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Enabling chain-wide transparency in meat supply chains based on the EPCIS global standard and cloud-based services

A. Kassahun [a,*], R.J.M. Hartog [a], T. Sadowski [c], H. Scholten [a], T. Bartram [c], S. Wolfert [b], A.J.M. Beulens [a]

[a] Information Technology Group, Wageningen University, Hollandseweg 1, 6706 KN, Wageningen, The Netherlands
[b] LEI, Wageningen UR, Hollandseweg 1, 6706 KN, Wageningen, The Netherlands
[c] GS1 Germany GmbH, Maarweg 133, 50825 Cologne, Germany

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ABSTRACT

Transparency in meat supply chains is necessary to guarantee the safety, quality and trust of consumers in meat products. However, transparency systems currently in place are often not adequate for sharing transparency data among food operators, providing consumers accurate transparency information, or enabling authorities to respond quickly and effectively in cases of food safety emergencies. Due to major meat crises and scandals the meat sector has in this respect attracted substantial attention. In this paper we identify regulatory, business, consumer and technological requirements for meat supply chain transparency systems and present a reference software architecture that will guide the realisation of these systems. The reference architecture is characterized by three main elements: the EPCIS standard for tracking and tracing, cloud-based realisation of transparency systems, and the provision of transparency systems as services by third-party transparency service providers (3pTSPs). Usage scenarios are presented to explain how the different types of meat supply chain actors can use transparency systems that are based on the architecture.

1. Introduction

Transparency in meat supply chains is necessary to guarantee the safety, quality and trust of consumers in meat products. Consumers' trust in meat products, production, origin and the actors[1] involved is crucial for the functioning and competitiveness of local, regional and global food markets (Brom, 2000; Schiefer, 2011). Particularly meat is a relatively sensitive product as highlighted by major crises and scandals such as the BSE (Bovine Spongiform Encephalopathy, commonly called mad cow disease) crisis (Collee and Bradley, 1997), the dioxin crisis (Verbeke, 2001) and the recent horse meat scandal (Premanandh, 2013). As a result a number of transparency measures are incorporated in food regulations such as the European regulation Reg. N° 178/2002 (also referred to as the General Food Law – GFL) and the more recent regulation Reg. N° 1169/2011.

Crucial aspects of transparency are tracking and tracing (traceability) and the ability to make consumers[2] aware of a wide range of quality attributes of their food. Traceability refers to the ability to *track* downstream the supply chain where a distinct batch or lot of product is (or is being processed) and to *trace* upstream the supply chain from where a distinct batch or lot came (van Dorp, 2004). In this article 'consumer awareness' refers to awareness of consumers about the diverse quality attributes of the meat products they buy, such as, nutritional value, place of origin or provenance, ingredients, specific quality attributes, and allergy risks.

Today's transparency systems rely largely on basic technologies, mainly, labelling and "paper trails" left by email, fax or EDI (Electronic Data Interchange) business interactions. Some large meat processing companies do have transparency systems in place as part of their enterprise system, however, the use of state-of-the-art enterprise transparency systems rarely extends entire meat supply chains (Trienekens et al., 2012).

Consumers rely almost exclusively on labels for information about meat products they buy from retailers. A label is a printed tag that is physically attached to the product and the information it carries can only be accessed if one can physically get hold of the product. The dependence on labels can be ascribed to the requirements of food regulations that mandate them as exclusive means of communication with consumers. Food regulations do not yet cover remote access to transparency information even though the Internet is a commonplace in today's society and

* Corresponding author.
E-mail address: ayalew.kassahun@wur.nl (A. Kassahun).

[1] We use the terms *actor*, *company*, *food operator* and *business* interchangeably in this article.

[2] We use the term *consumer* to mean shoppers as well as consumers at home or elsewhere.

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consumers increasingly rely on it for information. A notable exception in this respect is the recent European food regulation, Reg. N° 1169/2011, that goes beyond labelling and towards rules that govern other means of access to food information, including the Internet (article 27, EC, 2011c).

Food regulations have also major influence on the way food operators collaborate and exchange information. In Europe, GFL prescribes the one-back/one-forward principle to meat transparency. According to this principle food operators are only required to identify and share information with their immediate suppliers (one-back) and immediate customers (one-forward) (EC, 2007, 2011a). This leads to a linear one-back/one-forward collaboration chain where transparency data is passed to retailers through successive links from farms and across the various intermediate actors (*i.e.* slaughterhouses and meat processing companies). This method is however not robust because, in practice, not all food operators implement state-of-the-art transparency systems and the benefits of gathering detailed transparency data by one actor are largely lost when subsequent actors are not able to pass on the data.

Realizing chain wide transparency – for either addressing food safety emergencies or enhancing consumer awareness – requires that each individual food operator implements a transparency system inside its production facilities, and that information flows smoothly among the individual transparency systems. Chain-wide transparency systems can thus be considered to consist of two complementary sub systems – internal and external transparency systems (Gandino et al., 2009; Moe, 1998). Realizing internal transparency requires food operators to establish the logical links between the identification code of a specific batch of output products they deliver to their customers to the identification codes of specific batches of input products (ingredients) they obtained from their suppliers and used in the making of the output products. Realizing external transparency requires pairs of trading food operators to establish the logical links between identification codes of products delivered by the one and received by the other.

For food operators to engage in an efficient and effective information exchange their internal transparency systems should be based on electronic record keeping and the information exchanged should conform to standards. The need to share traceability data across a wide range of industries led the GS1, a global consortium of businesses, to develop the EPCIS (Electronic Product Code Information Services) standard (GS1 EPCglobal, 2014b). The standard specifies how traceability data are captured digitally and defines standard data types and interfaces for exchanging them. The information exchanged is about individual or a class of product items that are uniquely identified globally by an identification code called EPC (Electronic Product Code).

Chain-wide transparency systems can be realized using a linear, centralized or distributed model of collaboration (Bhatt et al., 2012; Folinas et al., 2006; GS1, 2010; Meuwissen et al., 2003). An example of the *linear model* of collaboration is the one-back/one-forward approach. In the *centralized approach*, such as national bovine animal registration systems in Europe (EC, 2000, 2004), a shared transparency system is created where transparency data is collected and from which it is accessed. In the *distributed approach* food operators maintain own transparency systems that are interconnected into a network. One approach to realize a distributed model of collaboration is to adopt the EPCIS standard (Shanahan et al., 2009; Thakur et al., 2011).

Recent experiences in practice as well as research literature indicate that, besides the one-back/one-forward method, both the centralized and the distributed scenarios are viable forms of collaboration for realizing chain-wide transparency systems (Bowling et al., 2008; Hartley, 2013; Myhre et al., 2009; Shanahan et al., 2009). However, besides the national (centralized) bovine animal registration systems and few experimental distributed (EPCIS-based) systems we are unable to determine a widespread use of these two approaches. The centralized approach is simple to implement but requires either trust among supply chain actors or regulatory mandate. In addition the centralized approach requires a trusted third-party that manages the centralized system to which all food operators will have to publish transparency data. Distributed systems, on the other hand, require that each food operator maintains state-of-the-art transparency system following global standards (such as the EPCIS standard). But, state-of-the-art systems are costly and in most cases beyond the means of small businesses.

In recent years, the cloud computing paradigm is enabling standard software packages to be available as a service following the SaaS (Software as a Service) business model. This new business model makes state-of-the-art software affordable and accessible on-demand over the Internet. The European Future Internet Public–Private Partnership (FI–PPP) programme (FI-PPP, 2013) aims to accelerate the adoption of this new Internet-centric technologies in Europe by providing the building blocks required to realize the technologies.

