UNIVERSITÀ DELLA CALABRIA

UNIVERSITA' DELLA CALABRIA
Dipartimento di Ingegneria Meccanica, Energetica e Gestionale

Dottorato di Ricerca in

Ingegneria Meccanica

Con il contributo di

Commissione Europea, Fondo Sociale Europeo e Regione Calabria

CICLO XXVI

TITOLO TESI

EFFECTIVE TRACEABILITY MANAGEMENT:

THE GLOBAL TRACK&TRACE SYSTEM

Settore Scientifico Disciplinare ING/IND-17

Coordinatore: Ch.mo Prof. Pagnotta Leonardo

Firma ____________________

Supervisore/Tutor: Ch.mo Ing. Giovanni Mirabelli

Firma ____________________

Dottorando: Dott.ssa Teresa Pizzuti

Firma ____________________

“To myself,
for the great effort.”

Table of Contents

Preface

This thesis presents the results of the research activities carried out over the three years of the PhD course at the Mechanical Department of the University of Calabria (Italy) and at the Computer Sciences Department of the Universidad Pontificia Comillas (Spain). The PhD course focuses on the Design of an Effective Traceability System.

In particular the PhD focuses on the methodological approach followed in order to model and develop a traceability system aimed at improving the supply chain management of the companies operating in the food sector. The system itself can assist users in case of food outbreak diseases and in case of recall procedures through the identification of the most relevant information for the problem resolution. By implementing the developed Global Track &Trace System at a high level of the supply chain, the competitiveness, and the effectiveness of the supply chain itself can be improved.

This thesis is a result of a multi-disciplinary research, which involves three main subjects: Logistics, Transformation and Production. The focus of the thesis is based on the Food Sector. The research work has been co-founded with the support of the European Commission, the European Social Found and the Italian Region of Calabria. Consequently, the focus and the domain of the thesis were mainly oriented by a deep analysis of the regional context of Calabria in order to identify some solution form improving the effectiveness and efficiency of the companies operating in the region itself. The results of the context analysis highlighted the presence, in Calabria, of a relevant number of companies operating in the agro-food sector. The agro-food sector, in fact, involves the majority of the Small and Medium Enterprises (SMEs) located in the region. To this end, the main aim of the research work is the improvement of the supply chain management of these companies and the quality and safety of their outputs, through the maintenance of information about products at each step of the supply chain. The final result of the research consists in such innovative system for products traceability, particularly devoted to the maintenance of traceability in the food sector.

Currently, traceability is one of the main issues attracting the attention of private companies and public authorities because of its relevance in the maintenance of food quality and safety. The implementation of an appropriate traceability system, able to guarantee the continuous monitoring of the flow of products and of information and capable of facilitating the process of products certification, is strategically essential to achieve continuous quality improvements.

After the serious incidents that invested the food sector (BSE, dioxin contamination, blue mozzarella, Escherichia Coli diffusion, etc.), several institutions have promoted the introduction of control systems able to effectively trace not conforming goods and to identify the factors of risks which compromise food quality and hygiene and create dangerous conditions for human health. Moreover, although important regulations have been introduced to define the general principles of food quality and safety, the food sector is continuously exposed to risks and dangers. To reduce this exposure, the widespread adoption of efficient traceability systems is desirable.

The ability to track and trace every single unit of product depends on the supply chain traceability systems, which in turn depends on the internal data management system and on the procedures for the information transmission among the different actors of the supply chain.

To this end, the research objective of this work is to develop a general framework for the traceability of food products, able to support quality and safety control. The solution adopted for the information management is generally applicable, which means that it meets the requirements of different types of food industries. The model can be applied in real-life situations that might benefits from the traceability solution.

Teresa

Abstract

The evolution of the information technologies and their impact in human life promotes an increasing demand of reliable information when security and safety plays a primary role. Nowadays, food traceability represents one of the main concerns for public authorities and industries. In particular, traceability has become a critical part of the agro-food industry. The aim of the agro-food traceability is to allow the full monitoring of a product in the supply chain and to trace the history of a good from the producer to the consumer. It is therefore a preventive instrument of quality and safety management. The proposed research study is oriented to the definition of a new Global Track and Trace (T&T) System in which the entire world's partners of a product's supply chain are involved. In this system the functionalities of a conventional traceability system are combined with the functionalities of a Food Ontology for the traceability domain. The Food Ontology is defined in order to solve the issue of information-systems integration and standardization. The idea is to recover and to have available in a short time period all the relevant information about a product. This is a critical issue especially in case of foodborne outbreak and food crisis. The proposed framework can be a strategic approach for information and process management, also at the farm level. The model permits the Supply Chain optimization and the food quality management. The system itself can be a valuable tool for assuring customers and promoting the liability of the production process, along with the compliance with the regulatory standards aimed at defining quality and safety requirements.

Keywords: *Food Supply Chain, Tracking, Tracing, BPMN, Information system, Ontology.*

Abstract

L'accresciuto interesse per la tracciabilità dei prodotti persegue la duplice finalità di rispettare le normative vigenti e di accrescere la fiducia dei consumatori migliorando sia l'immagine delle aziende sia dei prodotti da essi venduti. Non secondaria è la possibilità di compiere interventi rapidi e mirati capaci di ridurre i rischi di diffusione di intossicazioni alimentari derivanti da prodotti contaminati potenzialmente pericolosi per la salute dei consumatori. Dunque, un efficiente sistema di tracciabilità deve essere in grado di garantire la tracciabilità e la rintracciabilità dei prodotti. Il termine tracciabilità fa riferimento alla capacità di seguire un prodotto lungo la catena di fornitura, registrando i dati relativi a ciascuna fase produttiva, mentre la rintracciabilità è definita dal Regolamento 178/2002 della Comunità Europea come "la possibilità di ricostruire e seguire il percorso di un alimento, di un mangime, di un animale destinato alla produzione alimentare o di una sostanza destinata a far parte di un alimento attraverso tutte le fasi della produzione, della trasformazione e della distribuzione". Negli ultimi anni numerose iniziative sono state poste in atto dal punto di vista normativo per il mantenimento della tracciabilità dei prodotti alimentari. Come conseguenza di tali iniziative, differenti sistemi di tracciabilità sono stati proposti e implementati in diversi Paesi. Tuttavia, i recenti "food accident" hanno mostrato i limiti di questi sistemi e l'incapacità degli stessi di legare tra loro le diverse informazioni registrate lungo la supply chain con un conseguente aumento dei tempi per l'ottenimento dei dati necessari a fronteggiare le crisi derivanti da intossicazioni alimentari. Nasce quindi l'esigenza di sviluppare e proporre nuovi sistemi di tracciabilità più efficaci, in grado di registrare tutte le informazioni sull'intero ciclo di vita di un prodotto alimentare. Lo studio di ricerca proposto in questa tesi di Dottorato è orientato alla definizione di un nuovo Global Track and Trace (T&T) System per la tracciabilità globale dei prodotti in cui sono coinvolti tutti gli attori che partecipano alla realizzazione di un prodotto alimentare. Il sistema è stato ottenuto combinando le funzionalità di un sistema di rintracciabilità convenzionale, ottenuto mediante la modellazione dei processi di business e dei dati coinvolti nell'intera filiera, con le funzionalità di una Ontologia opportunamente definita per rappresentare per il dominio di conoscenza della tracciabilità alimentare. Il quadro proposto può essere un approccio strategico per la gestione dell'informazione e dei processi. Il modello consente l'ottimizzazione della supply chain e la gestione e assicurazione della qualità degli alimenti.

Keywords: *Filiera agro-alimentare, Tracciabilità, Rintracciabilità, BPMN, Ontologia*

Chapter 1:

General Introduction

1.1 Introduction

1.2 Problem Statement

1.3 Objectives

1.4 Practical Implications

1.5 Dissertation Organization

1.1 Introduction to the research problem

The increasing interest in food traceability directly interfaces with customer demands for food quality and safety. Customers are more and more exigent and they require the governmental control of the whole food system. As a consequence, different types of traceability systems are emerging as a result of regulatory interventions, at an industry-wide level, and as a competitive strategy at the level of individual supply chain. Moreover, the key issues frustrating the job of food safety agents are the inability to link food chains records, inaccuracy and errors in records and delays in obtaining essential data. The recent case of E. Coli in Germany is an example of the strong reaction of the market to a food crisis. In such a contest, the main goal of this research work is the development of a general framework for the traceability of food products able to support quality and safety control. Through the development of a global traceability systems it is possible to enable more targeted recalls, to easily identify the product's origin and consequently to limit the product recall only to the products actually affected by contamination (Pouliot and Sumner, 2009). A new traceability framework can be defined combining the advantages of an information system for food tracking with the advantage of an ontological model in which relations between concepts are standardized. This system can help governmental authorities in case of food outbreak disease and offer more information to the customers on the products they eat.

1.2 Problem Statement

Traceability systems are emerging in various guides, as result of both regulatory and industry initiatives.

A traceability system should satisfy three key functions (Golan et al., 2004; Hobbs et al., 2005, 2002):

- It should efficiently allow the trace-back of products and inputs when a food safety or herd health problem occurs. In such a case, efficient and timely trace-back could limit the size of product recalls and limit the number of people exposed to tainted food, thereby limiting human-health impacts, minimizing productivity losses from illness, etc.
- It should reduce information costs for consumers by identifying credence attributes through the labeling of environmentally friendly production practices, or assurances about feed, other ingredients or production practices. In this case the traceability system is directly connected with the quality system of the company.
- It may be considered as a means of strengthening liability incentives to produce safe food.

Potential of traceability systems and the numerous advantages that can be obtained through its implementation have been well documented in literature (Lo Bello et al., 2005; Moe, 1998). Figure 1 provides a visual representation of the potential public and private benefits from traceability, with the size of the circle representing the relative size of the potential benefits (Sparling et al., 2011). Benefits can accrue to the public in terms of more rapid and accurate response to food safety events but also in providing consumers with more information on the origin of food. Business stands to realize opportunities through reduced recall scope, greater quality assurance, and values capture and supply chain efficiency.

Despite multifaceted potential benefits, the operational conditions of current traceability systems are kept at bare minimum merely to fulfill legal requirements. Particularly Small and Medium Enterprises (SMEs) do not use traceability systems or use paper based systems due to the limited scale of their operations, the necessity of heavy investment and the nature of their manufacturing process (Nishantha et al., 2010). Meeting the traceability standard set by an industry organization or by government regulation generally affects the cost of production per unit of food. In addition, many barriers hinder the successful implementation of traceability, the major are: (i) necessity of costly investments, (ii) reluctance to change, (iii) lack of skilled staff to handle advanced systems and (iv) limitation of existing traceability systems. Moreover, tracing and tracking capabilities are crucial to confine the reaction to possible hazards and reduce the recovery cost (Bechini et al., 2005).

