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Review

Future internet and the agri-food sector: State-of-the-art in literature and research

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ABSTRACT

The food sector is one of the most important sectors of the economy, encompassing agriculture, the food industry, retail, and eventually, all members of society as consumers. With its responsibility of serving consumers with food that is safe, readily available, affordable and of the quality and diversity consumers expect, the food sector needs to be efficient, to build on an appropriate organization and control of processes, and to provide assurance on the safety and quality of its products which consumers could trust. Efficiency, process control and consumer communications are all closely related to the use of information and communication technology (ICT). Global networks, the internet, networked devices, sensors, and communication intelligence are of foremost relevance for the sustainability of the food sector in meeting its responsibility. This paper provides an overview on the state-of-the-art in three use cases within the application domain of the food sector. The three use cases capture the flow of food products from agriculture (use case 'agriculture') through the food industry (use case 'agri-food logistics') to the consumer as the final customer (use case 'food awareness'). In dealing with the state-of-the-art the paper has to focus on the major research and application domains that are of relevance in assuring the successful utilization of the potential of the future internet for reaching a concept for the organization of the use cases that has the potential for major improvements in coordination and communication activities along the chain but also for large scale adoption throughout the sector.

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Contents

1. Introduction

There is a long history of efforts in utilizing information and communication technology (ICT) for the food sector's needs. Precision agriculture in primary production (Zhang et al., 2002; Stafford, 2007; van Henten et al., 2009) as well as tracking and tracing of food products along the food value chain (Vernède et al., 2003; Trienekens and van der Vorst, 2006) and the identification of product characteristics through labels and logos for consumer support (Sahota et al., 2009; Yakovleva et al., 2010) characterize major initiatives in serving the sector's and consumers' needs.

The EU looks back at many years of tracking and tracing research while precision agriculture is dealt with in global conference series since many years as well. It is not the least due to deficiencies in the capability of ICT that these initiatives have not reached widespread adoption irrespective of needs (van der Vorst et al., 2005). Especially tracking and tracing as a baseline information and communication activity for transparency in the food sector has not reached a level of operation that matches the global network activity of the food sector in sourcing and sales (Fritz and Schiefer, 2009).

Research on the use of ICT in the agri-food sector builds on a broad range of earlier projects, developments, case studies, experiences from agriculture, industry or retail, experiments in living lab or field trial environments, and from scientific contributions related to the food sector and beyond. Just to highlight the depth of earlier contributions, the European Research Agenda has in 2011 organized a conference looking back at 10 years of European research in food traceability and food safety (Hoorfar et al., 2011). Similar relationships can be demonstrated in other areas including consumer communication, quality and environmental management, agricultural information exchange, logistics, and the use of ICT in the sector.

One might consider such long time frames a sign of limited engagement. However, the opposite is true. The agri-food sector is complex as few other sectors are, with its diversity of products, the deterioration of fresh products within a short time, the dependency of agricultural production on weather conditions as well as on the control of diseases or pests, the limitations in the evaluation of quality characteristics at the final customer, the consumer, the relevance of commodity products, the distances between areas of production and areas of consumption, the dependency on cultural backgrounds in production and consumption, the dominance of SMEs, the volatility of markets and prices, and many other issues of similar relevance.

Since many years, European research, complemented by national and international initiatives has dealt with many of these issues reaching from basic research to experimental field activities and beyond. It is a basis which makes a move from research and experiments to the development of prototype systems and their implementation in the sector feasible.

The emerging capabilities of the future internet promise to overcome major barriers of the past, such as the heterogeneity and interoperability of ICT solutions, and to support the sector in its global activities towards feeding the increasing world population with an ever decreasing resource base. However, the utilization of capabilities of the future internet can build on a wealth of knowledge from literature, experiments and best practice activities that can provide guidance on how and where to move.

This paper provides an overview on the state-of-the-art in three use cases within the application domain of the food sector. The three use cases capture the flow of food products from agriculture (use case 'agriculture') through the food industry (use case 'agri-food logistics') to the consumer as the final customer (use case 'food awareness'). In dealing with the state-of-the-art the paper has to focus on the major research and application domains that are of relevance in assuring the successful utilization of the potential of the future internet for reaching a concept for the organization of the use cases that has the potential for major improvements in coordination and communication activities along the chain but also for large scale adoption throughout the sector.

These domains involve issues of technology but also on information organization, information content, standards, data sources, data ownership and others to provide a picture as complete as possible, as deficiencies in any of the issues might jeopardize the success of the whole.

The paper bases its analysis on an extensive list of references relating to scientific literature, documentations and project activities. This broad variety of sources was especially relevant for this paper because of the broad variety of issues that need to be dealt with in assuring improvements in the use cases with the potential for broad acceptance and implementation potential. With the many years the sector was involved in, in moving forward in tracking and tracing, in transparency and similar issues but also with the long engagement of sector participants in experimental and prototype developments (exemplified by, e.g., the Metro 'Future Store' activity; Future Store, 2011), a lot of experience is available that may only partly be accessible through official documents.

It is especially failures of experimental or prototype solutions in industry that are known to 'insiders' but kept out of public discussion that are of relevance for the future to avoiding falling into similar traps. In referring to such experiences with no access through official documents that could be used as a reference, the authors are aware that this does not fit usual scientific rigor but consider it an acceptable (and necessary) approach that finds its justification by the competence of the expert groups it is based on. Apart from the authors of the paper the various sources including literature, project experiences, etc. were accessed through project partners within the FP7 SmartAgriFood project (SmartAgriFood, 2012), European working groups, stakeholder meetings, and industry partners.

As a first rough evaluation we can constitute that examples of failures are usually not based on deficiencies in technology as such but in deficiencies in fitting with the environment (processes, actors, etc.) they were used in. These 'soft facts' are especially crucial in a sector were trading relationships build on an open network approach with dynamically changing trade relationships without any dominant or coordinating group (Bijman et al., 2006).

The complexity in the analysis is due to the many overlapping research and activity domains that are involved and that are usually dealt with independently in the agri-food sector. The three use cases capture the flow of food products from agriculture through the food industry to the consumer. This complex scenario involves many dimensions that need to be taken into account and need to be linked together for better performance of the sector. The paper delineates the major relevant domains which provide the base for the presentation of the state-of-the art.

To provide a view and understanding of the state-of-the-art the paper introduces into the subject by first providing an overview on the sector and use case specifics for 'farming', 'logistics' and 'awareness' (Section 2). To gain some understanding of the sector with its peculiarities is a pre-condition for capturing the subsequent discussion on state-of-the-art issues. As an example, the sector has developed many approaches for facilitating communication (e.g. certificates) that might not become obsolete when more advanced information technology (IT) solutions become available as they might be needed to generate e.g. 'impressions'. In the food sector, communicating along the chain is not just moving collected information from the source to customers and consumers. Section 3 provides the overview on the state-of-the art in the research domains considered of major relevance for the future internet. It covers a broad range of issues reaching from technology to organization, content and security. Section 4 summarizes the consequences for the three use cases 'agriculture', 'logistics', and 'food awareness' and gives suggestions for future research needs.

2. Sector characteristics and use case relationships

2.1. Sector characteristics

The food sector is one of the major economic sectors in Europe (CIAA, 2009) and beyond. It amounted to more than four trillion US dollars sales worldwide in 2002 and produces key nutrition for the world population (Regmi and Gehlhar, 2005). It is comprised of supply industry, especially the chemical industry that provides inputs for agricultural production, agriculture itself, food processing and trade, and retail as the final link with consumers, the ultimate customer of the food value chain (Fritz and Schiefer, 2008). The actors constitute a complex business infrastructure which is characterized by globally active multinationals in the chemical industry and retail groups, at the beginning and the end of the value chain, and the dominance of small and medium sized enterprises in-between, not the least the many production farms (O'Reilly et al., 2003; CIAA, 2005).

In highly-developed countries food production is characterized by very different types of enterprises ranging from single-product specialists to multi-product generalists (van Witteloostuijn, 2009). They are involved in regional, national and/or transnational complex business infrastructures with vertical and horizontal interrelationships (Harland, 1996; Ménard, 1996). The variation in production organization ranges from local to global, from farm to fork, from McDonald's to Michelin gourmet restaurants and from laboratories to supermarket shelves (Dagevos and Bunte, 2009). Technological change as well as the demand for food with certain product characteristics, such as organic or environmental friendly food, contribute to an increasingly diversified food sector with a variety of producers and marketing channels (Trienekens and Wognum, 2009).

