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Virtualization of food supply chains with the internet of things

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ABSTRACT

Internet technologies allow supply chains to use virtualizations dynamically in operational management processes. This will improve support for food companies in dealing with perishable products, unpredictable supply variations and stringent food safety and sustainability requirements. Virtualization enables supply chain actors to monitor, control, plan and optimize business processes remotely and in real-time through the Internet, based on virtual objects instead of observation on-site. This paper analyses the concept of virtual food supply chains from an Internet of Things perspective and proposes an architecture to implement enabling information systems. As a proof of concept, the architecture is applied to a case study of a fish supply chain. These developments are expected to establish a basis for virtual supply chain optimization, simulation and decision support based on on-line operational data. In the Internet of Things food supply chains can become self-adaptive systems in which smart objects operate, decide and learn autonomously.

1. Introduction

The food sector is a challenging domain from a supply chain management perspective. It needs advanced control systems that can deal with perishable products, unpredictable supply variations and stringent food safety and sustainability requirements. Virtualization is a promising approach to meet these challenges. It allows for simulation and optimization of food processes using software systems instead of conducting physical experiments (Singh and Erdogdu, 2004). With current Internet technologies virtualization can also be used dynamically in the operational management of food supply chains (Saguy et al., 2013; Porter and Heppelmann, 2014; Verdouw et al., 2015). Consequently, food supply chains can be monitored, controlled, planned and optimized remotely and in real-time via the Internet based on virtual objects instead of observation on site.

Virtual supply chains build on food traceability systems that provide the information to track the location of certain items and trace its history (Thakur et al., 2011; Storøy et al., 2013; Kassahun et al., 2014). Sensor technologies are utilized to record state information over the lifecycle of the objects of interest. This may include the monitoring of temperature, microbiological information and other food quality parameters (Abad et al., 2009; Heising et al., 2013; Jedermann et al., 2014). The representation of these data in virtual objects allows for advanced capabilities that go beyond tracking and tracing, such as food quality deviation management, (re)planning and optimization functionalities (Verdouw et al., 2015). As such, virtualization adds (computer) intelligence to the chain, for example: early warning in case of food incidents, rescheduling in case of unexpected food quality deviations and simulation of product quality based on ambient conditions (resulting in e.g. dynamic best-before dates).

This type of virtualization is at an early stage in food supply chains. There are some preliminary examples of food companies that make advanced use of ICT and that are experimenting with virtualization applications. For example: fresh fish can be sold from the fishing vessel on the open sea in a virtual auction and directly shipped to end customers after arrival in the harbor. However, such examples are just the start of what could become a revolution in the food industry. A broad application of future Internet applications is expected to change the way food supply chains are operated in unprecedented ways. Until now the focus is very much on enabling technologies, such as Radio Frequency Identification (RFID) and sensors, but not on how the generated information can be used for control at a supply chain level. To gain a maximum profit,

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technologies need to be properly embedded into the food chain and aligned with business processes, which is currently not well addressed in research. Especially the implications of virtualization on food supply chain management need to be further clarified.

This paper analyses the role of virtualization in the context of food supply chain management and proposes an information system architecture to implement this. The first part defines virtual food supply chains from an Internet of Things perspective. The second part proposes the information system architecture that is designed to implement this concept. Finally, the third part describes how the architecture is applied to and validated in a case study of a fish supply chain.

2. Methodology

The research is based on a design-oriented methodology, which focuses on building purposeful artefacts that address heretofore unsolved problems and which are evaluated with respect to the utility provided in solving those problems (March and Smith, 1995; Hevner et al., 2004). The design artefact developed in this paper is an information system architecture for the virtualization of food supply chains. Design-oriented research is typically involved with 'how' questions, i.e. how to solve a certain problem by the construction of a new artefact (March and Storey, 2008; van Aken, 2004). A case study strategy usually fits best for this type of questions, because artefacts intended for real-life problems are influenced by many factors (van Aken, 2004). Case studies can deal with such complex phenomena, which cannot be studied outside their rich, real-world context (Eisenhardt, 1989; Benbasat et al., 1987; Yin, 2002). For the purposes of this paper, the case should highlight the dynamic usage of virtualizations in food supply chain management, i.e. a heterogeneous selection based on theoretical replication logic (Eisenhardt, 1989; Yin, 2002). Therefore a fish supply chain was chosen that has to deal with a low predictability of transport demand and late shipment booking cancellations. The unit of analysis is a supply chain for the export of fish from Norway to Brazil, focusing on container shipments from Norway to the port of Rotterdam in the Netherlands. The case companies are a container ship operator (focal company), a port, a freight forwarder and a terminal operator.

The research was organized in four phases: (i) literature review, (ii) requirements definition, (iii) design and implementation, and (iv) validation.

