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Managing food traceability information using EPCIS framework

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ABSTRACT

This paper introduces a new methodology for modeling traceability information using the EPCIS framework and UML statecharts. The method follows the approach of defining states and transitions in food production. A generic model is presented and evaluated based on its practical application by providing illustrations from two supply chains; frozen mackerel production and corn wet milling processes. All states and transitions for these processes as well as the information that needs to be captured for each state are indentified. This includes the product, process and quality information. The model presented in this paper is not just another process modeling tool but is used for mapping of food production processes to provide improved description and integration of traceability information. Information exchange technologies such as EPCIS are used for monitoring events based on logistic processes. Application of current EPCIS framework for managing food traceability information is presented by mapping the transitions identified in two product chains to the EPCIS events. The corresponding quality parameters to be linked to these EPCIS events are also identified. It was practical to map food production transitions for frozen mackerel to two EPCIS events; ObjectEvent and AggregationEvent. Because, EPCIS is based on discrete recording of events and event locations and corn wet milling is a continuous process, it was not possible to map transitions to AggregationEvent. Thus, quality parameters for transformation events for corn wet milling were linked to the subsequent ObjectEvent to provide certain extent of discretization.

1. Introduction

Food safety and quality issues generally occur due to incorrect processing and handling of food products. Monitoring the flow of products, their quality and the process parameters throughout production and linking them to each transition in the state of these products is an effective way of implementing and ensuring product safety and traceability. The European Union law describes "Traceability" as an ability to track any food, feed, food-producing animal or substance that will be used for consumption, through all stages of production, processing and distribution (Official Journal of the European Communities, 2002). A food supply chain consists of several stakeholders such as farmers, producers, processors, distributors, retailers, etc. that trade goods among each other. The raw materials are transported from one stakeholder to another where these raw materials may be processed into finished products while going through various transformations such as mixing, cooking, segregating, etc. The processed food products are then transported to distributors and retailers for sale to the customers for final consumption (Thakur and Hurburgh, 2009). In addition to the trade of goods and information between supply chain stakeholders, several product transformations take place within an enterprise. Besides the capability to track food products as they move through the supply chains, one important objective of any food traceability system is to ensure product safety and quality. The most important elements of traceability have been identified as unique identification, lot integrity, product transformations and data collection and retrieval (Jansen-Vullers et al., 2003; Bechini et al., 2008; Folinas et al., 2006; TraceFood Wiki, 2009; ISO, 2007).

Several product transformations and processing steps take place during industrial production of food. These transformations alter the food composition, and if not monitored properly, can affect the food quality as well as food safety. Little research has been conducted where the information related to the food product integrity, the processing techniques and their affect on the food quality and safety is recorded simultaneously. In order to perform efficient traceability, there is need to integrate all this information into a framework where a problem caused either due to processing or handling/logistics can be identified and traced back to the source.

Efficiency of information exchange is affected by lack of internal traceability systems and standardized way of information exchange. Absence of internal systems makes it impossible to

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connect the information related to incoming products to that of the outgoing products in any enterprise. Individual companies have made great progress in proprietary technologies for automated data capture and electronic data coding. However, the benefit of these is lost when the data element transmission is required for use outside the originating company as it is only effective when there is an identical software system at the receiving end (Donnelly et al., 2008). Previous studies have shown that there is currently no standardized way of formatting information for exchange in traceability systems. Research suggested that structured data lists, vocabularies and ontology will be appropriate tools in achieving effective universal data exchange (Donnelly et al., 2009a,b; Dreyer et al., 2004; TRACE 2, 2008). According to Folinas et al. (2006) standards must describe how information can be constructed, sent and received and also how the data elements in the information should be identified, measured, interpreted and stored. The traceability information needs to be captured in a precise, effective and electronic manner (FSA, 2002; Moe, 1998). UML statecharts are extensively used for describing the behavior of objects. In the next section, we discuss how statecharts can be used for modeling food traceability information.

1.1. Traceability and UML statecharts

UML statecharts depict the various states that an object may be in and the transitions between those states. A state represents a stage in the behavior pattern of an object, and it is possible to have initial states and final states. An initial state, also called a creation state, is the one that an object is in when it is first created, whereas a final state is one in which no transitions lead out of. A transition is a progression from one state to another and will be triggered by a transition that is either internal or external to the object. So, the statecharts depict the dynamic behavior of an entity based on its response to transitions, showing how the entity reacts to various transitions depending on the current state that it is in. A state is a stage in the behavior pattern of an entity. States are represented by the values of the attributes of an entity (Ambler, 2004).

A statechart is simply a network of states and transitions. A state is a condition during the life of an object or an interaction during which it satisfies some condition, performs some action, or waits for some transition. A composite state is a state that, in contrast to a simple state, has a graphical decomposition. A composite state is decomposed into two or more concurrent sub-states or into mutually exclusive disjoint sub-states. A given state may only be refined in one of these two ways. Naturally, any substate of a composite state can also be a composite state of either type.

UML statecharts are extensively used in computer science and related fields for describing the behavior of classes, but the statecharts may also describe the behavior of other model entities such as use cases, subsystems, operations or methods. The use of statecharts in production and manufacturing systems has been limited to applications such as automated production control and planning and modeling of manufacturing systems (Köhler et al., 2000; Guojon et al., 2007; Francês et al., 2005; Vijaykumar et al., 2002). Köhler et al. (2000) present a modeling approach using UML statecharts for flexible, autonomous production agents that are used for the decentralized production systems while Guojon et al. (2007) use stochastic statecharts to describe a manufacturing system model and to obtain performance data from the system. Although, a variety of applications of statecharts exist, their application for modeling traceability transitions at a food production facility has not been studied.

1.2. Tools for electronic traceability

According to the GS1 Traceability Standard, traceability across the supply chain involves the association of flow of information with the physical flow of traceable items. It also states that in order to achieve traceability across the supply chain, all traceability partners must achieve internal and external traceability (GS1 Global

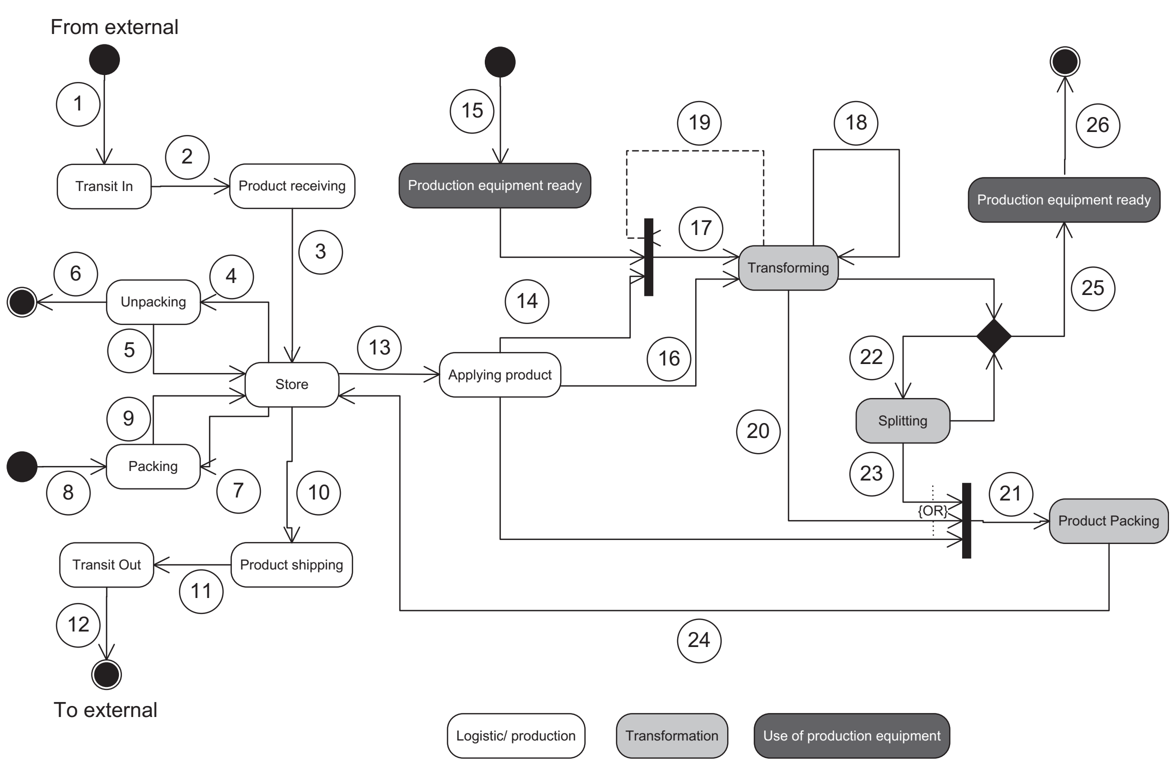

Fig. 1. Generic events in food production and processing.