It is common understanding that all stages of the food supply chain are closely interrelated and need to cooperate to remain competitive and to assure the safety and quality of products to consumers (Beulens et al., 2005). Food scandals have highlighted the close interdependencies between different stages in the value chain and the limitations of product based controls regarding food safety and quality at the consumers' end (Hobbs, 2004; Augusto de Matos and Vargas Rossi, 2007). It is one of the characteristics in food, that food safety and food quality cannot be completely guaranteed through an analysis of the final food product but need to build on appropriate control of processes throughout the food value chain. Two typical and well-known examples include the BSE issue (food safety) and animal welfare requirements (food quality). In both cases, the delivery of guarantees at the consumer's end requires information from the early stages of the food value chain and the controls in place, i.e. the organization of appropriate coordination and communication schemes.

However, this view changed during the last decades. Agriculture and the food industry were usually considered to be independent sectors. Agricultural policy was not linked to food policy and agricultural research and developments were separated from food industry issues. This is even exemplified within the organization of the European Commission where agriculture and the food industry are linked to different directorates. As a consequence, the understanding of food chain issues as well as the use of coordination and communication schemes or of integrated IT solutions along the food value chain are still poorly developed despite of needs (e.g. chain-wide tracking and tracing, access to quality information, online monitoring of product flows; Fritz and Hausen, 2009; Wolfert et al., 2010; Reiche, 2011).

This is in contrast to the specific needs for coordination and communication in the food sector that may reach beyond needs in others sectors. Apart from mutual dependencies of enterprises along the food value chain, the food sector is highly dependent on activities of competitors at early stages of the chain. Agricultural products and early food products are in most cases considered commodities not distinguished by market participants or consumers. Any deficiencies in food safety or quality in enterprises at early stages of the chain might negatively affect markets or even lead to complete market failures. Food scandals as e.g. the BSE scandal and others provide ample proof of this situation (Bredahl et al., 2001; van Plaggenhoef et al., 2007). As a consequence, improvements in processes and communication schemes to be really successful might either need to allow a dedicated market separation through transparency, one of the requirements in consumer awareness or one needs to make sure that the solutions do not remain isolated but are similarly accepted across the sector.

Furthermore, the food sector in general is not organized in chains but builds on dynamically evolving trade relationships that resemble a network situation (Bijman et al., 2006). There are different reasons for this, not the least the irregularities in production of agricultural produce which is dependent on weather developments on a global scale. As a consequence food production industry might have to change their suppliers frequently to secure their own sales markets. This constitutes an open network situation. Technologies in use case support need to fit this open network situation. Furthermore, any regulations and agreements on food safety or quality require acceptance in these networks to reach an impact.

The food sector builds its services, with their dependency on agricultural products from many different and globally dispersed production environments, on the most global chain activities. The natural and increasing spatial distances between the rural areas of production and the urban areas of consumption, the need for continuous delivery of affordable products to all consumers captured in the phrase of 'food security', one of the global goals formulated by the United Nations (2002), as well as the deterioration potential of food products puts especially high demands on the organization and efficiency of processes including logistics and on the coordination and communication within the value chain.

The sector is further distinct in its linkage with public health and its dependency, in this respect, on general sector rules and policy regulations. Guarantees for food safety are public responsibilities but because of evolving inadequacies in product based detection of food safety deficiencies, guarantees cannot be based on product inspection only but require the adherence of enterprises to distinguished process organizations and controls as exemplified by legal requirements (Arvanitoyannis et al., 2006) on the establishment of the HACCP (Hazard Analysis and Critical Control Points) principles (Caswell and Hooker, 1996), and the ability of the sector to recall products on short notice if deficient products have reached the market.

Difficulties in the provision of guarantees in food safety and quality have not only initiated the need for policy intervention in food safety concerns but a great number of private regulations for quality assurance established by retail and production groups as, e.g. BRC (British Retail Consortium), IFS (International Food Standard) or GlobalGAP (Global Good Agricultural Practice; Krieger and Schiefer, 2004; Krieger, 2007; Fulponi, 2006; Schulze, 2008; Trienekens and Zuurbier, 2008) as well as regionalized quality programs (Poignée and Schiefer, 2007). They may focus on, e.g. the origin of products, the organization of production processes, on process controls, or on product characteristics but also involve regulations on tracking and tracing requirements that reach beyond the ones required for food safety concerns. As a consequence, the food sector acts within public and private regulations that deal with food safety and food quality and, together, constitute a regulatory framework for the sector with different requirements for tracking and tracing capabilities. This provides a baseline for the identification of communication needs.

2.2. Specifics in use case views

The use cases focus, in principle on the three major stages of the food chain view, agriculture ('farming'), the food industry ('logistics'), and the consumer ('awareness'). Each one of these stages is distinct and has different problems to deal with. Those problems have been dealt with in research and IT solutions since a long time. It is not the focus of the paper to replace these solutions but to provide the appropriate linkages across the chain. As a consequence, this paper does not focus explicitly on the state-of-the-art in the different stages. There is a wealth of publications and references available in each one of them. However, with the following short introduction we provide a base on which the further discussions can build.

2.2.1. Farming

Management support for farming and the provision of appropriate IT support are areas that have traditionally been considered in a comprehensive way. Apart from publications, national and international conference series assure global exchange and transparency in solutions (e.g. Hardaker et al., 1997; Altieri, 2005; De Schutter, 2010).

With the establishment of the European Federation for IT in Agriculture, Food and the Environment (EFITA) about 15 years ago, a European conference series supported exchange and published proceedings that captured the current state-of-the-art in the field (EFITA, 2012). The Federation builds on national associations that organize their own conference series adapted to specific needs in the respective countries. This movement is complemented by similar movements and conference series in Asia, the Americas, Africa (forthcoming), and also on a global scale (World Conference on IT in Agriculture; WCCA, 2012).

Small and medium sized farms, which build the majority of the global agricultural production, are traditionally slow in adopting IT solutions for a number of reasons (e.g. not familiar with technologies that are available, perception of an undesirable cost-benefit ratio, too much information provided without knowing what to do with it; Bewley and Russell, 2010). Initially the focus was on management support through different types of bookkeeping solutions related to finance, animal production and plant production. Efforts in linking farm information to developments in the chain usually focus on linking the bookkeeping programs (or parts it them) to subsequent stages of the chain. There are many examples of successful linkages but they are usually local in scope and limited to a single recipient. Common agreements on communication standards are still in the development stage (Martini and Schmitz, 2009; Verdouw, 2010).

Actual developments in forming support focus on process improvements linked to 'precision farming', an area which is organizing its own conference series through various groups, among them the International Society of Precision Agriculture (ISPA, 2012), on increases in information collection for bookkeeping, and on a further automation in information collection, especially connected to developments in precision farming concepts. Further developments involve the increasing automation of agricultural production and improvements in environmental technologies.

2.2.2. Logistics

Logistics as a science and field of activity was intensively discussed during the last decades and has ever increased its scope and relevance. Early definitions are primarily focusing on transportation and storage management issues, modern definitions expand to the informational aspects of logistics also referred to as 'information logistic' (Arnold et al., 2008).

As such it is closely related to the organization of the coordination and communication schemes. It collects information from chain actors, starting with farms, and provides information to actors for supporting their procurement and marketing decisions but also to consumers as the final recipients of goods and information (awareness).

Logistics can be seen as part of supply chain management (SCM) as defined by Lambert and co-authors (1998). They base their definition upon a definition of the Council of Logistics Management (1985) and define logistics as '…part of the supply chain that plans, implements and controls the efficient, effective flow and storage of goods, services and related information from the point-of-origin to the point of consumption in order to meet customer requirements…'.

Following this definition logistics might include aspects such as customer service, transportation, storage, plant site selection, inventory control, order processing, distribution, procurement, materials handling, return goods handling and demand forecasting (van der Vorst et al., 2005). For detailed information about logistics, its development and further definitions see Ruffini (1999) and van der Vorst (2000). A presentation of the state-of-the-art in general logistics is out of scope for this paper. There is abundance of literature (see also the references above) supplemented by national and international conference series.

2.2.3. Awareness

The use case awareness has received increasing attention in research, industry, and consumer associations. The increasing attention has various backgrounds. Classical message like 'food is safe' have lost their value and consumers and consumer groups request more specific and detailed information on the food product, its origin, the organization of production processes with their environmental impacts, and issues of social concerns (Schiefer, 2002; Beulens et al., 2005; Codron et al., 2005; Verbeke, 2005; Trienekens and Zuurbier, 2008; Dagevos and Bunte, 2009; Wolfert et al., 2010; Schiefer and Deiters, 2012).