Nowadays, recent food safety incidents (e.g. dioxins in animal feedstuffs in Belgium, E. Choli in German) have demonstrated that traceability is a “buzz word” with regard to food: traceability systems have been shown to be weak or absent and hence slow or unable to assure consumers the food safety. In such cases, food recalls or warning have been applied to all suppliers, even to the supplier of products that did not contributed to the contamination. This is one of the main issues of traceability that can be easily solved through the introduction of a global traceability system capable to immediately identify, in case emergency, the origin of a food disease and to enable more targeted recalls. To take the today's requirements on food quality for health care into consideration, additional data that are not strictly necessary to traceability must be stored. For instance, for a cooking activity, oven temperature and humidity can be considered as important parameters in case of hazard. For a cultivation activity, operations on the parcel are fundamental to trace the proximity of the land of cultivation to a source of pollution.

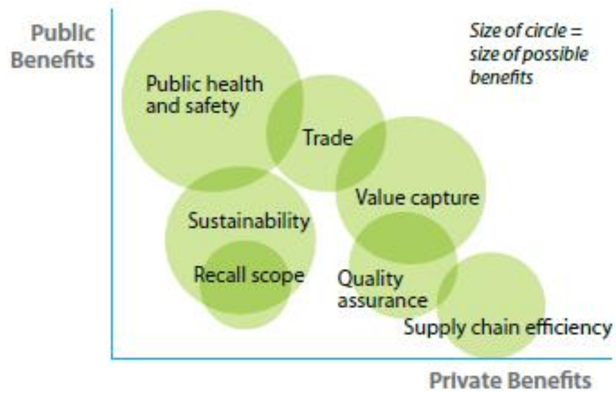


Figure 1 - Benefits from Traceability
Source: An Appetite for Traceability: results from OnTraceability Conference 2011

Regarding to the products identification mechanisms, today a variety of lot code markings and systems exists for products identification. Moreover, while these have merit, they do not link across the life cycle of the world's food supply. Generally information is recorded into data centers internal to the company connected in order to create a distributed database. With proper authority and access, agencies can query the global network of data centers to investigates and respond to food contamination concerns at Internet speed. In addition, when some problem occurs and the database is disconnected from the network, the traceability is lost. For this reason is highlighted the importance of contain all the information on the life of a products in its label.

In recent years the traceability of food products has attracted the attention of many researchers for several reasons (Jansen-Vullers et al., 2003): first traceability, according to the Regulation of the European Community N. 178/2002, has become a legal requirement within the European Union from January 1, 2005 (European Commission, 2002); secondly, food companies tend to view traceability as a strategic tool needed to increase consumer confidence and improve the both image of the company and of a specific product.

Moreover, currently consumers have no access to the information on the real origin of products, the activities in which the products were involved and the operators who manipulated it. Many initiatives have been started in the area of food traceability in the last decade and several authors have been interested in the development of food traceability systems (Bechini et al., 2008; Bevilacqua et al., 2009; Jansen-Vullers et al., 2003; Regattieri et al., 2007; Ruiz-Garcia et al., 2010; Thakur and Donnelly, 2010; Thakur and Hurburgh, 2009; Thakur et al., 2011a, 2011b; Verdouw et al., 2010). Despite the numerous efforts for developing effective traceability systems, current results obtained reveal some critical limitation of existing traceability systems (Bechini et al., 2005). Successful implementation of traceability systems requires elevate investment costs, staff training and global legal requirements.

The development of a traceability system has to face with other issues, especially in case of continuous transformation processes. Many of the difficulties in the phase of implementation of traceability systems within manufacturing systems are related to the determination of the traceable product unit size. Some of the key areas of difficulty are (i) continuous and batch processing and (ii) the transfers between such processes within the manufacturing system (UK Standard Organization). For instance, in case of handling of bulk products (sugar, salt, glucose syrup, flour), even where goods are delivered with clear batch identification in a tanker, they may be emptied into a single silo and mixed with earlier deliveries, so onward traceability may not be maintained. Silos also have dead zones in filling and emptying, which can cause the blending of successive batches. To this end, information about all the products used in the production process must be maintained, also referring to water used in food processing and manufacture.

1.3 Research Questions

Robust and effective systems/frameworks to provide "farm to fork" traceability of food are not present within the food industry at the moment, except in some very specific areas (e.g. beef and some retailer chains for meat and produce). We think that a Global Track and Trace (T&T) System is required to solve the problems stated in the previous paragraph. Following this line, the study is oriented to the definition of a new Global T&T System in which the entire world's partners of a product's supply chain are involved. In this system the functionalities of a conventional traceability system are combined with the advantages of Ontologies.

The aim of the study is twofold and it consists of:

1) Developing a traceability system prototype in a cost and user friendly manner in order to facilitate the integration of information across the entire supply chain and to ensure consumer trust and compliance with legal and quality standard;
2) Facilitating the identification of foodborne outbreak disease.

In the development of the general framework, the following questions have been considered:

(a) *Internal systems for registrations.* Traceability requires data from systems and registrations which have initially not been set up for products traceability but for other purpose, such as sales, purchasing, production, and laboratory management. It is necessary to consider interactions between traceability and other management systems. Within food manufacturing it is common to see traceability systems used alongside HACCP to provide verifiable documentation for monitoring the critical control points and allows remedial action to be taken if product falls below quality. Some manufacturers consider their traceability systems (dominantly linked to process control) to be separate to HACCP (linked to quality management). But others consider traceability and HACPP to be irretrievably intertwined as part of a product quality management system. These may not necessarily be opposing views, but represent different viewpoints related to how the systems have been implemented in practice.

(b) *Lack of standardization.* From the regulatory point of view, actors positioned within different context (UE, Japan, USA, etc.) deal with different implementations of products responsibility and liability. The regulatory framework for food traceability, in fact, is wide and diversified. From an information perspective, another important bottleneck is represented by the lack of standards for information encoding and exchange.
(c) *Financial obstacle*. The introduction of an information system for food traceability requires initial investments that represent a financial obstacle above all for Small and Medium Enterprises (SMEs). Many complex technologies only lie within reach of the big players. For the small players in the field (e.g. the farmer) these technologies are financially not feasible. Nevertheless, the large majority of companies involved in food chains are SMEs and consequently simple tools need to be available for their use.
(d) *Implementation issues.* The implementation of T&T must not be underestimated because it requires some changes in the way of working. All employers working with the T&T system must receive proper education and everybody should know the importance of extended registration.
(e) *Privacy and rights problems.* The flow of products lots along the supply chain is associated with the information exchanges among responsible actors and possibly third-party organizations. Because of its significance for the concerned enterprises, traceability and quality information must always be transmitted in a secure and reliable way. To this end, integrity requirements must be considered such as (i) access and user rights, and (ii) protection of privacy, autonomy, commercial interest and legal protection in case of responsibility.

On the base of the above-mentioned questions, a new Global T&T Framework for Food is developed taking into consideration the following assumptions:

- ✓ The traceability systems should connect easily with other systems that are pre-sent inside the company. Actors in the Supply Chain have their own Enterprise Resource Planning (ERP) and quality systems: in such a context, a tracking-tracing infrastructure must cooperate with all systems and infrastructures present in the company.
- ✓ The system must be easy to understand. A simple way of registration with bar code or RFID may increase the level of acceptance and decrease the possibility of mistakes (lots code must be automatically generated by the systems).
- ✓ Interchange standards are required to enable interfacing between enterprise systems. For a successful information exchange in the chain, we need to solve the issue of information-systems integration and standardization (Beers et al., 1994). Any enterprise must be able to connect to the information infrastructure so as to exchange information in the supply chain. To ensure system interoperability and communication between the different actors, it is necessary to identify a standard for encoding information not only for common companies operating in the single chain, but for all reference operators (De Cindio et al., 2011a).
- ✓ Agreements can be made on the exchange of information. In addition, the in-creased cooperation between the constituting organizations represents a possible way of dealing with uncertainties in the Supply Chain.
- ✓ The global traceability system should be developed and maintained with reduced costs. Modern communication technology can help SMEs in the development of their

internal traceability system. To this end, access to information technology and Internet may need to be facilitated.

- ✓ Such a kind of communication, especially when different enterprises are involved, can be regarded as an e-business transaction. For this reason, the adoption of e-business protocols becomes both appropriate and convenient. Electronic Business Extensible Markup Language (EbXML) can help in the phase of information exchange (Olivier et al., 2009). The ebXML specification provides organizations with a common, extensible, and automated method of exchanging business messages, conducting trading relationships, communicating data using common terms, and defining and registering business processes (ebXML official website). In addition, ebXML is a promising standard also for e-government distributed applications: in this perspective, monitoring activities from official organizations would be made easier by a common communication infrastructure among the actors taking part to the traceability system.

Summarizing, the main goal of the proposed research work is the creation of a "re-al" and "working" Global Track&Trace System for Food where all the actor in the chain are able to keep and share information on products and processes.

1.4 Practical Implications

The proposed framework can be a strategic approach for information and process management, also at the farm level. The model will lead to the Supply Chain optimization and the improvement of the food quality management.

The integration of the Global T&T Food System with the Food Track &Trace Ontology is a strategic approach that can help in the traceability maintenance. Through the final system, each food supply chain operator can:

- guarantee the origin and the quality of a food product;
- assure the compliance with regulation;
- improve Logistics;
- improve inventory management;
- manage the whole products lifecycle.

In addition, recorded data can be used for several analyses such as for the definition of:

- type and quantity of cultivation (plant, animals or fresh) per Locality or Region;
- type and quantity of cultivation per period or year;
- land surface availability to be allocated to a particular product;
- level of activities of a particular Locality/Region/Country;
- previsions;
- recommendations.

Finally, data and time information recorded in each production step help in identifying non-compliance in the case of storage. The system, in fact, can be used in order to avoid food fraud such as off-season sales and certify the total quality of the product.

1.5 Dissertation Organization

The PhD work is organized in five chapters. Chapter 1 defines the Problem Statement, enumerates the different research questions and introduces practical implication of the final research work. Chapter 2 provides a brief overview on the main concepts related with food traceability, focusing on benefits and disadvantages that can be obtained through the implementation of a traceability system and introducing standards and technologies that can be used for the maintenance of food traceability at the company level and the level of the entire supply chain. Chapter 3 passes through the description of several research works, as they run through the literature, according to the methodology or scientific approach they propose. The initial search identifies a huge number of references, which were reduced on the base of contents and quality. In particular two different parts have been analyzed: (i) regulation, recommendation, and practical guides; (ii) scientific literature. The analysis of the scientific literature highlighted the presence of three main categories of works, each of one devoted to the definition of Mathematical models, Information model and Ontological models for the traceability management. This PhD thesis comes in help of such research shortages by proposing a design methodology for the development of an effective traceability system obtained combining the advantages that can be obtained through the implementation of some informative systems with the advantages that can be obtained using ontologies defined for modeling the traceability domain of food.