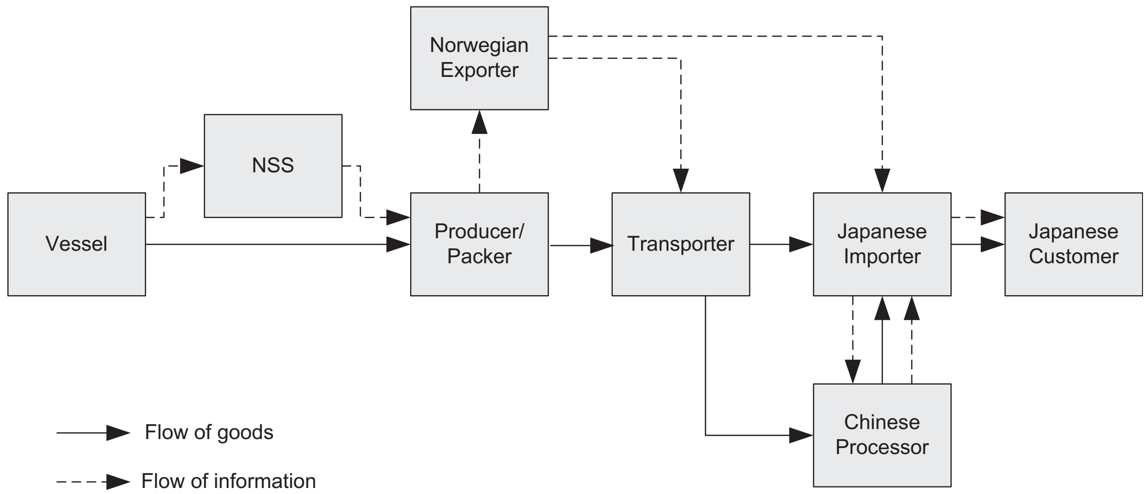

Fig. 2. Flow of goods and information in the mackerel supply chain from Norway to Japan.

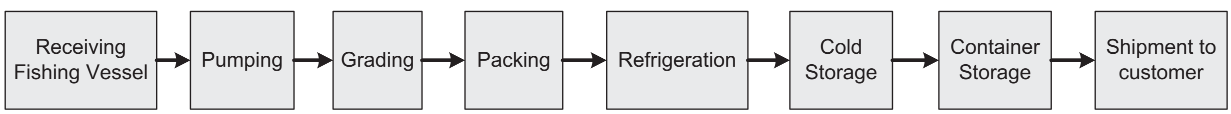

Fig. 3. Flow diagram for mackerel production process.

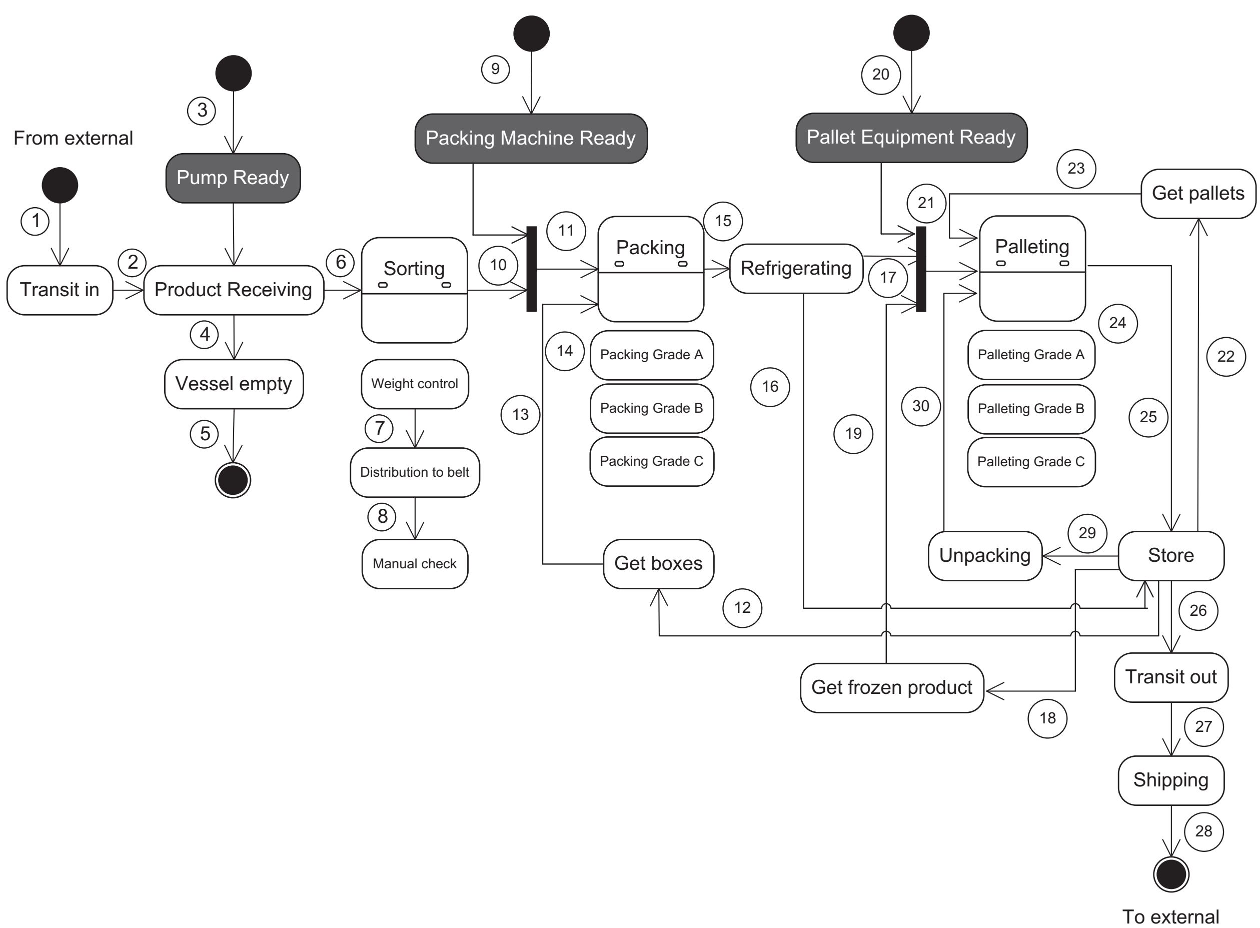

Fig. 4. States and events in frozen mackerel production process.

Table 1
Description of states in the frozen mackerel production.

State	Description	Start	End	Objects	Quality control
Transit in	Denotes that fishing vessel is received at the production plant	Fishing vessel to be received	Fishing vessel received at production plant	Actor, resource, traceable item	NA
Pump ready	Denotes that the pump is ready (clean) to be used for product receiving	Pump cleaned	Pump ready for use	Resource	Pump sterilized
Product receiving	Denotes that the fish is received by pumping into the production plant	Fish ready to be pumped into the production plant	Fish ready to be sorted	Resource, traceable item	Flow rate; other QC checks (freshness, color, bruises, belly damage)
Vessel empty	Denotes that the fishing vessel is emptied after pumping	Fish being pumped out	Fishing vessel empty	Actor, resource, traceable item	NA
Sorting	This is a composite state comprised of three sub-states: weight control, distribution to belt, and manual check	Fish ready to be sorted after pumping	Fish sorted into different grades based on weight and ready to be packed	Resource, traceable item	Weight visual inspection
Weight control	Denotes that fish is sorted using weight control technique	Fish ready to be sorted after pumping	Fish sorted based on weight	Resource, traceable item	NA
Distribution to belt	Denotes that fish is transferred to the conveyor belt after sorting	Fish ready to be distributed on conveyor belt after sorting	Fish distributed on conveyor belt	Resource, traceable item	Visual inspection
Manual check	Denotes that manual check is performed by taking random fish from the conveyor belt	Fish ready to be weighed manually	Fish checked manually and sorted into different grades based on weight	Resource, traceable item	Weight
Packing machine ready	Denotes that packing machine is ready to enter the packing state	Packing machine ordered	Packing machine ready for use	Resource	Packing machine sterilized
Store	Denotes the process of managing stock	Goods ready for storage	Goods stored	Resource, traceable item	Temperature (for fish storage)
Get boxes	Denoted the process of getting boxes from storage for packing	Boxes ready in storage	Boxes ready for use in packing	Resource, traceable item	NA
Packing	This is a composite state and denotes the packing process of fish using the packing material and graded fish. The state consists of 3 concurrent states:	Fish and packing material ready to be used	Fish with different packed into boxes	Resource, traceable item	Histamine analysis
Packing grade A	Denotes the process of packing of grade A fish	Grade A fish and packing material ready to be used	Grade A fish packed into boxes	Resource, traceable item	NA
Packing grade B	Denotes the process of packing of grade B fish	Grade B fish and packing material ready to be used	Grade B fish packed into boxes	Resource, traceable item	NA
Packing grade C	Denotes the process of packing of grade C fish	Grade C fish and packing material ready to be used	Grade C fish packed into boxes	Resource, traceable item	NA
Refrigerating	Denotes that the packed boxes are refrigerated in tunnel freezers	Packed boxes ready to be refrigerated	Packed boxes refrigerated	Traceable Item	Temperature
Get frozen product	Denotes the process if getting the frozen product from cold storage	Frozen product ready in cold storage	Frozen product ready to be palleted	Traceable Item	NA
Pallet equipment ready	Denotes that pallet equipment is ready to enter the palleting state	Pallet equipment ordered	Pallet equipment ready for use	Resource	Pallet equipment clean
Get pallets	Denoted the process of getting pallets from storage for palleting	Pallets ready in storage	Pallets ready for use in palleting	Resource, traceable item	NA
Palleting	This is a composite state and denotes the palleting process of boxes containing frozen fish of different grades. The state consists of three concurrent states as follows:	Packed fish and palleting material ready to be used	Pallets of packed fish created	Resource, traceable item	NA
Palleting grade A	Denotes the process of making pallets of boxes containing grade A fish	Grade A packed fish and palleting material ready to be used	Pallets of grade A packed fish created	Resource, traceable item	NA
Palleting grade B	Denotes the process of making pallets of boxes containing grade B fish	Grade B packed fish and palleting material ready to be used	Pallets of grade B packed fish created	Resource, traceable item	NA
Palleting grade C	Denotes the process of making	Grade C packed fish and	Pallets of grade C packed fish	Resource,	NA

Table 1 (*continued*)

State	Description	Start	End	Objects	Quality control
	pallets of boxes containing grade C fish	palleting material ready to be used	created	traceable item	
Unpacking	Denotes the process of splitting of pallets by unpacking and removing some boxes	Pallets in storage ready for unpacking	Pallets in storage unpacked	Resource, traceable item	NA
Transit out	Denotes the process of physical shipping of goods out from the production plant	Pallets ready for shipping	Pallets shipped	Resource, traceable item, actor	NA
Shipping	Denotes the process of getting the product ready for shipment	Pallets picked from storage	Pallets ready for shipping	Resource, traceable item, actor	NA

Table 2
Description of transitions in the frozen mackerel production.

