 Global Document Type Identifier (GDTI) can be used (GS1, 2014b). To create the transformation data, it is necessary to link the EPC of the outgoing unit (master EPC) with movement data from all incoming units (slave EPC) on the basis of documents. During the integration, movement data is collected for each incoming unit, and during the division, once detected movement data of the incoming unit enter into multiple transformation data. Transformations also occur at logistical processes when logistical units are changed in content

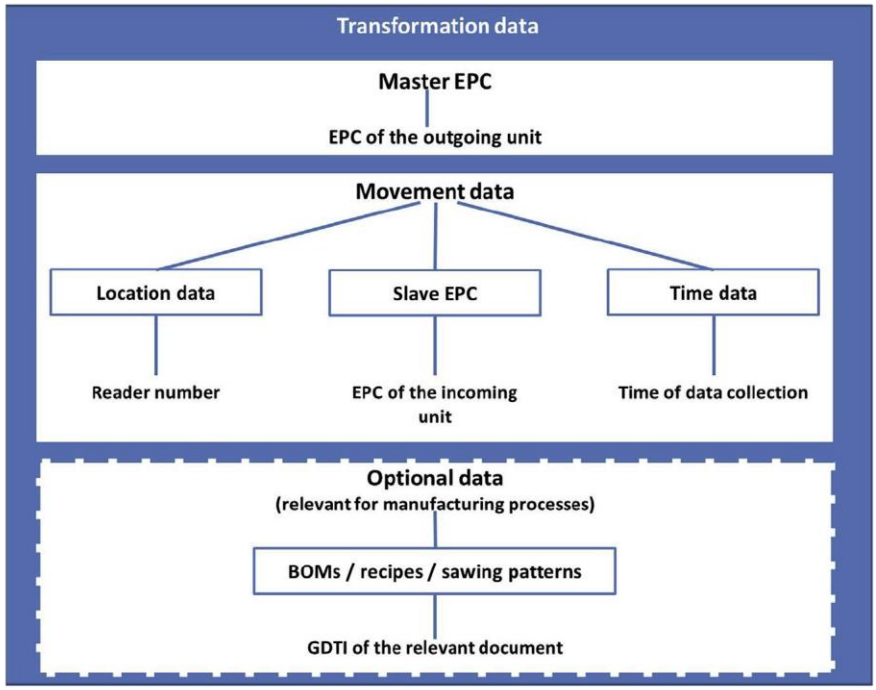

Fig. 6. Relationship between transformation and movement data.

and quantity. Thereby, no link to documents is required. Fig. 6 visualizes the relationship between movement and transformation data.

The transformation coefficients may also be used to calculate a consumer-preferred product information item, such as "carbon footprint". For the calculation of a cumulative value of CO_2 emissions along the entire supply chain from the log to the bookshelf as a final product, the carbon value of the incoming unit can be multiplied by the transformation coefficient.

The middleware represents not only the application interface, but receives and processes data provided from the infrastructure layer into data with which the applications work (data linkage including the creation of transformation data). The data is stored in EPC Information Services (EPCIS), guaranteeing an enterprise's connection with the EPCglobal network. Using the query interface, the data can be made available to the network participants. With the EPCIS, the networking layer of the system has been addressed, based on the event registry service. If an EPCIS event is stored, the EPCIS reports this in the event registry service. The event registry service server hosts a catalog storing the place on which the events to an EPC are found. Based on the wood furniture master EPC, this service determines the slave EPCs and thus the entire development path. This level also includes web services for communication with partners along the supply chain.

4.3. Application layer

The layer includes the PIS which performs the management of product information and is operated by furniture manufacturers. The PIS is based on the EPSIS of the independent organization and uses the EPC of finished products as an information key. Using event registry services, the values for consumers' valued product information items are extracted, supplemented with information about the statements, industry, and the required reference values and prepared as information packages for the three consumer segments (cf. Table 2). PIS makes information packages available in the form of mobile websites. Nevertheless, the presentation format (e.g. text, table, image, graphic) as well as the selection and presentation of reference values (e.g. according to the traffic light system popular in nutrition labeling) have to be determined in subsequent studies before the external information source can be selected.

To access the prepared mobile website using QR codes, the data must be structured according to the GS1 system rules. Element strings begin with an Application Identifier (AI), followed by the data that the AI denotes. The additional AIs (GTIN for the product class or SGTIN for items) can be included in the request for the information resource linked to the URL so that only precise and relevant information is returned to consumers (GS1, 2009). Since no metadata are present in the QR code to state whether the web page linked to the HTTP URL for product information is a generic website operated by the brand owner or if it is product-specific, including the additional AIs guarantees that the generic brand owner's web page can provide product information related to AIs included in the query. Thereby the HTTP request uses the HTTP 'GET' method and the standard form submission syntax for the query string part of the URL. The use of the HTTP 'GET' method with the query string format allows web resources to ignore part of the query. If the web resource at the URL cannot recognize or understand the query string or any particular AI included therein, it is simply not processed (GS1, 2009).

Fig. 7 shows the architecture of the proposed system.

5. Economic feasibility of proposed TS

5.1. Cost-benefit model

The system proposed in Section 4 requires investments of all supply chain participants. As the SMEs must be convinced about the economic feasibility, the relationship between achieved benefits and corresponding costs is analysed. The systematization of the actual cost elements and potential benefits helps to forecast cash