Firstly, virtualization of food supply chains was conceptually defined by identifying the objects, processes, stakeholders and their relationships that have to be virtualized. This was based on a review of the literature on virtualization, supply chain management and the food industry.

Secondly, an in-depth requirements definition study was conducted based on seven bilateral and four concerted workshops with key informants of the selected case firms and additional document reviewing. The requirements were elicited in six steps:

1. *High-level use case definition*: systematic description of the domain, business and actors, business processes and information exchange, by using templates for a structured use case description, process diagrams and tabular process descriptions;
2. *Challenge definition*: describing the main challenges as experienced by the use case actors, by using templates for structured challenge descriptions and connecting them to specific business processes;
3. *Root cause analysis*: systematic analysis of the business challenges, the main problems encountered and their causes (human, technical, organizational, etc.), by using a root-cause diagram template;
4. *As—Is scenarios*: describing in concrete and real scenarios how the challenges are experimented, by using templates for structured use case scenario descriptions and UML use case diagrams;
5. *Requirements specification*: identifying specific needs for improvement and desired solutions for each challenge and main root-cause, resulting in a list of concrete domain requirements;
6. *To-Be scenarios*: describing in concrete and real scenarios how solutions could be implemented, including mock-ups, use case stories and UML use case diagrams.

Thirdly, an information system architecture for the defined requirements was developed. This was done iteratively and interactively in an agile methodology by a development team of end users, business architects and technical developers. The architecture of FIspace was used as a basis for this design. FIspace is a cloud-based platform for business collaboration, which is based on a common set of internet technology enablers, i.e. FIWARE generic enablers (Verdouw et al., 2014). FIspace was selected because it was primary developed for highly dynamic and heterogeneous networks such as food supply chains and because virtualization is well embedded in its architecture especially through enablers for the Internet of Things (IoT) and Complex Event Processing.

Finally, the information system architecture was validated in a user acceptance test and a solution evaluation. The user acceptance test has verified the defined requirements and thus validated if the system works as expected. In total, six scenarios are tested in fifteen tests by the business architects and five tests by the key users of the use case. The tests were based on a protocol that specifies the test purpose, business processes (including specific tasks, involved actors and used apps), expected result, test data and test result for each step of the scenario. The solution evaluation has validated if the system helps to solve the defined business problems. This was done in structured fifteen open interviews based on a demonstration of the solution and a questionnaire including qualitative questions on the willingness to use the system, the expected benefits and the expected barriers. The respondents included experts of three sea carriers, three freight forwarders, one cargo owner, three information technology companies, two industry forums and three research organizations. A quantitative validation of the benefits was not possible for this research, because the developed system was not yet implemented in the operations of the case companies and it would hardly be possible to isolate the impact of the implemented system on supply chain performance.

3. Control virtualization of food supply chains

3.1. What is virtualization?

The concept of virtualization has been used as a compelling catchphrase to describe the revolutionary impact of ICT on business processes, organizations and society (Crowston et al., 2007). Basically, the word "virtual" is used in contrast to "real" and "physical". This means that it has an essence or effect without a real-life appearance or form (World English Dictionary). Virtualization is used in reference to digital representations of real or imaginary real-life equivalents. As such, virtualization removes fundamental constraints concerning (Verdouw et al., 2013):

- *Place*: virtual representations do not require geographic presence, i.e. physical proximity, to be observed, controlled or processed;
- *Time*: besides the representation of actual objects, virtualization can reproduce historical states, simulate future states or imagine a non-existing world;

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- *Human observation*: virtual representations can visualize information about object properties (such as temperature information or X-ray images) that cannot be observed by the human senses.

Although dealing with the same basic concept, virtualization has been applied to different domains and the concept has been used in different meanings and with different focuses. Verdouw et al. (2013) distinguish the following perspectives:

- *Virtual organization*: dynamic organizational structures that temporally bring together resources of different organizations to better respond to business opportunities (Goldman et al., 1995; Venkatraman and Henderson, 1998);
- *Virtual team perspective*: virtual working environments in which people collaborate via computer-mediated communication systems with co-workers they may never or rarely meet face-to-face (Crowston et al., 2007);
- *Virtual machine*: a software replication of a computer system or component that executes programs like a physical machine and that provides a uniform view of underlying hardware, independent from the specific implementation (Rosenblum and Garfinkel, 2005);
- *Virtual reality*: aims to create a digital environment that is experienced by human users as reality by the development of advanced human–computer interfaces that simulate visual, aural and haptic experiences (Steuer, 1992; Lu et al., 1999);
- *Virtual things*: physical entities such as products and resources are accompanied by a rich, globally accessible virtual counterpart that links all relevant information of the related physical object such as current and historical information on that object's physical properties, origin, ownership, and sensory context (Welbourne et al., 2009).