This is partly an issue of control evolving from lack of trust in claims but also a consequence of industrialization of food production with an increase in anonymity and of the increase in the variety of products where consumer groups with certain food sensitivities (e.g. allergens) need specific information for protection. Furthermore, global developments, such as diminishing production resources, limits in the availability of water, and the growing demand for energy (Standing Committee on Agricultural Research, 2007; Ringler et al., 2010), as well as sector-wide crises caused by animal diseases (e.g. BSE, swine fever, foot-and-mouth disease, avian influenza) or food contaminations (e.g. dioxin, nitrofen; Bredahl et al., 2001; van Plaggenhoef et al., 2007), together with increased consumer education, have led to a changing attitude of society towards the consequences of the food system's activities for social, economic and environmental issues (Aiking and de Boer, 2004; Fritz and Schiefer, 2008).

This describes the challenge for enterprises along the food value chain (French, 2008). For providing 'awareness', enterprises need to balance responsibilities to multiple stakeholders, such as consumers, other enterprises in their supply network but also to society to remain competitive (Hart, 1995; Starik and Rands, 1995; Kramer and Meeusen, 2003; Savitz and Weber, 2006; Kinsey, 2001; Krieger et al., 2007; Wognum et al., 2011). This requires solutions for the communication of social, economic and environmental issues (Schiefer, 2002; ten Pierick and Meeusen, 2004; van der Vorst et al., 2005) which could build on information that is already available (Kramer and Meeusen, 2003) and integrate systems that are already in place to find acceptance (Wolfert et al., 2010). The complexity for enterprises is apparent in the variety of solutions and indicators that are discussed (Ondersteijn et al., 2006; Sonesson et al., 2010). With the dynamic development of the field, it is essential to understand the dynamics (Gunasekaran et al., 2001, 2004; Schiefer, 2003a; Gerbens-Leenes et al., 2003; Aramyan et al., 2007) to assure appropriate flexibility in the system.

Consumers demand transparency, which implies a shared understanding of, and access to, product and process related information that they request, without loss, noise, delay and distortion (Hofstede, 2003). New initiatives in communication between retail and consumers, such as eco labels, fair trade labels and similar indicators, reflect some of these developments (Pretty et al., 2005; Fritz and Schiefer, 2008; Sahota et al., 2009; de Haes and de Snoo, 2010; Deimel et al., 2010; Yakovleva et al., 2010). The appropriate communication could increase the perceived value of sustainably produced food for consumers, expressed as willingness-to-pay, and, in turn, could offset potential additional costs that enterprises might face (Fritz and Schiefer, 2009).

2.2.4. The state-of-the-art

The discussion should have made it clear that the deficiencies in the food sector are primarily in coordination and communication and, in turn, in the utilization of appropriate technology for its operation. The improvements in processing activities within enterprises are not the focus of the paper. This relates to all use cases. However, there is one exception. Improving coordination and communication needs a focus. Improvements in efficiency and consumer communication are to be complemented by improvements in quality, represented by improvements in pesticide control, and by improvements in environmental impacts, represented by improvements in greenhouse gas emissions. As one of the major 'hot spot' in improvements in these areas is in agriculture, the paper involves opportunities for process improvements in agriculture.

Even with the limitations in scope, this complex scenario involves many dimensions that need to be taken into account. Previous failures in attempts to solve the problems inherent in the use cases can be traced back to deficiencies in any of the layers be it at the level of technology, organization, information or cost benefit distribution. We need to be aware that in the food system scenario, there is no single dominant group that could enforce the implementation of systems against the interest of others if deficiencies are being perceived. It was some years ago that one of the globally leading chemical companies in cooperation with certain system providers developed the vision of a 'Global Traceability Network' (GTNet) which it tried to introduce into the market on a big scale. As enterprises still perceive possible risks of sharing information, such as the risk of unauthorized use of information, uncertainty about additional profits or cost savings, or the loss of independence (Beulens et al., 2005), efforts to push it into the market through retailer groups were not successful and the vision never came true. In the network situation of the food sector scenario, a solution has to fit the needs in all layers to find acceptance by stakeholders on a voluntary basis.

Each of the layers builds on different expertise and involves different lines of development that are by and large independent of each other. Looking at the different use cases, the different layers are of relevance in each of the use cases. The differences between use cases evolve from their specific constellation and combination.

The paper will therefore focus on the state-of-the-art in the different layers and refer to specifics and the chain relevance where appropriate. The final chapters will provide some conclusions for the integration into the chain view. The discussion of the state-of-the-art will place its focus on the following major domains that deal with technology, information content, information organization, communication, and developments in process and business management on farms.

To support linking the discussions on the state-of-the-art in individual domains with developments towards the future internet reference is made to the documents on 'Fundamental Limitations of Current Internet and the Path to Future Internet' (EC FIArch Group, 2011) and on 'Why the Internet only just works' (Handley, 2006).

3. State-of-the-art in development domains

3.1. Technology: networked devices and networks for communication support

3.1.1. Introduction

Developments in ICT as well as in communication networks are fast paced and provide opportunities for continuous improvements in their system environments. This is especially true for networked devices such as RFIDs (radio-frequency identification) that are closely linked to the organization of inter-enterprise processes in food networks reaching from farm to retail (Ruiz-Garcia and Lunadei, 2011).

However, given the wide variety of devices and the speed in technological developments, the selection and specification of suitable technologies for improving business processes is a complex task. It involves not only an analysis of the state-of-the-art in possible process support but also an analysis of process support potentials that could be expected from advances in technology and embedded functionalities.

Developments in networked device technology are complemented by developments in functional communication networks and developments in social media networks. Social media networks within internet technologies are emerging developments that provide potentials beyond technology by combining network technology with human actor networks.

In summary, this chapter concentrates on the identification and description of relevant technologies for the collection, processing, presentation, and communication of data and information (involving meanings to users).

3.1.2. Networked devices

3.1.2.1. Overview. Definition and characteristics of different networked devices from the perspective of human operators were summarized in the European CuteLoop project (CuteLoop, 2008b; Sundmaeker, 2008b). The analysis of developments in currently available networked devices demonstrates a tendency towards the convergence of specific purpose devices into multi-purpose devices. This is especially apparent with multi-purpose devices like laptops, personal digital assistants (PDAs) or smartphones that integrate diverse enabling technologies and features. As they increasingly provide similar functionalities, it is difficult to systematically differentiate between them from a user's point of view (CuteLoop, 2008b). The user centric view is linked to the performance of tasks in the business processes that carry the coordination and communication scheme across the food value chain.

A complementary technology centric view allows to identify enabling technology components of generic as well as of unique nature, that are required for providing specific integrated functionalities. The identification of generic components such as components for the collection (input), processing, communication or presentation (output) of data allows to reduce the technological complexity and to identify the minimum level of technological complexity required within a physical environment to realize a networked devices' enabled intelligence (Sundmaeker, 2008b).

The basic components of a networked device from a technology centric view are providing complementary features when aiming at the realization of an ICT based solution. Any specific process design might not need to incorporate all of them or some might be physically located outside the networked device as e.g. a power supply in passive tags. Such basic components of a networked device might involve processing power, human to machine interfaces, memory, storage, security, machine to machine interfaces, sensors, actuators, and power supply (Sundmaeker, 2008b).

3.1.2.2. RFID and scanner technology. Radio-frequency identification (RFID) technology represents a specific type of networked device. It is currently one of the most promising auto-identification and data capture (AIDC) technologies. The main focus of an RFID system is to carry data on a transponder (tag) that can be retrieved with a transceiver through a wireless connection. The ability to access information without a line-of-sight in a tag can be utilized for the identification of goods or locations (CuteLoop, 2008a; Ruiz-Garcia and Lunadei, 2011). This capability is of relevance in tracking and tracing systems for food that build on the identification of individual product batches. Furthermore, the development of RFID versions reaching beyond identification and integrating other technologies such as sensor technology opens new opportunities (Sundmaeker, 2008a; Riemer, 2009; Yong-Dong et al., 2009; Mattoli et al., 2010; Ruiz-Altisent et al., 2010; Reiche, 2011).

Following these development towards RFIDs that are cheap enough to be attached to any physical object but at the same time employ a two-way communication ability with the environment opens the way for advanced organizational schemes known as the ‘Internet of Things’ (ITU, 2005). RFIDs are expected to create opportunities for new business models that will take advantage of a global network in which any object can be linked with any other.