No.	Transition	From state	To state	Description
1	Fishing vessel to be received	Start state; Another actor	Transit in	This transition denotes that the fishing vessel is in transit to the production plant
2	Fish to be pumped	Transit in	Product receiving	This transition denotes that the handover of fish from vessel to production plant
3	Pump made ready for use	Start state	Pump ready	This transition denotes that the pump is made ready for use in product receiving
4	Vessel to be emptied	Product receiving	Vessel empty	This transition denotes that the pumping of fish from vessel into the production plant
5	Vessel to exit	Vessel empty	End state	This transition denotes that the empty vessel left the production plant
6	Fish to be sorted	Product receiving	Weight control	This transition denotes the sorting of received fish based on weight control
7	Fish to be distributed on conveyor belt	Weight control	Distribution to belt	This transition denotes that the sorted fish is distributed to the conveyor belt
8	Fish to be checked manually	Distribution to belt	Manual check	This transition denotes that the fish on conveyor belt is checked (weighed) manually
9	Packing machine made ready for use	Start state	Packing machine ready	This transition denotes that the packing machine is made ready for use in production
10	Sorted fish to be packed	Manual check	Packing	This transition denotes that sorted fish is ready for packing
11	Packing machine used in packing process	Packing material ready; Manual check	Packing	This transition denotes that the packing material is used to pack the sorted fish
12	Boxes to be taken from storage	Store	Get boxes	This transition denotes that the boxes are taken from storage to be used for packing
13	Boxes used in packing process	Get boxes	Packing	This transition denotes that the boxes are used to pack the sorted fish
14	Concurrent events for packing material used in packing of different grades of fish	Packing material ready; Manual check	Palleting	This transition denotes that the packing material is used to pack the sorted fish based on grade
15	Packed fish ready to be refrigerated	Packing	Refrigerating	This transition denotes that the packed fish is refrigerated in tunnel freezers
16	Frozen fish ready to be stored in cold storage	Refrigerating	Store	This transition denotes that the frozen fish is stored in cold storage
17	Frozen fish ready for palleting	Refrigerating	Palleting	This transition denotes that the frozen fish is ready for palleting after refrigerating
18	Frozen fish to be taken from cold storage	Store	Get frozen product	This transition denotes that the boxes containing frozen product are taken from cold storage for palleting
19	Frozen product to be palleted	Get frozen product	Palleting	This transition denotes that the frozen product is ready to be palleted
20	Pallet equipment made ready for use	Start state	Pallet equipment ready	This transition denotes that the pallet equipment is made ready for use in production
21	Pallet equipment used in palleting process	Pallet equipment ready; Get frozen product	Palleting	This transition denotes that the pallet equipment is used to make pallets of boxes containing frozen fish
22	Pallets to be taken from storage	Store	Palleting	This transition denotes that the pallets are taken from storage to be used for palleting
23	Pallets used in palleting process	Get pallets	Palleting	This transition denotes that the pallets are used for palleting the packed boxes
24	Concurrent events for pallet equipment used for palleting of packed graded fish	Pallet equipment ready; Packing; Unpacking	Store	This transition denotes that the pallet equipment is used to make pallets of packed fish based on grade
25	Pallets to be stored	Palleting	Store	This transition denotes that the pallets are ready to be stored
26	Pallets to be delivered	Store	Transit out	This transition denotes that the stored pallets are taken for storage for shipping
27	Pallets to be shipped	Transit out	Shipping	This transition denotes that pallets are ready to be shipped
28	Pallets shipped	Shipping	End state; Another actor	This transition denotes that the pallets are shipped and outside the control of the production plant
23	Pallets to be unpacked	Store	Unpacking	This transition denotes that pallets in storage are unpacked
30	Boxes to be palleted	Unpacking	Palleting	This transition denotes that unpacked boxes are palleted

Traceability Standard, 2007). Therefore, all the stakeholders involved in the food supply chain are required to store necessary information related to the food product that links inputs with outputs, so that when demanded, the information is available in a timely manner.

Automated traceability is based on electronic data capture and exchange. Electronic data capture can be optical or radio-wave systems, for example, barcodes and RFID technology. The interest in these systems for traceability has been increasing recently. RFID tags essentially contain EPC codes generation 2 (EPCglobal, 2007). Most of the research in this field presents traceability solutions where only the product packaging is tracked through the supply chains but fail to address the internal traceability issues linked to the production events within a food facility. Regattieri et al. (2007) presented the application of an RFID system integrated with alphanumeric code to trace Parmigiano Reggiano cheese through the complete supply chain. Shanahan et al. (2009) proposed the use of RFID for the identification of individual cattle and biometric identifiers for verification of cattle identity. They also proposed a data structure for RFID tags and a middleware to convert animal identification data to the EPC data structure. Bottani and Rizzi (2008) studied the impact of RFID technology and EPC system on the main processes of the fast moving consumer goods supply chain that composed of manufacturers, distributors and retailers. The outcomes of their study provided economical justifications for implementation of RFID and EPC in fast moving consumer goods supply chains. Senneset et al. (2010) suggested a new data model for exploiting technologies like RFID in the food industry. This model considers load carriers and other equipment equally important as traceable units. The model facilitates flexibility and allows for better precision as the production processes are changed to accommodate finer granularity.

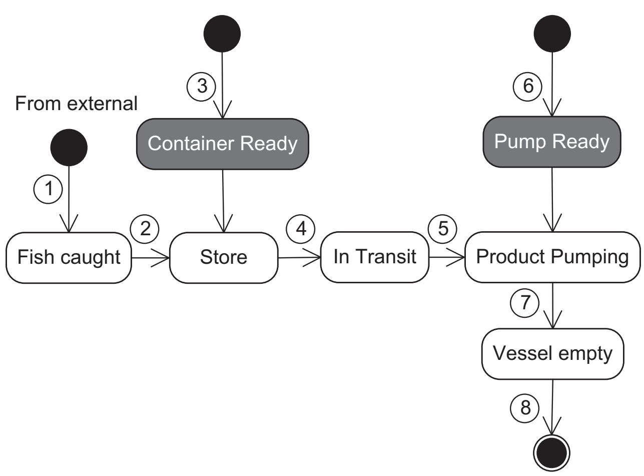

Fig. 5. States and events for fishing vessel entity.

EPC provides a method for unique identification of all items in a supply chain. The use of EPC also makes it possible to register internal and external events electronically that are related to the movement of tagged items. The standard for using RFID is based on EPCglobal standard. EPCIS is an EPCglobal standard designed to enable EPC-related data sharing within and across enterprises (EPCIS Standard, 2007). Automated traceability systems have existed in Nordic countries for several years (Storøy and Olsen, 2007) but EPCIS makes the data capture and exchange electronic thus making EPCIS an applicable standard. There are two kinds of EPCIS data, event data and master data. Event data is created in the process of carrying out business processes, and is captured through the EPCIS Capture Interface and made available for query through the EPCIS Query Interfaces. Master data is additional data that provides the necessary context for interpreting the event data. It is available for query through the EPCIS Query Control Interface. The EPCIS events cover normal logistic and stock control processes by the use of the Event classes: ObjectEvent, AggregationEvent, QuantityEvent and TransactionEvent. The basic chain traceability requirements with respect to managing and recording transactions between different business actors are directly covered by EPCIS Events. EPCIS has promising properties related to food supply chain traceability (Sørensen et al., submitted for publication). Myhre et al. (2009) provided a conceptual solution on how EPCIS (EPC Information Services) can be used to achieve both upstream and downstream traceability. The use of EPCIS and RFID is limited to tracking the product packages between stakeholders but the additional food product transformations (or transitions) that include process and quality parameters are not covered under the basic EPCIS specification (EPCIS standard). Before EPCIS can be implemented as a tool for food traceability information exchange, it is crucial to identify the specific transitions that take place internally at a food business operator. In the next section, we present the method for application of EPCIS.