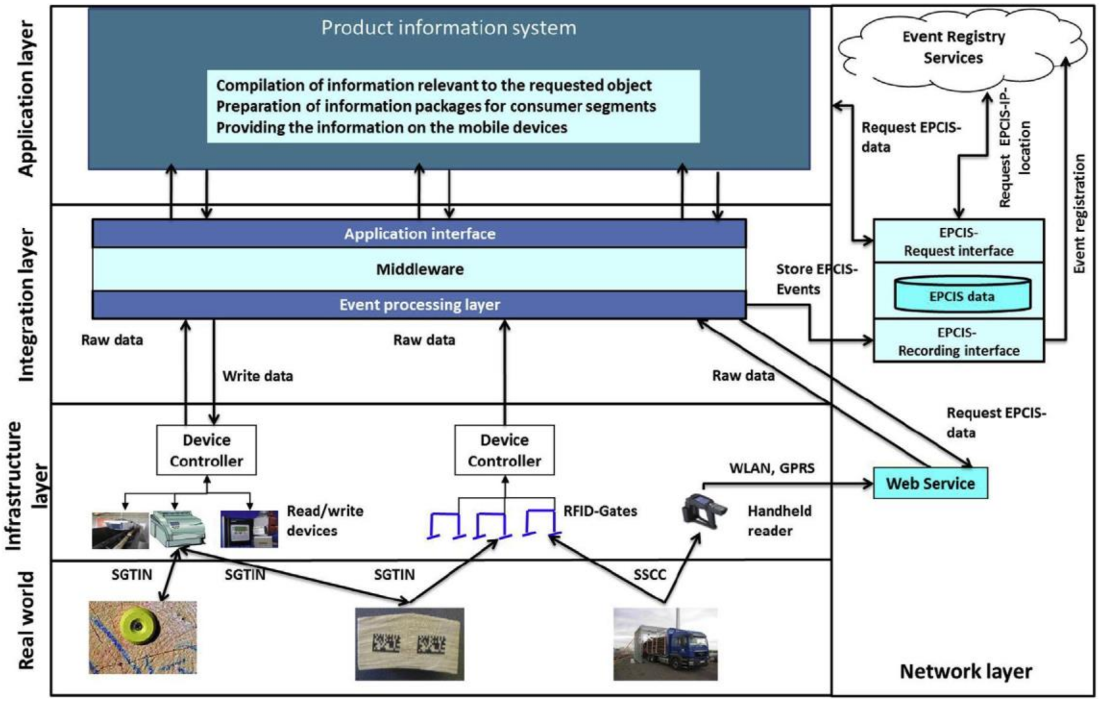

Fig. 7. System architecture (according to Thoroe et al., 2011).

flows. Since the acquisition of the system components is an extensive infrastructure measure used across multiple time periods, the dynamic methods of the capital investment account (e.g. present value method) can be selected.

Two measures indicate the direct benefits of providing consumers with product information: willingness-to-pay, referring to consumers' cost participation for information provision, and higher purchase probabilities, which are associated with an increased demand (cf. Section 3). The proposed TS achieves high supply chain transparency increasing indirect benefits based on process improvements (cf. Fig. 3) and expressed through cost reduction (Bajric, 2010).

Costs are divided into one-time investment and recurring costs (Melski, 2009). The former can be divided into:

- Hardware costs: costs of read/write units, their installation, and RFID tags (used several times in closed systems); incurred at each supply chain stage.

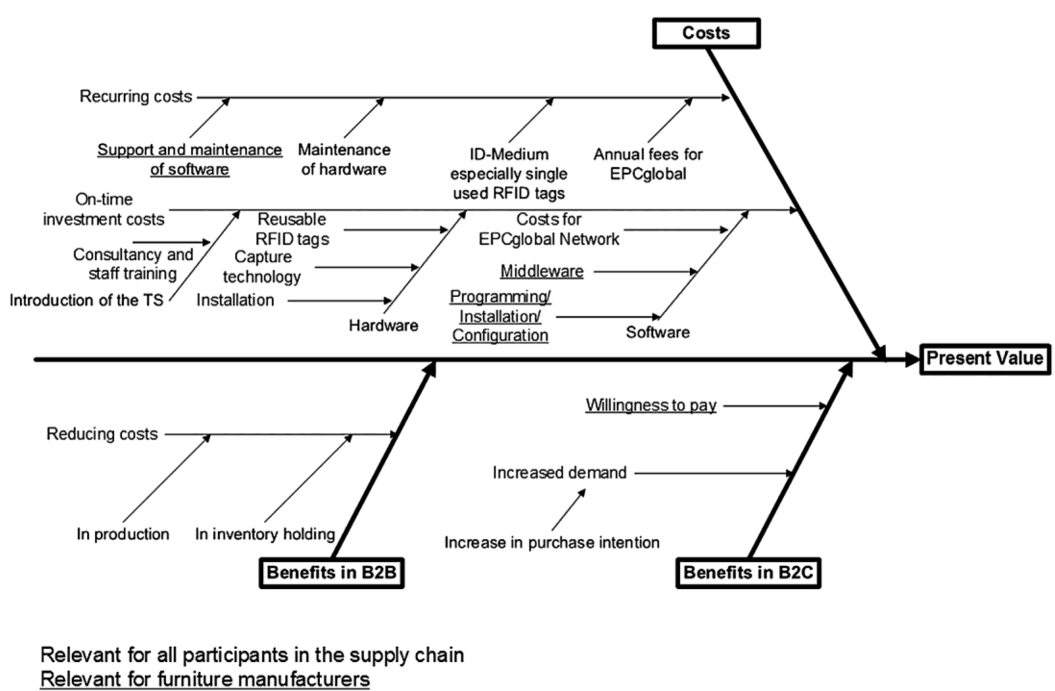

Fig. 8. Costs and benefits included in the model.

Table 4
Model parameters.