The main results of the research activity are presented in Chapters 4 and Chapter 5. Chapter 4 describes the design and development of the Global Track&Trace System for Food. In particular, the first section of Chapter 4 describes the methodological approach followed for the design and development of the Track and Trace Information System, with a particular focus on the general architecture that characterize the system. Successful cooperation within chains requires common vocabulary for inter-organizational communication, and requires the issue of information-systems integration and standardization to be resolved. To this end, in the second part of Chapter 4 the Food Track &Trace Ontology (FTTO) is presented, with the main aim of describing classes and relationship between classed. The ontology definition helps in the semantic research in case of food contamination and product recall.

Chapter 5 presents some case studies related to the application and adaptation of the Global Track& Trace Framework. Practical examples allow understanding the use of the methodologies followed for the Global Track and Trace System. In addition, the first section of Chapter 5 the working principles of the Global Track&Trace Systems are explained.

Analyzing the core stages of the research work, the work progresses through the following steps:

Design and Development of a Web Based Track & Trace Information System. The general framework is obtained through the definition of a T&T Information System. The development of the information system requires the modeling of business processes and associated data results. In the proposed framework the supply chain has been initially modeled according to the BPMN standard. BPMN allows for reconstructing patterns of process or the Business Process Diagram (BPD) by means of graphs or networks of objects. These objects represent the activities of the process and they are connected by control flows that define logical relationships, dependencies, and the execution order. From the modeling and the analysis of product processes in the chain, we want to become aware of data to be recorded. A general data model is proposed enough flexible for developing the strategy of traceability and open to incorporate new future features to be taken into account. The data modeling and management approach is achieved through the creation of a web-based system. The software tool utilized directly generates a web application model that assures the connection to each operator of the supply chain. Each agent stores the data of the product worked and collaborates with the other neighbor agents of the track chain by making available all information necessary for traceability. The created framework and its corresponding application is an important tool for management of all the information related to the traceability process.

Food Ontology Definition. A new Food Ontology is developed for the domain of food traceability. To enable information sharing, data and the way they are organized should be standardized and their meaning and carrying semantics should be commonly agreed by the different operators along the food supply chain (Salampasis et al., 2008). Both products and processes may form key components (known technically as core entities) in a traceability system with information stored in relation to each. The new Food Ontology is defined to set up a traceability semantic model in order to reuse the information resources in the process of tracing and promote the accuracy and efficiency of information management. The quality ontology proposed by (Kim et al., 1995) represent, at the moment, the base for a lot of research work in the field of traceability. Based on the ontology, a semantic research can be made and it can help in the phase of products tracing.

Chapter 2

Fundamentals of Food Traceability

2.1 Introduction to Traceability

This section provides a brief overview on the main concepts related with food traceability, focusing on benefits and disadvantages that can be obtained through the implementation of a traceability system and introducing standards and technologies that can be used for the maintenance of food traceability at the company level and the level of the entire supply chain.

A well-organized supply chain should have the ability to reconstruct the history of each product and follow the food through the various processing steps, identifying and recording the materials used and the operators involved, correctly combining this information to the single product package introduced in the market.

This result can be conveniently achieved if each company of the supply chain adopts an internal system for controlling and recording information ("*internal traceability*") and if transitions between the actors are regulated and managed in a coherent and shared form ("*external traceability*"). In this way is possible to trace the path followed by a food product that moves from "farm to fork". A traceability system requires consequently the definition of internal system for recording information and facilitating the identification of the product's origin and the utilization of particular technologies able to maintain the connection between products and related information.

2.2 Traceability Definition

Several definition of Traceability has been specified in different regulatory standards. The International Standard Organization defines traceability as the "ability to trace the history, application or location of an entity, by means of recorded identifications (*UNI EN ISO 8402: Sistemi Qualità. Gestione per la Qualità e assicurazione della Qualità - Termini e definizioni*, 1995).

In the food sector, the Codex Alimentarius Commission introduced the term "traceability" in 1999 to define the "ability to trace the history, application or location of an entity by means of recorder information. In Europe, the regulation (EC) 178/2002 represents the main regulatory reference for the food legislation on food traceability and safety. The Regulation EC 178/2002 defines traceability as "the ability to trace and follow food, feed, and ingredients through all stages of production, processing and distribution" (Art. 18, EC.178/2002).

In the scientific literature, (Moe, 1998) defines traceability as "an ability by which one may track a product batch and its history through the whole, or part, of a production chain from harvest through transport, storage, processing, distribution and sales, or internally in one of the steps in the chain, for example the production step.

The maintenance of traceability is a complicated and expensive process, especially with regards to processed food. In case of processed foods, in fact, different lots of various raw materials are combined into several production batches typically distributed in various points of sale (Hu et al., 2009). Hence, data to record must include information on products and on processes that operate on products (such as transport, transformation or combination). Kim et al., (1995) state, in fact, that a traceability system must be able to track both products and activities operate on products. This goal can be reached through the implementation of an efficient traceability system supported by appropriate architectural solutions (Bechini et al., 2008). In particular, a traceability system must support information tracking and tracing. The meaning of tracking and tracing is defined in the next sub-paragraph.

2.2.1 Tracking and Tracing

Traceability is obtained through the combination of two different processes: tracking and tracing (Figure 2). These terms are often used in an interchangeably way even though they have different meanings. *Tracking* is the informative process by which a product is followed along the supply chain keeping records at each stage, from the production to the transformation and distribution process. *Tracing* is the reverse process of tracking. Tracing is defined as the ability of reconstructing the history of a product, identifying its origin through the complexity of resources involved in its lifecycle. While the tracking process operates in order to record the important information at each step of the supply chain, the tracing process represent the ability of identify the origin of a product through the analysis and elaboration of the information previously recorded by each actor involved in the chain.

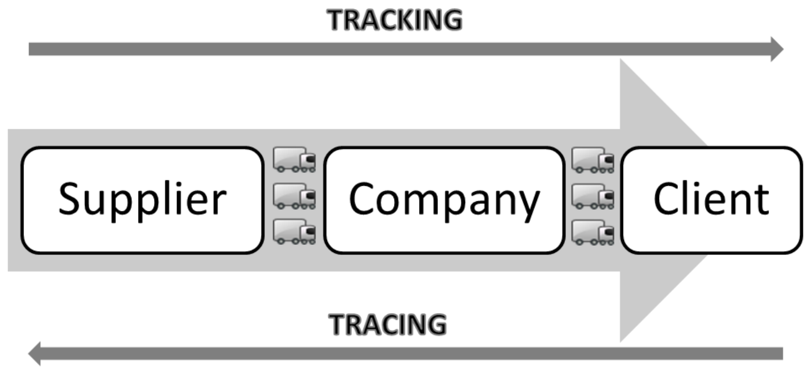


Figure 2 - Tracking and Tracing

In the context of this PhD thesis, the term traceability system is used for identifying the informative system used to assist in the process of information tracking and tracing.

The operations required by a traceability management system can be divided into two main activities, which refer to internal traceability and supply chain traceability. The *internal traceability* is realized by internal procedures, different for each business, that allow tracing the origin of products involved in the production process, process operations and food destination. The food supply chain traceability or *external traceability* is guaranteed by the integration and coordination of the tracking procedure adopted by each operator of the chain, and represents the ability to follow the path of a specific unit of product along the production chain. It is generally obtained through the linkage of the different traceability systems internal to the company belonging to the food supply chain to each other.

In particular, the definition and implementation of a food supply chain traceability system depends on both the supply chain and the relationships between the various partners that collaborate in the production process. Manufacturers, distributors, authorities and consumers should be able to track and identify food and raw materials used for food production to comply with legislation and to meet the requirements of food safety and food quality (Ruiz-Garcia et al., 2010). This result can be conveniently achieved if each company along the supply chain is able to adopt a system of internal control and recording (internal traceability) information and if transitions between actors are regulated and managed in a coherent and shared form (De Cindio et al., 2011b).

2.3 Traceability in the Food Sector

This section introduces the concepts of food supply chain and traceable resource unit or lot that are required for the traceability maintenance.

2.3.1 Food supply Chain

The Food Supply Chain (FSC) is a complex structure in which are involved several actor that contribute to the production, distribution, marketing and supply of food products.

On the basis of the definition provided by the Food Traceability Handbook (Revision Committee on the Handbook for Introduction of Food Traceability Systems, 2007) five basic actors are involved in a typical FSC. These actors are: the primary producer, the processing company, the distributor, the retailer and the transporter or third part carrier. Each actor performs a specific task. The primary producer, such as the fisherman, the grower or the farmer, is devoted to the production of raw material and ingredient that are successively transformed by the processing companies or factories; the transporter moves the products from one actor to another; the distributor handles the food commodities; the retailer sells the food directly to the consumer. The presence of these actors highlights that the concept of food chain is extended both to the individuals upstream and downstream in the supply chain.

A typical FSC differs from the other supply chain because of the perishability that characterizes food product. As specified by Nishantha et al., (2010) the time windows in which food products moves from the raw material producer until the consumer remains relatively shorter in FSC. Food products, in fact, are extremely time critical and, by their nature, they are characterized by a short shelf. Food products are perishable and the harvesting means, transformation processes, transporting ways, and storage conditions condition their shelf life. This aspects, along with the wide variety of food products, contribute to making more difficult the design, implementation, and management of an efficient system of traceability (De Cindio et al., 2012a).

In Italy, the food sector is formed by four main subsectors:

- ✓ Agricultural Industry (which includes agriculture, livestock farm and aquaculture);
- ✓ Food Industry (for food transformation and conservation);
- ✓ Food Distribution Sector;
- ✓ Commercial Catering and Restaurants.

Figure 3 shows a typical agri-food supply chain. As before mentioned, the food supply chain can assume different configuration according with the number of actors which collaborate for the definition of the final product and of the number of processes operated on primary food commodities and processes food before they are introduced into the market. Two actors are always present in the food supply chain: the primary producer and the consumer. When the activities of production, processing and sales are carried out directly from the farm, it refers to the so-called short chain. Typical examples are the co-operatives of farmers cultivating fruits and vegetables that they directly sell them to the final customer in bulk or packaged without any commercial intermediary. Long food supply chains refer to complex agro-industrial systems in which the food, before reaching the consumer, passes through different stages of processing, transportation and distribution that are usually managed and controlled by different actors.