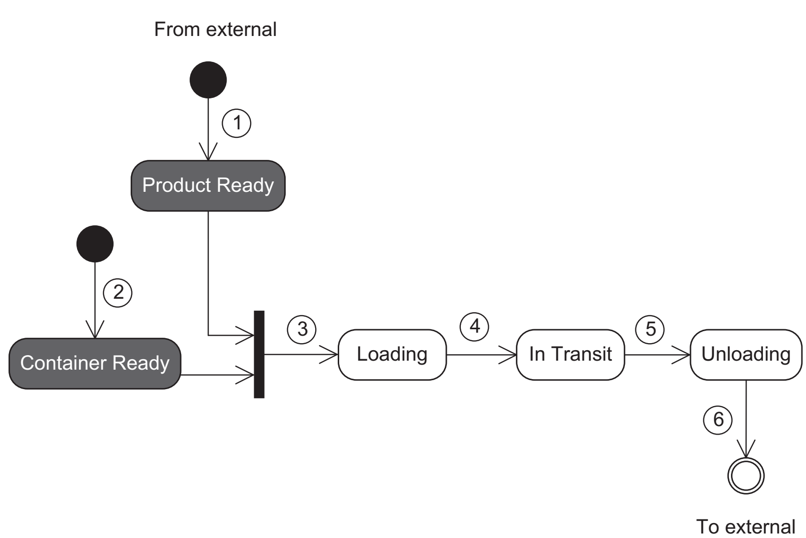

Fig. 6. States and events for shipper entity.

2. Methodology

Under the TraceFood framework, traceability data is defined as all the data necessary to manage traceability within a stakeholder and between stakeholders in a food chain. This includes information about the *what* (traceable unit), *where* (resource), *when* (trace event), and the *who* (stakeholder, TraceFood Wiki, 2009). This section introduces a new methodology for modeling this traceability information using the EPCIS framework and UML statecharts. A generic statechart for food production is presented and applied to two supply chains; pelagic fish and grain. A state-transition model with emphasis on identifying both traceability transitions and food safety and quality data is developed. Application of current EPCIS framework for managing food traceability information is presented by mapping the transitions identified in two product chains to the EPCIS events; ObjectEvent and AggregationEvent. The corresponding states where the quality parameters are recorded are also identified and linked to these EPCIS events. The results are presented in the next section.

3. Results

3.1. Modeling traceability transitions in food production

Fig. 1 shows an overview of generic states and transitions for general industrial production and/or processing of products. We identified 13 states and 26 generic transitions that may be used to provide traceability information based on data collection at specific points in the production process. The transformation processes may include treatments like heating, boiling, smoking, cooling, mixing, etc. The state diagram is agnostic to which kind of products that are managed. Further, the use of load carriers is not explicitly shown neither as states nor transitions, but is supposed managed by the transitions within the diagram. The same applies to other physical products that are used within the different states. Thus, the state model has emphasis on transitions that includes objects rather than the object themselves. Chain traceability is covered by registering transitions in *Product receiving/Product shipping* states, while the *Transit in/Transit out* states designate that goods are commissioned or in transit from one stakeholder to another. As can be noted in Fig. 1, only registering transitions related to these states, will not give a transparent view of the flow of goods between stakeholders. In total, 12 different transitions (Nos. 1–12) are directly relevant to typical logistic processes while 14 additional transitions (Nos. 13–26) are relevant to achieve transparency related to production management and product quality and safety. The product, process and quality data is recorded corresponding to each state and can be linked to the consequent transition and thus carried to the next state.

3.2. Case studies

In this section we present the two different product supply chains and apply the state-transition model presented in the previous section to these products. The states where food safety and quality information should be recorded and transitions where traceability information should be recorded are identified are described for each product.

3.2.1. Pelagic fish supply chain (mackerel)

Small pelagic fish species such as herring, mackerel, horse mackerel, etc. swim together in shoals. The fish is caught by trawling

Table 3
Description of states for fishing vessel entity.

State	Description	Start	End	Objects	Quality control
Fish caught	Denotes the process of catching fish	Fishing vessel ready	Fish caught	Resource, traceable item	NA
Store	Denotes the process of storing fish on the vessel	Fish ready for storage	Fish stored	Resource, traceable item	Temperature
Container ready	Denotes that the container is ready (clean) to be used for storage	Container cleaned	Container ready for use	Resource	Container sterilized
In transit	Denotes that fishing vessel is in transit to the production plant	Fishing vessel in transit	Fishing vessel received at production plant	Actor, resource, traceable Item	NA
Pump ready	Denotes that the pump is ready (clean) to be used for product receiving	Pump cleaned	Pump ready for use	Resource	Pump sterilized
Product pumping	Denotes that the fish is pumped into the production plant	Fish ready to be pumped into the production plant	Fish pumped into the production plant	Resource, traceable item	Flow rate
Vessel empty	Denotes that the fishing vessel is emptied after pumping	Fish being pumped out	Fishing vessel empty	Actor, resource, traceable item	NA

Table 4
Description of events for fishing vessel entity.

No.	Transition	From state	To state	Description
1	Fishing vessel to be caught	Start state	Fish caught	This transition denotes that the fishing vessel is ready to catch fish
2	Fish to be stored	Fish caught	Store	This transition denotes that the fish is ready to be stored on the vessel
3	Container made ready for use	Start state	Container ready	This transition denotes that the container is made ready to store fish
4	Vessel to start transit	Store	In transit	This transition denotes that the vessel starts the transit towards the production plant
5	Fish to be pumped into production plant	In transit	Product pumping	This transition denotes that the fish is ready to be pumped into the production plant
6	Pump made ready for use	Start state	Pump ready	This transition denotes that the pump is made ready for use in product pumping
7	Vessel to be emptied	Product pumping	Vessel empty	This transition denotes that the pumping of fish from vessel into the production plant
8	Vessel to exit	Vessel empty	End state	This transition denotes that the empty vessel left the production plant

Table 5
Description of states for shipper entity.

State	Description	Start	End	Objects	Quality control
Product ready	Denotes that pallets of packed fish are ready to be shipped	Packed fish in storage	Packed fish ready	Resource, traceable item	NA
Container ready	Denotes that the container is ready (clean) to be used for shipping	Container cleaned	Container ready for use	Resource	Container sterilized
Loading	Denotes the process of loading the shipping contained with pallets of packed fish product	Packed fish and container ready	Packed fish loaded into container	Resource, traceable item	Weight
In transit	Denotes that container is in transit to the customer	Container in transit	Container received by the customer	Actor, resource, traceable item	Temperature
Unloading	Denotes the process of unloading the product from shipping container	Container arrives at customer	Container unloaded	Actor, resource, traceable item	NA

Table 6
Description of events for shipper entity.

No.	Transition	From state	To state	Description
1	Product made ready	Start state	Product ready	This transition denotes that the packed fish is ready to be loaded for shipping
2	Container made ready	Start state	Container ready	This transition denotes that the container is ready to be loaded for shipping
3	Product ready for loading in container	Product ready; Container ready	Loading	This transition denotes that the container is loaded with packed fish product
4	Shipping container to start transit	Loading	In transit	This transition denotes that the shipping container starts the transit towards the customer
5	Shipping container to be unloaded	In transit	Unloading	This transition denotes that the packed fish product is ready to be unloaded from the container
6	Shipping container unloaded	Unloading	End state	This transition denotes that the container is unloaded and product delivered to the customer

vessels in hauls and stored in one or more containers on board the fishing vessel. Pelagic fish is essentially handled as a bulk product until it arrives at the production facility. Fig. 2 shows the mackerel supply chain from catch to consumption. In this case, we investigated the mackerel supply chain from Norway to Japan. The fish is caught by trawling vessels in hauls and stored in one or more containers on board the fishing vessel. The haul is a Traceable Unit (TU) that is recorded in the official log. Each haul is stored in one or multiple tanks onboard the vessel. When the trip ends, the vessel reports the catch as one or multiple TUs to the Norwegian Sales Organization for pelagic fish (Norges Sildesalgslag or NSS). NSS is an economic interest organization for Norwegian fishermen of pelagic species, and the leading marketplace for all first-hand sales of pelagic fish in the northeast Atlantic. NSS plays a central role inside the pelagic sector. This TU will be used through auction and sales. NSS enters catch data into auction and the sales report is sent to the buyer (processor in this case). At landing (at the production/packing facility), fish is weighed and quality is verified. If disparity in quality is detected, the original TU may be separated into several new TUs. Each TU is identified with a unique ID. After packing the fish, the boxes are stacked on pallets are stored in freezers. The product can be in storage from 2 to 3 days and up to 6 months before it is shipped to the customer. Outgoing packed TU are pallets. The bill of lading is sent from the producer to transporters and Japanese importers through the Norwegian exporter. About 60% of the exported fish goes directly to the Japanese importer which is further sold to the mackerel processor. The remaining 40% arrives at the Chinese processor to be processed into the end product and then sent to Japan where it is sold by the importers to the Japanese customers.

3.2.1.1. Frozen mackerel production process. The flow diagram for the mackerel production process is shown in Fig. 3. The frozen mackerel production can be described as following:

1. The fishing vessel is received at the production facility and the fish is pumped into the production plant.
2. The quantity of fish received from a vessel is determined by the flow rate during pumping.