In this paper we argue for such a cloud- and standards-based approach for realizing chain-wide transparency systems. We further argue that these systems have to accommodate both centralized and distributed forms of information sharing and collaboration. We present a reference architecture that shows how this can be achieved.

The paper is organized as follows. In Section 2, we describe the methodology followed. In Section 3, we discuss the current state of transparency systems in meat supply chains with the help of an illustrative example. In Section 4, we formulate a number of requirements for the reference architecture. In Section 5, we present the reference architecture based on the requirements outlined in Section 4. Finally we make concluding remarks in Section 6.

2. Research approach

The work presented in this paper is design-oriented research conducted in the context of two research projects: Smart Agri-Food (SAF) (SAF, 2013) and its follow-up FIspace (FIspace, 2013). Both projects are part of the European FI-PPP programme. In this programme a new integrated IT infrastructure is being developed and tested in three phases. At the core of FI-PPP is the FI-Ware project (FI-Ware, 2013b) that develops a core platform consisting of a set of IT Generic Enablers (GEs). Around the FI-Ware project are a number of use case projects, in which requirements are gathered and the resulting platform tested (Brewster et al., 2012). SAF and FIspace are two of such use case projects. This paper is based on a pilot study within SAF and FIspace in which the architecture is designed.

The design process is done in three steps. First, we analysed the current state of meat supply chain transparency. The analysis is based on a beef supply chain in Germany (hereafter referred simply as *the supply chain*), which we consider to be representative of major meat supply chains in Europe. To gain insight two focus group workshops were conducted in November and December of 2011 involving representatives of relevant organisations, food operators, retailers, and members of the FIspace research team. We also visited a large slaughterhouse (hereafter simply referred to as *the slaughterhouse*) that is part of the beef supply chain of our pilot study. The organisations involved in the workshops include GS1, Orgainvent, EHI, Global G.A.P., QS, the slaughterhouse and two supermarket chains in Germany. GS1 is a global not-for-profit organisation that is responsible for developing global standards to improve the efficiency and transparency of supply chains; Orgainvent is an organisation responsible for standardizing meat labelling in Germany; EHI is a scientific institute of the German retail industry; Global G.A.P is a global organisation that promotes good agricultural practices and QS is an independent meat quality assurance company in Germany.

Second, we identified a number of requirements through the workshops and subsequent formal and informal contacts with the representatives. The workshops were followed by facility visits of a meat processing plant and informal interviews of the representatives of the slaughterhouse, the meat processing plant and two of the major supermarket chains in 2012. The visits, interviews and the materials we received provided us with detailed information about the processes in meat supply chains. Besides, we received additional information in bilateral correspondence with the representative of the slaughterhouse, Global G.A.P, GS1 and other relevant organisations to obtain a rich appreciation (Checkland and Winter, 2005) of the state of transparency in meat supply chains and formulate possible improvement options.

Last, we designed the reference architecture incrementally and iteratively following the requirements identified in the previous step. We employed usage scenarios to demonstrate how a transparency system based on the reference architecture can be utilised and improved on the design using the insights gained. Even though the architecture builds mainly on the FIspace platform our aim is to provide a reference architecture that will serve as a blueprint for future meat transparency systems on any comparable cloud-based platform.

3. The current state

Transparency systems in today's meat supply chains are too diverse to make a general description. We, therefore, use our pilot study as an illustrative example of the current state. The example is from a beef supply chain in which the slaughterhouse involved is the focal company.

3.1. An illustrative example

The supply chain from the perspective of a representative of the slaughterhouse is depicted in Fig. 1. The figure shows that the slaughterhouse plays a key role in the flow of transparency information; it shows how the slaughterhouse gathers data from farmers and passes them along the flow of products to the various downstream actors. The slaughterhouse and farmers share data with third parties too (orthogonal to the flow of products). The third parties involved are the QS quality assurance agency, the HIT national bovine animal registration office, veterinaries, laboratories, provider of a trade fair web portal (Mynetfair) and an independent third-party (hereafter referred to as *the 3pTSP – the third-party transparency service provider*) that provides a transparency system called fTRACE. fTRACE is a subject of this paper and will be described in detail in the next section.

Within the slaughterhouse labels are used during many of the internal processing steps in order to comply with European regulatory prescription (see Fig. 2). The labels are standardized using the Orgainvent voluntary labelling scheme. An internal transparency system is realized using an ERP (Enterprise Resource Planning) system.

3.2. fTRACE

A system that is used in *the supply chain* but that is not representative of the current state elsewhere is the fTRACE system; in fact it is unique in Europe. fTRACE is a web-based third-party transparency system consisting of a smartphone application (the fTRACE smartphone app) and a transparency database managed in the fTRACE server. The database is regularly updated by the slaughterhouse using data from its own operations and its suppliers, which are mainly farmers. The fTRACE system works as follows. A QR-code is printed on the meat package alongside other labelling information. The code encodes the web address (URL) of the fTRACE server and the unique identification code (ID) of the batch from which the meat product comes. A user scans the QR-code in supermarkets or at home with his or her smartphone. The smartphone decodes the QR code into a web address and a unique batch number, fetches transparency information from the fTRACE server and presents the information to the user in a user-friendly form. The user interface of the fTRACE smartphone app used during testing in a Spanish supermarket in connection to this study is shown in Fig. 3.

fTRACE was originally commissioned by a meat processing company for use by its own consumers. Realizing that its use is better managed by an independent and trusted third party the meat processor transferred fTRACE to the 3pTSP. Since then fTRACE has been used in a number of supermarkets in Germany.

3.3. The architecture of the transparency system

We describe the architecture of the transparency system of the illustrative supply chain by starting with a 'walk through' the system and continue with an analysis of its key aspects.

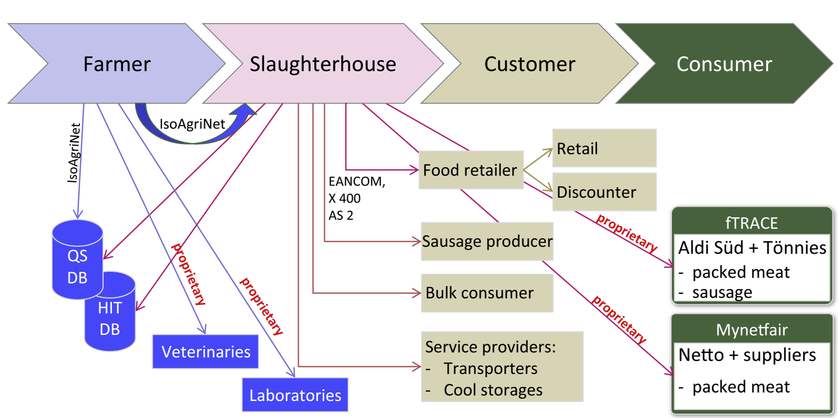

Fig. 1. Data flow in a German meat supply chain (courtesy of the representative of the slaughterhouse; translated from German). QS (Qualität und Sicherheit) is a German quality assurance scheme with an associated company by the same name that does the bulk of meat quality assurance audits in Germany (Albersmeier et al., 2009). HIT (Herkunftssicherungs- und Informations system Tiere) is a German national database for registration of movement of bovine animals established in accordance with the EC Regulation 1760/2000 (EC, 2011b). Mynetfair is a trade fair web portal (Mynetfair, 2013). fTRACE is a third-party meat transparency system offered by GS1 Germany (fTRACE, 2013).