$b_{i,t}$	Profit per product unit at stage i in year t
$CST_{TSfWPI,i}$	Costs of consultancy and staff training at stage i
D_t	Demand in year t
$d_{TSfWPI,t}$	Increase in demand by the application of TSfWPI (percentage) in year t
$EPC_{AF,D,i,t}$	Annual fees for EPCglobal depending on the demand D at stage i in year t
$EPC_{PC,D}$	Provision cost for EPCglobal Network depending on the demand
i	Stage of the supply chain
I	Number of stages in the supply chain
$IB_{i,t}$	Indirect benefits at stage i in year t
IC_r	Installation cost per reader as a percentage of the reader costs
IC_{SM}	Installation and configuration costs for software as a percentage of the software cost
$IC_{TSfWPI,i}$	One-time investment costs for stage i
$MC_{HW,t}/MC_{SW,t}$	Maintenance cost of the hardware/support and maintenance cost of the software as a percentage of hardware/software costs in year t
$MR_{RFID,i}/MR_{ink,i}$	Number of mobile RFID/ink-printing readers at stage i
$p_{i,t}$	Price per product unit at stage i in year t
$p_{MR,ink}/p_{SR,ink}$	Price of mobile/stationary ink-printing readers
$p_{MR,RFID}/p_{SR,RFID}$	Price of mobile/stationary RFID readers
$p_{reusable\ RFID}$	Price of reusable RFID tags
$p_{RFID,t}/p_{ink,t}/p_{qr,t}$	Price of RFID tags/ink-printing/QR code per unit in year t
$p_{SR,QR}$	Price of stationary QR readers
r	Discount rate
$RC_{TSfWPI,i,t}$	Recurring costs at stage i in year t
SMC_i	Software cost (including middleware cost) at stage i
$SR_{RFID,i}/SR_{ink,i}/SR_{QR,i}$	Number of stationary RFID/ink-printing/QR readers at stage i
t	Year
T	Time horizon for the years t = 1, …, T
WTP_{TSfWPI}	WTP per unit of bookshelf by the application TSfWPI (percentage)
$x_{reusable\ RFID,i}$	The number of TRUs provided with a reusable RFID tags at the stage i
$x_{RFID,D,i,t}/x_{ink,D,i,t}/x_{QR,D,i,t}$	The number of TRUs provided with RFID tags/ink-printing/QR code depending on the demand D at stage i in year t
y_i	Transformation coefficient for the product at stage i

- Software costs: costs of middleware, additional application software (e.g. PIS), software installation and configuration (including connection to existing back-end systems); assumed by furniture manufacturer; GS1 package required for each supply chain member (to assign the EPCs to TRU).
- System introduction costs: costs of consultancy and staff training.

Recurring costs include hardware maintenance and support as well as maintenance software costs (i.e. percentage of relevant acquisition cost in the calculation). The other considered component is the cost of data medium acquisition (RFID tags for open systems or ink-printing per TRU). While hardware costs are paid at each supply chain stage, software costs only occur at the stage of furniture manufacturers. Furthermore, annual fees for EPCglobal have to be considered.

The Ishikawa Diagram (Fig. 8) summarizes the model's costs and benefits with the following assumptions:

- Only the costs and benefits described above are considered. Further costs can be covered by benefit effects not reflected in the model. For example, no staff overhead is taken into account through the introduction of TS, since these costs are more than compensated by personnel savings (Holzmann, 2009; cf. Sections 2.3 and 4.1).
- The potential demand increases during the first period but remains constant for the entire time horizon. Possible competitor reactions are not considered.
- Transformation coefficients for non-manufacturing companies (e.g. transportation, commercial enterprise) are equal to 1, since they do not feature any product transformation.
- On-time investment and recurring costs of middleware at the independent organization must be distributed between furniture manufacturers taking part in the association. Consumers participate in the incurred costs in the form of WTP, which is claimed in full by the furniture manufacturer.

Subsequently, mathematical formulas represent the individual components of the Ishikawa diagram. Table 4 introduces the model parameters.

As the costs and profits of the furniture manufacturers differ from other supply chain stages, calculating the TSfWPI present value is performed along two different paths: for furniture manufacturers and other supply chain participants.

Formula 1 calculates on-time investment costs per stage i for all participants, with the exception of furniture manufacturers, as the sum of hardware and their installation costs $((MR_{RFID;i} * p_{MR;RFID} + MR_{ink;i} * p_{MR;ink} + SR_{RFID;i} * p_{SR;RFID} + SR_{ink;i} * p_{SR;ink})(1 + IC_r))$, costs of consultancy and staff training $(CST_{TSfWPI;i})$, cost for reusable RFID tags $(x_{reusable\ RFID;i} * p_{reusable\ RFID})$ and for EPCglobal network $(EPC_{PC;D})$.

Formula 1:

$$IC_{TSfWPI;i} = (MR_{RFID;i} * p_{MR;RFID} + MR_{ink;i} * p_{MR;ink} + SR_{RFID;i} * p_{SR;RFID} + SR_{ink;i} * p_{SR;ink})(1 + IC_r) + CST_{TSfWPI;i} + x_{reusable\ RFID;i} * p_{reusable\ RFID} + EPC_{PC;D}; \quad i \neq \text{furniture manufacturer} \tag{1}$$

To determine furniture manufacturers' investment costs, Formula 1 is extended by the costs of QR code hardware $(SR_{QR;i} * p_{SR;QR})$, software and its installation and configuration $(SMC_i(1 + IC_{SM}))$ (Formula 2).

Formula 2:

$$IC_{TSfWPI;i} = (MR_{RFID;i} * p_{MR;RFID} + MR_{ink;i} * p_{MR;ink} + SR_{RFID;i} * p_{SR;RFID} + SR_{ink;i} * p_{SR;ink} + SR_{QR;i} * p_{SR;QR})(1 + IC_r) + SMC_i(1 + IC_{SM}) + CST_{TSfWPI;i} + x_{reusable\ RFID;i} * p_{reusable\ RFID} + EPC_{PC;D}; \quad i = \text{furniture manufacturer} \tag{2}$$

All participants' recurring costs, with the exception of furniture manufacturers, are calculated as the sum of hardware maintenance costs $((MR_{RFID;i} * p_{MR;RFID} + MR_{ink;i} * p_{MR;ink} + SR_{RFID;i} * p_{SR;RFID} + SR_{ink;i} * p_{SR;ink}) MC_{HW;t})$, costs for data media $(x_{RFID;D;i;t} * p_{RFID;t} + x_{ink;D;i;t} * p_{ink;t})$ and annual fees for EPCglobal $(EPC_{AF;D;i;t})$ according to Formula 3.

Formula 3:

$$RC_{TSfWPI;i;t} = \left(MR_{RFID;i} * p_{MR;RFID} + MR_{ink;i} * p_{MR;ink} + SR_{RFID;i} * p_{SR;RFID} + SR_{ink;i} * p_{SR;ink}\right) MC_{HW;t} + x_{RFID;D;i;t} * p_{RFID;t} + x_{ink;D;i;t} * p_{ink;t} + EPC_{AF;D;i;t}; \quad i \neq \text{furniture manufacturer} \tag{3}$$

Furniture manufacturers' running costs comprise costs according to Formula 3 plus maintenance costs of QR hardware $\left(SR_{QR;i} * p_{SR;QR} * MC_{HW;t}\right)$, maintenance and support software costs $(SMC_i * MC_{SW;t})$ and costs for QR code markers $\left(x_{QR;D;i;t} * p_{QR;t}\right)$ (Formula 4).