Processes operated in a generic food supply chain include agricultural processes, food transformation processes and other business processes of support such as procurement, inventory management, packaging and labeling, shipping, transportation. The field of agricultural and food transformation processes is wide and diversified. Agriculture is the process of producing food, feeding products, fiber and other desired products by the cultivation of certain plants and the raising of domesticated animals (livestock) or of fish and shellfish. The practice of agriculture is also known as farming. The outputs of the agricultural processes in the context of this research work are called primary food commodities.

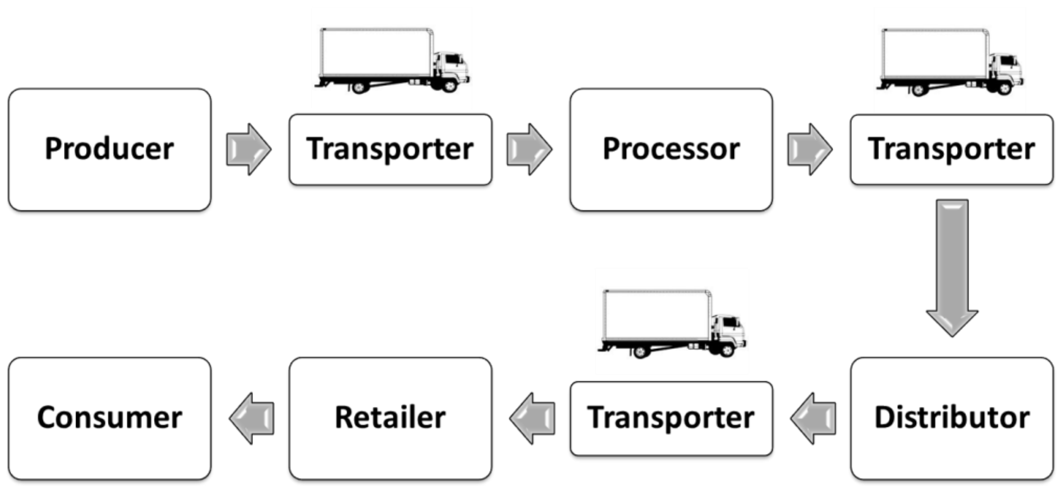


Figure 3 - Representation of the product flow in a typical agri-food supply chain

Transformation processes refers to the practice of Food processing. For definition, food processing includes the methods and techniques used to transform raw ingredients into food for human consumption. Food processing takes clean harvested or slaughtered and butchered components and uses them to produce marketable food products. Transformation operations are critical for the traceability maintenance because they require in input different products belonging to different lots for producing a particular processed food that are combined in a single final product. Food which undergone a transformation process is called processed food.

A vast global transportation network is required by the food industry in order to connect its numerous parts. These include suppliers, manufacturers, warehousing, retailers and the end consumers. Transportation's operation can be done in different way and using different means of transportation, involving third part carries. Transportation and storage are critical phase for products quality and safety because of the perishability that characterize food. Typical parameters to be monitored are humidity and temperature.

2.3.2 Unique identification of lot

The batch or lot definition is a fundamental step when constructing traceability systems. Unique identification and traceability in any system hinges, in fact, on the definition of what is the batch size, or using the terminology used by Kim et al., (1995), the traceable resource unit (TRU) (Moe, 1998).

A Traceable Resource Unit is defined by the GS1 Standards as "any item upon which there is a need to retrieve predefined information and that may be priced, or ordered, or invoiced at any point in any supply chain" (GS1 Standards Document, 2010).

The identification of the batches is necessary at least in two fundamental stages: at the beginning of each process and at the end. At the beginning of each process, it is necessary to identify the different batches of incoming raw materials, semi-finished products or auxiliary materials (additives, flavorings, spices, etc.). At the end of each process, instead, it is necessary to identify and distinguish the different batches of semi-finished products that are generally bound to other companies for further processing, and/or the batches of finished products that are sent the market and bought by the final consumer. In the above-mentioned moments the batches must be recognizable and uniquely identifiable using the most appropriate tools (codes, alphanumeric codes, barcodes, tags, etc.) in order to define the lines of responsibility and to identify all those individuals who have contributed to their formation.

The identification of batches and elements to trace depends on the process' stages under analysis. The definition of TRU is a complex task especially in case of continuous processes. According to (Moe, 1998), in fact, defining the TRU for continuous processing can be challenging. It may depend on how the raw material TRU was received and or on a change in processing conditions such as the clean out process for production equipment. One of the major challenges in regards to establishing whole chain traceability is the transformations that TRU goes through throughout its life cycle (Schwägele, 2005).

Transformation can be described as an operation, which happens between different traceable resource units. Transformations occur when products move from upstream to downstream through the supply chain. TRU transformations can occur when products belonging to different TRUs are mixed, joined, split-up, added or converted into another TRU within the company or between companies in a value chain (Donnelly et al., 2009).

The composition of the batches represents a critical point in determining the accuracy of the traceability system.

Because a lot is characterized by products obtained under homogeneous conditions by location, type and date of treatments, different types of lot can be defined at each step of the production process. As defined by the (Revision Committee on the Hanbook for Introduction of Food Traceability Systems, 2007):

- ✓ the lot formed at the production stage is sometimes called a production lot.
- ✓ the lot that is formed when processing a product is sometimes called a product lot.
- ✓ the lot that is formed when shipping is sometimes called a shipping lot.
- ✓ there are cases when a new lot is formed when receiving lots are rearranged at the distribution stage. This is sometimes called a distribution lot.

As defined by the Ministry of Agriculture, Forestry and Fisheries of Japan in the Guidelines for Introduction of Food Traceability Systems (Ministry of Agriculture, Forestry and Fisheries of Japan, 2003) the lot behavior can be modeled by the following 6 activity patterns, also described by (Bechini et al., 2008) .

- ➢ *Lot integration*: A number of lots are integrated into a unique lot, and a combination lot is formed (Figure 4). Real examples of lot integration are mixing and packing.

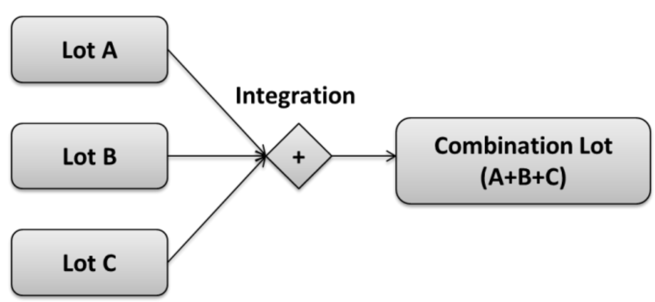


Figure 4 – Integration Pattern

- *Lot division*: A lot is split into a number of lots (Figure 5). Real examples of lot division are cutting and splitting.

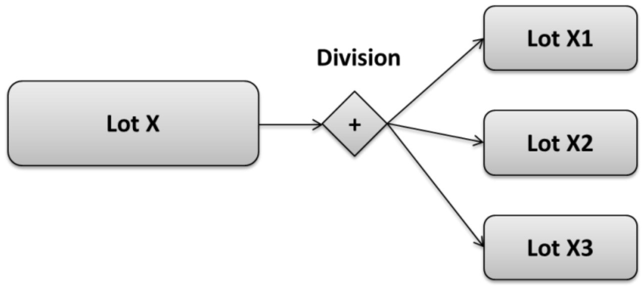


Figure 5 – Division pattern

- *Lot alteration*: The Lot Alteration pattern describe the condition by which a new lot is generated from a lot by an alteration activity (Figure 6). Real examples of lot alteration are heating, freezing, and drying.

Figure 6 - Alteration Pattern

- *Lot movement*: A lot is moved from one storage site (actual site) to another (destination site) internally to a single company (Figure 7). Information on storage conditions is fundamental at this stage because of the perishability feature of food.

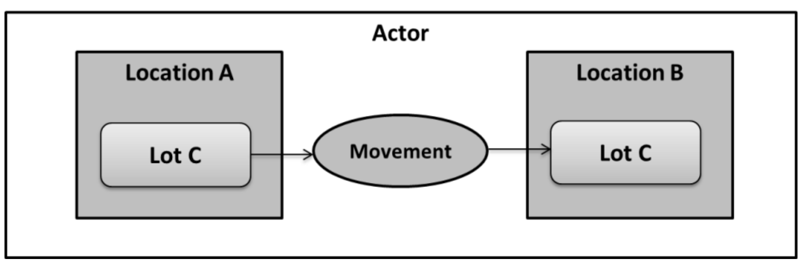


Figure 7 - Movement Pattern

- *Lot providing*: An actor (supplier) of the supply chain provides another actor (client) with a lot (Figure 8). The provider generates a new lot and creates an association between the pre-providing lot and the post-providing lot.

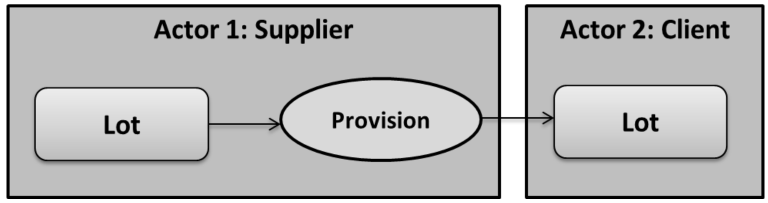


Figure 8 - Provision or Supplying Pattern

- *Lot acquisition*: An actor (client) of the supply chain acquires a lot from another actor (supplier) (Figure 9). The client can generates a new lot and creates an association between the pre-acquisition lot

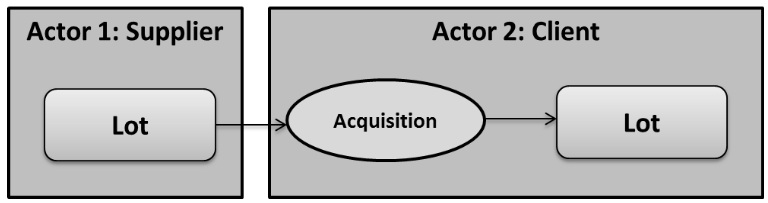


Figure 9 - Acquisition Pattern

From a dynamic point of view, the lot integration, lot division, lot alteration and lot movement can be modeled as a generic *Lot transformation* from X lots to Y lots (Figure 10). Thus, a lot division into X separate lots, and the integration of Y lots into a unique lot are represented as a transformation of one lot into X lots and of X lots into one lot, respectively. Unlike the transformation pattern, in the acquisition and providing patterns the incoming and outgoing lots have distinct associated responsible actors.