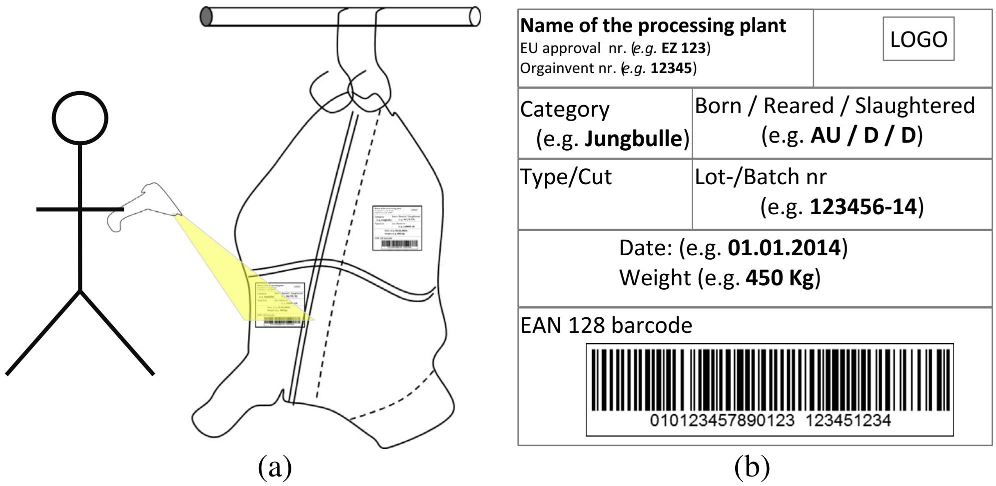

Fig. 2. An example of an intermediate meat product i.e. a carcass quarter (a) and paper (printed) label placed on the intermediate product (b) (based on real-life images obtained from the slaughterhouse).

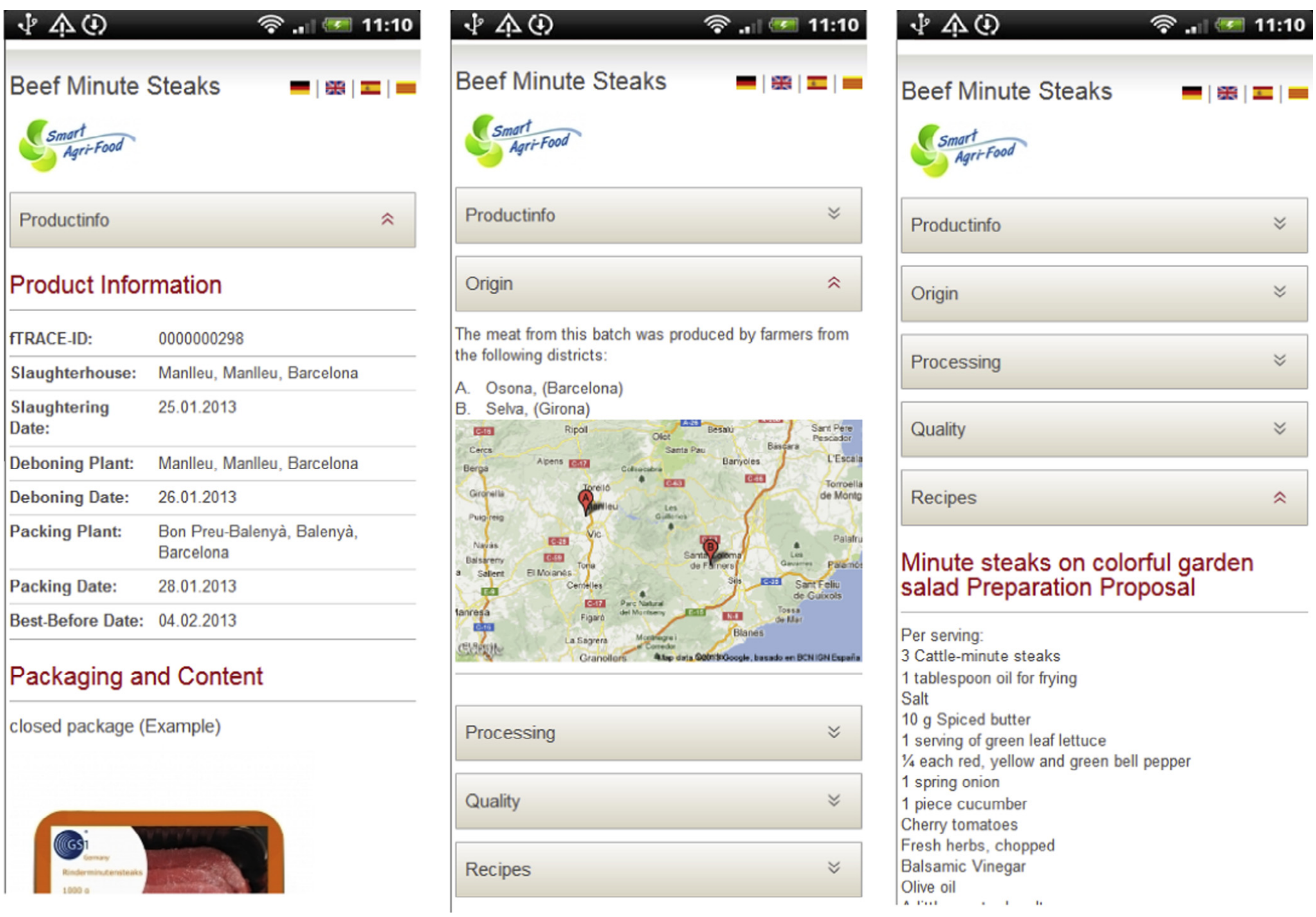

Fig. 3. fTRACE mobile app (version of January 2013 being tested in a Spanish supermarket).

3.3.1. A walk through the current transparency system

Fig. 4 depicts the supply chain under consideration along with the flow of information through the transparency system. The transparency system consists of two information flow channels through which transparency data travel. The first is a paper-based information channel wherein transparency data are passed via labelling and delivery notes. The second is a digital information channel wherein transparency data are transmitted electronically.

Chain-wide transparency starts with capturing transparency data (1) (see Fig. 4) either by scanning a label on the product (as in Fig. 2) or entering data manually. The data captured are then stored in the information system of the food operator. The slaughterhouse uses an advanced ERP system; farmers use diverse basic (or desktop) information systems; other food operators use various types of systems (2). When a meat product is processed and passed to the next food operator, the meat is labelled and the delivery is usually