Although RFIDs developments show potentials for being a key technology for the next step in technical evolution in different industry sectors (Kärkkäinen, 2003; McFarlane and Sheffi, 2003; Angeles, 2006), the diffusion in the food sector is still low. A few successful applications (METRO, 2006; NORTURA, 2008; Future Store, 2011) demonstrate that RFID technology could create benefits for process improvements on enterprise and on chain level. However, the preferred identification technology in the food sector is still based on barcodes.

This might be due to a number of reasons. There is a lack of system integrators (Martínez-Sala et al., 2009) which involves the risk that RFID applications might remain isolated solutions that might not be compatible with future developments. Furthermore, uncertainty about future developments (Kärkkäinen, 2003) as well as differences in costs and benefits of investments at early stages of the chain and those at later stages of the chain (Martínez-Sala et al., 2009; Tamm and Tribowski, 2010) reduce investment incentives. While costs for enterprises providing market products with RFID-tags are expanding, most beneficial effects are realized at retail stage. This represents a major organizational and managerial barrier (Tamm and Tribowski, 2010).

3.1.2.3. Technology for data capturing and information collection. Present technology for data capturing is characterized by a great variety of different devices that are in use at different parts of the food sector. Data capturing devices involving data input and collection functionalities are an essential part in all use cases. The most prominent examples are:

(a) Data collection on farms with sensor networks providing data about production indicators such as e.g. rainfall, water level in soil, use of pesticides and fertilizers, driving lanes of farm machines, etc.
(b) Data capturing of transports including data about the position, ambience information from inside and outside the truck such enabling the evaluation of the current situation in transport logistics.
(c) Data capturing of product quality indicators such as humidity, oxygen and nitrogen content or ethylene content in the air around a product as indicator for perishing fruits and vegetables, which is relevant in storage facilities and during transport.
(d) Data capturing from a products packaging (e.g. logos) for supporting the retrieval of additional information from the cloud.

All these data capturing activities can be realized through devices and functionalities at different levels of sophistication. Sensors are at the centre of developments.

A sensor is an electro technical device that measures physical quantities from the environment and converts it into a signal which can be read by an instrument. All measurement systems include different types of sensors, which are able to monitor a wide variety of ambient conditions that could include temperature, humidity, vehicular movement, lighting condition, pressure, soil makeup, noise levels, the presence or absence of certain kinds of objects, mechanical stress levels, the current characteristics such as speed, direction, and size of an object (Akyildiz et al., 2002; CuteLoop, 2008a; Ruiz-Altisent et al., 2010).

Sensors play an important role in data capturing and for improvements in automation and tracking of business operations. Sensors can be implemented in single sensor-based systems or in distributed sensor networks (Lee et al., 2010; Garcia-Sanchez et al., 2011). The difference between a smart sensor and a sensor in the classical meaning is the ability to communicate its data. Smart sensors are able to link data between them and the object they are attached to. The communication aspect of smart sensors can be used to transfer information between the sensor and a recipient (Haller and Hodges, 2003).

Sensor-based applications are widely used in the agri-food sector:

– *Precision agriculture*: Sensors are used to optimize the use of pesticides, fertilisers and water.
– *Transportation*: Sensors are integrated into telematics systems or monitoring truck movements for identification of fuel usage, speed and position as well as other relevant indicators required for optimizing transportation processes.
– *Control of cold supply chains*: Sensors are used to continuously measure the ambient temperature around a product in order to detect breaches of the cold chain (e.g. time temperature indicators).
– *Warehouse management*: Sensors are used to monitor and control the temperature in different storage areas in order to maintain product quality and safety.

For realizing ambient intelligence systems, the use of sensors always requires additional systems for filtering and processing of sensor data as well as for making decisions or triggering alarms when sensor data indicates deviations from the norm. As a consequence, most sensors are deployed as networks of sensors wired or wireless, dependent on architectures and circumstances.

One example of a major project in this area is the Socrates project which does not concern agriculture directly but focuses on the design of self-organizing wireless networks, and specifically networks which are designed to achieve self-optimization, self-configuration and self-healing. The project is of relevance not only because of the importance of effective wireless networks in rural areas, but also because the same technologies are applicable for decentralized wireless sensor networks which are key technologies in the Smart Farming area (Wang et al., 2006; Lee et al., 2010; Garcia-Sanchez et al., 2011). The ability of the network consisting of sensor nodes to configure, optimize, and heal itself is a necessary requirement. Furthermore, some elements of self-organization in telecommunications management, such as the detection of problems/failures and the suggestion of the corresponding countermeasures might find applications for intelligent cargo concepts in agri-logistics (Socrates, 2011).

Another example is the Water-Bee project which focused on applying wireless sensor networks in intelligent irrigation systems. This example has the potential to have a major impact on water and cost saving, as well as in protecting the environment. An important lesson from wireless sensor network research, confirmed in the Water-Bee project, is that the network topologies may need to be significantly different depending on the area of interest. Namely, for small fields, the communication between the sensor nodes and the gateway is direct, while larger fields require mesh network topologies with intermediate routers. In the latter case, the energy constraints on the sensor nodes might present a primary hindrance, and special attention must be paid to the development of energy constrained communication protocols (Water-Bee, 2011).

Agricultural sensor networks and wireless sensor networks (WSNs) provide significant improvements in data quality but also challenges for data mining methods. Research might need to improve existing data mining methods that are related to statistics, artificial intelligence, machine learning and database systems. Specific challenges include outlier detection and distributed data mining (applicable in highly distributed environments where there are prohibitions on complete data utilization). A considerable body of research exists in these areas (cf. Akyildiz et al., 2002; Kowalczyk et al., 2003; Hodge and Austin, 2004; Wolff and Schuster, 2004; Bandyopadhyay et al., 2006; Boyd et al., 2005; Wolff et al., 2006; The DREAM Project, 2011).

3.1.3. Networks

Communication networks describe the communication infrastructure available within the enterprise or its environment. Communication networks are generally divided into earthbound cable-based and different wireless radio-based communication networks (Wamba et al., 2008). Wide area networks (WANs), local area networks (LANs), wireless local area network (WLAN) and the Global System for Mobile Communications (GSM) are considered state-of-the-art communication networks with a great variety of systems and devices in daily use in enterprises in the food sector. The applicability of satellite based communication is still just an option in specific situations and the absence of other communication networks.

3.1.4. Integrated 'Smart Devices': smartphones

Newest developments in networked devices are characterized by integration of all major functionalities embedded into a single networked device that could communicate with the variety of networks available. The 'smartphone' is a prototype of these developments. The capability might involve functionalities like:

– Interactive communication with networks through reception and sending of information.
– Sensors for scanning and identifying objects like barcodes or logos (object recognition).
– Sensors for location identification.
– Sensors for environmental scanning (temperature, movement of objects, etc.).
– Communicating with other digital devices like RFIDs.
– Filtering of information (exception reporting, etc.).
– Processing of information (aggregation, calculation, matching with information requests, etc.).
– Presentation of information to recipients.
– Audio capability.

Smartphones are a commonly known technology that will not be discussed further in this paper. However, it is important as a prototype for professional integrated systems that might be used all along the food value chain for a broad range of purposes.

Deficiencies in professional applications are not due to a lack of functionalities but of their use in large scale and fast movements of objects in processes. As an example, the fast scanning of truckloads of product batches requires a higher level of technological development than implemented in smartphone technology. However, these deficiencies will be overcome in due time. For a discussion of some of the ideas around smart devices we refer to The Hammersmith Group (2009, 2010).

3.2. Information content

3.2.1. Overview

The need of customers for information and transparency in dealing with the inherent complexities of the food chain calls for three initiatives (Schiefer et al., 2008):

(a) Establishment of communication services that build on customer loops, serving the communication needs. These services have to build on an infrastructure that allows the interaction with network actors from outside the coordinated business relationships.
(b) A framework which has to assure system trust through the provision of information that supports the reliability of information, the integration of appropriate system security schemes, and the protection of data ownerships.
(c) A framework which has to integrate different applications or existing systems that could provide the necessary information through appropriate information collection and processing schemes to serve the actual actors‘ needs which are specified previously. The integration could mean new developments or, alternatively, the adaption of existing applications to the chain and network based communication services.