3.2. *Virtualization from an internet of things perspective*

This paper especially looks at virtualization from a virtual things perspective, which is related to the Internet of Things (IoT) concept. IoT combines the concepts "Internet" and "Thing" and can therefore semantically be defined as "a world-wide network of interconnected objects uniquely addressable, based on standard communication protocols" (Infso and EPoSS, 2008). The concept was first introduced by the MIT Auto-ID Center to label the development towards a world where all physical objects can be traced via the internet by tagging them with RFID transponders (Schoenberger, 2002). In the meantime the meaning is expanded towards a world-wide web of smart connected objects that are context-sensitive and can be identified, sensed and controlled remotely by using sensors and actuators (Atzori et al., 2010; Kortuem et al., 2010; Porter and Heppelmann, 2014).

The interaction between real/physical and digital/virtual objects is an essential concept behind this vision. In the IoT, physical entities have digital counterparts and virtual representations; things become context-aware and they can sense, communicate, act, interact, exchange data, information and knowledge (Sundmaeker et al., 2010). The Internet acts as a storage and communication infrastructure that holds a virtual representation of things linking relevant information with the object (Uckelmann et al., 2011). As such, virtual objects serve as central hubs of object information, which combine and update data continuously from a wide range of sources. Virtual objects can be used to coordinate and control business processes remotely via the Internet as illustrated in Fig. 1.

3.3. *Virtualization of food supply chains*

Virtualization allows the decoupling of physical flows from information aspects of operations (Clarke, 1998; Verdouw et al., 2013). Virtual SCM does no longer require physical proximity, which implies that the path or route followed by the physical products from source to destination is no longer dependent on the location of the partners executing control and coordination. These partners thus may not have physical access to the products and resources and may have no hierarchical control over the partners that execute operations.

Virtualization of food supply chains has to deal with a high network, object, process and control complexity. Fig. 2 tries to capture this, but it is still a simplified representation of reality. The next section will more specifically define these complexity dimensions.

3.4. *Food network complexity*

Food supply chains have diverse network structures where many small and medium enterprises trade with huge multinationals. Fig. 2 depicts some of the major participants. Other relevant organizations include food packaging firms, producer cooperatives, certification and inspection organizations, food labs, advisors, traders and food service companies. The permissions for access and usage of virtual objects may differ per actor. Furthermore, there can be multiple representations of the same object for different stakeholders based on their specific purposes of usage. There must be procedures to provide access to virtual objects and ensure the consistency of different representations. In order to effectively virtualize such highly networked, often border-crossing, dynamic supply chains, a collaborative business environment is needed that enables food companies, including SMEs, to easily connect to virtual objects in a secure and trusted way, managing integrity between different views.

3.5. *Food object complexity*

Food supply chains handle multiple interrelated objects, which result in different levels of object virtualization. In common with traceability systems, the granularity of virtualization is important for its value (Bollen et al., 2007; Bottani and Rizzi, 2008; Karlsen et al., 2012). Virtualization of a fine granularity level, e.g. up to individual products, adds more value, but it is also more difficult to implement, which results in higher costs. In case of a fine granularity, a key challenge is to manage the interdependences between virtual objects at different granularity levels.

Food supply chains handle a large variety of objects, depending on the type of food product and the stage of the supply chain. At the farm, main objects are farming inputs including seeds, feed, fertilizers or pesticides, farm resources including farm land parcels, stables and machinery, and agricultural products including cattle and produce. These farm outputs are processed into food products in batches. After processing, products become discrete objects when they are packaged (fresh products are directly packed without processing). Food products are shipped in different containers (e.g. boxes on pallets in a sea container) and distributed to retailers. Product flow diagrams can be used to visualize the object hierarchy throughout the food supply chain for more specific supply chain configurations (Verdouw et al., 2010).

In food industry the need for a fine granularity of virtual objects is relatively high because of the variability and perishability of products. Virtualization of containers is not enough to ensure food safety and quality, but information about the conditions of food products inside is crucial for proper SCM in this sector.

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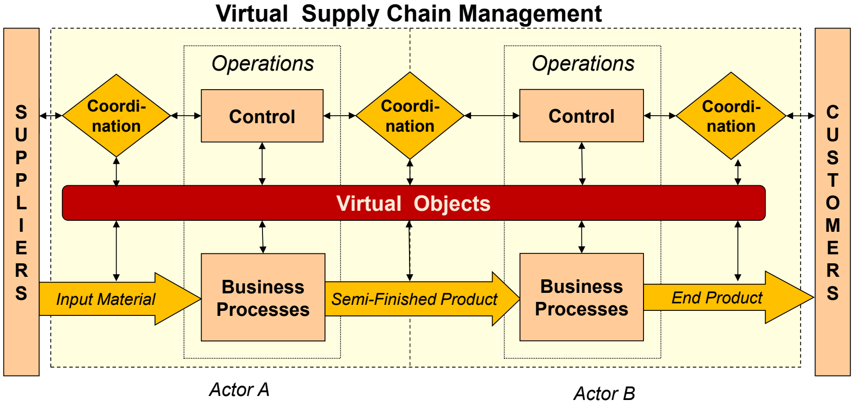

Fig. 1. Virtualization from an Internet of Things perspective (Verdouw et al., 2013).