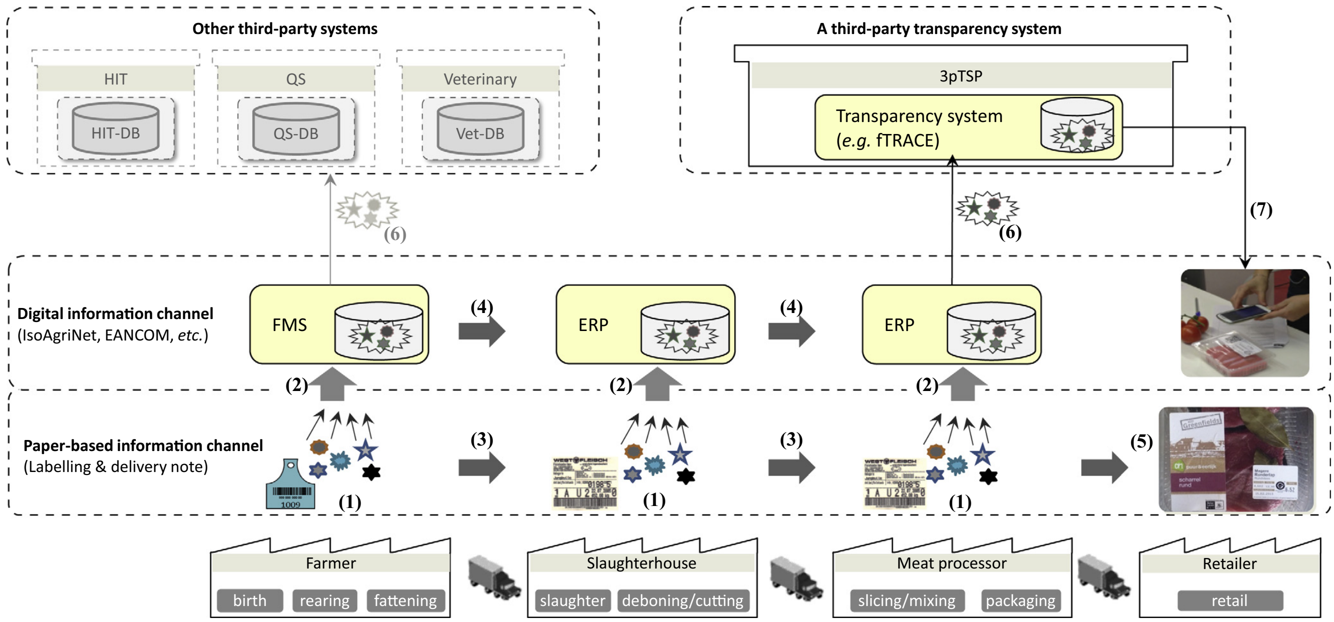

Fig. 4. The transparency system of the meat supply chain of the pilot study. (FMS = Farm Management System, DB = Database/Repository). The figure is explained in detail in the text.

accompanied by a paper delivery note (3). At the same time order and delivery information is transmitted electronically (4). The product is finally delivered to retailers. In the retail shop the label on the product is the main source of transparency information (5). In the supply chain under consideration data is also submitted to the 3pTSP by *the slaughterhouse* (6). In such cases users can access detailed transparency information with their smartphones (7).

3.3.2. Key aspects of the system

Based on the above descriptions we identify six key aspects of the system. The first aspect relates to how information is provided to consumers (and shoppers). Clearly, the last meat supply chain actor responsible for the packaging and labelling of the meat product is the information provider. The supply chain under consideration is in this respect different because the slaughterhouse is able to provide transparency information digitally to consumers with the help of a 3pTSP using a smartphone app. As a result, the ease with which information is provided to consumers and the level of detail of the information is significantly different from label-based information provision.

The second aspect relates to the way food operators collaborate to realize chain-wide transparency. Dictated by food regulations they collaborate and exchange information only with their direct suppliers (one-back) and direct customers (one-forward). As a result food operators normally have no way of asking for information directly from the suppliers of their suppliers and they also don't have the means of reaching the customers of their customers directly. Again, the supply-chain of our case is an exception, since the slaughterhouse can reach the customers of its customers (i.e. shoppers at supermarkets) through the fTRACE system.

The third aspect relates to data sharing. Food operators share data among each other using a diversity of data transfer methods, including labels, emails, fax and EDI. Businesses communicate using such communication protocols as X.400 (ITU-T, 1999) and AS 2 (Moberg and Drummond, 2005) but the main purpose of communication is for handling business transaction and not exchanging transparency information. Transparency data have to be filtered from the business transaction data.

The fourth aspect relates to data format. Two food operators can share information only if they use a shared data format and semantics. In the supply chain both standardized and proprietary data formats are used. Farmers pass data to the slaughterhouse using the ISOagriNET standard (ISOagriNet, 2013); the slaughterhouse uses the EANCOM standard (GS1, 2013a) to communicate with its customers. Both farmers and the slaughterhouse use a number of specialized or proprietary formats to communicate with third parties, including the fTRACE system.

The fifth aspect is related to data storage. Each food operator is required to keep a record of transparency information according to the requirements of GFL. Food operators do keep a record of data required by regulations but not always in a digital form – as the regulatory requirements do not demand electronic record keeping. In fTRACE, transparency information is stored digitally both in the information system of the slaughterhouse and at the 3pTSP. Storing data digitally at 3pTSP has been a sensitive issue for the slaughterhouse and it may in future not transfer bulk data to the 3pTSP but allow it to query data on-demand.

The sixth aspect refers to access to information, particularly, by regulatory authorities in case of food safety emergencies. Authorities have the right to obtain information from all actors in cases of emergencies but there is currently no standard or specification we know of that allows them to query data across the entire meat supply chain electronically and quickly in a uniform manner. The fTRACE system can provide an effective means of tracking and tracing in case of food safety emergencies but this aspect has so far never been tested or used.

4. Architectural requirements

We categorise architectural requirements for future chain-wide meat transparency systems into regulatory, business, consumer and technological requirements. These requirements are described below.

4.1. Regulatory requirements

Food regulations impose specific requirements on how transparency systems shall function because they cover aspects of record keeping and data sharing – besides quality and safety aspects. These aspects pose specific IT requirements on transparency systems. We mention only the most significant EU food regulations in this regard.

EU regulation Reg. N° 1760/2000 (EC, 2000) requires the identification and registration of bovine animals and the labelling of beef and beef products. Paragraph 1 of article 13 of the regulation particularly states: "The compulsory labelling system shall ensure a link between, on the one hand, the identification of the carcass, quarter or pieces of meat and, on the other hand, the individual animal or, where this is sufficient to enable the accuracy of the information on the label to be checked, the group of animals concerned".

The General Food Law (EC, 2002) and its amendments mandate the one-back/one-forward traceability model. The commission clarifies the essence of this principle as: "... the requirement for traceability is limited to ensuring that businesses are at least able to identify the immediate supplier of the product in question and the immediate subsequent recipient" (EC, 2007).

Though these regulations seem to demand sound record keeping they do not mandate electronic record keeping or automated tracking and tracing. As a result, some food operators keep only paper-based documents. When a crisis or a scandal breaks out identification of the source of the problem takes much time and crisis response requires unnecessary effort from food operators that are not involved in the crisis.

A recent regulation, Reg. N° 1169/2011 (EC, 2011c), on food labelling aims at providing consumers "a high level of health protection and to guarantee their right to information" so that they will have the right information "to make informed choices and to make safe use of food". This regulation, which introduces additional obligatory nutritional labelling requirements, is also designed to keep up to date with consumers' demand to new information and requires sufficient flexibility in transparency systems.

4.2. Business requirements

Whenever a crisis or a scandal breaks out the whole meat sector suffers. During the dioxin crisis of 1999 many companies in the meat as well as the feed sector suffered the consequences. In the recent horse meat scandal a large number of businesses (around 370) were affected and a large volume of meat (50,000 tonnes, part of which was already consumed) was recalled (Holligan, 2013). Naturally, the vast majority of businesses in the meat sector would like to have a system in place that will overcome such crises or scandals from happening in the first place; they would naturally also like the response to a crisis or a scandal once it occurs to be surgical and quick.

Realizing a chain-wide transparency system for the entire meat sector is at present not realistic. Instead, it is possible to realize chain-wide transparency systems for specific supply chains as is the case in the illustrative example. However, the meat sector is characterized by many small businesses who cannot afford to make large initial investments and implement state-of-the-art transparency systems. Even for medium and large food operators the cost-benefit analysis may not favour large investments because the break-even point of traceability may not be reached (Meuwissen et al., 2003). When transparency systems are in place as part of enterprise systems, detailed transparency data is rarely shared outside the boundary of the company (Trienekens et al., 2012) partly because transparency data are intertwined with sensitive business data (see Section 4.4.3). These problems require solutions that will capture and process transparency data directly and that will accommodate a range of information systems, from simple ones used by small businesses to complex systems used by large food operators. 3pTSPs, defined here as trusted independent companies or organisations that provide transparency systems as a service, play a crucial role in facilitating information exchange.