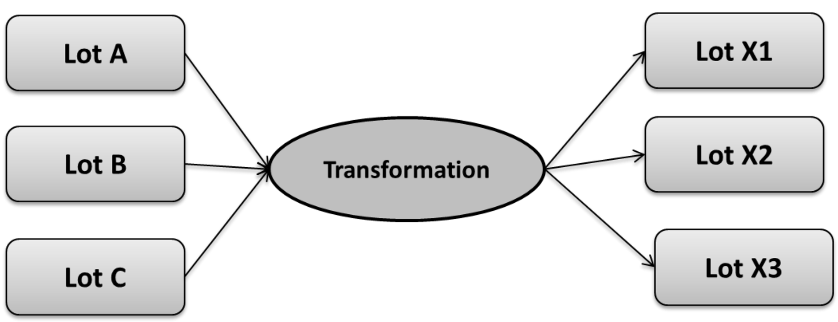


Figure 10 -Transformation Pattern

The definition of lots is a fundamental step for the traceability management and it requires the linkage of information on products and processes.

2.4 Traceability Benefits versus Disadvantages

The advantages that can be achieved through the implementation of a traceability system concern both internal organization of companies and external aspects related with the supply chain management. Some authors, as Golan et al. (2003), have identified in the following aspects the reasons behind the adoption of traceability systems:

- Improvements in the management of the entire supply chain
- Products differentiation and creation of added value products through the guarantee of quality assurance and security;
- Easy identification of not-compliant products.

Advantages pursued with the implementation of external traceability systems are directly related with benefits that can be gained from the adoption internal traceability systems. According to Moe (1998), the implementation of effective system for the internal traceability allows to:

- Increase the process control;
- Identify the relations of cause and effect in case of non-conform of products;
- Reduce recall costs in case of risk;
- Facilitate the retrieval of information for quality auditing,
- Facilitate the introduction of information systems for the management of production and stocks in the warehouse.
- Possibility to correlate data about products with data about raw materials and processes;
- Optimize the input of raw material;
- Improve inventory management and control.

According with the first point stated by Moe et al (1998), traceability mainly consists in a powerful tool for the overall process control, because it allows to full monitoring of all the production stages and to efficiently govern the distribution activities. Consequently, it leads to substantial improvements in the management of the logistics flows.

Benefits in the improvement of the logistics flows can be analyzed from the point of view of internal and external flows. If considering the internal logistics flows, traceability allows to easily detect the presence of defective products and to faster introduce corrective actions to eliminate the causes of non-conformity. In addition, the great availability of information can be used to define with accuracy the production planning, the overall lead-time, delivery times and estimated delays. With regard to the internal warehouses, the monitoring of the products and control of material flow lead to a better use of spaces, reductions in handling cost and stocks.

Another important benefit related with the use of a traceability system is that it allows achieving improvements in the control and management of the production system. In fact, the management of material flows allows knowing at any time what’s happening, to identify with certainty the causes of non-conforming products, to manage operations and materials for the improvement and standardization of quality, reduction costs, streamlining flows and logistics process.

From the point of view of the management of external logistics flows, modern technologies developed for products traceability support the monitoring of the products flows and permit to instantly identify their position. The monitoring of logistics flows and the localization of products offer the ability to activate a direct channel with customers in the communication of delays or advances in deliveries.

With regard to the commercial aspects, the use of such traceability systems is a powerful promotional tool for products differentiation, in fact it ensures transparency of processes and contents of food, it represents a measure of precaution against food fraud, it links each single food with the raw materials involved for its production and their origin and provides the elements to ensure the typicality of a product and to protect companies that operate in a given territory. In such a context, traceability can be used to obtain in short time windows and with less expenses such product certifications (UNI CEI EN 45011, 1999), process certifications (*UNI EN ISO 9001*, 2008), environmental certifications (*UNI EN ISO 14001*, 2004) and/or sanitary certifications (D.Lgs 193/07, 2007)

Traceability, in fact, is an information-based proactive strategy to food quality and safety management. It is a complimentary tool to other quality management programs such as Hazard Analysis and Critical Control Points (HACCP) systems.

Traceability is a vital element of food safety in terms of identification and control of food contaminations. An effective traceability system can help to limit the extension of a particular food contamination and reduce costs for products recall. A key strength of traceability chain management is that it facilitates the identification and isolation of hazards and implementation of effective corrective actions in the event of an incident.

Summarizing, the benefits that can be obtained through the implementation an efficient and effective traceability system are:

- greater internal and chain efficiency;
- reduction of organizational costs and production;
- precise allocation of responsibilities;
- greater control of the supply chain;
- Increased speed of intervention in case of danger food;
- reduction of commercial risk;
- protection of production and reduction of food fraud;
- improving the image company (limited to companies displaying on the market own brands);
- greater capacity for loyalty of customers;
- increased sales.

Despite the numerous advantages that can be achieved through the implementation of such traceability systems, traceability can be an effective tool only if shared rules and unique standards are adopted by all the operators belonging to the same chain and by all the Nations in which food is produced and sold. In addition, communication among different operator requires the acceptance and respect of the same methods for information encoding to ensure the continuity of the traceability along the different links of the supply chain. Without a common standard for information transmission and encoding, information exchange becomes an impossible practice or complex task.

The main disadvantages related with the introduction of a traceability system are generally attributable to the following aspects:

- the need modify the organization structure of the company involved in the supply chain;
- modification and rehabilitation of the entire supply chain;
- use of new technology;
- Use of new protocols for the management of data and information (acquisition, recording, storage and communication);
- increase in the organizational and management costs especially in early stage;
- need of training for staff;
- definition of an agent responsible for the management of the whole System Traceability.
- penalizations for the companies bounded by supply contracts imposed by commercial intermediaries (wholesalers, GDO, etc.).

From the economic point of view the introduction of traceability system leads to an increase in the overall costs for the introduction of such technologies and their management. Moreover, expected benefits in the medium period make the investment extremely convenient. Only through the development and analysis of the information provided by an effective traceability system is possible to "surgically" intervene and limit the economic damage successive to a recalling procedure identifying the contaminated food with precision and in short time windows.

In conclusion, an efficient traceability system can improve food safety and quality and increase the customers' confidence on products. Benefits have a greater weight than disadvantages if compared. This assertion is overly supported by the fact that the final customers prefer to buy products from organizations able to demonstrate greater transparency in their business and to certify their products.

2.5 Technologies for Products Identification

The traceability maintenance requires the use of methods and technologies for acquiring, recording, managing and providing data about products. The main aim is to guarantee the continuous connection between products and information during their flow in the supply chain.

The product identification process makes use of a series of technologies for recording and transferring information. Auto-identification technologies available for food traceability are: bard code, Radio Frequency Identification (RFID) technologies, Near Field Communication (NFC) systems, and Real Time Locating Systems (RTLS) systems.

The bar code is the most common and widespread technology for encoding data. In this technology the information are present in form of sequence of vertical bars characterized by different spacing and thickness (Figure 11). Encoded coded data is stored through the use of optical systems (optical scanners) that, reading the sequence of symbols, allow obtaining the desired information.

Figure 11 - An example of liner barcode

Recently, the linear bar codes have been joined by the two-dimensional bar codes. The latter adopt a matrix representation and encode information in ordered sequences of white and black modules (Figure 12).

Such codes can contain much more information than that encoded in a linear bar code, in a more compact and with redundancy. This latter feature allows the system to read the complete information even if apiece of code is illegible or is damaged (torn) through the passing from one point in the chain to another. In fact, even if the image is damaged or irregular due to the effects of light or reflection, it is possible to reconstruct and decode the code through the use of appropriate algorithms. The reading of the two-dimensional code is possible through the use of imager or camera-based scanner that captures an image of two-dimensional using the same principle of industrial vision systems. The disadvantages in the use of two-dimensional codes are related to the shortcomings of the technologies used to capture images that are seriously affected by dirt and/or inadequate lighting conditions. The most common formats for the two-dimensional bar codes are: the standard QRCode, (especially prevalent in Japan and Asian); Datamatrix standard used in Europe, and the EZCode standards that are "proprietary solutions" present in various forms (Spain, Italy, USA, and Mexico).

Figure 12 - An example of two-dimensional (2D) barcode

Currently, the market is characterized by a significant growth of two-dimensional barcode and a progressive development of self-identification systems based on RFID. The radio frequency identification technology, called "RFID System", uses some electronic components called reader and transponder.

The reader is the device installed at the control center and has the ability to interrogate the transponder, send and receive data, interfacing with the corporate information systems.

The transponder is an intelligent electronic device that is applied to the object that must be tracked and/or monitored. It consists of a tag, an antenna and a support that includes the other components. The tag is the electronic component used to store the information, the antenna allows the tag to receive and transmit information, while the packaging ensures their adequate protection from bumps and weather. The antenna enables the communication between the reader and the tag and allows the tag to receive the energy necessary for its operation. The information exchange takes place via a radio signal generated by and reflected from the tag reader.

Depending on the type of power required the tags could be classified as active or passive. The first are characterized by autonomous internal power, or battery, and enable greater power transmission and greater working distance. Passive tags do not have instead internal energy sources and are characterized by a smaller overall size. The transmission frequency is the most important technology parameter for the correct application of RFID technology. There are four different frequency bands for transmission:

- LF (Low Frequency) 125 kHz - 131 kHz;
- HF (High Frequency) 13.56 MHz;
- UHF (Ultra High Frequency) 433 MHz and 866 MHz - 915 MHz;
- MW (MicroWave) 2.45 GHz and 5.8 GHz.

The last frequency band is not really used because of the low number of applications and the high costs of employment. The use of different frequency bands affects the ability of communication, and the construction and environmental conditions in which the tag is able to work. In fact, the higher is the operating frequency the higher is the distance of employment, the amount of information that can be transferred per unit time, the moving speed of the object to be traced and the manufacturing cost, while the operational sensitivity is significantly conditioned by the presence of metals, liquids and electromagnetic activity.

Table 1 - Operating Frequencies of RFID systems

Operating frequency	**125-135 kHz**	**13,6 MHz**	**860-960 MHz**	**2,4 GHz**
Spectrum	low frequency (LF)	high frequency (HF)	ultra-high frequency (UHF)	microwave
Magnitude order of the operating distance	0,5 m	1 m	3 m	1 m
Power	passive	passive	passive, active	passive, active
Bit rate	up to 1 kbit/s	25 kbit/s	100 kbit/s	250 kbit/s
Application examples	animal tracking, access control, containers, vehicles identification	smart card, logistics, ticketing, baggage handling	logistics: pallet and objects, control	supply chain and logistics

Table 1 shows, for different operating frequencies, the spectra, the reading distance, the type of power, the bit rate and areas of application (Puddu and Mari, 2011).