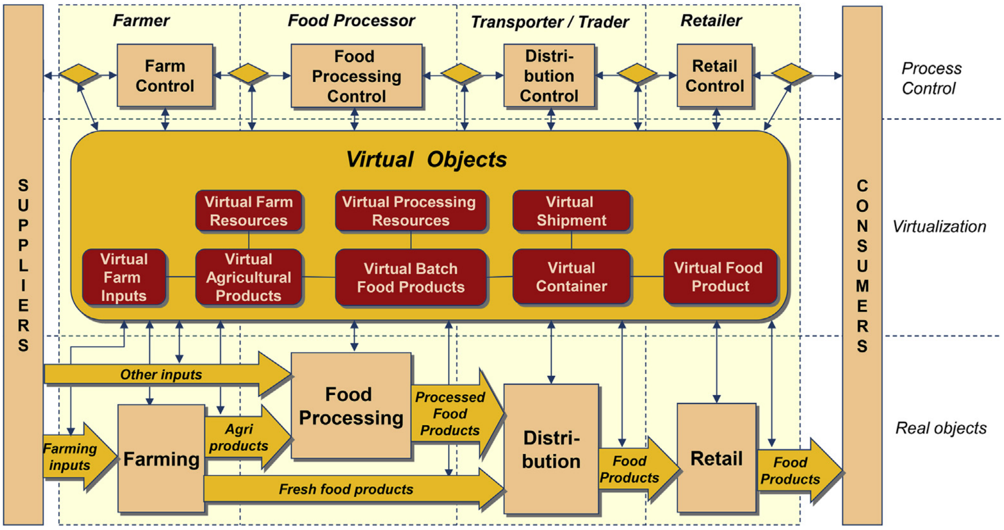

Fig. 2. Simplified overview of virtualized food supply chains.

3.6. *Food process complexity*

Virtual objects are used for multiple business processes, which may cover applications in the complete food supply chain. The business processes of farming significantly differ between different types of production, e.g. livestock farming, arable farming and greenhouse cultivation. A common feature is that agricultural production is depending on natural conditions, such as climate (day length and temperature), soil, pests, diseases and weather. Also food processing is characterized by a high process variety because many different food products can be produced by applying different processing techniques. In general, food processing is characterized by a combination of continuous or batch processing and discrete processes after packaging. Furthermore, there are many alternating diverging and converging processes and by-products, which means that different objects are combined into a single object (e.g. blending) or split into multiple objects (e.g. slaughtering). Distribution of food products combines high volumes with frequent delivery and increasingly intricate distribution. Processes can vary depending on the distribution network layout, which can include different consolidation strategies and different modes of transportation. Food retail processes are diverse since there are different outlet channels, including supermarkets, specialized food shops, food service providers including restaurants and caterers, and increasingly popular web shops. Due to this high process complexity, implementation of virtualization is quite a challenge.

3.7. *Food process control complexity*

The network, object and process complexity of food supply chains demand for advanced systems to keep food supply chains in control. In addition, food control is complicated by a high uncertainty of both demand and supply. Markets are becoming more turbulent, consumer preferences are changing and consequently demand is diverse and difficult to predict. Food processes throughout the supply chain should be continuously monitored, (re)planned and optimized based on real-time information of the location, food quality and other relevant parameters. As a result, sophisticated control systems are needed that provide Supply Chain (SC) capabilities for: (i) monitoring, (ii) event management, (iii) optimization, and (iv) autonomy (based on Porter and Heppelmann, 2014).

Virtual SC monitoring enables the comprehensive monitoring of a product's condition, operation, and external environment through sensors and external data sources. A virtual object can alert supply chain participants on e.g. food safety incidents, temperature deviations or food quality problems. Monitoring also allows companies and customers to track an object's location, owner and other

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operating characteristics, as well as to trace its history, its destination and usage by end customers.

Virtual SC event management adds intelligence for corrective actions, i.e. rules that direct how objects must respond to specific events (e.g. “if E. coli contamination is detected, trigger food recall procedure” or “if an inbound shipment is delayed, reschedule outbound logistics). The condition or environment of objects could be corrected remotely by using actuators (e.g. “if temperature gets too high, switch on the cooler”).

Virtual SC optimization improves supply chain operations by applying advanced algorithms and analytics for simulation and decision support based on operational data. Moreover, proactive actions can be implemented based on optimization models and predictive analytics (e.g. shelf life simulation to determine consequences of detected quality changes by the time the product reaches its destination).