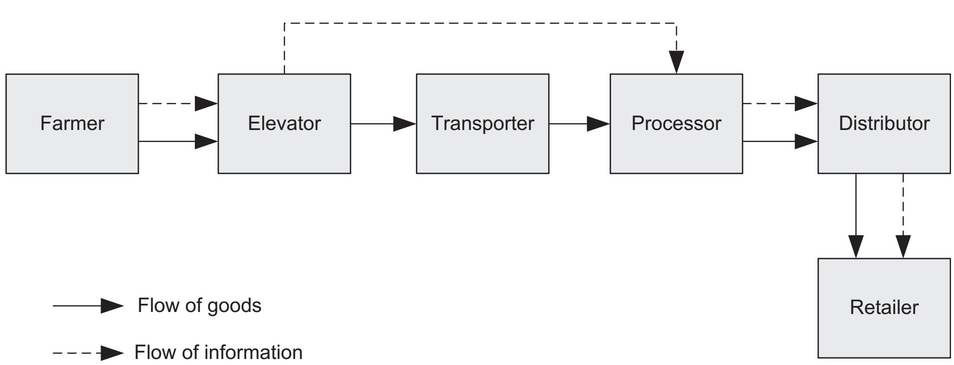

Fig. 7. Flow of goods and information in the corn supply chain.

3. When fish enters the production plant, it is graded and divided based on weight (size) using automatic graders. Manual checks are also performed to ensure the accuracy of graders and provide a visual quality control.
4. After grading, fish is packed in 20 kg boxes and labeled. The label identifies several product and process parameters described in the later sections.
5. After packing the fish, the boxes are stacked and refrigerated in freezing tunnels.
6. After refrigeration, the boxes are stored in cold storage. When in storage, the temperature measurements of the product are taken at fixed intervals. The boxes closer to the walls of the storage unit are retrieved for temperature measurements. The optimum temperature for storage of mackerel is −18 °C.
7. The boxes are palleted for shipment and stored in containers (temperature controlled) before shipping to the customers. The product can be in storage from 2 to 3 days and up to 6 months before it is shipped.

It was noted that a shipping container can carry one or more orders from one or several production batches. A production batch refers to 1 day of production.

3.2.1.2. UML statechart modeling. Based on the analysis of the production process, we developed the UML statechart for the frozen mackerel production process, the fishing vessel and shipper entities. Fig. 4 represents the states and transitions for the frozen mackerel production process. 17 states consisting of 3 composite states and 30 transitions were identified in the production process. The different states and transitions are described in Tables 1 and 2, respectively.

Three composite states were identified in the process. *Sorting* of fish as it enters the production plant comprises of three sub-states: *Weight control*, *Distribution to belt* and *Manual check*. As the fish is pumped into the production plant, it is sorted into three grades (A–C) based on the weight before transferring to the conveyor belts. After sorting, fish of each grade is handled separately and never mixed again during the entire production process. The sorted fish on conveyor belts is weighed manually as a quality control check. The second composite state *Packing* represents three concurrent states for packing of graded (sorted) fish separately. Similarly, the third composite state *Palleting* represents the three concurrent states for palleting of boxes of graded (sorted) fish separately. It must be noted that production of frozen mackerel is a continuous process and each state ends when there is no product available in the system. Figs. 5 and 6 represent the states and transitions for the fishing vessel and shipper entities. The various states and transitions for these entities are described in Tables 3–6.

3.2.2. Bulk grain supply chain (corn)

Corn is the most widely produced feed grain in the United States, accounting for more than 90% of the total value and production of feed grains. Corn is processed into several food and industrial products including starch, sweeteners, corn oil, beverage and industrial alcohol and fuel ethanol. The United States is a major player in the world corn trade market, with approximately 20% of the corn crop exported to other countries (Economic Research Service, 2009).

Corn is handled as a bulk commodity as it moves from the farmer to the consumer. Three corn chain stakeholders are presented in this paper; farmer, elevator and processor. Fig. 7 shows a simple flowchart of the corn value chain. The farmer is the first link in the corn value chain. Farmers purchase seeds from a seed company and sell their crop to an elevator after harvesting. Several chemical compounds including fungicides and herbicides are used for soybean seed treatment to inhibit damage to the crop. Combines are commonly used for harvesting the corn crop. After harvest, corn can be stored on farm before selling to an elevator. An elevator is a very important link between the farmer and the processor. Elevators buy corn from the farmers, keep it in storage, and blend it before selling to the processors. Corn crops received at the elevator are sampled and graded based on moisture content, test weight, foreign material and damaged material. The farmers are paid according to the quality grade. The grain is then conveyed to the storage silos before shipping to the customers. One storage silo can contain grain from several farmers. The incoming lots from the farmers are blended before shipment in order to meet the buyer's quality specifications. Thus, a specific lot shipped to the processor can contain grain from all different sources that may end up in the finished product. In this paper, we present the corn wet milling process and develop the UML statechart for defining the states and transitions for recoding traceability information.

3.2.2.1. Corn wet milling process. The corn wet milling is a process for separating corn into its component parts using a water sulphur dioxide system. The products of the corn wet milling process are: (1) Starch: used as starch or converted to syrup such as glucose, dextrose or high fructose corn syrup which can be further used in production of ethanol by fermentation, (2) Germ: pressed to remove corn oil and the fibrous residue is used as cattle feed, (3) Gluten: used for poultry feed enrichment, and (4) Fiber and steep water solids: used as livestock feed.

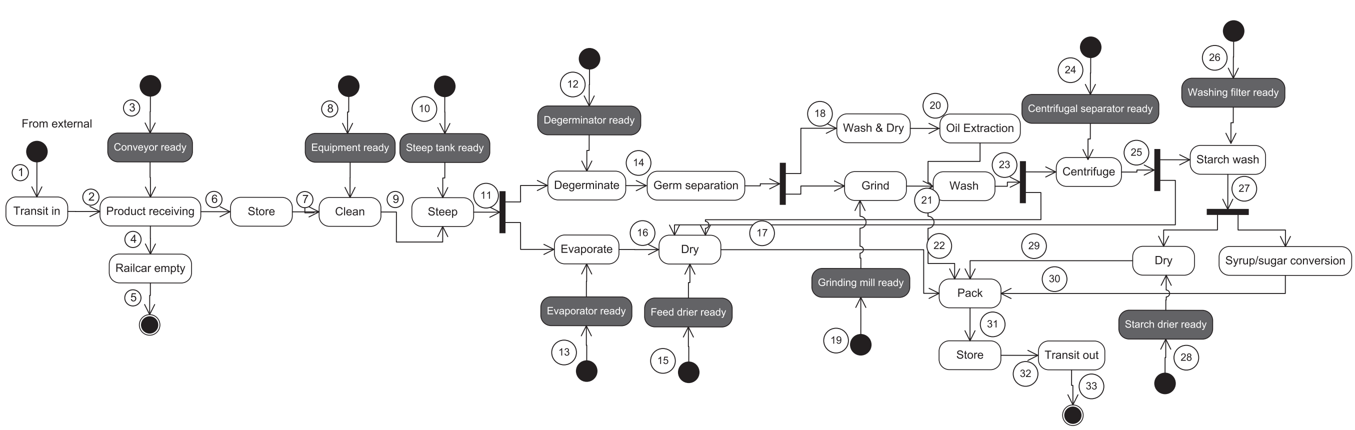

Fig. 8. States and events in corn wet milling process.

Table 7
Description of states in the corn wet milling process.

State	Description	Start	End	Objects	Quality control
Transit in	Denotes that grain container is received at the corn wet milling plant	Grain container to be received	Grain container received at production plant	Actor, Resource, Traceable Item	NA
Conveyor ready	Denotes that the conveyor is ready (clean) to be used for product receiving	Conveyor cleaned	Conveyor ready for use	Resource	Conveyor cleaned
Product receiving	Denotes that the grain is received by conveying into the storage bins	Grain ready to be conveyed to the storage bins	Grain transferred to the storage bins	Resource, Traceable Item	Product quality (moisture, test weight, foreign material, damaged material)
Railcar empty	Denotes that the railcar is emptied after receiving grain	Grain being transferred	Railcar empty	Actor, resource, traceable item	NA
Store1	Denotes that the grain is stored in the storage bins at the production plant	Grain ready to be stored after conveying	Grain stored until ready to be used in wet milling	Resource, traceable item	Product moisture; temperature
Equipment ready	Denotes that the equipment for cleaning grain (screens) is ready	Cleaning equipment available	Cleaning equipment ready for use	Resource	Equipment cleaned
Clean	Denotes that grain is cleaned	Grain ready to be cleaned	Grain cleaned	Resource, traceable item	Visual inspection
Steep tank ready	Denotes that the steep tank is ready to begin the steeping process	Steep tank available	Steep tank ready for use	Resource	Steep tank cleaned
Steep	Denotes that the cleaned grain is steeped in steep tanks	Clean grain ready for steeping	Corn ready for degermination and evaporation processes	Resource, traceable item	Water temperature; SO_2 concentration
Degerminator ready	Denotes that the degerminator is ready to begin the degermination of corn	Degerminator available	Degerminator ready for use	Resource	Degerminator cleaned
Degerminate	Denotes the process of degermination where endosperm is separated from the corn kernels	Corn ready for degermination process after steeping	Corn ready for germ separation	Resource, traceable item	Mill clearance
Evaporator ready	Denotes that the evaporator is ready to concentrate the steeping water	Evaporator available	Evaporator ready for use	Resource, traceable item	Evaporator cleaned
Evaporate	Denotes the process of evaporating steep water	Steep water is ready for evaporation after steeping	Steep solids ready to be dried	Resource, traceable item	Moisture content
Germ separation	Denotes the process of separating germ from the corn kernels	Corn kernels are ready for germ separation after degermination	Separated germ is ready for washing and drying and slurry for grinding	Resource, traceable item	Flow rates
Wash and dry	Denotes the process of washing and drying of germ	Germ separated from corn kernels is ready for washing and drying	Dried germ is ready for oil extraction	Resource, traceable item	Moisture content
Oil extraction	Denotes the process of oil extraction from germ	Dried germ is ready for oil extraction	Extracted oil is ready to be packed	Resource, traceable item	Oil quality
Grinding mill ready	Denotes that the grinding mill is ready	Grinding mill available	Grinding mill ready for use	Resource	Grinding mill cleaned
Grind	Denotes the process of grinding the slurry from germ separation	Slurry from germ separation is ready to be ground	Ground slurry is ready to be washed	Resource, traceable item	Mill clearance
Wash	Denotes the process of washing the ground slurry	Ground slurry is ready to be washed	Hulls separated from wash ready to be dried and remaining mixture to be centrifuged	Resource, traceable item	Moisture content
Centrifugal separator ready	Denotes that the centrifugal separator is ready	Centrifugal separator available	Centrifugal separator ready for use	Resource	Centrifugal separator cleaned
Centrifuge	Denotes the process of centrifugal separation of gluten and starch	Remaining mixture after grinding ready for centrifuge separation	Gluten and starch separated using a centrifuge: gluten ready to be dried and starch to be washed	Resource, traceable item	Flow rates; specific gravity (Baume degrees)
Washing filter ready	Denotes that the washing filter is ready	Washing filter available	Washing filter ready for use	Resource, traceable item	Washing filter cleaned
Starch wash	Denotes the process of washing starch	Starch separated by centrifuge ready to be washed	Washed starch ready for drying and sugar conversion	Resource, traceable item	Moisture content; specific gravity
Starch drier ready	Denotes that the starch drier is ready	Starch drier available	Starch drier ready for use	Resource	Starch drier cleaned
Feed drier ready	Denotes that the feed drier is ready	Feed drier available	Feed drier ready for use	Resource	Feed drier cleaned