The Near Field Communication (NFC) represents a recent evolution of RFID systems. NFC technology provides wireless connectivity (RF) two ways short-range. NFC operates on a frequency of 13.56 MHz and can achieve very high transmission rate with up to 424 kbit/s. The basic elements involved in transmission are the initiator (or the first device to interrogate) and the target. Initiator and Target have symmetrical roles, and, once the communication has been initiated, they are alternate equally in the transmission. Unlike traditional RFID systems, NFC technology allows therefore a two-way communication in which initiators and targets create a peer-to-peer network in which they can both send and receive information.

A further RFID evolution is represented by the RTLS systems. These systems, using the same technology used by RFID, can identify a product, locate its position, and track their movements over time. A typical active RTLS uses active tags placed on the good you want to locate, reader devices that detect the information sent by the tag and, finally, hardware and software devices that, processing the received information, are able to determine the position of the product under observation (Figure 13). RTLS systems may use different communication standards, the most common are: GPS Protocol, Wi-Fi, ZiBee, RFID and Ultra Wide Band (UWB). The choice of these standards depends on the type of application: for this purpose ZiBee technologies, RFID, Wi-Fi, and the Ultra Wide Band can be classified as indoor localization systems, while the GPS and active RFID are outdoor localization systems.

Figure 13- Working features of RTLS Systems

The most commonly used systems are bar codes and RFID; the use of RTLS is limited to those products of high value or particularly dangerous. The choice of the appropriate technology depends on many factors such as the value of assets, the size of objects, the nature of the products, the type of packaging, the amount of data to be stored, the supply chain characteristics, construction and operating costs. It is clear that the choice of RFID is the most appropriate for valuable and critical products, while bar codes are preferred for products characterized by low value, small size and low hazard of perishability.

Therefore, the possibility to use radiofrequency identification is connected with the adoption of the same frequency band for the data transmission common to all the operators of the supply chain. As a consequence, for the large adoption of RFID systems in the food supply chain is indispensable to identify a free band at global level. Finally, some privacy problems occurs during the phase of information exchange between different operators, even if some researches are trying to avoid security and privacy risks (Juels, A., 2006; Sanchez et al., 2009).

The choice of the technology depends on the specific application that can ensure the lowest total cost of ownership (TCO) and faster return on investment (ROI). Of course, bar codes are more convenient for individual packages of product (consumer units) even if the adoption of RFID systems is preferable for multipacks (packaging unit and pallets).

Chapter 3

Food Traceability Models: A State of the Art Overview

3.1 Introduction

The development of a global and efficient food traceability system faces with the knowledge of the previous research works conducted in the field. The analysis of the state of the art is a requirement of any step previous at the development of a traceability system. The need to analyze and classify the previous works carried out in the area of food traceability, led to the definition of a review of the state of the art of the food traceability models (Mirabelli et al., 2012a).

Two different parts have been analyzed:

- Regulation, recommendation, and guides of Governments;
- Scientific literature.

The analysis of the scientific literature highlighted the presence of three main categories of works, each of one devoted to the definition of Mathematical models, Information model and Ontological models for the traceability management.

Under the category of Mathematical models are included the scientific works oriented to the definition of mathematical models aimed at containing the mixing problem and reduce the risk transmission in case of contamination. The definition of the rules for the identification of product units and their complete monitoring plays an important role for the reduction of batch dispersion and the optimization of products recall.

On the other hand, the category of Information models includes works on the definition and development of innovative traceability information systems. In this area, important considerations have been done on the evaluation of the different technologies that can be used for recording, managing and transferring information. These technologies, known as auto-identification technologies are: bard code, Radio Frequency Identification (RFID) technologies, Near Field Communication (NFC) systems, Real Time Locating Systems (RTLS). The awareness of benefits and costs related to the introduction of these technologies is fundamental in the development of a traceability information system. In addition, new tendencies show that ontologies can be used to set up innovative traceability semantic models.

3.2 Regulatory Overview

The increasing concern on food safety matter has promoted that many governments have begun thinking the adequacy of the private traceability system and the possibility of adopting mandatory traceability systems to improve the social food safety level. Some of the nations and regions have required mandatory food traceability systems or encouraged voluntary traceability programs (Wang et al., 2011). In many developing countries, traceability initiatives have been started in the last decade. They mainly refer to perishable and high-risk food export products like beef and fish, fruits and vegetables, but also coffee or wine.

In Europe, Regulation (EC) 178/2002 of the European Parliament and of the Council lays down the general principles and requirements of a food law. The principal aim of this Regulation is to protect human health and consumer interests in relation to food. It applies to all stages of production, processing and distribution of food and feed, but there is an exemption for primary production for private domestic use, and the domestic preparation, handling, or storage of food for private domestic consumption. The traceability requested is known as "one step back-one step forward", which means to identify the immediate supplier of the product in question and the immediate subsequent recipient. In fact traceability is a requirement limited to ensure the ability for businesses to identify at least the direct supplier of a product as well as the immediate client, with the exemption for retailers (European Commission, 2002, European Commission 2004). Each food business operator must record and preserve information such as (1) name, address of supplier, and type of products supplied, (2) name, address of customer, nature of the products delivered to the customer, and (3) date of the transaction/delivery (European Commission, 2002).

Therefore, each operator can independently choose different tools and methods to achieve this goal. The critical aspect related to the Regulation (EC) 178/2002 is that it obliges every operator to only record the information related to their immediately preceding suppliers and immediately successive client (Charlier and Valceschini, 2007). It doesn’t introduce any prescription on the internal traceability that enables to trace the path followed by each single unit of raw material and ingredient utilized in the production process in the company.

Implementing voluntary internal traceability systems can fill this information gap. A voluntary traceability system requires to record additional information that enable companies to effectively monitor each production phase.

Table 2 summarized the main regulations about traceability in the food sector.

In Italy, The Italian National Unification Agency (UNI) has introduced the standards (1) UNI 10939 "Traceability systems in the agricultural chain: general principles for design and development" (April 2001) and (2) UNI 11020 "Traceability System in the agri-food industries: principles and requirements for development" (December 2002). In 2008, this standards where placed by the (3) UNI EN ISO 22005:2008 that defines "General principles and basic requirements for system design and implementation".

Table 2 - European and Voluntary standards for the food sector

European Standards	
Directive 93/43/EEC on the hygiene of food	It defines general rules of hygiene for food and the procedures for verification of compliance with these rules.
EC Regulation 1760/2000	It establishes a system of identification and registration of cattle and defines a system of mandatory labelling of beef and beef products.
EC Regulation 2065/2001	It sets out the procedure for implementing Regulation (EC) 104/2000 for informing consumers on the products of the field of fisheries and aquaculture, providing traceability of fish products.
Directive 2001/18/EC on the deliberate release of GMOs	It requires to the Member States to adopt measures to ensure traceability and labelling for GMOs.
EC Regulation 178/2002	It sets out general principles of food law, establishes the European Food Safety Authority and defines procedures in matters of food safety. It introduces for the first time in a horizontal manner, and therefore applicable to all types of food, the instrument of traceability.
EC Regulation 2295/2003	It defines the procedures for implementing Regulation (EEC) 1907/90 to ensure traceability of eggs, the control of their origin and of the production method.
EC Regulation 1830/2003	It defines the rules on traceability and labelling of products containing GMOs or formed by them.
Voluntary standards	
UNI 10939:2001	It provides general principles for the design and development of traceability systems in the agricultural sector.
UNI 11020:2002	It defines principles and specific requirements for the development of a system of traceability in the agro-industries.
ISO 22000:2005	It defines the requirements for the design and implementation of a system of food safety management in any company in the agro-food industry.
UNI EN ISO 22005:2008	It defines the principles and specifies the basic requirements for the design and implementation of a food traceability system.

Currently, the European regulatory framework requires food and feed labeling and identification documented by recorded information. This goal is achieved by introducing European Directives and specific nation laws. In this context, the European Community has focused its attention to certain foods, such as fresh and processed meats (Revision Committee on the Handbook for Introduction of Food Traceability Systems, 2007) (Reg. CE 1760/2000), milk, eggs (Reg. CE 2295/2003), fish products (Reg. CE 2065/2001), genetically modified foods (Dir. 2001/18/CE) and it has introduced specific regulations for them. Other regulations where introduced for lipids (Re. CE 20.7.98, n. 1638 art. 4 bis), grape and vine transformation (D.M. 29.05.2001), olive oil.

In Japan, the Government has supported the development of traceability systems from 2003 with the establishment of the Food Safety and Consumer Affairs Bureau within the Japanese Ministry of Agriculture, Forestry and Fisheries (MAFF). The MAFF policy is to encourage food business operators to voluntary establish traceability systems (Ministry of Agriculture, Forestry and Fisheries (MAFF), 2004). The government has taken decisions to support the development of traceability systems. In 2003, the Food Safety and Consumer Affairs Bureau was established within the (MAFF). Although traceability systems are not legally required except for domestic beef, MAFF policy is to encourage food business operators to voluntarily establish traceability systems. Supporting this policy, MAFF has provided funds for projects such as developing traceability systems utilizing advanced ICT and formulating a handbook to guide the establishment of traceability systems. The handbook for the introduction of food traceability systems was created for food business operators and aims to facilitate cooperation between the various operators throughout the food chain (Revision Committee on the Handbook for Introduction of Food Traceability Systems, 2007). The handbook covers definitions, basic objectives of traceability, the role that each operator should play to establish traceability, and how to precede with the introduction of a traceability system. It outlines examples of general traceability systems as well as guidelines for specific food items. An English translation has been produced for overseas suppliers. In June 2003 the Japanese Govern introduced the Beef Traceability Law and in October 2010 enacted the Act on Recording Source Data and Other Information Relate to the Trade of Rice and Other Gains. In this act is reported, "The government has drafted a plan calling for a new law to establish the traceability of all food products" (Summary of FY2010, 2008).

In China the first Food Safety Law becomes effective in July 2009, and it requests the food company to keep the account book of procurement and sale for at least two years to be reviewed by food safety authorities once needed. No mandatory regulation was in effect till that the General Administration of Quality Supervision, Inspection and Quarantine of the P. R. C. released a new regulatory to ask diary industry to adopt IT system to record critical information (AQSIQ of PRC, 2010). The Announcement No.119, 2010 might be treating as a trend on the food traceability system adoption.

In Canada, traceability initiatives were mostly oriented to animal identification and tracking, through the creation of the Canadian Cattle Identification Agency (CCIA). In 2001, Québec was the first province implementing a traceability procedure for cattle, sheep, and pigs under Agri-Traçabilité Québec, which provides a framework for identification of animals and premises, as well as animal transportation tracking.