Formula 4:

$$RC_{TSfWPI;i;t} = \left(MR_{RFID;i} * p_{MR;RFID} + MR_{ink;i} * p_{MR;ink} + SR_{RFID;i} * p_{SR;RFID} + SR_{ink;i} * p_{SR;ink} + SR_{QR;i} * p_{SR;QR}\right) MC_{HW;t} + SMC_i * MC_{SW;t} + x_{RFID;D;i;t} * p_{RFID;t} + x_{ink;D;i;t} * p_{ink;t} + x_{QR;D;i;t} * p_{QR;t} + EPC_{AF;D;i;t}; \quad i = \text{furniture manufacturer} \tag{4}$$

The present value (PV_{TSfWPI}) is the sum of all discounted payments-in and payments-out over the period T. While payments-out for all participants, excluding furniture manufacturers, have already been defined (Formulas 1 and 3), payments-in include the additional profit based on the increased demand $\left(D_t * d_{TSfWPI;t} * b_{i;t} * p_{i;t} * \prod_{l=i+1}^{I} y_l\right)$ and indirect benefits $(IB_{i;t})$ (Formula 5).

Formula 5:

$$PV_{TSfWPI;i} = -IC_{TSfWPI;i} + \sum_{t=1}^{T} \left(\left(D_t * d_{TSfWPI;t} * b_{i;t} * p_{i;t} * \prod_{l=i+1}^{I} y_l + IB_{i;t} - RC_{TSfWPI;i;t} \right) (1+r)^{-t} \right); \quad i \neq \text{furniture manufacturer} \tag{5}$$

For estimating the furniture manufacturers' present value, Formula 5 must be extended by another payment-in, WTP $\left(\left(D_t (1 + d_{TSfWPI;t}) * p_{i;t} * WTP_{TSfWPI}\right)\right)$ (Formula 6).

Formula 6:

$$PV_{TSfWPI;i} = -IC_{TSfWPI;i} + \sum_{t=1}^{T} \left(\left(D_t * d_{TSfWPI;t} * b_{i;t} * p_{i;t} + D_t (1 + d_{TSfWPI;t}) * p_{i;t} * WTP_{TSfWPI} + IB_{i;t} - RC_{TSfWPI;i;t} \right) (1+r)^{-t} \right); \quad i = \text{furniture manufacturer} \tag{6}$$

5.2. Use case

The developed cost-benefit model is now applied to an exemplary use case. In addition to the described assumptions, retailers are not considered, and manufacturers are supposed to ship their products themselves. Since a practical implementation has not been performed, the cost-effectiveness calculation relies on estimates. The value estimates (Tables 5–7) are predicated on expert testimony (GS1 Germany; leading international and local hardware and software manufacturers operating in Germany such as Schreiner Group GmbH & Co. KG, Plöckl Media Group GmbH, Data Elektronik GmbH, Hans Turck GmbH & Co. KG; associations for solid wood, sawmill and furniture industry; market research companies) and previous studies (Lev and Viniak, 2012; Melski, 2009; Nilsson, 2010; Uusijärvi, 2010). For one-time and recurring costs (T = 5), the values listed in Table 5 are set.

Table 5
Parameters of the cost components.

Mobile RFID readers (+ barcode scanning)	2230 €
Mobile RFID readers (+ barcode scanning and bulk reading)	2550 €
Transponder applicator and harvester RFID reader	6500 €
Stationary RFID reader	3000 €
Harvester log ink marker	5000 €
Log ink reader (stationary)	7000 €
Ink marker (stationary)	13,000 €
Ink reader (stationary)	8000 €
QR code printer	1000 €
Reader/printer installation	20% of reader costs
EPCglobal network provision	273.70 €
EPCglobal annual fees	178.50 €
Ink marking variable costs	0.01 €/item
QR code printing variable costs	0.03 €/item
RFID tag with UHF Chip (EPC Class 1 Gen 2, 860–960 MHz)	0.30 €/tag
Rewritable RFID tag with UHF Chip (EPC Class 1 Gen 2, 860–960 MHz)	0.35 €/tag
RFID tag on metal price premium	0.05 €/tag
Software: (PIS + middleware)	80,500 € (solid wood furniture); 113,500 € (furniture made from veneered particleboard)
Software installation and configuration	30% of software cost
Consulting and staff training	5000 € (furniture manufacturer); 2500 € (other participants)
Hardware maintenance cost	15% of hardware cost
Software maintenance cost	25% of software cost

Table 6 shows direct and indirect TSfWPI profits based on previous wood-based supply chain studies and implemented pilot projects. Since the lower limit for the demand increase has not yet been studied, a break-even analysis allows its determination.

Subsequently, scenarios for bookshelves made from solid wood (scenario 1) and veneered particleboard (scenario 2) are set (cf. Table 7). Prices, dimensions of individual products, and sizes of individual trade items were taken from suppliers (Wald-Prinz.de; Weyland GmbH; Behrens-Wöhlk-Gruppe; Landesbetrieb Wald und Holz Nordhein Westfallen; Templin OHG; Pickawood GmbH). Transformation coefficients for the chosen dimensions and sizes of individual products were calculated using the cutting optimization program (Cutting Optimization Pro version 5.7.8.11). The Appendix B documents the equipment of the individual supply chain stages. As a reference value for the discount rate, the German furniture industry's average return after taxes is used. According to experts of the Department “Economy and foreign markets” the associations of the German wood, furniture and finished

Table 6
Parameters of the profits.

Profit	Value	Source
Direct profits		
WTP	12.2%	Cai and Aguilar, 2013
Indirect profits		
Cost reduction in forestry (production + inventory)	5 €/m³ of logs	Bajric, 2010
Cost reduction for sawmill/veneer or particleboard manufacturers (production + inventory)	5.2 €/m³ of wood material	
Cost reduction for furniture manufacturers (by fault avoidance)	20 €/defective pieces of wood furniture	Tribowski et al., 2009

Table 7
Parameter for scenario with bookshelves made from solid wood and veneered particleboard.