Table 7 (*continued*)

State	Description	Start	End	Objects	Quality control
Dry	Denotes the separate processes of drying starch, hulls and gluten	Products ready for drying	Dried products ready to be packed	Resource, traceable item, actor	Moisture content
Syrup/sugar conversion	Denotes the process of converting starch into syrup/sugar	Washed starch ready for conversion to syrup/sugar	Syrup/sugar ready to be packed	Resource, traceable item	Sugar quality
Pack	Denotes the process of packing of various products	Products ready to be packed	Packed products ready to be stored	Resource, traceable item	NA
Store2	Denotes the process of managing stock	Products ready for storage	Products stored	Traceable item	Temperature
Transit out	Denotes the process of physical shipping of goods out from the production plant	Products ready for shipping	Products shipped	Resource, traceable item, actor	NA

The corn wet milling process can be described as following (Corn Wet Milled Feed Products, 2006)

1. The processor receives corn from the elevator usually delivered by truck, barge or railcar.
2. The grain is cleaned and stored in large storage silos. The cleaned corn is transported to large tanks called steep where warm water (at about 130 °F) containing dissolved sulphur dioxide is circulated for approximately 40 h to soften the corn kernels.
3. Next, the softened corn kernels pass through attrition mills that break them up, loosen the hull and free the germ from the endosperm. Centrifugal force is used to isolate the germ.
4. The clean germ is dried and crude corn oil is removed either by mechanical press or solvent extraction method. The extracted germ meal is used in animal feed.
5. The remaining mixture of hull and endosperm then passes through a series of grinding and screening operations. The hull particles are removed on screens, while the finer particles of protein and starch pass through. The hull is used as a constituent in animal feed or for production of refined corn fiber for food use.
6. The water slurry of starch and gluten is separated in centrifuges. The gluten is dried and sold as gluten meal or used as an ingredient in corn gluten feed.
7. The starch slurry is washed to remove small quantities of solubles. The starch slurry may be used to make sweeteners or further processed to make corn starch.

All constituents obtained from the corn wet milling process are used for further processing into several components that can be used for food, feed and fuel purposes.

3.2.2.2. UML statechart modeling. Based on the analysis of the production process, we developed the UML statechart for corn wet milling process, the elevator and the farmer entities. Fig. 8 represents the states and transitions for the corn wet milling process. 31 states and 34 transitions were identified in the production process. The product, process and quality data collected during production can be linked to one of these states or transitions and can be used to provide traceability information. The different states and transitions are described in Tables 7 and 8, respectively. It must be noted that corn wet milling is a continuous process that produces several products and each state ends when there is no product available in the system. Figs. 9 and 10 represent the states and transitions for the farming and elevator operations. The various states and transitions for these entities are described in Tables 9–12.

3.3. Application of EPCIS for food information management

The basic EPCIS specification does not cover all of the events (transitions) described in the previous sections. The main event missing is related to transformation of products where new products are produced based on the consumption of other products. It is thus necessary to either specify how to use the existing framework to define the missing processes and/or events or define new events. The application of EPCIS to represent the state-transition model and thus manage the food traceability information is provided in this section. The use of existing EPCIS events is illustrated by identifying the corresponding transitions in the statechart for frozen mackerel production and corn wet milling processes. Different food processing transitions (identified by the statecharts) can be mapped to either an ObjectEvent or an AggregationEvent currently included in the EPCIS framework. Tables 13 and 14 show the transitions mapped to the ObjectEvent and the AggregationEvent, respectively for the frozen mackerel production. Table 13 shows the EventName (EPCIS event), which transitions (from the statechart) it is related to, which business step is carried out and the event disposition for the transitions mapped to the ObjectEvent. In addition, it also identifies the corresponding states where the quality parameters are recorded. Similarly, Table 14 shows the EventName, related transitions, business step, the corresponding action and the states where quality parameters corresponding to these transitions are recorded.

This logic can be better understood by the following example. If we consider the EPCIS event "Goods left storage", it is related to the transitions 12, 17, 21, 25 and 28 in the frozen mackerel production statechart shown in Fig. 4. The business step carried out for this event is "stocking" which implies that it is a stock management process. The object disposition refers to the business condition of the event's objects, subsequent to the event. For this example, the object disposition is "sellable_accessible" which implies that the objects subsequent to this event are accessible and sellable by the business (mackerel producer in this case). The product quality information is also linked to the EPCIS event and is available from the state "store". The corresponding quality information for this state can be found in Table 1 (temperature in this case). To summarize, the transitions identified in the statechart are mapped to the EPCIS ObjectEvent and linked to the quality parameters of the related states. In case of the AggregationEvent, the "action" field describes the event's relationship to the lifecycle of the

Table 8
Description of transitions in the corn wet milling process.

No.	Transition	From state	To state	Description
1	Grain railcar to be received	Start state; Another actor	Transit in	This transition denotes that the railcar containing grain is in transit to the corn wet milling plant
2	Grain to be received	Transit in	Product receiving	This transition denotes that the transfer of grain from railcar to production plant
3	Conveyor made ready for use	Start state	Conveyor ready	This transition denotes that the conveyor is made ready for use in product receiving
4	Railcar to be emptied	Product receiving	Railcar empty	This transition denotes that the transfer of grain from railcar into the production plant
5	Railcar to exit	Railcar empty	End state	This transition denotes that the empty railcar left the production plant
6	Grain to be stored	Product receiving	Store	This transition denotes the storing of received grain in storage bins
7	Grain to be cleaned	Store	Clean	This transition denotes that stored grain is cleaned before starting the wet milling process
8	Cleaning equipment made ready to use	Start state	Equipment ready	This transition denotes that the equipment is made ready for product cleaning
9	Clean grain (corn) to be steeped	Clean	Steep	This transition denotes that clean corn kernels are transferred to the steep tanks
10	Steep tank made ready for use	Start state	Steep tank ready	This transition denotes that the steep tank is made ready for the steeping process
11	Steeped kernels to be degerminated and steep water to be evaporated	Steep	Degerminate; Evaporate	This transition denotes that the corn kernels after steeping enter degermination process while the steep water is evaporated to recover the solids
12	Degerminator made ready for use	Start state	Degerminator ready	This transition denotes that the degerminator is made ready for degermination of corn kernels
13	Evaporator made ready for use	Start state	Evaporator ready	This transition denotes that the evaporator is made ready for evaporation of steep water
14	Germ to be separated from degerminated corn kernels	Degerminate	Wash & Dry; Grind	This transition denotes that the germ part is separated from the corn kernels after steeping
15	Feed drier made ready for use	Start state	Feed drier ready	This transition denotes that the feed drier is made ready for drying
16	Steep water solids to be dried	Evaporate	Dry	This transition denotes that the steep solids are dried using the feed drier
17	Dried products to be packed	Dry	Pack	This transition denotes that the dried products including hull and gluten are packed
18	Germ to be washed and dried	Germ separation	Oil extraction	This transition denotes that the germ separated from corn kernels is washed and dried
19	Grinding mill made ready for use	Start state	Grinding mill ready	This transition denotes that the grinding mill is made ready to grind the corn kernels
20	Dried germ to be used for oil extraction	Wash & Dry	Oil extraction	This transition denotes that the washed and dried germ is used to extract corn oil
21	Ground corn kernels to be washed	Grind	Wash	This transition denotes that the ground corn kernels are washed
22	Corn oil to be packed	Oil extraction	Pack	This transition denotes that the corn oil is packed
23	Ground kernels ready to be separated into constituents	Wash	Centrifuge; Dry	This transition denotes that the ground corn kernels are washed to separate hulls which are dried and rest is centrifuged to separate gluten and starch
24	Centrifugal separator made ready for use	Start state	Centrifugal separator ready	This transition denotes that the centrifugal separator is made ready to centrifuge the gluten-starch mix
25	Centrifuged parts to be dried or washed	Centrifuge	Starch wash; Dry	This transition denotes that the separated gluten is dried and starch is washed
26	Washing filter made ready for use	Start state	Washing filter ready	This transition denotes that the washing filter is made ready to wash the separated starch
27	Starch to be dried or converted into sugar	Starch wash	Dry; Syrup/sugar conversion	This transition denotes that the washed starch is dried into dry starch or converted into syrup/sugar
28	Starch drier made ready for use	Start state	Dry	This transition denotes that the starch drier is made ready to dry starch
29	Dried starch to be packed	Dry	Pack	This transition denotes that the dry starch is packed
30	Syrup/sugar to be packed	Syrup/sugar conversion	Pack	This transition denotes that the syrup/sugar is packed
31	Packed products to be stored	Pack	Store	This transition denotes that the packed products obtained from corn wet milling process are stored
32	Packed products to be delivered	Store	Transit out	This transition denotes that the stored products are taken from storage for shipping
33	Products to be shipped	Transit out	Shipping	This transition denotes that the products are ready to be shipped
34	Products shipped	Shipping	End state; Another actor	This transition denotes that the products are shipped and outside the control of the production plant