4.3. Consumer requirements

Today consumers have only limited information about the products they buy and they have even more limited means of providing feedback. Since producers do not have effective means of communication with their consumers there arises a substantial communication gap between them and consumers (Duffy et al., 2005). In recent years smart devices (smartphones and tablets) enable to bridge this gap. There are today many examples of retail shops where instant and detailed product information is made available to consumers using smartphones (Ebling and Cáceres, 2010). While such smartphone apps can be considered as a luxury convenience for many shoppers and consumers certain smartphone apps help improve the quality of life significantly. This is for instance demonstrated by the popularity of food allergy smartphone apps for sufferers of food allergy such as gluten intolerance.

However, even when a system like fTRACE is in place, communication between consumers and actors upstream the supply chain is in most cases not realized. For instance, individual farmers who have made animal welfare a priority have no way of informing consumers about their effort – and getting a better value for their product. Future transparency systems should reduce the communication gap between consumers and producers.

4.4. Technological requirements

New technological enablers provide new possibilities for realizing affordable and improved transparency systems. We identify standardization of transparency systems and new computing paradigms as two major technological enablers. These enablers impose requirements as technology push effects (Chau and Tam, 2000) instead of pull effects (business, consumer or regulatory). Below we describe the effects of these enablers on future generation transparency systems in meat supply chains.

4.4.1. Standardization

Currently, transparency data in meat supply chains are mainly extracted from business transaction data, as the sector lacks widely adopted standards for capturing and communicating transparency data. But, business transactions do not contain all events that are relevant for transparency purposes. As a result relevant transparency information can escape detection. Moreover, the need to secure sensitive business data requires a solution that will capture and process transparency data independently from sensitive business transaction data (see Section 4.2).

If such a solution is to be widely adopted it should be based on well-recognized standards. The EPCIS standard is such well-recognized global standard that can be used to realize internal and external transparency systems in the meat sector as demonstrated by few case studies (Grande and Vieira, 2013; Hartley, 2013). Below we describe what the standard specifies.

The EPCIS standard specifies how a trading company captures and stores data and makes it accessible to its trading partners. The standard adopts a distributed information system architecture. This means companies have full control over their data and provide and receive information using a common interface. Fig. 5 depicts a transparency system based on the EPCIS standard.

The figure shows the components of a transparency system based on the EPCIS specification. The main components are EPCIS Capturing Applications, EPCIS Repositories, EPCIS Accessing Applications and Master Data Repositories. Capturing Applications are mostly linked to scanners, sensors or any other data capturing mechanisms. The data so captured are called EPCIS events. EPCIS events are also referred to as dynamic data because they are captured in the course of the product's journey through the supply chain and accumulate overtime. A Capturing Application sends

EPCIS events to an EPCIS repository through the EPCIS Capture Interface of the repository. The repository makes data accessible through its EPCIS Query Interface. Trading partners query the repository using their EPCIS Accessing Applications. In this article we refer to the EPCIS repository and its capture and query interfaces as an *EPCIS system*. Master Data Repositories contain additional data (also referred to as static data) pertaining to products, locations of food operator facilities, or other contextual data that are necessary for describing EPCIS events (GS1 EPCglobal, 2007).

The recent version of the standard (EPCIS 1. 1) defines four event types: an *object event* occurs when an object is observed (or is not observed while it should), an *aggregation event* occurs when an object is added to or removed from a containment (mainly used to track palletized objects), a *transaction event* occurs when an object is associated or disassociated with a business transaction, and *transformation event* occurs when one or more (input) objects are consumed and transformed into (output) objects. There is, in fact, a fifth event type, *quantity event*, coming from the previous version of the standard (GS1 EPCglobal, 2007) used for counting the inventory level of a product. But, this event is deprecated in the new standard since the object event now enables to capture the same information what was previously captured by the quantity event. Events contain data about the identity of the product, the date and time of event occurrence, the location where it occurred, and the reason why the event occurred. These are conveniently abbreviated as the *what*, *when*, *where* and *why* of the event. The *what* (the identity) and *where* (location) are represented by EPCs and are globally unique. The *when* (date and time) is a local time and time zone or UTC (Universal Time Coordinated) timestamp. The *why* (reason) of the event is described using a predefined but extensible vocabulary of business process steps (GS1 EPCglobal, 2014a).

When users request for transparency information, traceability data from EPCIS repositories and contextual information from master data repositories are combined to create transparency information that is understandable to human users. Dynamic data become meaningful to users only when combined with static data (contextual information) that represent the various attributes of the events such as the description of the products, the locations where the events occurred and the circumstances of the events. For instance, consider a query that submits the ID of a product item (in the meat sector that could be the product code with a batch number) and gets a query result consisting of only one *object event* (in practice a query returns many events from more than one repository): "Object:*epc*1, Time:*t*1, Time zone: *z*1, ..., Location:*epcLoc*1, ...". To make this query result meaningful to users, the IDs *epc*1, *epLoc*1, *etc.* have to be translated to meaningful information, therefore, *epc1* and *epcLoc1* have to be looked up in a master data repository. The look up may, for instance, return "veal shoulder blade, *etc.*" for *epc*1 describing the product and "*x* house number, *y* street, *z* city, *etc.*" for *epcLoc*1 describing the full address of the processing plant where the event is generated (GS1 EPCglobal, 2007).

Querying for transparency information is a challenge since the product information has to come from several EPCIS repositories whose web-addresses have to be discovered. Specifically, given an EPC (an ID of a specific product item) one should be able to obtain pointers to the EPCIS systems from which one can retrieve the events related to the EPC. Two standards are proposed for this purpose. The ONS (Object Naming Service) standard (GS1 EPCglobal, 2013b) is a standard that defines how a product EPC can be resolved to the authoritative EPCIS system associated with the issuer of the EPC. The Discovery Services standard, which is still work-in-progress, will enable to discover who else may have information for a given EPC (GS1 EPCglobal, 2013a).

The fact that the discovery services standard is still under development while almost all other EPC related standards were made available in quick succession between 2004 and 2007 and the few remaining by 2011 (GS1 EPCglobal, 2013c) indicates the difficulty of devising a way of global discovery. We argue instead for supply chain specific discovery service provided by 3pTSPs. Since 3pTSPs serve specific supply chains (see Section 4.2) they can also provide integration with legacy (non-EPCIS) transparency systems. Integration with legacy systems is crucial in realizing chain-wide transparency since some food operators have already invested on these legacy systems, and these food operators may not be willing to adopt yet new transparency systems. In addition, end-user applications (such as smart phone apps for consumers) are preferably made available by 3pTSPs instead of by individual food operators for diverse reasons including reducing the cost of development of the applications and promoting their widespread use.