Scenario 1: Bookshelves made from solid wood	
Selling rate	2000 units
Bookshelf measure (length x width x depth)	197 cm × 49 cm × 37 cm with 4 shelves
Price of bookshelfs	249 V
Glued wood panel measure (length x width x thickness)	250 cm × 121 cm × 1.9 cm (strands 40–41 mm wide in a single length)
Price for m^2 of glued wood	72 V/m^2
Unit of sale by glued wood	Single panel
Log measure (diameter x length)	45 cm × 5 m
Price for m^3 of round wood	107.50 V
Volume of round wood shipment	Ca. 27 m^3
Supply chain	Forestry-sawmill-furniture manufactures
Transformation coefficients	{-; 0.018 Fm/glued wood panel; 1.33 panel/bookshelf}
Error rate	1% of selling rate
Profit per unit	10% of price

Scenario 2: Bookshelves made from veneered particleboard	
Selling rate	10,000 units
Bookshelf measure (length x width x depth)	202 cm × 40 cm × 28 cm with 5 shelves
Price of bookshelf	89 V
Veneer measure (length × width × depth)	246 cm × 100 cm × 0.3 cm
Price for m^2 of veneer	4 V/m^2
Unit of sale by veneer	32 sheets
Volume of chip shipment	95 m^3
Particleboard (length × width × thickness)	280 cm × 207 cm × 1.9 cm
Price for m^2 of chip board	9.84 V/m^2
Unit of sale by chip board	45 boards
Industrial wood log measure (diameter × length)	30 cm × 4 m
Price for m^3 of industrial wood	45 V/m^3
Volume of round wood shipment	Ca. 27 m^3
Supply chain	Forestry-veneer manufactures (sawmill)-particleboard manufactures-furniture manufactures
Transformation coefficients	{-; 0.00246 m^3 round wood/veneer; 0.177 m^3 (industrial wood + chips + waste wood)/particleboard; 0.48 particleboard and 2.48 veneer sheet/bookshelf}
Error rate	1% of selling rate
Profit per unit	10% of price

construction, the current value is in the range between 2 and 3%. Since the current value is an estimate, the official value in the amount of 3% for the year 2011 is used for calculations.

The break-even analysis determines the lowest value for the demand increase leading to the TSfWPI investment: $d_{TSfWPI} = 2.58\%$ for scenario 1 and $d_{TSfWPI} = 6.84\%$ for scenario 2. Table 8 represents the TSfWPI present value for each supply chain stage and along the entire supply chain using the example of $d_{TSfWPI} = 10\%$ for both scenarios.

According to the calculations (cf. Table 8), only furniture manufacturers benefit from the investment for a given demand increase. To motivate the remaining supply chain participants to invest, they should be substituted based on the WTP profit. Since the supply chain members for solid wood furniture can even bear the hardware maintenance cost, the furniture manufacturer needs to exclusively take over the hardware purchase. In the veneered particleboard supply chain, furniture manufacturers must pay maintenance costs completely for forestry and veneer manufacturers and partially for chipboard manufacturers.

To reduce the uncertainties resulting from the use of historical data and approximation methods and to evaluate the risks in the context of the calculation, sensitivity analyses were performed. Using charts, the effects of fixed changes (±5%, ±10%, ±15%) to each particularly important model parameter with constant values of the remaining parameters on the outcome of the present value of the investment are represented for both scenarios (Fig. 9).

As shown in Fig. 9, the sensitivity in scenario 2 is higher, inter alia due to the higher number of supply chain stages and the lower bookshelf prices. Four supply chain stages must introduce the TS (high payments-out especially for on-time investment costs) in scenario 2. As the price of bookshelves is the basis for the calculation of benefits in B2B and B2C segments, the payments-in are also reduced. Thus, the cost-benefit ratio in scenario 2 deteriorates.

The WTP most strongly influences the investments' profitability. A 5% WTP reduction leads to a negative net present value in both scenarios. In order to achieve the positive present value for the given parameter values, WTP should be at least 9.80% for scenario 1 and 11.41% for scenario 2. Another critical factor is the discount rate. While in scenario 1, only the 15% increase of the discount rate leads to a negative net present value, as little as a 5% change in scenario 2 renders the investment not profitable. This results from the amount of cash flows which are higher compared to scenario 1 (cf. Table 8). The maximum value for the discount rate is 13.89% in scenario 1 and 6.36% in scenario 2. The comparative effects arise from the variation from another benefit in the B2C sector, namely an increase in demand.

The situation looks different for the parameter "selling rate". Thus, a 15% fall in demand leads to a still positive present value in scenario 1. In scenario 2, a negative present value is to be expected in such a change. This is due to high fixed costs and low prices for bookshelves made of veneered particleboard. Since one-time investment costs are about six times higher than recurring costs, higher selling rates can help to increase the investment's profitability.

The payments-out in the form of on-time investment and recurring costs influence the present value, but to a smaller extent than previous parameters. Only the 15% increase in costs in scenario 2 causes a negative present value. The influence of the recurrent costs is lower than the influence of on-time investment costs, because combining various marker technologies and designing the central hub for the integration and communication layers reduce the recurring costs. The lower sensitivity may be important if costs will be higher than the estimated values. For example, since the technology is new, and the optimal readout rate

Table 8
Examples for the calculation of the present value of the investment in the proposed system.