Virtual SC autonomy: a combination of monitoring, control, and optimization capabilities enables objects to operate autonomously when travelling through the supply chain, without on-site or remote intervention by humans. Autonomous objects could also become self-adaptive systems that are able to learn about their environment, self-diagnose their own service needs, and adapt to users' preferences.

So far, the concept of food supply chain virtualization and its underlying complexity were defined. The next section will present the information system architecture that is designed to implement this concept.

4. Information systems architecture for supply chain virtualization

Virtual supply chains build on food traceability systems that provide the information to track the location of objects and to trace their history. Chain-wide traceability systems can be based on a centralized, linear or distributed approach (Kassahun et al., 2014). In a centralized approach, traceability data is collected in shared databases, e.g., the national bovine animal registration systems in Europe (EC, 2004). In a linear approach, traceability data are passed from one partner to the next one, while each partner records the supplier and customer of specific products. This principle is also referred to as the ‘one step forward and one step back principle’, as required by the European General Food Law (Beulens et al., 2005). In a distributed approach, the participants of food supply chains interconnect their own traceability systems to exchange traceability data. In food supply chains the Electronic Product Code Information Services (EPCIS) standard is increasingly used to realize distributed traceability systems (Shanahan et al., 2009; Thakur et al., 2011; Ringsberg and Mirzabeiki, 2013; Kassahun et al., 2014). EPCIS-based traceability systems capture events of food items passing through a supply chain network, store these on one or more EPCIS-repositories and enable querying these events using appropriate security mechanisms (GS1, 2014). 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. They are mainly generated by AutoID technologies, such as bar code scanning and Radio Frequency Identification (RFID), biometrics, magnetic stripes, Optical Character Recognition (OCR), voice recognition, and smart cards (Sundmaeker et al., 2010).

The architecture of the present paper is based on a distributed approach, because it is most appropriate for virtualizing a network of dispersed objects, as is the case in the Internet of Things. In comparison with traceability systems, virtualization not only requires tracking and tracing the location of objects (‘whereabouts’), but also sensing and recording of information about its dynamic state. Moreover, virtualisation should allow for controlling objects using actuators and for dynamically projecting its future state to support planning and optimization (Verdouw et al., 2015). As a consequence, the four basic elements that are needed to virtualize food supply chains are (i) identification, sensing and actuation, (ii) data exchange, (iii) information integration and (iv) application services (based on Atzori et al., 2010; Ma, 2011; GS1, 2012; Verdouw et al., 2013).

Starting point is sensing and actuating physical objects i.e. the real-life things that are to be virtualised (e.g. product, box, pallet, truck). It must be possible to automatically identify the physical objects. The main AutoID technologies used in food supply chains are barcodes or RFID transponders (Ruiz-Garcia and Lunadei, 2011; Costa et al., 2013; Trienekens et al., 2012). Due to cost-benefit considerations, most RFID applications focus on container or pallet level, while single items are identified by barcodes (Bottani and Rizzi, 2008). The designed architecture allows for the application of different Auto ID technologies at different granularity levels by using standardized GS1 unique identifiers, especially Serial Global Trade Item Numbers (SGTIN), Serial Shipping Container Codes (SSCC), the Global Returnable Asset Identifier (GRAI) and the Global Location Numbers (GLN) (GS1, 2012).

In addition to AutoID, sensors and other devices measure dynamic properties of physical things including ambient conditions (e.g. temperature, ethylene and humidity), microbiological information and other food quality parameters (Heising et al., 2013; Jedermann et al., 2014). These sensors can be integrated with RFID tags (Abad et al., 2009). Object sensing is also supported by mobile devices such as smartphones or barcode/RFID readers, which enable humans to perform additional actions such as visual quality inspections. In addition to sensors, devices may be equipped with internet-connected actuators that can remotely operate objects such as coolers, lights and food processing machines.

The next step is to communicate object information in the supply chain in an efficient and secure way. The data are first sent to intermediary platforms (internet gateways or cloud proxy machines) using technologies such as networked RFID, near-field communication and wireless (sensor) networks, including Bluetooth, Zigbee, Wi-Fi and GPRS. These intermediary platforms are local computers that are usually located at proximity of the devices to be connected. The remaining communication in the supply chain is done via electronic EDI or XML messages, usually in a service-oriented approach.

The successive layer is information integration. This layer starts with object abstraction i.e. creating virtual representations of the heterogeneous set of underlying physical objects. Based on the exchanged object data, virtual objects are created and updated in the Internet. Virtual objects filter irrelevant information or include additional data (e.g. simulations of future states) dependent on the specific purposes of usage. Each view should only be accessible for authorized users and the reliability must be unquestionable. The information integration layer includes basic data management capabilities such as cloud storage and security. Virtual objects must be updated continuously, which imposes stringent requirements on the timeliness of object sensing and data exchange.