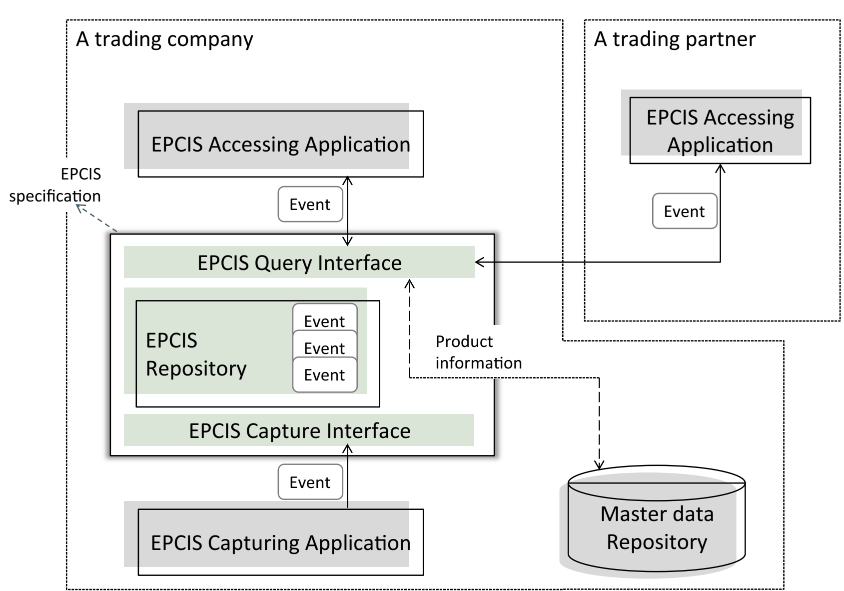

Fig. 5. The components of an EPCIS-based transparency system and how information flows among the components. (adapted from GS1 EPCglobal, 2007).

4.4.2. New computing paradigms

Realizing a transparency system requires a set of software systems that may require large initial capital investments in software and hardware. Cloud-computing enables software to be available as a utility or service (instead of a product) making large initial capital investments in software and hardware unnecessary. Cloud computing refers to software applications, or the lower-level infrastructure for building software applications, delivered as services or over the Internet (Armbrust et al., 2010). Since the cloud paradigm to computing is relatively recent, no coherent set of generic functionalities were available. In Europe the FI-PPP program aims to change this by providing the FI-Ware platform and the resulting cloud-based platforms and software applications.

The FI-Ware platform offers GEs for building new software platforms and applications. There are currently dozens of GEs available in the FI-Ware platform. These GEs are categorized as Cloud Hosting (CH), Data and Context Management (DCM), Internet of Things (IoT), Interface to Networks and Devices (IND), Identity and Security (I&S) and Marketplace and Mashup Frameworks (MMF) GEs (FI-Ware, 2013a). FIspace is one of the platforms built using FI-Ware GEs. FIspace is a business collaboration platform designed as a 'social-network', much like Facebook, but for businesses. The platform provides a set of basic applications, a business process engine that allows systems designers and software developers to link the apps and services into a collaboration business process, and a set of APIs for developing apps and business processes. The development of FIspace as a SaaS platform fits the current trend that is characterized by increasing adoption of the cloud computing paradigm (Patidar et al., 2012).

4.4.3. Constraints on technical requirements

Functional requirements are usually accompanied by non-functional characteristics such as usability, security, and performance (Chung and Leite, 2009; Glinz, 2007). Many of these non-functional characteristics (referred to as non-functional requirements) specify implementation or external constraints (Glinz, 2007) and thus depend on the technical choices made in a specific software product development rather than the choices made in a reference architecture. But, some non-functional requirements may directly be related to the choices made in the reference architecture. Specific non-functional requirements put forward during the pilot study are mainly related to data security, namely: data ownership, data storage location and vendor (in)dependence. Many businesses want to maintain ownership of their data so that they can control who may or may not have access to them. They want to have control over where their data will be stored; they want to decide on which data will be stored locally and which in *the cloud* (remote data repositories). Many businesses demand that they be able to specify the confidentiality of their data that are stored remotely and accessed through cloud-based services. In addition, businesses want to avoid getting trapped in vendor specific platform. In case of FIspace they made their preference for multi-instance and distributed FIspace platform over a single instance (like Facebook) platform.

5. Results and discussion

A software architecture describes the components of a software system, their interactions and the relation of the system with its environment based on software design principles, styles and patterns (Bass et al., 2003; ISO/IEC/IEEE, 2011). A reference architecture describes these characteristics but for a class of software systems using a combination of one or more reference models and architectural patterns (Bass et al., 2003 pp. 24–6). In this section we describe our proposed reference architecture and show how it addresses the generic requirements outlined in the previous section.

5.1. Transparency system based on EPCIS

By choosing for the EPCIS standard to fulfil one of the generic requirements (see Section 4.4.1) we also choose to align the way data is captured, stored and accessed with what is specified in the standard. Since the EPCIS standard is not specifically made for, and does not fully address the requirements of, meat supply chains we shall identify where it meets our needs, what its shortcomings are, and how the shortcomings can be addressed.

According to the EPCIS standard transparency data are captured as events unfold during the physical flow of products. Events are captured with the help of four data items: *what* (in the meat sector using a Global Trade Identification Number (GTIN) (GS1, 2013c) together with the batch ID), *where* (usually using a Global Location Number (GLN) (GS1, 2013b)), *when* (using a globally unique timestamp (ISO, 2004)), and *why* (using standard vocabularies). Capturing meat transparency data as EPCIS events requires understanding the processes involved in meat supply chains and identifying where and when an event should be captured. At the farm level, events critical for transparency are the birth of animals and their transfer from one farm to another farm or to a slaughterhouse. Other relevant events include those related to feed, vaccination, medication and veterinary inspection. At processing facilities critical events are the slaughter of the animal, the processing of meat (splitting, chilling, cutting/portioning, *etc.*), inspection, testing and packaging. In logistic operations critical events are transport (loading and unloading) and storage. At retail the important event is the sale of the product. At all stages the withdrawal of a product for whatever reason is an important event that needs to be captured.

To address specific aspects of the meat supply chains we identify two aspects related to metadata where transparency systems – even if built to the EPCIS standard – need to be augmented. First, metadata vocabularies related to business operations in the meat sector need to be defined by the sector. While the vocabularies used for logistic operations, such as *loading*, *picking*, and *packing*, are common across many sectors (Blackstone and Cox, 2005; GS1 EPCglobal, 2014a), meat production processes like *birth*, *medication, slaughtering*, *splitting*, *etc.* have to be defined in a uniform manner.

Second, meat product metadata that provide consumer awareness about meat product quality attributes such as nutritional value, ingredients, and safety should be captured in product master data repositories. Various meat attributes, such as cuts and grades, are standardized to facilitate communication and electronic trading (Polkinghorne and Thompson, 2010; UN/ECE, 2006). However, such information is also valuable to consumers and should be part of the transparency information provided to them.

5.2. Storing and sharing transparency data

As the EPCIS standard addresses the requirement for electronic record keeping and data sharing, it also requires that all food operators implement an EPCIS software system within their organisations. However, small companies in the meat sector (mainly farmers) use basic information systems or simple desktop applications. They deal with limited amount of transparency data that, in many cases, will not justify implementing full-fledged EPCIS systems (see Section 4.2). We argued for 3pTSPs that will fill this gap. 3pTSPs can fill this gap by providing EPCIS systems that can be either shared among several companies or leased privately, in both cases based on the *use on-demand, pay-as-you-go* (Armbrust et al., 2010) business model to IT provisioning.

Fig. 6 shows how food operators, large and small, can use the services provided by 3pTSPs. Small businesses that do not have their own EPCIS system use a shared EPCIS system to store and share transparency data. 3pTSPs provide them with a web-based interface for uploading and managing data (1). Large food operators with their own EPCIS systems provide EPCIS query interfaces with which others can query for transparency data (2). Sharing compulsory transparency information with immediate suppliers and customers to fulfil regulatory requirements (see Section 4.1) can be realized using either the shared EPCIS system or direct exchange of information through mutually agreed protocols (3). If some of the companies use proprietary protocols or other standards (such as IsoAgriNet) 3pTSPs can adopt the additional methods in (1).