- ✓ In the Health of Animals Act, cattle, bison and sheep identification became federally regulated by 2004.
- ✓ In 2003, Agriculture and Agri-Foods Canada consulted with federal, provincial and territorial governments, where a consensus “that traceability is necessary in a safe food supply” was established; this was incorporated into the Agricultural Policy Framework (APF).
- ✓ Can-Trace, created in 2003, released the 2nd version of the Canadian Food Traceability Data Standard in 2006, based on the EAN.UCC system. Can-Trace is a collaborative, multi-commodity effort to establish traceability standards for all food products in Canada.

Participation in the Can-Trace is currently on a voluntary basis.

In the United States, after the Bioterrorism Act program regulation of 2002, local and foreign food businesses that produce food products for sale in the United States must be registered with the U.S. Food and Drug Administration (FDA). Importers and processors are required to keep records of their immediate suppliers and buyers for 2 years after transaction, and must be able to reproduce these records upon request for inspection by the FDA. In 2007, the FDA issued the Food Protection Plan (FPP), which objective is improving the food safety and defense for all domestic and imported products in the United States. A component of the FPP is the emergency response development, under which traceability practices are in the process of being defined, in collaboration with the food industry and other stakeholders. Recently, the FDA Food Safety Modernization Act (FSMA) signed as law on January 4th, 2011establishes within the FDA a tracing system able to receive information that improves the capacity to effectively and rapidly track and trace food in United States, or offered for importation into the United States.

In Australia, under the Legislative Instrument Act, the Australian New Zealand Food Standards Code was stipulated in 2003. Through this standard code the food businesses must be able to identify where their products come from (Diogo and Julie, 2004).

South Korea and Taiwan have included a definition of traceability in their food legislation and they have also implemented traceability programs for some categories of domestic products, where participation of food operators in most of these programs is voluntary.

A schema of the introduced regulation in the earth context is showed in Figure 14 from a chronological point of view.

An interesting finding by reviewing the history of food traceability regulations is that not only the approaches to establish the systems are different, but also the breadth, depth and precisions of these systems are different. While most chains allow only one step forward and one-back trace, a deeper traceability system back to the producer of raw materials is required e.g. for ensuring that products have not been genetically modified (Golan et al., 2004). Additional requirements should be satisfied to ensure food security and to improve food quality (Food Standards Agency, 2002). Additional information should be collected in each stage of the supply chain in order to ensure the availability of data for the production analysis and optimization (Thompson et al., 2005). All trading partners in the supply chain must guarantee both the internal and external, or well-known supply chain, traceability.

Therefore, the lack of a global standard for food traceability hinters the communication between the different actors of the supply chain and consequently the traceability chain. An important bottleneck for traceability is, in fact, the lack of a global standardization. Companies positioned in different geographical contexts (America, EU, Asia, Africa) have to deals with different implementation for the products responsibility and liability, and different standards for labeling. A global traceability system can be conveniently achieved if each company in the supply chain follows a common system for information encoding, registration and control, and the transactions between actors involved are regulated in a coherent and shared form (De Cindio et al., 2011b).

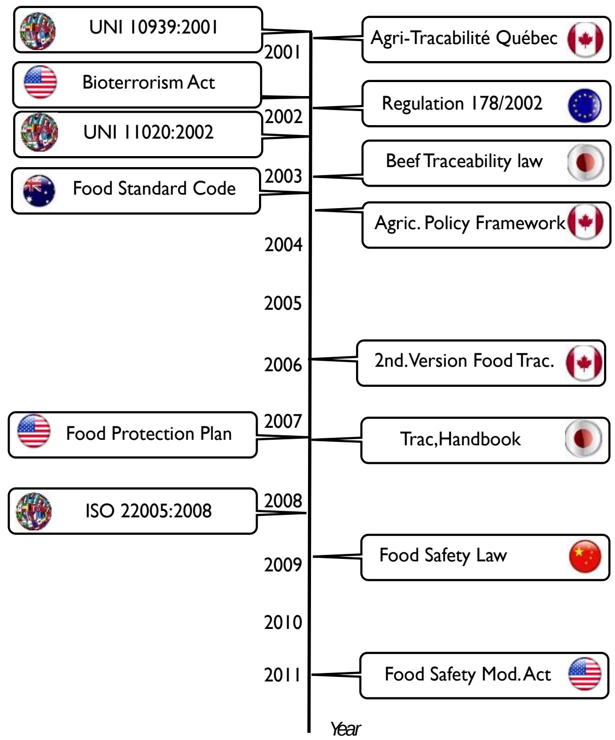


Figure 14 - Food Traceability Regulatory Framework

3.3 Scientific Literature

In this section is presented a review of the scientific literature on food traceability, with a particular focus on the fruit and vegetable field.

The increased interest of the scientific world in the research area of the supply chain traceability is the result of a long series of developments aimed at improving food quality and safety management (Opara, 2003).

3.3.1 Mathematical Models

The implementation of an effective shop floor traceability system does not only consist of recording, manually or using computers, the various supply chain batches. Indeed, it implies a deep modification of the organization and, sometimes, of the company fabrication processes. A traceability system must ensure the linkage between products and information, and must guarantee this connection through the supply chain. Moreover, as mentioned before, the maintenance of traceability is a complicated and expensive process especially with regard to processed foods. In case of processed foods different lots of various raw materials are combined into several production batches typically distributed through various points of sale

(Hu et al., 2009). Some mathematical models have been proposed in order to solve this problem and to model the lot behavior.

Dupuy et al., (2005) propose a mathematical model to reduce batch dispersion, for controlling the mixing of production bathes in order to limit the size, and consequently the cost and the media impact of batches recalled in case of problem. The problem studied aims to minimize the quantity of products recalled in case of a problem that occurs in a particular situation with a 3-level ‘‘disassembling and assembling’’ bill of material. For the development of the mathematical model they implemented a model proposed in (Dupuy et al., 2002), a method based on the concepts of Traceability Resource Unit (TRU) and batch dispersion.

Bollen et al., (2007) and Riden and Bollen, (2007), studied and analyzed the traceability in fruit supply chains in order to improve the traceability control of different batches. They proposed a mixing model that was able to assign the probabilities of bin origin to individual fruit at the point that they are packed into their final packs. The model can significantly reduce fruit mixing and improve the traceability. They introduced concepts for quantify aspects of processing transformations, implementing a model based on enable simulations that examine the effect of splitting throughput into multiple output lines. They stated that there is a potential to implement high precision and fine granularity traceability in agricultural supply systems, which can also meet a number of other purposes such as improvement feedback to producers and benefits to supply system efficiency, as well as being acceptable for compliance purposes.

Hu et al., (2009) studied the traceable information flow and risk transmission throughout food supply which contains raw material, process and distribution. They propose a mathematical model based on dynamic programming in order to solve the risk transmission problem in a China dumpling factory, using Radio Frequency Identification (RFID) to identify and transfer traceable information. The purpose of the study in the factory is to minimize the cost due to a food safety crisis. If a food safety problem comes from a raw material batch, the factory will trace and identify all products. This model takes into consideration the previous research work of (Dupuy et al., 2002). They propose a graphical model to describe the risk transference problem, according to the Gozinto graphs proposed by (van Dorp, 2003).

Tamayo et al., (2009) used the traceability information in order to reduce the size of products recalls. Three principal subjects are defined as follows: dispersion evaluation and optimization, criticality determination and final product delivery optimization. To achieve the final purpose of reducing the recall size and cost they stated that it is important to perform an intelligent delivery allocation. The developed expert system uses the information produced by a genetic algorithm and an artificial neural network to optimize product dispatches.

Wang et al., (2010) developed an integrated optimization model in which the product safety related traceability factor is incorporated with operations factors to develop an optimal production plan. The model aims to improve traceability and manufacturing performance by simultaneously optimizing the production batch size and batch dispersion with risk factors.

3.3.2 Information Models

In recent years, many works have been conducted on the development of traceability systems in food supply chain.

Jansen-Vullers et al., (2003) proposed a reference-data model for tracking and tracing of food based on the Gozinto Graph, a tree-like graphical representation of raw materials parts, intermediates and subassemblies, in which a particular production process transforms an end-product through a sequence of operations. In the paper the tracking and tracing requirements from three business cases situated in a production network (breeder, grower and egg producer) are discussed. A concise overview of the main requirements is identified for each business case and a data model is constructed. The development of the reference data model is described by explaining the model-part of the bill of lots and/or batches, the model-part of operations and variables and the integration of these two model-parts. The reference data model supports the registration of historic relations between lots and batches (where-from and where-used relations), the registration of operations on lots and batches in production, the registration of associated variables and values, on operation control, and the registration of capacity units on which operations are executed. The reference data model includes tracing of generating properties, which have been identified as an overlaying requirement.

Lo Bello et al., (2005) proposed a general approach based on distributed collaborative information systems where every company exchanges traceability data with the others over a network. XML was used as the format to represent data, for its ability to cope with data structures of different size. Web-Services based technology has been adopted to interface different suppliers which communicate through HTTP protocol.

Regattieri et al., (2007) develop a traceability system for Parmigiano Reggiano (the famous Italian cheese) introducing a general framework based on the integration of alphanumeric codes and RFID. The characteristics of a product are identified in its different aspects along the entire supply chain, from the bovine farm, the dairy, the seasoning warehouse, and lastly to the packaging factory. The complete supply chain of Parmigiano Reggiano is traced by an RFID system integrated with an alphanumerical code. Technically the system developed is based on a central database that collects data from bovine farms and from dairies. Manufacturers can check the progress made in production at any time and, if problems occur in the market place, they can re-trace the development of the portion of infected products and introduce effective re-call strategies.

Bechini et al., (2008) introduce a data model for identifying assets and actors and show a formal description of the lot behavior throughout the Supply Chain. The lot behavior has been modeled by six activity patterns (integration, division, alteration, movement, acquisition and providing) using a UML activity diagram. The standard Unified Modeling Language (UML) notation is adopted to formally describe the different aspects of the modeled system. The model of a simply cheese supply chain with a UML communication diagram is presented. An independent, private data-sharing networks (PDSNs) is proposed as proper infrastructure for business process integration and Enterprise Service Bus (ESB) as architectural scheme for connecting third party applications. The ebXML Message Service (ebMS) is used for transporting business documents in a secure, reliable, and recoverable way in the inter-enterprise business collaboration scenario. In case that one of the business partners cannot manage ebMS messages (for instance, in the case of legacy systems), the communication is handled via ESB.