Supply chain stage	Scenario 1	Scenario 2
Forestry	$-13633.30 + \sum_{t=1}^{5} \frac{(3148.11-1736.10)}{(1+0.03)^t} = -7166.707655$	$-36633.30 + \sum_{t=1}^{5} \frac{(616.07745-2297.26)}{(1+0.03)^t} = -44332.62381$
Sawmill/Veneer manufacture	$-40369.30 + \sum_{t=1}^{5} \frac{(8532.2160-6633.60)}{(1+0.03)^t} = -31674.19466$	$-51074.50 + \sum_{t=1}^{5} \frac{(1631.465760-6744.70)}{(1+0.03)^t} = -74491.61560$
Particleboard manufacturer	–	$-59105.3 + \sum_{t=1}^{5} \frac{(7755.426-8537.90)}{(1+0.03)^t} = -62688.8018$
Furniture manufacturer	$-1.2817330 \; 10^5 + \sum_{t=1}^{5} \frac{(72251.60-22642.00)}{(1+0.03)^t} = 99024.14$	$-2.1396080 \; 10^5 + \sum_{t=1}^{5} \frac{(1.30538000010^{5}-36488.500)}{(1+0.03)^t} = 216758.37$
Total	60183.24 V	35245.33 V

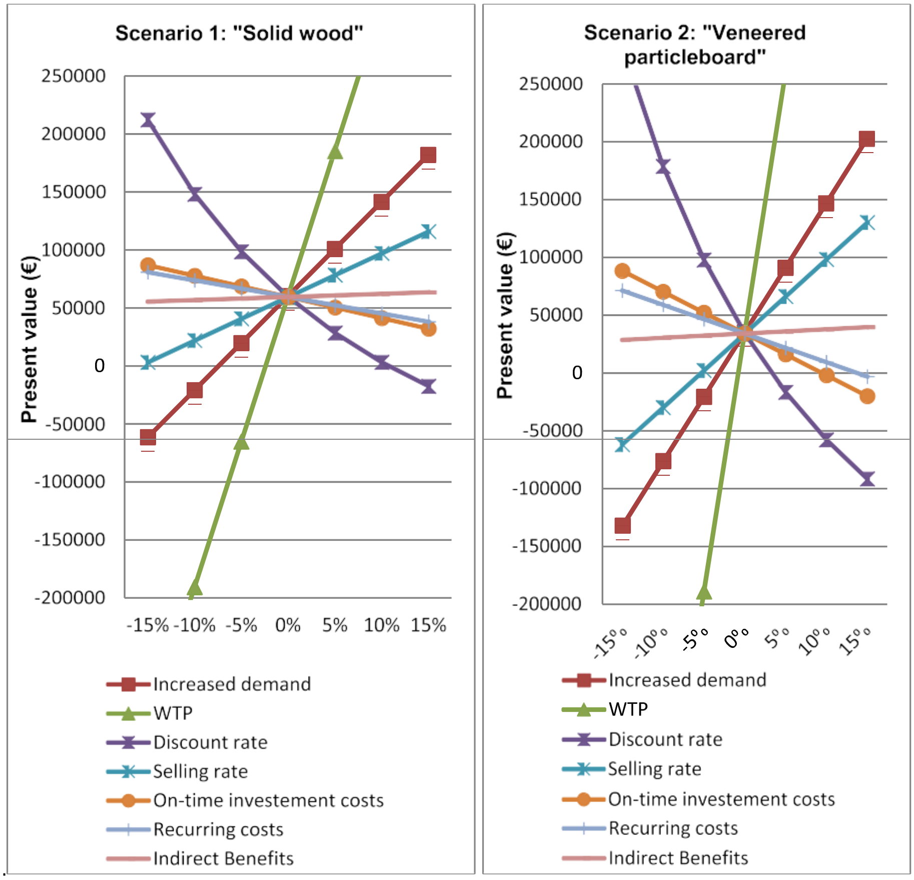

Fig. 9. Impact of fixed changes in the parameters on the present value.

is only achievable by intensive testing, the test phase could fail extensively. Moreover, the combination of several traceability methods must be ensured. Downtime can occur during the system's introduction which can increase on-time investment cost. Price increases for data media, various adjustments, the gradual system extension, and even unexpected maintenance are other factors influencing the amount of recurring costs.

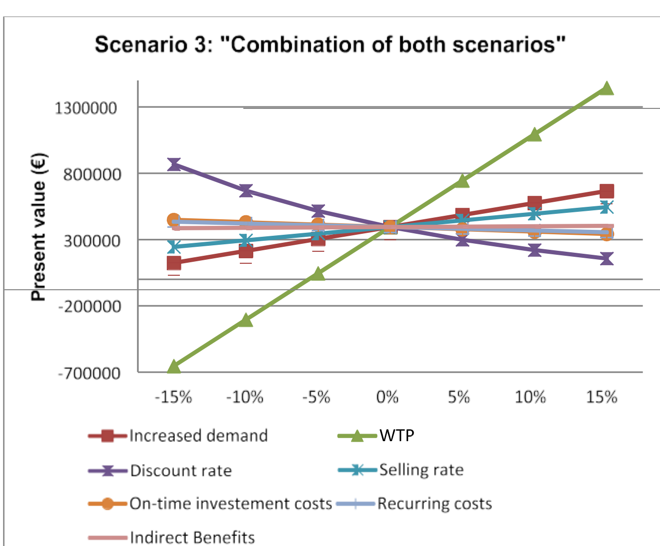

Fig. 10. Impact of fixed changes in the parameters on the present value in the scenario 3.

The indirect effects have a small impact on the present value due to the assumption that the process change's costs as additional work are covered by indirect benefits and the few existing studies about effects in the B2B sector resulting in the elimination of personal savings and until now unquantified effects. So there is still no examination of the relationships between B2B and B2C effects. For example, positive effects in the B2B sector can influence the B2C effects. The TS data can help to overcome the weaknesses of the current practice of the Chain-of-Custody certification, which may positively affect the confidence in the product.

The two scenarios refer to relatively small companies. To illustrate a larger company, both scenarios can be merged, so that the furniture manufacturer sells bookshelves made of solid wood and veneered particleboard (scenario 3). Assuming that the veneers are made by saw mills, the investment can be profitable at WTP ¼> 8.03% and d_{TSfWPI} ¼ 0. If WTP ¼ 12.2% and d_{TSfWPI} ¼ 10%, then the present value for the supply chain is 394154.51 V. The sensitivity analysis for scenario 3 shows that only one parameter is to be considered critical, namely WTP (cf. Fig. 10). But even here improvements are observable. The present value at the 5% reduction of WTP still remains positive.

6. Discussion

The proposed system is based on traceability without gaps at the item level. The data collected along the entire supply chain is the basis for the aggregation and provision of consumers' valued product information. This information can be accessed via smartphones in the POS. To achieve this, a four-layer architecture was conceived. However, its implementation requires trust between

Table 9
Summarizing the conception of the proposed system.