5.3. Transparency system powered by cloud-based services

We envisage that EPCIS systems are better provided as cloud-based services for at least three reasons. First, small businesses may only afford a shared EPCIS system provided as a cloud-based service by 3pTSPs. Second, not all food operators who want to use their own EPCIS system may choose for a potentially expensive on-premise EPCIS system; they would rather use a cloud-based EPCIS system (see Section 4.4.2) leased from 3pTSPs. Third, the necessary query and discovery services are more easily made available as cloud-based services provided by 3pTSPs. In the remainder of this section we describe a usage scenario of a single shared EPCIS system; scenarios involving more than one EPCIS system (shared, on-premise or cloud-based) are described in Section 5.4.

Fig. 7 depicts a shared EPCIS system, provided by a 3pTSP, and its relationship with its environment – *i.e.* the FIspace collaboration platform (and through which the FI-Ware GEs), supply chain companies, and end-users (members of the 3pTSP, participating companies, authorities and consumers). The FIspace platform provides basic apps (some of which are recently referred to as services) which do one specific job. The apps support business processes by providing the logic and the user interface for specific task they are developed for while the business process engine (part of the core internal feature of FIspace – not depicted in the figure) manages the status of the tasks to be done.

The five apps depicted in the picture: *business profile app*, *product information app*, *logistic planning app*, *marketplace* app and *SLA* (*Service Level Agreement*) *management app*, represent the basic features of the platform. A business profile app is used by businesses to maintain their business profiles in FIspace. A product information app is used to display information about products and services. A marketplace app is used to announce products and services businesses are interested in or are offering. A logistic planning app enables businesses to plan transport using real time logistic information. An SLA management app provides services related to SLAs such as establishing SLAs and signalling deviation from them during execution.

3pTSPs can leverage these basic apps and most importantly provide new ones required for realizing chain-wide transparency systems. We identify four new apps that 3pTSPs should provide: *admin app*, *user/consumer app*, *data capture app* and *EPCIS query app*. The admin app is a type of SLA management app that allows the 3pTSP and its customers (food operators) to manage agreements concerning data sharing and other transparency related services. These include, among others, managing subscription to systems provided by the 3pTSP and managing data access rights to users. The other three apps are variations of a product information app. The user/consumer app resembles the fTRACE smartphone app (see Fig. 3 and Section 4.3) and provides users access to transparency information. The capture and query apps are used to capture and query EPCIS event data. In EPCIS terms the capture app is an EPCIS Capturing Application; likewise the query app is an EPCIS Accessing Application. The user app uses query results from the query app to provide consumers with user-friendly information.

5.4. Chain-wide transparency system usage scenarios

Fig. 8 shows how a chain-wide transparency system involving a number of food operators can be set-up. The FIspace platform simplifies the setting up of the transparency system because the platform provides food operators basic services that enable them to present their business profiles, discover trading partners, view product offerings and facilitate business interactions. To be part of such a chain-wide transparency system food operators should use one of the three options: implement their own internal transparency system based on the EPCIS standard, use a shared EPCIS system in FIspace offered by a 3pTSP or adapt their legacy internal transparency system in a way that it can be queried by the apps of 3pTSPs (see Sections 4.2 and 4.4.3). Food operators using a shared

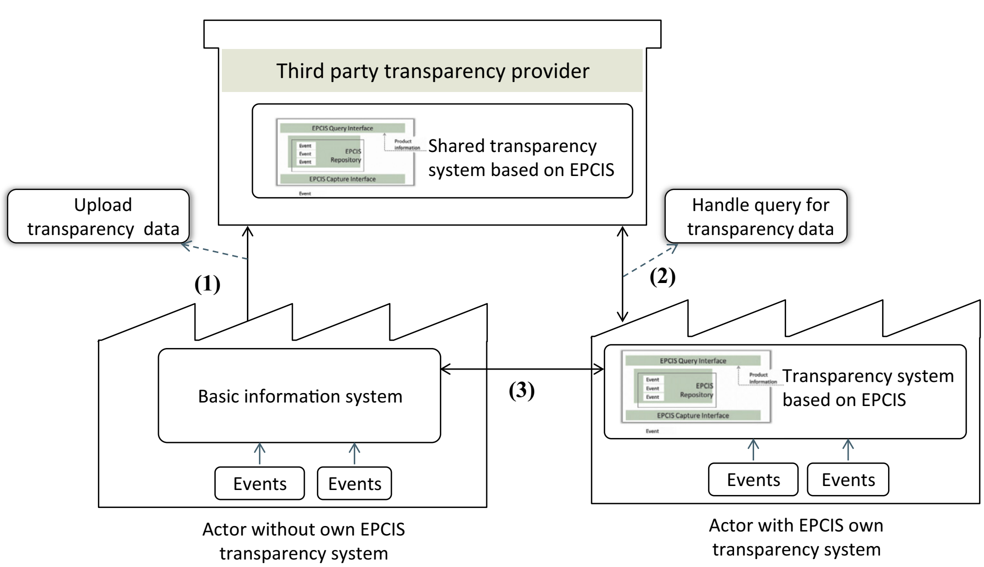

Fig. 6. Sharing transparency data. (1) Transferring transparency data to a shared EPCIS repository managed by a 3pTSP. (2) Querying transparency data using query interfaces. (3) Sharing compulsory transparency information with immediate suppliers and customers directly using either EPCIS query interfaces or through mutually agreed protocols.

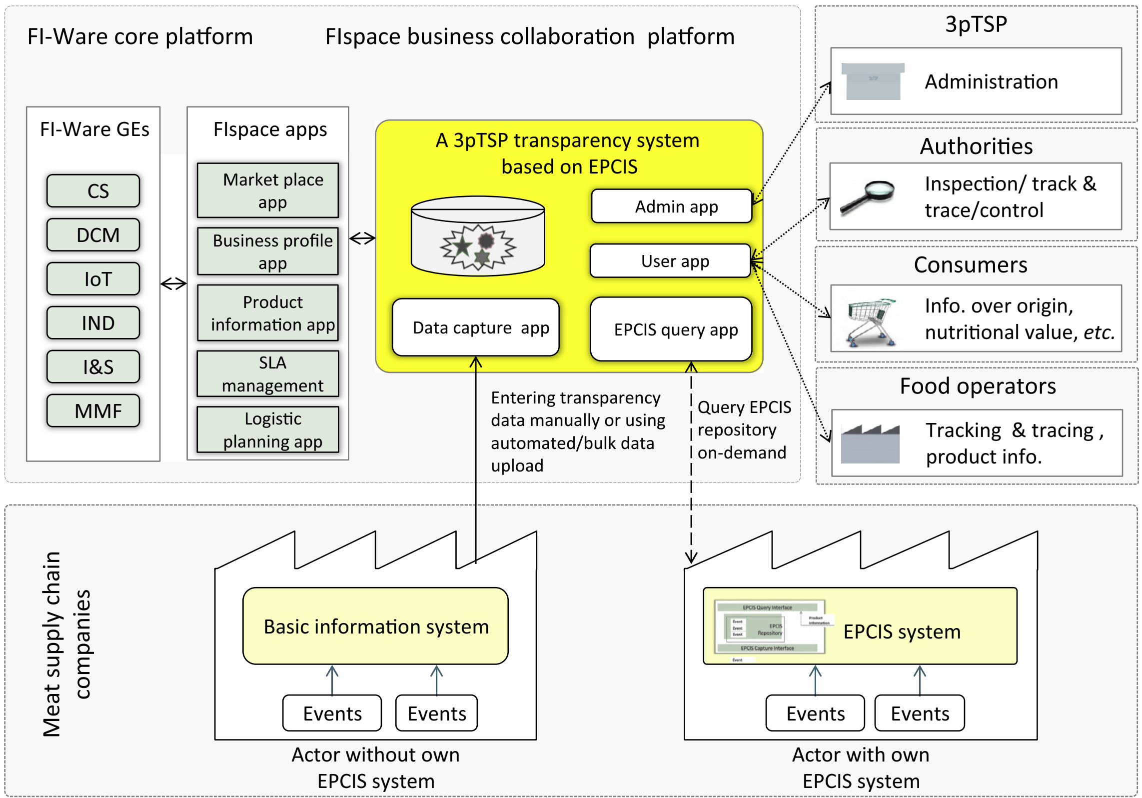

Fig. 7. A chain-wide transparency system based on FIspace: the various apps provided by 3pTSPs and their users.