aggregation. For instance, “action” value “ADD” implies that the EPCs of the child objects were aggregated to the containing entity.

Similar steps were carried out for the corn wet milling process. The transitions identified by the statechart presented in Fig. 8 were mapped to the EPCIS ObjectEvent with corresponding business step, object disposition, and quality parameters shown in Table 15. Because, EPCIS is based on discrete recording of events and event locations and corn wet milling is a continuous process, it was not possible to map transitions (such as transformations) to AggregationEvent. Thus, quality parameters for transformation events in this process were linked to the subsequent ObjectEvent to provide certain extent of discretization as shown in Table 15. It must be noted that these Tables 13–15 do not contain all attributes related to the EPCIS events (such as time stamps) but only provide a method for managing food traceability and quality information.

3.4. Discussion of results

Technologies such as EPCIS can be used for implementing electronic food traceability systems within and across enterprises once the specific transitions that take place during food production are identified. Detailed descriptions of the states and transitions for each entity in the two supply chains are provided. These descriptions include the start and end point of each state, the corresponding objects and the quality control parameters. The objects corresponding to each state are identified and these objects can

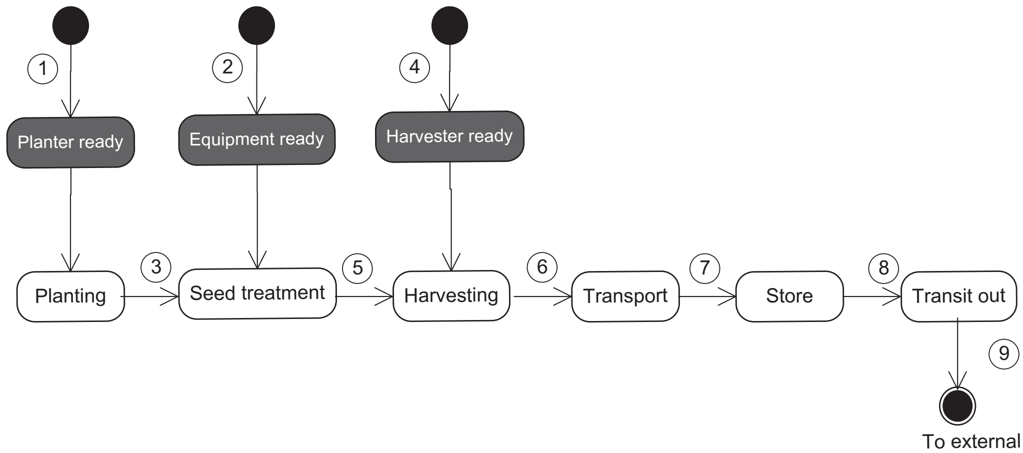

Fig. 9. States and events in corn farming operation.

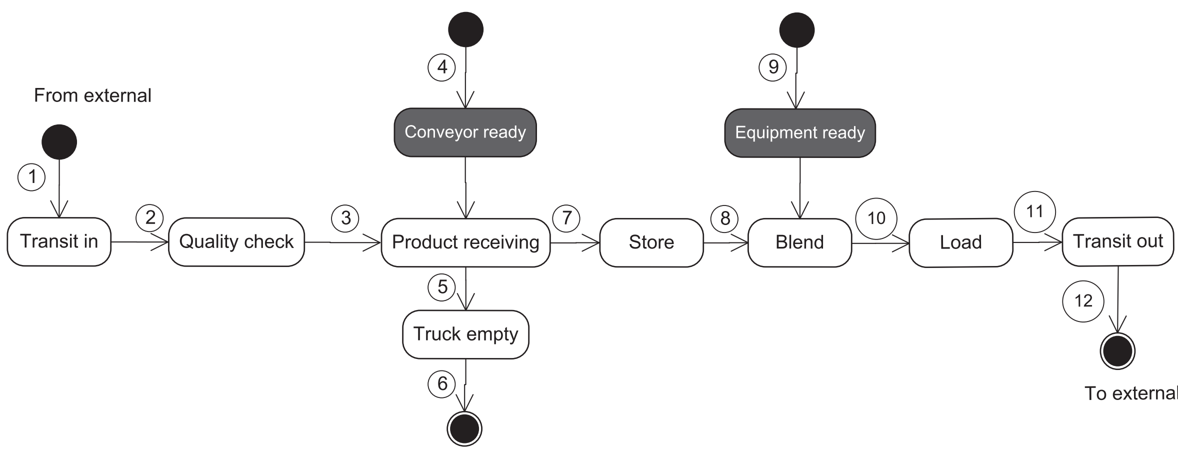

Fig. 10. States and events in elevator operation.

Table 9
Description of states for farmer entity.

State	Description	Start	End	Objects	Quality control
Planter ready	Denotes that the planter is ready to be used for planting seeds	Planter cleaned	Planter ready for use	Resource	Planter cleaned
Planting	Denotes the process of planting seeds	Seeds to be planted	Seeds planted in field	Resource, traceable item	NA
Equipment ready	Denotes that the equipment is ready for seed treatment	Equipment cleaned	Equipment ready for use	Resource	Equipment cleaned
Seed treatment	Denotes the process of treating seeds: applying pesticides, fungicides, etc.	Planted seeds to be treated	Planted seeds treated appropriately	Resource, traceable item	Application rates
Harvester ready	Denotes that the harvester is ready for harvesting the crop	Harvester cleaned	Harvester ready for use	Resource	Harvester cleaned
Harvesting	Denotes the process of harvesting the crop	Crop ready to be harvested	Crop harvested	Resource, traceable item	Yield
Transport	Denotes the process of transporting harvested crop to on-farm storage	Harvested crop to be transported	Crop transported to storage	Resource, traceable item	NA
Store	Denotes the process of storing the crop on on-farm storage	Crop ready to be stored	Crop stored in storage bins	Resource, traceable item	Grain quality (moisture)
Transit out	Denotes the process of transporting and selling the crop to an elevator	Crop ready to be transported	Crop transported and sold to an elevator	Actor, resource, traceable item	NA

either be a stakeholder, a resource or a traceable item. The kind of object/s related to a given state allow in determining the information that needs to be recorded for a particular state. Similarly, the quality control parameters are identified for each state and can be linked to either the resource or the traceable item or both. This demonstrates that the proposed model is suitable for describing traceability for food production. In addition to the states, transitions in food production for the two chosen products are also

Table 10
Description of events for farmer entity.

No.	Transition	From state	To state	Description
1	Planter made ready for use	Start state	Planter ready	This transition denotes that the planter is made ready to plant seeds
2	Equipment made ready for use	Start state	Equipment ready	This transition denotes that the equipment is made ready for seed treatment
3	Planted seeds to be treated	Planting	Seed treatment	This transition denotes that the planted seeds are treated
4	Harvester made ready for use	Start state	Harvester ready	This transition denotes that the harvester is made ready for harvesting the crop
5	Crop to be harvested	Seed treatment	Harvesting	This transition denotes that the crop is harvested using the harvester
6	Harvested crop to be transported to storage	Harvesting	Transport	This transition denotes that the harvested crop is transported to on-farm storage
7	Crop to be stored	Transport	Store	This transition denotes that the harvested crop is stored in storage bins on farm
8	Stored crop to be transported to elevator	Store	Transit out	This transition denotes that the crop is taken from storage to be transported to the next supply chain entity (an elevator)
9	Crop shipped	Transit out	End state; Another actor	This transition denotes that the crop is sold to the elevator and outside the control of the farmer

Table 11
Description of states for elevator entity.