Looking on the diversity of information needs in the area of transparency, technical barriers such as the interoperability of existing systems occur inhibiting the exchange of information between enterprises in the sector. Due to the naturally grown number of enterprise-centric, individual and heterogeneous systems at the different enterprises, the sector has to deal with a number of challenges concentrating on four major aspects:

(a) The availability of information, especially focussing on organizational processes and dynamic product characteristics (e.g. sensor networks, networked devices and systems for data collection; Schiefer, 2004; Beulens et al., 2005; Reiche, 2011).
(b) Accessibility of information (e.g. information systems, portals, technical architectures, interfaces) based on flexible connections between different systems protecting the interests of the providing enterprise (data ownership; see among others Beulens et al., 2005; CuteLoop, 2008a, 2008b; Bunte et al., 2009; Wolfert et al., 2010).
(c) Commonly agreed information reference models providing content based on vocabularies and semantics, as well as standards for information exchange (Bunte et al., 2009; Martini et al., 2009a, 2009b, 2009c).
(d) Ways of delivering information to stakeholders using web-based technologies for services and content (Beulens et al., 2005; Lehmann et al., 2011).

3.2.2. Tracking and tracing

Traceability is defined as '...the ability to track and/or trace product flows in a production and distribution chain...' and this '...implies that product flows are uniquely identifiable, that at critical points in the production and distribution processes the identity of product flows is logged and that the information is systematically collected, processed, and stored...' (Vernède et al., 2003). Reasons for an increasing importance in the food sector are mainly related to new legislative requirements and the growing number of quality assurance and management systems (Food Standards Agency, 2002; Theuvsen and Hollmann-Hespos, 2005).

Tracking always follows the flow of goods whereas tracing can be divided into downstream and upstream tracing. Tracking is the ability to follow products in downstream direction in real-time (e.g. for generating status information) while downstream tracing is independent from time. Both, tracking and tracing play a major role in quality control. Downstream tracing enables specific product recalls or it can also be used for marketing purposes. Upstream tracing is defined as the ability to follow a product backwards, from the final product towards its origin. For enterprises in food supply network this allows for an identification of potential problem sources (re-active) and a differentiation based on a proof of origin (pro-active; e.g. Jansen-Vullers et al., 2003; Schiefer, 2003b, 2008; Vernède et al., 2003; Trienekens and van der Vorst, 2006; Fritz and Schiefer, 2009).

There are quite a number of reports on successful tracking and tracing projects as well as on guidelines for the organization of tracking and tracing systems available. Examples as representatives of many similar ones are discussed in Panella (2001) and GS1 (2012a, 2012b). However, the analysis of literature on successful cases might draw a picture which does not match reality. None of the experimental and prototype implementations which cover the last 10 years has gained attention or acceptance outside the experimental space. Critical arguments have been discussed in more detail in Fritz and Schiefer (2009). There is a big difference between the state-of-the-art which allows batch based tracking and tracing even in commodities and the reality implemented in industry (Jensen and Hayes, 2006; Fritz and Schiefer, 2009). This example makes it very obvious that the understanding of the state-of-the-art might not be sufficient for improving situations.

The establishment of a working group of European system providers within the project Transparent_Food (2011) has clarified many of the issues that act as barriers towards large scale implementation. An analysis of state-of-the-art solutions revealed about 40 system providers that are primarily active in a regional context. However, none of them has reached European prominence. There are no deficiencies in concepts or deficiencies in the integration of concepts into solutions but deficiencies in motivation and guidance. Guidance is required as individual investments by enterprises would not provide solutions for chain communication. Solutions required a coordinated initiative by all members of a chain with trading relationships. Motivation is required based on a fair distribution of investment needs and the distribution of expected benefits.

The experience of tracking and tracing developments provides a strong signal on requirements for success. The need for combining technological concepts and solutions with motivational initiatives and guidance has been clearly demonstrated. It is with this background that leading representatives of industry have remarked towards the project that implementation initiatives need to capture from the beginning at least 70–80% of members of chain trade relationships to have a chance for acceptance and sustainability.

From a technological point of view, emerging technologies in networked devices, networks, and functionalities of the future internet could change the picture and, for the first time, open the way for concepts and system implementations that substantially lower the implementation barriers and open the opportunity for large scale acceptance in the sector. The project CuteLoop (2011) has discussed these issues in detail and has especially stressed technology-driven opportunities for autonomy of integrated product/information batches that are less dependent on centrally managed tracking and tracing schemes.

Increasing integration of functionalities into networked devices improves service efficiency but also the devices capability which in turn allows the design of tracking and tracing concepts that employ decentralized approaches with increased autonomy allocated to product/information batches.

The message is clear: traditional IT technology could not match the requirements of the sector's open network situation with changing trade relationships on a global scale. Emerging technologies with advanced networked devices with data capture, storage, processing, and communication ability, combined with future internet flexibilities provide the potential for reaching the 'match'.

3.2.3. Information content: product characteristics in food safety, food quality, chain integrity

The food scares of the 1990s (e.g. BSE, foot-and-mouth disease) have led to several changes in the European Union's legislation and have made food safety one of the main priorities of its policy agenda. Public authorities at national and international levels have reacted by setting up regulations on the safety of food products, such as the European Union's General Food Law, and by establishing new agencies with food safety responsibilities, such as the European Food Safety Authority (EFSA; Krieger et al., 2008; Trienekens and Zuurbier, 2008). Apart from developments in regulatory activities, enterprises in the food sector, and especially those in countries with abundance of food, usually follow additional non-regulatory food safety assurance schemes (mostly related to quality assurance schemes) that reach beyond compliance with legal requirements to better meet the expectations of their customers and to avoid reputational disasters (Schiefer, 2003a; Havinga, 2006).

Since the early 1990s considerable efforts, in particular the extensive development of quality systems and certification schemes, have been made to identify and meet food quality requirements on a regional, national and transnational level. Krieger (2007) gives a comprehensive review on quality systems in the food sector, including among others quality management systems (QM; see also Luning et al., 2002) and quality assurance systems (QA; see also Schulze, 2008). Examples for quality certification schemes that were mostly initiated by large western retailers (Jahn et al., 2004), are the British Retail Consortium (BRC), Global Good Agricultural Practice (GlobalGAP), Integrale Ketenbeheersing (IKB), International Food Standard (IFS), Qualität und Sicherheit (Q&S) and Safe Quality Food (SQF).

Food in developed countries has never been safer, but safety perception of consumers has decreased significantly (Verbeke et al., 2006; Trienekens and Zuurbier, 2008). There is a need for guarantees on food safety (Wilson and Clark, 1998; van der Vorst et al., 2005; Schiefer, 2006) as they constitute a baseline guarantee level and a prerequisite for consumers' trust and market acceptance (Henson and Hooker, 2001; Grunert, 2005; Verbeke, 2005). The basic provision of information on food safety, food quality, and environmental impacts with relevance for the food chain takes place at the farm gate and at the customer enterprises of farms. Farms can provide information on origin and on production processes, while the receiving enterprises can provide information on product characteristics that require equipment for analysis.

In principle, information collected is available as a cluster of factual information that could be communicated throughout the food chain. However, there are different alternatives in place which developed during the past years and facilitated communication at a time with increasing requirements on communication. One alternative is to capture the relevant data in a certificate. A different but common approach is the match of products with requirements of retail groups on product characteristics such as the acceptable levels of pesticide residues or usage of coloring. There are different requirements on characteristics in place from different retail groups. By sending products into the distribution channel towards specific retail groups, products carry the information with them that relate to the requirements, information that could be unbundled at retail for communication with consumers.

These approaches and especially the requirements on product characteristics define different communication formats that could provide the base for a standardized communication format. This argument is further supported by efforts from retail groups to specify 'field passes' as a basic format for capturing farm data for use in the chain.

3.2.4. Information content: forecasts and online monitoring of timing and quality

Of major interest in logistics are forecasts of production (production plans) and forecasts in delivery (logistics plans; see also CuteLoop, 2011) as well as subsequently online information on actual production and delivery characteristics.

3.2.4.1. Forecasts. In production, the interest is in forecasts in terms of timing and quality and in subsequent online information on the actual timing and quality. In delivery, forecasts in timing and product quality need to be matched with online information (monitoring) on timing in transportation and changes in product quality along the way.

Forecasts of production represent the ability to deliver defined products to markets and to negotiate sales contracts. This ability is a base for the organization of distribution and logistics programs. In agricultural products these forecasts and in turn sales contracts differ widely in reliability, both regarding the timing of product availability as well as regarding the quality of products. Differences in reliability are not only due to variability of climate but also due to regions with differences in disease pressures, etc. and to products with their differences in dependency on external impacts. As an example, the production of fruits and vegetables is more dependent on outside conditions than the raising of animals and the production of meat.

With the interest of end of the chain market participants and especially retail to receive best information on expected delivery dates and delivery qualities, appropriate information would be part of the information need information systems would have to deal with. While this could be organized in regular trade relationships, it would constitute a problem in changing trade relationships in an open network organization. This could be overcome by the development and provision of data bases that identified reliabilities of production forecasts according to variability of relevant factors. Such data bases are not yet in use.