EPCIS system can choose between two ways of transferring transparency data to the shared system: (a) manual data transfer, or (b) automated data capture. We identify four types of data query with the corresponding internal transparency system: (1) EPCIS query from a shared EPCIS system, (2) EPCIS query from a cloud-based EPCIS system, (3) EPCIS query from on-premise EPCIS system and (4) proprietary query from a legacy system.

The various types of food operators that can take part in a chain-wide transparency system provide us with three major scenarios of chain-wide transparency. First, we consider the two extremes and the corresponding scenarios, which are less likely to be used in practice. Next, we elaborate the most likely scenario. In all scenarios we assume there is a 3pTSP either established by the trading food operators (as a consortium) or as independent business as is the case in the fTRACE system. The 3pTSP provides a shared EPCIS system instance fully managed by itself. It also leases EPCIS system instances to food operators who will use and manage them privately. On-premise EPCIS and non-EPCIS transparency systems reside outside of the FIspace platform.

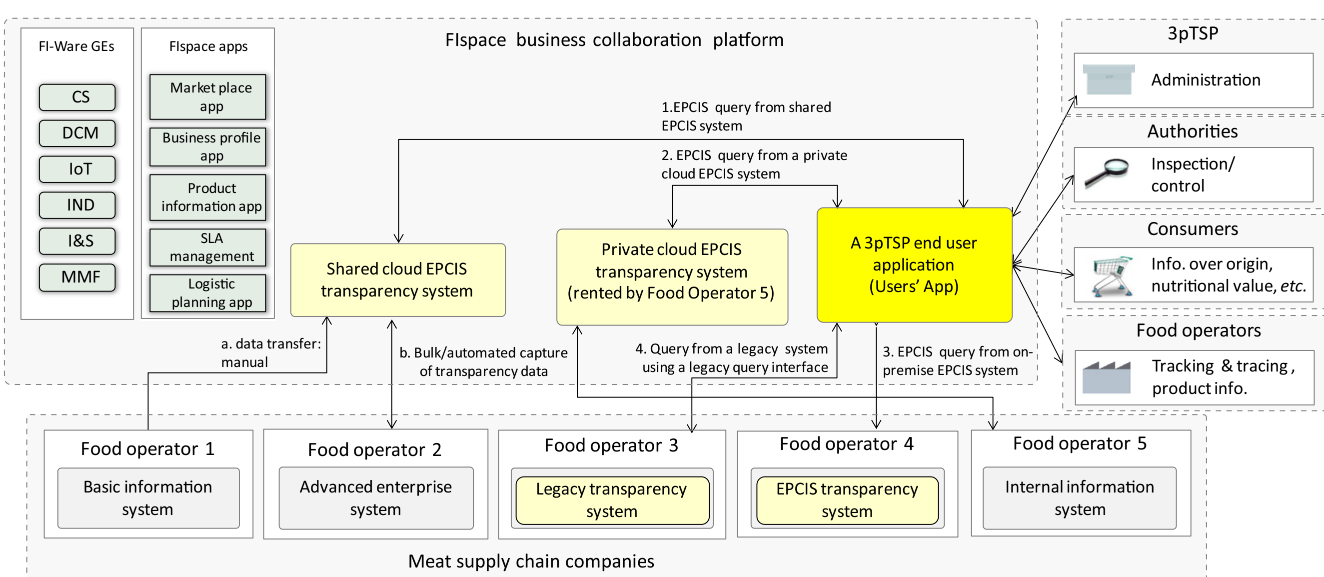

Fig. 8. A chain-wide transparency system based on FIspace: how various types of food operators provide access to transparency information.

On the one extreme all food operators will have their own EPCIS systems (*i.e.* all food operators are of type 4 or 5 in Fig. 8). Food operator 5 differs from Food operator 4 in that Food operator 5 uses a cloud-based EPCIS system offered by a 3pTSP. Food operator 4 and 5 type companies are usually medium and large companies. Since all food operators have their own EPCIS systems a shared EPCIS system is unnecessary. In this scenario all food operators have also full control over their transparency data and can control who accesses what type of information at all times. The main purpose of the 3pTSP is providing a discovery service and a consumer app, which the various customers of the food operators can use to get transparency information.

On the other extreme all food operators use a shared repository (*i.e.* all food operators are of type 1 or 2 in Fig. 8). Food operator 1 represents small companies (*e.g.* small farmers) who use basic ICT systems and generate only a limited amount of transparency data that are usually recorded manually. This food operator will use a data capture app to manually enter transparency data in the shared EPCIS system. Food operator 2 represents medium-sized companies that use advanced information systems but no internal transparency systems. This food operator generates relatively large amounts of transparency data and the preferred mechanism of transferring data to the shared transparency system is through an automated bulk data upload. This food operator will use the capture app through the data capture API. In this scenario complying with the EPCIS standard may not even be necessary because this scenario represents a centralized system. This scenario is similar to the fTRACE system used in our pilot study supply chain.

A practical scenario that lies between the two extremes accommodates the four different types of food operators that use EPCIS systems. In this scenario a food operator may choose to use either a shared EPCIS system or its own private (on premise or cloud-based) EPCIS system. This guaranties that all nodes of the distributed system are EPCIS systems as is required by the EPCIS standard.

Besides the four types of food operators, meat supply chains usually involve yet another type of food operator: food operator 3 (see Fig. 8). This food operator represents most of the large food operators in today's meat supply chains. This food operator has its own non-standard (thus non-EPCIS) internal transparency system and cannot directly exchange information with those who use EPCIS systems. This food operator may not be willing to upgrade its system to adopt the EPCIS standard and, as a result, creates the greatest challenge in realizing a chain-wide transparency system. For a 3pTSP to serve a supply chain with this type of food operators the 3pTSP should support the proprietary query interfaces and data formats the food operator uses.

To provide chain-wide transparency involving EPCIS and legacy (non-EPCIS) systems requires a tedious work of coupling. Therefore, 3pTSPs will play a crucial role in devising practical solutions for the current day situations. However, to be able to join future chain-wide transparency systems food operators of type 3 may have to use private internal EPCIS systems and become a type 4 or 5 food operator or use a shared transparency system and become a type 1 or 2 food operator.

6. Conclusion

In this paper we presented a reference software architecture for chain-wide transparency systems in meat supply chains. We showed how such transparency systems can be realized based on the EPCIS standard and using cloud-based services. We argued for third-party transparency service providers who will play an important role of providing shared and private EPCIS systems as cloud-based services, integration with legacy transparency systems, end-user apps and a discovery service to identify on-premise EPCIS systems.

Before designs based on the reference architecture can be widely implemented and evaluated in practice the proposed architecture should be tested. Currently a prototype chain-wide transparency system and the platform on which it will run (the FIspace collaboration platform) are being developed. When these are completed, we will be able to start evaluation in practice.

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