The last layer is concerned with application services that provide specific functionalities for different supply chain users based on the virtual object information that is accessible via the middleware layer. The type of services is determined by the level of intelligence of virtual objects, which may differ from basic virtualizations that only show the whereabouts of physical objects to smart virtual objects that proactively take actions. As a consequence, application services can be classified into information handling, problem notification and decision making services (Meyer et al., 2009). Information handling is concerned with basic operations with object data such as collecting, storing, and

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delivering (e.g. to legacy information systems of the different supply chain actors). Problem notification assumes informing the relevant stakeholders and users if something is wrong (e.g. temperature too high) or if there are any events causing deviations from the planning. This functionality is often coupled with certain rules which are applied to filter the collected data and extract the exception message. Finally, decision making is concerned with assisting or completely replacing humans in performing sophisticated decisions and triggering certain actions concerning the virtualised object. This presents the highest level of intelligence in which objects are able to make relevant decisions by themselves (Meyer et al., 2009).

Fig. 3 presents the four layers of virtualization and shows how FIspace functions as an intermediary platform between them. FIspace is based on a Software-as-a-Service (SaaS) delivery model, in which ICT developers can easily develop smart software application services ('Apps') based on FIWARE generic enablers (FIWARE, 2015). These Apps should collaborate seamlessly together to support business control processes, facilitating data exchange and information integration.

The FIspace architecture contains several modules. A module called 'System and Data Integration' enables the integration of legacy systems and services and includes facilities for data mediation. This module generates and updates the virtual objects by integrating data from real-world physical objects through AutoID devices, sensors and other sources, based on the requirements from the application service layer. An 'App Store' module provides a tool-supported infrastructure for publishing, finding, and purchasing Apps, which provide re-usable IT-solutions, supporting business collaboration scenarios and which can be used and combined for the individual needs of users. The Apps are accessed through a *User Front-End* that constitutes of a configurable graphical user interface so that Apps can be located at different points (smartphone, machine terminal, bar code reader, etc.). The 'B2B Collaboration Core' module intermediates between the data application services and ensures that all object information and status updates are provided to each involved App and real object in real-time. It supports the modeling of customized collaborative workflows in guard-stage-milestone (GSM) models (Richard Hull et al., 2011). These models are based on an entity-centric approach, in which entities (i.e. artifacts or objects) have a central role in guiding business processes. Key elements of such entities are an object lifecycle schema and a data schema that evolves as it moves through a business process. All connections with the FIspace platform - as well the data from virtualized objects as user interaction through applications — are managed through the module 'Security, Privacy and Trust'. This framework provides secure and reliable access and, where needed, exchange of confidential business information and transactions using secure authentication and authorization methods that meet required levels of security assurance. The interaction between all modules is handled by an *Operating Environment* which ensures the technical interoperability and communication of (distributed) FIspace components and Apps and the consistent behavior of FIspace as a whole. A *Software Development Toolkit* (SDK) provides tool-support for the development of Apps. The SDK will ease the work of App developers during the implementation of the Apps, providing specific tools and libraries that hide the more complex aspects of the platform. A more technical, detailed description of the FIspace platform can be found at https://bitbucket.org/fi-space/doc/wiki/Home.

The next section will describe how the introduced information systems architecture is applied and validated in a case study of a fish supply chain.

5. Use case fish distribution

The Fish Distribution case deals with the export of fish from Norway to overseas markets. The objects are dry and frozen fish packed in boxes, stabbed in pallets, stuffed in refrigerated containers, and then shipped on reefer vessels from Norway with transhipment to ocean carriers at large hub ports in Northern Europe. Fish export is a typical spot market for regional sea carriers, characterized by homogeneous services, high competition and relatively low customer loyalty or use of long-term contracts. The low predictability of transport demand and a high number of changes and cancellations in bookings represent a challenge for carriers, affecting the capacity utilization and limiting their potential to offer customized services. Hence the aim of the Fish