State	Description	Start	End	Objects	Quality control
Transit in	Denotes that grain is received at elevator from farm	Grain to be received	Grain received at elevator	Actor, resource, traceable item	NA
Quality check	Denotes the process of grading grain by checking quality	Grain ready to be graded	Grain graded	Resource, traceable item	Moisture, test weight, damaged matter and foreign matter
Conveyor ready	Denotes that the conveyor is ready (clean) to be used for transferring grain	Conveyor cleaned	Conveyor ready for use	Resource	Conveyor cleaned
Product receiving	Denotes that the grain is received by conveying into the storage bins	Grain ready to be conveyed to the storage bins	Grain transferred to the storage bins	Resource, traceable item	NA
Truck empty	Denotes that the truck is emptied after transferring grain into storage bins	Grain being transferred	Truck empty	Resource	NA
Store	Denotes that the grain is stored in the storage bins at the elevator	Grain ready to be stored after conveying	Grain stored until ready to be shipped	Resource, traceable item	Grain quality; Temperature
Equipment ready	Denotes that the equipment is ready for blending grain	Blending equipment cleaned	Blending equipment ready for use	Actor, resource, traceable item	Equipment cleaned
Blend	Denotes that the grain is blended before shipment to meet customer specifications	Grain ready to be blended	Grain blended according to specifications	Resource, traceable item	Quality specifications
Load	Denotes that the blended grain is ready to be loaded on railcars	Blended grain ready to be loaded	Grain loaded on railcars	Resource, traceable item	NA
Transit out	Denotes the process of transporting the grain to a processor	Grain ready to be transported	Grain transported to a corn wet miller	Actor, resource, traceable item	NA

Table 12
Description of events for elevator entity.

No.	Transition	From state	To state	Description
1	Grain truck to be received	Start state; Another actor	Transit in	This transition denotes that the truck containing grain is in transit to the elevator
2	Received grain to be graded	Transit in	Quality check	This transition denotes that the received grain is graded by quality check at the elevator
3	Grain to be received	Quality check	Product receiving	This transition denotes that the grain is received at the elevator
4	Conveyor made ready for use	Start state	Conveyor ready	This transition denotes that the conveyor is made ready for transferring grain
5	Truck to be emptied	Product receiving	Truck empty	This transition denotes that the transfer of grain from truck to the elevator
6	Truck to exit	Truck empty	End state	This transition denotes that the empty truck left the elevator
7	Grain to be stored	Product receiving	Store	This transition denotes the storing of received grain in storage bins
8	Grain to be blended	Store	Blend	This transition denotes that the grain is blended to meet customer specifications
9	Equipment made ready for use	Start state	Equipment ready	This transition denotes that the blending equipment is made ready for use
10	Blended grain to be loaded on railcars	Blend	Load	This transition denotes that the blended grain is loaded on railcars
11	Grain to be transported to processor	Load	Transit out	This transition denotes that the railcars are prepared to be transported to the next supply chain entity (corn wet milling plant)
12	Grain shipped	Transit out	End state; Another actor	This transition denotes that the grain is transported to the corn wet milling plant and outside the control of the elevator

described. An event takes place when a traceability object transitions from one state to the next. It is important to link each transition to the corresponding states. Identifying the transitions in food production helps in determining the transformations that occur so

Table 13
Frozen mackerel production transitions mapped to EPCIS ObjectEvent.

EventName	Related to transition	BizStep	Disposition	Quality parameters related to state
Goods received	1 2 3	Bizstep:receiving	Disposition:in_progress	Transit in Pump ready Product receiving
Goods created	10 and 15	Bizstep:commisioning	Disposition:active	Sorting Packing
Goods entered storage	16 25	Bizstep:storing	Disposition:sellable_not_accessible	NA
Goods left storage	12 18 22 26 29	Bizstep:stocking	Disposition:sellable_accessible	Store
Goods staged	27	Bizstep:staging_outbound		NA
Goods shipped	28	Bizstep:shipping	Disposition:in_transit	NA

Table 14
Frozen mackerel production transitions mapped to EPCIS AggregationEvent.

EventName	Related to transition	Action	BizStep	Quality parameters related to state
Goods packed	11,13,14 21,23,24 30	ADD	Bizstep:packing	Packing machine ready Packing Pallet Equipment ready
Goods unpacked	29	DELETE	Bizstep:unpacking	Store
Goods transformed	16 17	OBSERVE	Bizstep:transforming	Refrigerating
Goods split	10	ADD	Bizstep:transforming	Sorting

Table 15
Corn wet milling transitions mapped to EPCIS ObjectEvent.

EventName	Related to transition	BizStep	Disposition	Quality parameters related to state
Goods received	1 2 3	Bizstep:receiving	Disposition:in_progress	Conveyor ready Product receiving
Goods created*	17 22 29 30	Bizstep:commisioning	Disposition:active	(Oil) Steep tank ready, Steep, Degerminator ready, Degerminate, Germ separation, Wash & Dry, Oil extraction (Gluten Feed) Steep tank ready, Steep, Evaporator ready, Evaporate, Feed drier ready, Dry (Hulls) Steep tank ready, Steep, Degerminator ready, Degerminate, Germ separation, Grinding mill ready, Grind, Wash, Dry (Gluten Meal) Steep tank ready, Steep, Degerminator ready, Degerminate, Germ separation, Grinding mill ready, Grind, Wash, Centrifugal separator ready, Centrifuge, Dry (Starch) Steep tank ready, Steep, Degerminator ready, Degerminate, Germ separation, Grinding mill ready, grind, Wash, Centrifugal separator ready, Centrifuge, Washing filter ready, Starch wash, Dry (Syrup/sugar) Steep tank ready, Steep, Degerminator ready, Degerminate, Germ separation, Grinding mill ready, Grind, Wash, Centrifugal separator ready, Centrifuge, Washing filter ready, Starch wash, Syrup/sugar conversion
Goods entered storage	6 31	Bizstep:storing	Disposition:sellable_not_accessible	Product receiving
Goods left storage	7 32	Bizstep:stocking	Disposition:sellable_not_accessible	Store 1 Store 2
Goods staged	33	Bizstep:staging_outbound		NA
Goods shipped	34	Bizstep:shipping	Disposition:in_transit	NA

* The quality parameters are identified for combination of states for each product (oil, feed, etc.) and mapped to EPCIS ObjectEvent named "Goods created". The corresponding state in the statechart is "Pack".

that appropriate information can be stored corresponding to these transitions. It must be noted that the product, process and quality information is integrated in this model and corresponds to a given state or transition in food production.

The use of EPCIS enables efficient information management in food production. Since, the current EPCIS specification does not cover all of the events identified by the state-transition model, the main missing event being transformation of products; we present the use of current specifications to model traceability and quality information. The transitions related to logistics processes in frozen mackerel production are mapped to EPCIS ObjectEvent while the ones related to product transformations (aggregation and splitting) are mapped to EPCIS AggregationEvent.

Because of the continuous nature of the corn wet milling process, it is not feasible to discretely capture EPCIS events for each product transformation and therefore, it was impractical to map transformations to AggregationEvent. However, we can use the state-transition model to identify states with related quality information that can then be mapped to an EPCIS event when the product can be identified as a discrete unit.

Current industry practices involve obtaining food production information from several isolated systems, such as process maps, quality management systems, logistics and supply chain management systems. The approach presented in this paper integrates all this information into one model. Therefore, all the information about the food product, the processing steps it undergoes as well as the material flow and logistic processes can be obtained from one system. This functionality is of great importance in industry where information is often lost or information access is time consuming because of a lack of communication between different systems. In addition, this model also presents a sequential view of food processing transitions.

Traceability is a tool to connect a specific food item to all kind of information that can be captured during its lifetime. Event-based data capture gives the ability to generate traceability graphs to be traversed in the case of a food safety incident, whether originating upstream, within, or downstream of a specific location in a supply chain. Food safety issues can either be linked to contamination in the received input factors or may be caused by unsafe processes, storage or transport. Monitoring the flow of goods through a production facility and all related transitions is very important to document food safety properties.

The generic model was based on the model developed by Sørensen et al. (submitted for publication). The event "Goods transformed" was mapped to the EPCIS AggregationEvent with action value "ADD" in the generic model. However, for frozen mackerel production, as shown in Table 14, the "Action" value for Event "Good transformed" was set to "OBSERVE" which is connected to the quality information related to state "refrigerating" because in this case, the objects are not aggregated or split but only the physical properties are altered (fresh fish to frozen fish). This adaptation to the specialized case could be generalized back to the generic model.

4. Conclusions and future work

The current EPCIS specification does not provide the functionality to manage product transformations which are crucial for food traceability purposes. This paper has presented an approach to manage food information using the current specification. In order for any traceability system to meet requirements of ensuring food quality and safety, there is need to integrate all this information into a functional system so that a problem caused either due to processing or handling/logistics can be identified and traced back to the source. The state-transition model presented integrates all product, process and quality information as well as material flow and logistics processes into one system. This model forms the basis for mapping food production transitions to EPCIS events and linking them to corresponding food quality parameters.

EPCIS seems to be an efficient way of managing food information for discrete food production. However, not built for continuous processes, it can still be used to achieve a certain level of discretization. This is done by first, using the state-transition model to identify the states where the product undergoes a continuous process. Second, linking the quality information identified in these states to the subsequent state where the product is identified as a discrete unit.

Monitoring and recording state changes in a production process may be difficult to achieve practically in the short run, but the technological evolution within RF-based technology and digital sensing is very promising to enable a holistic picture of the history of any food item. Electronic recording and collection of information will be paramount to enable the different stakeholders in the food chain to effectively provide documentation of and ability to react to food safety issues.

The modeling approach presented in this paper would be tested in future by conducting pilot studies in various food processing environments.

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