Forecasts on the reliability of shipments (transportations) are easier to deal with. In delivery, the major need for information system support is on the actual monitoring of transportation activities and the quality changes of products along the way. Sophisticated systems for monitoring of location and quality have been developed during the last years processing large amount of data and providing results in near real-time. While the monitoring of location and traffic conditions is straightforward utilizing GPS technology and traffic monitoring schemes, the monitoring of product quality and the communication of changes that may affect the marketing of products is a complex issue. Systems for the monitoring and analysis of quality changes building on indicators like temperature developments are in place (e.g. Tracetracker, 2012) but the underlying communication system is not yet sufficiently developed.

3.2.4.2. Monitoring. Monitoring of product quality characteristics and their change during the distribution process is especially relevant for fresh products such as e.g. raw meat or fresh fruits and vegetables, which require continuous cold storage in order to inhibit microbiological growth and thus spoilage.

Quality-related information is needed to maintain the product quality during transport. The chance for intervention in critical situations rises with real-time data available. This prevents the loss of cargo due to quality deficits. A good example is the transportation of fruits and vegetables from southern European countries to Germany. The average transport time from Spain to Germany takes about 50 h. In this time, the product quality decreases under insufficient conditions. In the case of a malfunctioned cooling system the described system sends real-time information to the owner of the cargo. The cargo can be brought to a nearby cold storage house until the cooling system of the vehicle is repaired or a replacement is advised.

The monitoring of a product's positioning is straightforward with little data communication and processing needs. Technological advances in sensor technology (Akyildiz et al., 2002) combined with communication technology enable the real-time observation of trucks and their status. However, these technologies are just adopted by first movers and innovative logistic service providers today. These logistic service providers collect real-time monitoring information and are able to provide them to suppliers and customers of fresh produce as a service. Especially distribution process-related information including approximated arrival times and the status of the transport enable improvements in the business organization of distribution centres (e.g. assignment of a dock for a specific transport in advance). These improvements reduce time that is needed to arrange the reception of goods and the shipping of goods from distribution centres.

The situation is different regarding quality monitoring which makes it a communication and processing challenge. Successful monitoring of food quality requires sophisticated sensor and data communication technology (Ruiz-Altisent et al., 2010). Fresh produce is sensible to changes in its environment. The most important factors for preserving food quality that need to be controlled and communicated within the information service are temperature and humidity throughout the distribution process from harvest to retail outlets. Future interests in monitoring could reach beyond direct product related quality characteristics and include more complex information from the environment (e.g. CO_2 emissions; Sonesson et al., 2010).

The monitoring challenge has been documented in a number of studies form different subsectors including organic products (e.g. certification, chemical agents; EUREKA, 2011), animal products (e.g. cold chain management, animal welfare; Stewart et al., 2005; Kunc et al., 2007; Flir, 2011), and plant products (e.g. changes in quality and safety; ECAS, 2011a, 2011b; Floraholland, 2011; FlowerWatch, 2011; MPS, 2011).

3.3. Information organization

3.3.1. Service-oriented architecture as a baseline modeling approach

The concept of service-oriented architecture (SOA) is generally known and described extensively in literature. This paper does not elaborate on the concept but present a short discussion that relates it to the paper's objectives. SOA and information logistics are closely related. While information logistics focuses on the task-oriented and context specific provision of information for an individual, SOA focuses on how this information provision can be realized in an architectural way.

The framework of service-oriented architecture concentrates on the provision of information as a service. It is described by Gabhardt and Bhattacharya (2008) as '...SOA is about connecting customer requirements with enterprise capabilities, regardless of technology landscape or arbitrary organisational boundaries...'. Linking this general definition to the food sector's needs, SOA is about meeting information needs of customers by facilitating enterprise informational resources and exchange capabilities.

The implementation of SOA as a technology architecture consist of a combination of different technologies, systems as well as interfaces, focusing on (Erl, 2007; Gabhardt and Bhattacharya, 2008):

- The orchestration of operational resources such as existing systems, applications and databases, that are individually developed or provided by others.
- The establishment of services that link and re-arrange content from different operational resources and provide more sophisticated content.

The services are developed to satisfy information needs of business units and other enterprises in interlinked business processes and are listed in service inventories. A service inventory '...is an independently standardized and governed collection of complementary services...' (Erl, 2007) linked to an organizational unit such as a business unit or an enterprise. These inventories allow the identification of available services and the point where they can be requested (Gabhardt and Bhattacharya, 2008).

The documentation on the project Traceback provides further information and suggestions on the utilization of the SOA (CEDI, 2010; Martinez-Simarro et al., 2010; Traceback, 2011).

3.3.2. Data base information (standard data) vs. on-site collection

Information on quality, environmental, or social issues might show little variation for products that are produced according to certain processes, certain production conditions, in certain regions and at certain times of the year. In these circumstances, data could be collected once and stored in databases for later use by anybody (e.g. if organized as public data bases) who is engaged in similar production activities (Lehmann, 2011). The respective data could be linked to all products that fit the specific circumstances. A number of projects during the last years and still on-going have been initiated by industry (including supply/chemical industry, food industry, and retail), especially under the guidance of the World Business Council on Sustainable Development (WBCSD, 2012) but also on national levels to collect such data for experimental use.

Just for making the point more clear, if products have been produced in countries with high level of social standards, a high level of social responsibility could be attached to consumer products as guaranteed, even if the specific conditions in the producing enterprises have not be monitored directly. The same is true for typical production schemes utilized in different countries with e.g. more or less sensitivity in using pesticides or being subject to diseases that required treatment.

The more alternative conditions have been captured in such data bases the less need will be for direct data collection. In the end, process specific data collection will be reduced to monitoring of the distribution process including dynamic changes in quality during or changes in location.

These food related data base developments match with earlier developments of data bases for non-food processing and transportation activities primarily supported by PE International (PE International, 2012), a development closely linked with early developments in Life Cycle Analysis (Pennington et al., 2004; Sonesson et al., 2010; Institute for Environment and Sustainability, 2012) and the engagement of universities, especially the university of Stuttgart with its GABI development activities (GABI, 2012).

The discussion on the utilization of standardized data to evaluate the characteristics of products for market preparation is gaining more and more attention in industry and project activities. A major initiative was directed by WWF, the Öko Institut, the Potsdam Institute for Climate Impact Research (PIK) and a number of companies including the REWE Group as retailer representative (REWE, 2011).

3.3.3. Certificates as information carrier

Certificates on products, production processes, and origin have gained a high level of relevance for market activities in the food sector. If of direct relevance for products they are usually represented as logos on product packages. As such they are part of the product and an element of communication that could be utilized in the use cases.

Information does usually build on individual information items that are being collected, processed and, if needed, communicated along the food value chain. Originating from standardizations in quality management represented by the ISO9000 standards and the BSE crises, the food sector has developed many initially so-called quality management systems that extended the ISO9000 rules with specific requirements on the characteristics of products and production processes (Luning et al., 2002; Krieger, 2007). The developments took primarily place during the last 10 years with a continuing relevance for the industry and a continuous extension of the characteristics considered to environmental and social issues. Following requirements of such quality systems is usually linked with the provision of a certificate.

Depending on the specific certificate, the requirements could involve very concrete information items such as limits on the use of pesticides or animal welfare conditions. As such, the certificates carry information items with them which can be picked up where needed. While the utilization of certificates has become a common approach in the food sector and covers by now a majority of enterprises and products in whatever form, the dedicated utilization of the inherent information items has not yet been widespread. This is a potential line of development.

Some of the certificates in use pick up information from individual enterprises for potential use in the chain. Examples involve GlobalGAP for farms, or the IFS and BRC certificates for industry. GlobalGAP is a good example for developments that took place in the certification requirements over the years. Initially focused on food safety and product quality issues it extended later to environmental issues and has recently incorporated social concerns (e.g. Deimel et al., 2010). This symbolizes not just a development but also demonstrates the broad range of information items that could be represented by certificates.

Apart from enterprise focused certificates certain certificates have a chain focus building on requirements for different stages along the chain. Prominent examples include the Q&S or the IKB certificates as well as fair trade certificates and certificates of the organic movement.