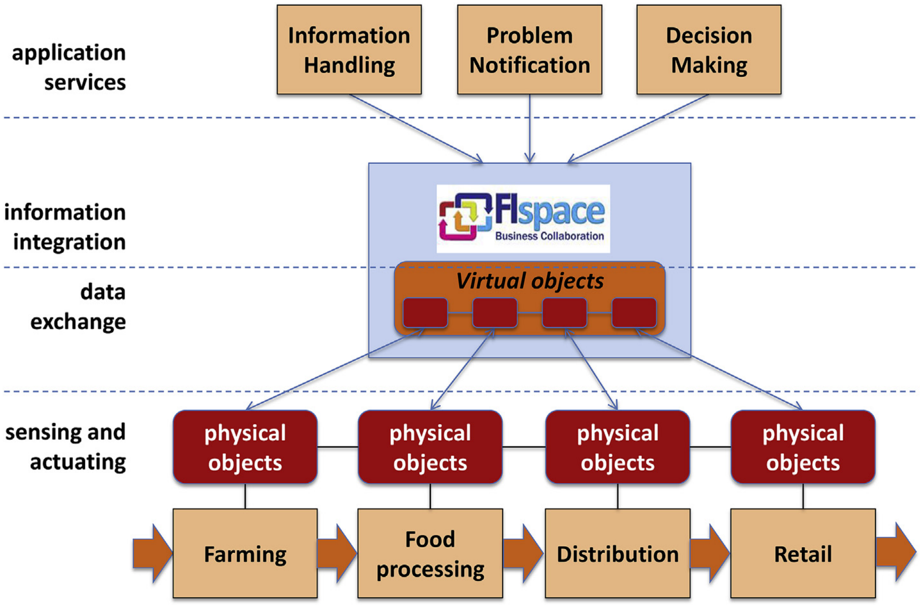

Fig. 3. Information systems architecture for supply chain virtualization based on the FIspace platform.

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Distribution case is to show how virtualization of the supply chain and a new business collaboration model can enhance transparency and visibility in container shipping, thus improving the quality of transport planning for both ship operators and cargo owners, and lead to higher capacity utilization and service level.

Fig. 4 shows how FIspace is supporting several business control processes of a virtualized fish supply chain in a simplified way (not all relationships between components are shown). The product (fish in boxes) is virtualized through the Product Information App (PIA) that - at a later stage - can be used to provide information to consumers. The logistics unit (in this case a sea container) is virtualized through the Shipment Status App (SST) that is connected to back-end systems. The business-to-business (B2B) core service keeps track of the product and of the shipment status, including late cancellations. This information is fed into to the Logistics Planning App (LPA) that supports logistics operation planning of shippers. It establishes a transport execution plan, which is appropriate for the specific product and shipment type. Subsequently, the LPA selects adequate transport services based on real-time information on the available transport services in the Market Place Operations Service App (MOS). Finally, the Cargo Search App (CargoSwApp) is used by carriers to find cargo to ship. It also supports the replacement of late cancellations, by searching information on transport demand available in the MOS App. This functionality is important to improve vessel capacity utilization, in particular because the inherent uncertainty of fish supply. The CargoSwApp also supports the booking negotiation process (receiving and sending bids) between the carrier and the transport user (shipper).

The information system architecture as developed in the case study was validated in a user acceptance test and a solution evaluation. The user acceptance test has verified the following test scenarios: (i) Booking and cancellation of shipment, (ii) Search for cargo to increase vessel capacity utilization, (iii) Early anticipation of cancellation, (iv) Transport planning, (v) Automatic booking of transport, and (vi) Early anticipation cancellation alternatives. The scenarios include in total thirty-one tasks that all are approved after fifteen tests by the business architects and five tests by the key users of the use case team.

The solution evaluation confirmed that the system provides a good solution for the challenge of late cancellations. The respondents acknowledge that it enhances an efficient and effective transport (re)planning and matchmaking between service offer and demand, based on real-time information and early detection of deviations. The main expected benefits are improvement of the booking performance, operational costs, value for transport users and vessel utilization (see Table 1). In addition, the focal company has calculated the potential saving concerning booking performance for a representative vessel voyage (capacity of 350 containers). Their planning team can save 30% of their time for handling bookings, changes and cancellations. However, the benefits were expected to be most likely for spot market shipments. Furthermore, the respondents addressed several potential barriers to a successful realization, implementation and uptake of such a system. The most important are: (i) a lack of willingness to share information, (ii) skepticism regarding data security and reliability, (iii) limitations of existing contractual relationships and pricing strategies, (iv) absence of a critical mass, and (v) uncertainty about impact on current business practices and business models.

6. Discussion and conclusions

This paper has argued that virtualization can play a major role to meet specific challenges of food supply chains, including a high perishability, unpredictable supply variations and stringent food safety and sustainability requirements. The concept of virtual food supply chains is defined from a virtual things perspective in which four dimensions of complexity of supply chain virtualization are addressed: (i) network, (ii) object, (iii) process and (iv) control. Virtualization can be a powerful approach to manage this complexity because it enables decision-makers throughout a food supply chain to monitor, control, plan and optimize business processes remotely and real-time via the Internet based on virtual objects. Implementation of virtualization in food supply chains requires an infrastructure that supports food companies, including SMEs, to easily connect to virtual objects in a secure and trusted way, while managing integrity between different views. For that purpose, the FIspace platform architecture was designed as a coherent business environment in which smart Apps and services interact with each other to manage virtual objects.