Layer/Prerequisites	Description	Challenges
Prerequisites		
Standardization	EPCglobal specifications ➔ Concept "Data-on-network"	Other standards need to be developed, e.g. data-on-tag by furniture manufacturers
Operator of system	Independent organization ➔ data in central database (middleware including EPCIS) Furniture manufacturer ➔ PIS	Potential loss of control over data by supply chain participants ➔ trust between supply chain members
Four-layer model		
Infrastructure layer	Identification of TRUs at the item level through combining RFID and ink-based solutions; equipment for every delivery or sales unit with RFID tag provides a backup solution if the marked ink technology in these units are unreadable	Difficulties with the creation of the TRU in continuous processes. Solution: use of process data for TRU identification ➔ Process data must be recorded continuously and automatically; Extensive tests, particularly to achieve the maximum possible read rate: selecting the appropriate data medium (resistant to moisture in the wood and suitable for industrial use), determining the installation location for data mediums and position of the antennas and cameras for stationary readers
Integration and networking layers:		
• Data linking	Creation of the transformation data to capture consumer-relevant information	Presence of environmental information systems in the enterprise for the capturing of carbon footprint; Before the 100% read rate is achieved, it is necessary to pass the traceability information in accompanying documents. This will also help if the data medium is unreadable. The approach may lead to additional manual effort (paper-based documentation) or the development of additional interfaces (including any EDI documents)
• Middleware	Central point of the entire system: represents both, integration and communication	Poor scalability and the problem of a single point of failure: If there is a failure at the system's central point, the entire supply chain and the PIS are affected
Application layer	Functionality of PIS: Compilation, preparation and providing relevant information to the requested object on the mobile devices	Any fees for the explaining information from external sources and the development of appropriate interfaces; Further studies regarding the selection and presentation of explaining information are required

supply chain members. Additionally, the implementation of each layer is connected with challenges that are summarized in Table 9.

Profitability is another requirement for the proposed system. The economic analysis shows that even the identification on the item level for SMEs is possible. Therefore, the combination of RFID (for expensive items at the item level and for cheaper products at the delivery or sales unit level) and ink (at the item level for cheaper products) identification technologies was proposed. However, the performed sensitivity analyses have shown that both direct effects are required, especially if the furniture manufacturers are small enterprises. Most importantly, consumers have to pay a surcharge for the information provision. The detailed investigation of indirect effects and their influence on direct effects should help to reduce consumers' surcharge. It was also found that with increasing size of the company, the profitability of the investment increases and the sensitivity decreases with respect to the model parameters. Furthermore, a higher profitability was found for solid wood than veneered particleboard furniture as solid wood is more expensive and relies on a shorter supply chain leading to smaller payments-out. The risks associated with a new technology and the lack of experience can also be covered by lower sensitivity regarding cost. Additionally, the larger the WTP and the smaller the demand increase are, the higher the probability that furniture manufacturers have to support other participants financially, as profits from preliminary stages decrease.

7. Conclusions

This paper proposes a traceability-based information system for wood products capturing, processing wood product information, and providing consumers with their valued items. The system was conceived based on a four-layer system architecture. An efficiency analysis and discussion about the conversion of the four-layer model were carried out. The proposed system allows satisfying customers' needs for wood product information at acceptable costs overcoming barriers to consuming eco-friendly products. The item-level identification was proposed, allowing the provision of fine-grained and detailed product information. To achieve this, a combination of several existing ID methods for the wood-based supply chain was suggested. The readout rates, determining the appropriate data carriers and read/write units' position as well as compatibility and integration problems, will be investigated during a pilot study with the prototype implementation. The fine-grained and detailed TS data can also be used in the B2B sector to efficiently solve planning and allocation problems along the wood supply chain, which can, inter alia, increase the resource efficiency of CO_2-neutral wood.

To successfully implement the proposed approach, consumers and supply chain participants have to accept the new service. Hence, consumers should be informed and instructed about this service. Additionally, the costs should be distributed fairly among the parties. Based on the cost-benefit model laid down in this work, the economic profitability for three different scenarios was analysed in the context of a use case. Although the use case has many limitations (e.g. historical data taken from literature, no consideration of trade and logistics companies), general conclusions can be drawn. Firstly, the investments are more profitable for solid wood products and for larger companies by combining solid wood and veneered particleboard products. Secondly, the WTP is an important determinant stimulating the furniture manufacturer to introduce the PIS. Hence, consumers should partially compensate the costs. The proportion can be reduced by considering B2B effects. Furthermore, profits in B2B relationships were considered superficially. Future studies should analyse B2B impacts in more detail and represent them adequately in the model for the present value of the investment. It is particularly important to focus on the process restructuring leading to both positive and negative effects. It must also be analysed whether the proposed system and the model of economic analysis are generalizable to other wood products (e.g. expensive wood houses, cheap paper). Thirdly, the investments' success depends on the willingness to support each other financially. Specifically, furniture manufacturers must be willing to purchase the hardware and partially finance the maintenance costs of hardware goods. In turn, this willingness is based on trust and power distribution between supply chain members. However, to our knowledge, the organizational patterns in supply chains for furniture products supporting the introduction of interorganisational IS have still not been investigated. Further restrictions relate to the demand increase. It is assumed that competitors respond with their sales-promoting measures, thus reducing the demand increase over time. However, the sufficiently high WTP can compensate this.

This study extends existing knowledge and provides new insights for science by presenting a four-layer system architecture for the provision of consumer-relevant wood product information with associated traceability methods for the considered TRUs. The presented cost-benefit-model can be further elaborated and refined in future research. The models and the analysis of identification methods also provide support in investment decision-making and the system implementation by the actors of the furniture supply chain. With this work, the potential for further research was revealed. Such possibilities include the investigation of organizational patterns in the supply chain for wood products, especially the influence of the independent organization presence, a B2B effects analysis and their influence on B2C effects, studies regarding the selection and presentation of explaining information, a prototypical concept implementation, and adapting the cost benefit model based on real data from the prototype implementation.

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Appendix A

Description of the technical solutions along the wood-based supply chain under consideration of characteristics of the individual stages.