To make the point: Certificates and/or logos carried with products provide information that is ‘hidden’ behind the logos but could be picked up at the providers of the certificates or logos. This opens specific opportunities for all enterprises along the chain but especially for consumers who could pick up this information already now without any changes in chain communication schemes through interaction with providers of certificates or logos at the point of sales via the internet (Reiche et al., 2012). In particular younger generations, who tend to use more IT devices, such as smart phones or other multi-purpose devices, could be a first target group of such services. The consideration of certification schemes is facilitated as they are well documented, usually by the providing organization but also in commentaries in literature (e.g. SGS, 2005; BRC, 2011; GFSI, 2011; IFS, 2011).

The utilization of certificates as information carriers has been extended in recent years to trade objects. Certificates may be separated from the products they are initially attached to and traded independently for use with other products, produced under different circumstances. This development towards independent information markets is represented among others by the ‘book and claim’ approach. In the book and claim approach, certificates are traded on electronic trade platforms. It is evident that such developments cannot be utilized with certificates that involve information relevant for the safety of products or their direct quality but information related to their production processes, environmental impact or social concerns. Selling products with certificates bought on the information market is linked with the production of products according to the requirements represented by the certificates. So from an overall point of view, the effects represented by the certificates are being reached whatever product they are attached to.

3.3.4. Data ownership (how to deal with it)

Data ownership has increasingly developed into a critical issue for the development of information systems for the sector. In the past it has scarcely received attention. The change in attitude has mainly two reasons. First, the need for the communication of information in support of claims on food safety, food quality, environmental protection and the consideration of social concerns has very much increased in recent years. This is also demonstrated by the increasing number of EU initiatives towards transparency in food (e.g. Transparent_Food, 2011). The second issue concerns the position of data providers. Up till now, the major providers of information needed in the provision of transparency are farms and, to a lesser extent, SMEs along the chain. Request for information from farms even ask for a complete transparency in their production processes and production activities. This is met by increasing resistance. Apart from a lack of trust in the use of data by recipients (Beulens et al., 2005) it is also backed by economic reasoning. Farms have to bear the costs of data collection and provision while the benefits of transparency appear to remain with the subsequent stages of the chain including retail.

Information markets that take care of the differences in cost/benefit relationships have not yet been developed. There have been discussions in the sector, that 'market power' will eventually assure that information is being provided as requested. However, it has been demonstrated that this view might not be valid for the sector as a whole apart from some realizations in dedicated and limited market environments. Examples are specific niche markets as in organic farming or markets that build on certain retailer initiatives. It has also been proven in some countries that the farming community might find understanding with consumers in protecting its own standing. A case in point is the dairy conflict in Germany where retailers had to identify to consumers how much of the retail price was given to farmers. In some cases retail even promised to provide a price increase in full to farmers.

As a consequence, any developments towards higher levels of communication within chains would need to provide an organizational base on which data ownership and the different interests could be negotiated.

In a new European project named TransFOP (2012) the European commission tries to identify (make transparent) the pricing mechanisms in chains and to contrast them with necessary efforts by chain members to improve in the 'quality' of products regarding food safety, food quality, environmental impacts and social concerns. As a first rough indication, farms will have to bear major costs and to also provide increased information in support of the evolving claims which puts further pressure on solving the data ownership issue.

3.3.5. Security issues

Security involves a technical and an organizational aspect. The technical issues involving firewalls and related system activities in hardware and software have been dealt with extensively in the IT industry and are not subject to a discussion here.

Problems refer to the organizational aspect. Trade relationships do not automatically involve information exchange at least not on a higher level with relevance for competitiveness of industry. Such information exchange is within trusted relationships. The problem is how to develop trusted relationships in an open network environment with changing trading relationships (Fritz and Canavari, 2008; E-Trust, 2009; Deiters, 2010; Canavari et al., 2011). There have been experimental efforts to integrate new partners into information schemes through interaction with actors already participating in the information exchange along the line: if anybody has trusted relationships with the newcomer, then the trusted information relationship is extended to everybody (CuteLoop, 2011).

A different approach has been tried in scenarios where products are traded which carry access codes with them (e.g. through RFID tags, etc.). The recipient might receive a second access code together with the trade contracts. Both codes together allow access of information from supplier's data base. Such and similar schemes could be easily integrated (and need to be integrated) into emerging information systems (CuteLoop, 2011).

The ISO organization has published the standard ISO28000 on chain security management. This general standard does, however not specifically focus on the open network scenario and the related security needs of the food network (SGS, 2007). Examples of efforts in logistics and transportation are presented in LOGSEC (2011a, 2011b, 2011c) and TAPA (2011).

3.4. Information collection from farms

The provision of data from farms builds primarily on its farm and process management solutions and the documentation of activities in the various bookkeeping initiatives. Bookkeeping deals with activities in plant production, in animal production, and in farm management dealing with the purchase of inputs and the sales in products. Information on the various solutions have been captured in the proceedings volumes of the conferences of the European Federation for IT in Agriculture, Food and the Environment (EFITA, 2012) and the presentations at the World Conferences on IT in Agriculture (WCCA, 2012).

The documentation of product characteristics that require equipment for analysis is usually performed not at farms but at customer enterprises such as agricultural trade. Their product analysis complements the bookkeeping information of farms. As a consequence, linking up with farms as originators of agricultural products would not be sufficient for the specification of the quality of agricultural products.

On an operational level, farmers have since about 15 years increasingly started to use computers and software systems to organize their financial data, to keep track of their transactions with third parties and to monitor their crops more effectively (Batte, 2005).

Recently, and also in connection with the development of the internet's communication abilities, agriculture is rapidly developing into a data intensive business sector where farmers need to collect and evaluate an ever increasing amount of information to remain efficient and focused on market requests (Csótó, 2010). Market requests for increased transparency and changes in production orientation relate to a number of emerging quality characteristics such as ecological footprint, water footprint, improved product safety guarantees, social issues in employment contracts, nutritional responsibility, animal welfare, economic responsibility and local market presence (Schiefer and Deiters, 2012). These request concern all stages of the food chain but have farms as origin. Any failures in agricultural products cannot (or not easily) be eliminated by later stages of the chain. This is the background for the pressures on farms from its trading partners to provide all relevant information that might become relevant not only in the traditional but especially also in the emerging domains of interest.

Farmers often experience an overload of information and information requests as they are the origin of various different chains including e.g. the meat chain, cereal chain, pork chain, fruits and vegetable chain, dairy chain, potato chain, etc. Usually the enterprises in stages subsequent to farms are specialized for the requirements of a dedicated chain. It is only the farms which have to respond to requests from the many different chains simultaneously.

This contributes to farmers' reluctance to respond to newly emerging requests as documented frequently but also to the need to automate information collection wherever possible. Opportunities are provided through systems such as meteorological stations with sensor technology used to measure temperature, humidity, soil moisture (Wang et al., 2006). Precision farming or smart farming are providing assistance in automation and the establishment of computer based farm management information systems (FMISs) that support in collecting, combining, processing, and communicating information.

Comprehensive support as a basis for farms to comply with all the future emerging information, production and management requests it will face from the different food chain lines is the vision of the Future Farm (Future Farm, 2011) as discussed in Sørensen et al. (2010a, 2010b).

The Future Farm project has demonstrated how management strategies and compliance to standards may be dynamically integrated in an FMIS of tomorrow. Information on regulatory requirements, required documentation, voluntary standards and management strategies will be made available in a standardized machine-readable form via web-service interfaces. The FMIS can search the web-services based on catalogues to find all relevant information for use by farmers. Eventually, the FMIS software is envisaged to be able to use this knowledge for analyzing farm data and developing production plans that conform to a pre-determined management strategy and relevant sets of standards (Future Farm, 2011).

'Precision agriculture' is a decisive concept for the future in farm data collection. It utilizes GPS and sensor technology to facilitate farm activities like spraying or fertilizing but at the same time allows automatic data collection on process activities. With the many different farm activities, processes, products, and specific technologies for automation, precision agriculture has become a research and implementation domain in its own right. Precision agriculture allows improvements in farm processes regarding efficiency and environmental concerns (Zhang et al., 2002). The state-of-the-art is captured in the proceedings volumes of the international conferences on precision agriculture that are freely available for use (e.g. Stafford, 2007; van Henten et al., 2009).

For the provision of information towards the food chain, precision agriculture technology does not provide principally new opportunities but facilitates data collection and provision. It avoids manual data collection and allows farms to keep track on its processes in digital format. This in turn could improve the capability of farms to more easily comply with information requirements of its customers and the chain. From this point of view, an increase in the utilization of precision agriculture concepts supports the provision of information for use in the chain. Further insight into the concept is provided in López Riquelme et al. (2009), Barber and Bevan (2011), Bazzanella (2011), ETP (2011), Mayer (2011), and Papadimitriou (2011).