The main contribution of this paper lies in the introduction of a novel approach to virtualization of business control in food supply

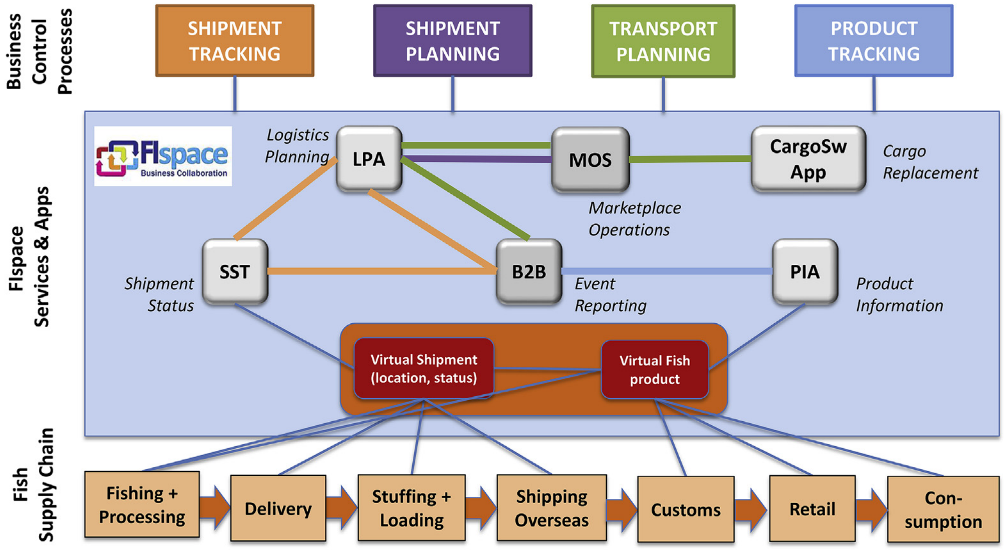

Fig. 4. FIspace supporting various control processes in the fish supply chain.

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Table 1
Benefits as expected by the solution evaluation respondents.

Category	Key performance Indicators	Contribution of virtualization by FIspace apps
Booking Performance	Automatic booking: share of bookings not made by mail/phone/fax	LPA, B2B
	Booking reliability: share of bookings and requests that result in actual transport	MOS, B2B, CargoSwApp
	Share of booking cancellations replaced	CargoSwApp, MOS, B2B
	Early warning: booking cancelled earlier than 48 h before departure (instead of within 48 h)	LPA, B2B
Operational Costs	Planning costs: man-hours for handling bookings	CargoSwApp, MOS
	Re-planning costs: man-hours for handling replacement of cancellations	CargoSwApp, MOS
Values for Transport Users	Lead time and manual work to find a transport service	LPA, MOS, B2B
	Lead time and manual work to compare transport services	LPA, MOS, B2B
	Frequency of correct and up-to-date information	LPA, MOS, PIA, SST, B2B
	Operational costs of following and tracking a shipment	LPA, SST, PIA
Vessel Utilization	Average load factor of transport capacity	MOS, CargoSwApp
	Share of late cancellations replaced	CargoSwApp, MOS, B2B
	Active time to find replacement after cancellation	CargoSwApp, MOS, B2B

chains. This is based on virtual objects that are real-time and remotely connected to the real objects and that provide rich representations of the objects and its context. Applications based on these virtualizations also enable stakeholders to act immediately in case of deviations. This goes beyond the virtualization of experiments that simulate and optimize food processes, which are usually based on historical data sets. A second contribution of the paper is related to the proposed information systems architecture, which is based on the FIspace platform. It has shown how this new virtualization approach can be implemented by using generic technology enablers, including Internet of Things (IoT) and Cloud Computing capabilities.

The architecture is applied to and validated for a case study of a fish supply chain, including an evaluation of the expected benefits by companies and industry experts. Further research is needed to systematically quantify the impact of virtualization on supply chain performance. Such research could profit from studies on the economic value of traceability and RFID (e.g. Bottani and Rizzi, 2008; Sarac et al., 2010; Mai et al., 2010). However, to the best of our knowledge, quantitative studies on the benefits of IoT are not yet available.

Last but not least, it should be noticed that the type of virtualization as addressed in this paper, is still at an early stage of development in food supply chains. Existing virtualization applications mostly focus on virtual supply chain monitoring and event management or they virtualize objects at a high granularity level. Management at lower granularity levels is often still too expensive and integrated software solutions are lacking. Using generic technologies and SaaS-approaches, such as the FIspace platform, can provide broadly affordable solutions, especially for SMEs. These developments establish a basis for the next level of virtual supply chain control: virtual supply chain optimization, simulation and decision support based on on-line virtualization of objects. Ultimately, food supply chains can become autonomous, self-adaptive systems in which smart virtual objects can operate, decide and even learn without on-site or remote intervention by humans.

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