Step of the supply chain	Characteristics	Solution	Description
Forestry	Outdoor work (snow, mud, sunshine, rain, etc.) high water content of the wood; logs in different quality: high grade timber and industrial wood log	Solution for high grade timber log: RFID for industrial application on wood; automatic (transponder applicator and harvester reader) or manual (mobile reader) application of RFID tag on wood to logs during the harvest	Robust solution for expensive wood supporting the high degree of automation of processes such as wood sorting, commissioning, inspection of wood etc. at the item level
		Solution for industrial wood log: Combination of ink-printing at the item level and RFID on metal or wood at the delivery level; automatic application of ink-printing (ink-marker) on each log during the harvest; attaching RFID to the delivery during commissioning using mobile readers	Solution for cheap wood at the item level with backup system using RFID at the delivery level. The use of RFID supports both external traceability and the automation of the processes such as receiving and inspection, invoicing, auditing of wood for the delivery level.
Sawmill/Veneer producers	Change of product state using division (one log results in several lumbers/ lamellae or veneer sheets and sawmill by-products) and integration (several lamellae are glued together to form edge-glued wood); continuous production of sawmill by-products	Solution for edge-glued wood: Identification of incoming logs with stationary or mobile RFID readers; automatic application of ink-printing on each lumber/lamella using stationary ink printer after the sawing; before gluing identification of the lumbers/lamellae using mobile or stationary ink readers; attaching RFID tag on wood to edge-glued wood panel during gluing using mobile or stationary readers	The combination of markers allows implementing both internal and external traceability. Attaching ink-printing not only serves the purpose of traceability but also improves processes using data retrieval at the point of action (e.g. reducing drying damage of lumbers). RFIDs support a high degree of automation of processes such as commissioning, auditing, invoicing.
		Solution for veneer sheets: Identification of incoming logs with stationary or mobile RFID readers; automatic application of ink-printing on each veneer sheet using stationary ink printer after sawing, slicing, or peeling; attaching RFID to the trading unit during the commissioning using mobile or stationary readers	
		Solution for by-products: Identification of incoming logs with stationary or mobile RFID readers; creation of batches using process data e start and end time point for the fulfillment of the silo cell; updating rewritable RFID on metal at the silo cell using mobile readers; attaching RFID to the shipment during commissioning using mobile readers	In this solution, it is important to create the flows of continuous batches. To this purpose, silo cells with rewritable RFID are used. The current status with the filled volume and composition of by-products can be recorded and retrieved via the RFID tags. The start and end times of filling the silo cell are responsible for linking the input and output units. The precision of the solution depends on the cell's volume and the emptying conditions (optimally, it's completely emptied prior to re-filling). On that basis, deliveries to customers can be created, which are marked with RFID tags for external traceability and automation of processes.

(continued)

Step of the supply chain	Characteristics	Solution	Description
Particleboard manufacturers	Change of industrial log state (production of wood chips); mixing of input materials (sawmills, own or waste wood chips) during storage and wood processing; continuous production of particleboard fleece	Solution for particleboard: Identification of incoming logs with stationary or mobile ink readers (e.g. RFID readers with 2D-barcode scanning); identification of incoming shipment of by-products with stationary or mobile RFID readers; updating rewritable RFID on metal at the silo cell using mobile readers, creation of batches using process data for the determination of residence time e the ratio of the wood types in fleece or moisture content; automatic application of ink-printing on each particleboard using stationary ink printer during cutting; attaching RFID to the trading unit during commissioning using mobile or stationary readers	The internal traceability plays a very important role here. First, in order to control the mix, rewritable RFID tags on silo cells are used (cf. solution for by-products). Second, process data are necessary to generate the virtual batches of continuous streams. Third, the particleboard cut from virtual batches is marked with ink-printing. The ink-marking allows tracking and controlling the refinement of the particleboard from generation up to commissioning. RFIDs at the trading unit level allows, as explained earlier, the implementation of external traceability and the automation and support of multiple processes.
Furniture manufacturers	Change of product state using alteration (e.g. coating) and integration (joining furniture parts); producing the final product using packaging as a medium for communication with consumers	Identification of incoming trading units of particleboard, veneer sheets and edge-glued wood with stationary or mobile RFID reader; identification of each particleboard and veneer sheets using stationary or mobile ink readers (e.g. RFID readers with 2D-barcode scanning); automatic or manual application of RFID tag on each furniture part after the first process step using mobile or stationary readers; updating rewritable RFID at the furniture part during production process using mobile RFID readers; automatic application of QR code on each package of wood furniture during commissioning using stationary QR code printer	In order to shorten lead times, and reduce the number of mistakes, using rewritable RFID in closed systems is proposed. The data on the tag can include instructions for both workers (e.g. during assembly) as well as for machines (grinders and drills). In addition, the current status of the product can be stored. The intermediate products produced during the first production step are immediately equipped with RFID tags, e.g. edge-glued wood panels after cutting or veneered particleboards after claiming. The product carries the complete information to the last step (packaging of the item). Since consumers prefer scanning QR codes, it is placed here on the packaging.

Appendix B

Hardware equipment in the furniture supply chain.

Stage of the supply chain	Scenario 1: "Solid wood"	Scenario 2: "Veneered Particleboard"
Forestry	1 bulk reading capable RFID readers; 1 transponder applicator and harvester RFID reader	1 bulk reading capable RFID readers; 1 transponder applicator and harvester RFID reader; 1 Harvester ink marker
Sawmill/Veneer manufacturers	2 bulk reading capable RFID readers; 1 mobile RFID reader; 1 stationary RFID Reader; 1 ink marker (stationary) and 1 ink reader (stationary)	2 bulk reading capable RFID readers; 5 mobile RFID reader; 1 stationary RFID Reader; 1 ink marker (stationary) and 1 ink reader (stationary)
Particleboard manufactures	e	2 bulk reading capable RFID readers; 14 mobile RFID readers; 1 ink marker (stationary) and 1 ink reader (stationary)
Furniture manufactures	5 mobile RFID Readers; 1 QR-Code printer; 1 stationary RFID Reader; 200 rewritable RFID tags	20 mobile RFID Readers; 1 QR-Code printer; 850 rewritable RFID tags

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