3.5. Data exchange and interoperability

3.5.1. Overview

Improvements in information exchange require improvements in technical infrastructures and collaboration among actors within a supply network (Lehmann et al., 2009, 2011). Such collaboration would not only enable the aforementioned benefits, it would also offer further potentials for increasing the competitiveness of the entire supply network (e.g. Cox, 1999; Christopher, 2000; Lambert and Cooper, 2000; Yu et al., 2001; Vickery et al., 2003; Narayanan and Raman, 2004). Or in other words, as Ford and co-authors (2001) phrase it: 'co-operate-to-compete'. Even though a cooperative approach in the food sector would not be trivial, it would be feasible (Beulens et al., 2005).

In addition to the technical barriers, an improvement in communication is also aggravated by the lack of willingness to share information with other actors within a supply network (Fritz and Hausen, 2009). Enterprises still perceive possible risks of sharing information, such as the risk of unauthorized use of information, uncertainty about additional profits or cost savings, or the loss of independence (Beulens et al., 2005). Even though enterprises are starting to see the benefits of sharing specific information (Bunte et al., 2009), further measures to reduce the perceived risk are needed for the agri-food sector.

The present communication landscape is dominated by enterprise focused applications and solutions with very limited communication across enterprise borders that reach beyond the exchange of basic business documents as, e.g., bills or product documents. As a consequence, the agreement on and the utilization of communication standards has not yet received the attention required for the establishment of comprehensive food chain coordination and communication schemes. To make it clear, there is not a deficiency in standards but a deficiency in agreements on standards ('which one to use') and the development of standards for broad based application ('working in all kinds of circumstances'). An overview is discussed in Martini et al. (2011) prepared within the project Transparent_Food (Transparent_Food, 2011). General discussions on communication opportunities are available in Agri-Food Living Lab (2011), iGreen (2011), Open Innovation (2011), RASFF (2009, 2011), Verdouw et al. (2011), and Wolfert et al. (2011).

3.5.2. Syntax specification mechanisms

The discussions on syntax specifications are being dominated by the GS1 standards dealing with data exchange industry and the agro-XML standard dealing with data exchange between farms as well as between farms and its trading partners. They are complemented by some more specific standards that focus on specific data exchange requirements as e.g. the standard ISOagriNet (ISOagriNet, 2011).

The standards have been developing over quite some time and, especially the standards GS1 and agro-XML build on a wealth of documentation, experiences, projects, and implementations.

3.5.2.1. Agro-XML. When exchanging data, both communication partners (sender and receiver) have to agree not only on a protocol for data exchange, but also on syntax. The syntax describes the structure of the data. Technically, the data fields and how they can be identified and separated out for further processing have to be defined (Mietzsch et al., 2010).

The most common language for data structuring is currently XML (Extensible Markup Language). XML files are text files, where each data field is marked with a tag pair. Hierarchical, tree-like structures can be implemented by nesting the tags accordingly. For agricultural products, a specific variant of XML, agro-XML employs a data model that covers processes in agricultural production with a view on farm management information systems. Data elements in agro-XML are defined using the XML scheme, which is generally used for describing document structures and data storage formats. Third party data structures like e. g. polygon data types from the Geography Markup Language (GML) are integrated by the import mechanisms provided by the XML scheme (Martini et al., 2011). The standard GS1 XML is an XML variant that supports enterprises along the chain. It is part of the GS1 standard family that supports the different layers in data communication (GS1, 2011a). Agro-XML has been dealt with in many publications but also in project cooperations. Selected readings can be found in Martini and Schmitz (2009), Martini et al. (2009a, 2009b, 2009c, 2010), AgriXchange (2011), and agro-XML (2011).

3.5.2.2. ISOagriNet. ISOagriNET is a data exchange standard for livestock farming. It is a standard for data exchange mainly between process computers and between process and management computers in livestock farming. It supports networking in stables between feeding computers, climate control and regulation machinery, etc. but it is also used in dairy production and cattle breeding to transport milk recording data between farmer and dairies or breeding associations. As such, it provides an on-farm bus system as well as an inter-enterprise communication channel. ISOagriNET conformant bus systems are now available on the market and a number of research initiatives exist, that leverage and process ADIS/ADED (Agricultural Data Interchange Syntax/Agricultural Data Element Dictionary) data in novel ways. Further information is provided in ISOagriNET (2011).

3.5.3. Agreements on ontologies

Any communication requires not only a fitting technological base but agreements on ontology, i.e. on vocabulary. The difficulty is that there are various ontologies in place but no agreement on standardization. There are certain overlaps but the overlaps would not be sufficient for serving the information needs within the chain and towards consumers. The AGROVOC thesaurus by the Food and Agricultural Organization of the United Nations (FAO) is nowadays the most comprehensive multilingual thesaurus and vocabulary for agriculture (Martini et al., 2011). Originally, it was devised for indexing of literature, but it is increasingly used also in facilitating knowledge sharing and exchange through electronic media and machine-readable data formats. It contains approximately 30,000 so-called concepts (terms) that are at least in part available in more than 30 languages. The vocabulary is provided in standard RDF (resource description framework) and SKOS (simple knowledge organization system) and concepts are identified by URLs. Therefore, it is easy to reference these concepts or create mappings to other vocabularies. Apart from several agricultural ontology relations (for a complete list see FAO, 2012) AGROVOC uses common thesauri relationships like 'broader term', 'narrower term', 'related term', etc.

The National Agri-Environmental Standards Initiative (NAESI) – a collaborative initiative from 2004 to 2009 between Environment Canada and Agriculture and Agri-Food Canada, was established to gain a better understanding of relationships between agriculture and the environment and to develop a suite of science-based agri-environmental performance standards for water, air, biodiversity and pesticides. NAESI developed two types of performance standards: Ideal Performance Standards (IPSs) and Achievable Performance Standards (APSs; see also deGraaf, 2010).

3.5.4. Data exchange protocols

Data exchange protocols involve EDI (Electronic Data Interchange) and are standards for the exchange of data on product movement. The standard EPCIS (Electronic Product Code Information Service) is meant to be complementary to EDI. It deals with questions such as 'what' (product identified by manufacturing data e.g. EPC number), 'where' (location of enterprise, position in supply chain), 'when' (time of event) and 'why' (status, process step). For more information see GS1 (2010, 2011b, 2011c, 2011d, 2011e, 2011f), Prozeus (2008a, 2008b), and EANCOM/DESADV (2010a, 2010b).

4. Summary and conclusions

The technologies of interest do not differ significantly between the various use cases. They all build on networked devices of various kinds and utilize networks for communication. Furthermore, the interest concerning networked devices is in developments towards increased integration and increased communication ability between each other, with information opportunities in the cloud, and with actors in the chain including consumers. However, the way they are integrated into the relevant processes are different.

In farming, the major interest is in production control. In logistics, the major interest is in tracking and tracing, in the monitoring of movements, of product quality, and of environmental impacts, and in communication of information between stages of the chain. In awareness the major interest is in communication with consumers.

The collection of information for use by consumers is closely related with the communication of information in logistics. It builds on the same principal types of information and is to some extent identical. From an organizational and technological point of view, information collected and communicated along the chain should serve both, enterprises in logistics as well as consumers in their purchasing activities.

Consumer awareness can be served by utilizing 'hidden' information in labels and logos through the use of smartphone type of devices and interaction with the cloud for release of hidden information from providers of labels and logos. Logistics can assure improvements in location management and quality monitoring during transportation. Agriculture could improve in automation in data collection and the preparation of appropriate schemes for data communication.

A specific problem of adoption is in agriculture. This is especially true when considering the global sourcing of food. The conferences of EFITA (2012) and WCCA (2012) have constantly integrated a specific workshop or session dealing with the 'Adoption of ICT Enabled Information Systems for Agriculture'. The sessions provide a comprehensive picture on the development of IT adoption in agriculture over time and the reasoning for deficiencies. Some of the results are published in the e-book 'ICT in Agriculture: Perspectives of Technological Innovation (Gelb and Offer, 2006).

Improving communication and coordination along the food value chain involves the development of suitable communication schemes which utilize information on food safety, food quality and food integrity from and for all partners in the chain including consumers. This has to assure uninterrupted communication opportunities which require solutions for bridging gaps (non-compliance by individual enterprises, technical problems, etc.). To open the network to production sources not participating in the coordination and communication scheme it would need to find ways to integrate the products into the communication scheme and to link products up (through whatever means) with information, relevant for enterprises and consumers.

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