Thakur and Hurburgh, (2009) developed a model for implementing internal traceability systems for a grain elevator that handles specialty grain and a model for information exchange among the supply chain actors. A UML sequence diagram shows the information exchange in the grain supply chain when a user requests additional information about a suspected product. The usage requirements of the traceability system are defined by the UML Use Case diagram technique. One of the most important goals of defining system requirements is to synchronize the requirements of all the actors. Integrated Definition Modeling (IDEF0) is used to develop the system for the internal traceability that they use and each actor records all the information in a RDBMS (Relational Database Management System) form. Finally some suitable technologies to enable this information exchange, such as the XML documents, are discussed. A relational database model to facilitate internal traceability at grain elevator is presented in Thakur et al., (2011a). In this reference the entity-relationship modeling technique is used to develop the internal traceability grain handling a RDBMS for constructing and implementing the Entity Relationship model. The main purpose of the database is to connect the incoming grain lots with the outgoing grain lots. Once the data is stored in the database, the manipulation is accomplished through the use of queries written using the Structured Query Language (SQL).

Thakur and Donnelly, (2010) presented a model for information capturing in the soybean supply chain. Actors involved in the supply chain are responsible for production, handling and processing. The soybean value chain and the main inputs and outputs of each stage are modeled using a simple flowchart. Conceptual process flow diagrams are created for farming, handling and processing sectors in the soybean value chain. Information capture points are identified for each sector and the corresponding products, processes and quality information to be captured are determined. A UML class diagram is developed for modeling products, processes, quality and transformed information. Finally some technologies available for transferring the information, such as the XML, are presented.

Thakur et al., (2011b) presented a new methodology for modeling traceability information using the EPCIS framework and UML statecharts. EPCIS is an EPCglobal standard designed to enable EPC-related data sharing within and across enterprises. The model presented is used for mapping of food production processes in order to provide improved description and integration of traceability information. The method follows the approach of defining states and transitions in food production. A generic statecharts 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 are developed. The 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: Object Event and Aggregation Event. The corresponding states where the quality parameters are recorded are also identified and linked to these EPCIS events.

Bevilacqua et al., (2009) used the business process reengineering (BPR) approach to create a computer-based system for the management of the supply chain traceability information flows. They present a computer-based system for the traceability of fourth range of vegetables. They used an Event-Driven Process Chains (EPCs) technique to model the business processes. In order to ensure the traceability, each single unit or lot of the food products has been uniquely identified combining GTIN and the lot code. The business processes database follows the Entity Relationship Model (ERM). In the paper, moreover, the data model is not presented, and the front-and generated, based on the software ARIS, is only discussed.

Ruiz-Garcia et al., (2010) presented a web-based system to process, save and transfer data for tracking and tracing agricultural batch products along the SC. The development of the prototype involved the integration of several information technologies and protocols. The tracking system is based on a service-oriented architecture (SOA) and the communication is through messages in XML. Moreover, the work not deals with the problem of process and data modeling. In addition, there are only few authors using the BPMN standard for process modeling.

In the area of information modeling, several research works have been conducted on the analysis and evaluation of the different tools that can be used for recording, managing and transferring information such as barcode and Radio Frequency Identification (RFID) technologies. RFID systems have found applications in the agri-food sector especially in fresh-produce companies (Amador et al., 2009; Gandino et al., 2009; Jedermann et al., 2009; Martínez-Sala et al., 2009) and meat processing companies (Abad et al., 2009; Bo et al., 2008; Hsu et al., 2008; LiWei et al., 2009; Reiners et al., 2009; Shanahan et al., 2009).

3.3.3 Ontological Models

The increased need of food quality and safety required in a global market lead, in recent years, to the introduction of several mechanisms for the guarantee of food traceability. At the same time, important technologies, such as the Internet and the new generation of communication infrastructure, have been developed for supporting new traceability application. The first traceability schemes were based on working papers used to record information on incoming and outgoing products, while more recent systems are based on the use of the new information technologies. New research activities are currently investigating how ontology can be used to set up a traceability semantic model in order to reuse the information resources in the process of tracing and to promote the accuracy and efficiency of the information management. Furthermore, information shared in a general SC is heterogeneous and it is recorded into different data collection. In such a context, ontologies can be used for integrating heterogeneous databases and enabling inter-operability among different systems, since consistent vocabulary is needed for unambiguous querying and unifying information from multiple sources (Jagadish, 1990). The aim of an ontology is to capture knowledge in related field, provide shared understanding to conceptual knowledge, definite common vocabulary in this field and give clear definition to the mutual relationship between these jargons and words from different levels of formal model (Heijst et al., 1995). Ontologies, defined as explicit formal specifications of terms in the domain and relations among them (Kim et al., 1995), have become common in the World-Wide Web.

The need for ontologies has increased in computer science recently due to the need of a common core for heterogeneous agents for communicating and expressing knowledge. This Section illustrates the relevant literature on food ontologies and the semantics of food traceability and introduces the main features that should be included in a new ontology for representing the whole knowledge related to the domain of food traceability.

A systematic literature review approach has been used for identifying the current food supply chain ontological models. The general idea was to classify the scientific literature focusing on the specific domain area of the works published in order to reuse the main concepts for the definition of the FTTO ontology. Three main subsections have been identified. The first subsection describes the current ontological models developed for describing the food world from a top-level point of view. Moreover, these ontologies mainly refer to the nutrition, diet and health domain. In the second subsection, a deep analysis has been conducted focusing on the main works carried out for the definition of ontologies devoted at describing the knowledge related to specific food products. The last subsection includes some concepts related to the traceability domain and some works carried out in this area are analyzed. Finally some considerations are provided, highlighting the main features to include in a new ontology for food traceability purpose.

Table 1 presents the main work carried out with a short description on the main topic and the specification of the domain area (Bansal and Malik, 2011; Batista et al., 2006; Cantais et al., 2005; Chifi et al., 2007; Drummond et al., 2007; Graça et al., 2005; Gutiérrez-Villarias, 2004; Heflin, 2000; Noy and McGuinness, 2001; Snae and Bruckner, 2008; Wang et al., 2012; Yue et al., 2005).

3.3.3.1 Food ontologies for the domain of healthcare, diet and nutrition

The definition of a complete taxonomy for food is fundamental for modeling the domain of food traceability. There are various types of information about food, such as name, ingredients, stuff, package, processing condition etc. Currently, some food ontologies are emerging mainly related to nutritional concepts, such as the food ontology proposed by (Snae and Bruckner, 2008) as a part of the Food-Oriented Ontology-Driven Systems (FOODS). FOODS has been mainly devoted to assist customers through an appropriate suggestion of dishes and meal. The ontology contains specifications of ingredients, nutritional facts, recommended daily intakes for different regions, dishes and menu. Food is categorized by nine main concepts: regional cuisine, dishes, ingredients, availability, nutrients, nutrition based diseases, preparation methods, utensils and price.

Table 3 - Main works carried out in the food domain

Authors	Year	Title	Description	Food Area	Context
Cantais et al.	2005	An example of food ontology for diabetes control	The food ontology proposed in PIPS organizes foods in 13 main categories, each one describing either a type of unprocessed aliment, miscellaneous categories or food types determined by the main ingredients.	General	Nutrition and health
Snae and Bruckner	2008	FOODS: A Food-oriented Ontology-Driven System	The ontology contains specifications of ingredients, nutritional facts, recommended daily intakes for different regions, dishes and menu. Food is categorized by nine main concepts: regional cuisine, dishes, ingredients, availability, nutrients, nutrition based diseases, preparation methods, utensils and price.	General	Nutrition and diet
Batista et al.	2006	Ontology construction: cooking domain	The ontology comprehends four main modules covering the key concepts of the cooking domain (actions, food, recipes, and utensils) and three auxiliary modules (units and measures, equivalencies and plate types).	General	Cooking
Eugene Kim	2012	Korean Food Ontology	The ontology organized the Korean food in three main classes: main stample food, side dish and dessert. Information on nutrients, recipes, ingredients and taste are provided.	Food of a specific Country (Korea)	Korean Food
Chifu et al.	2007	Ontology-enhanced description of traceability	The ontology described the participants involved in the traceability chains, the services and products they offer/use, and the main features of the products. The core	Food of animal origin	Traceability in the domain of meat

		services	ontology defines six generic concepts: Business Actors, Service, Service Input, Service Output, Product and Feature.		industry
Bansal and Malik	2011	A Framework for Agriculture Ontology Development in Semantic Web	The ontology pointed out the most important classes for modeling the world of crop production such as soil, plant, cultivation method, cultivation stage, and fertilizer.	Food of plant origin	Crop production cycle
Yue et al.	2006	Ontology Based Vegetable Supply Chain Knowledge Expressing	To implement vegetable supply chain knowledge searching, authors build three Ontologies: the vegetable supply chain domain Ontology, the user Ontology and the knowledge content Ontology.	Food of Plant Origin, Vegetable s	Vegetable supply chain
Heflin	2000	Beer Ontology 1.0 (Draft)	The beer ontology is based on the SHOE (Simple HTML Ontology Extension) framework and it models brewers and types of beer.	Beverage	Beer
Noy and McGuinn ess	2001	Ontology development 101: A guide to creating your first ontology	Two main classes form the ontology: wine and food. The wine class is categorized in White wine, Red wine, Rosé wine. Information on wine refers to their color, body, flavor, sugar content and location of a winery.	Beverage	Wine
Graça et al.	2005	Ontology building process: the wine domain	The ontology for the wine domain id proposed according to several features: (i) maceration; (ii) fermentation process; (iii) grape maturity state; (iv) wine characteristics; (v) classification system according to country; and (vi) region where the wine was produced.	Beverage	Wine
Drummo nd et al.	2007	Pizza Ontology v1.5 (2007/02/12)	The ontology models the knowledge related to the pizza domain. The class pizza is dived into Pizza topping and Pizza Base. In addition different type of topping are proposed depending on the main element of the topping (cheese, meat, seafood, vegetable, pepper).	Processed Food	Pizza
Easwaran et al.	2011	Farm-Agro Ontology formation: A black pepper model	The pepper ontology is modeled considering as main categories the cultivation type, the pepper variety, the type of propagation, the disease that can attack the plant, the Farm processing and the Value added products	Food of Plant Origin	Pepper

One more food ontology oriented to the nutritional and health care domain, has been developed by (Cantais et al., 2005) for assisting in sharing the knowledge between the different stakeholders involved in the PIPS (Personalized Information Platform for Health and Life Sciences) project. The food ontology proposed in PIPS organizes foods in 13 main categories, each one describing both a type of unprocessed aliment, miscellaneous categories and food types determined by the main ingredients. It is mainly addressed to provide provision of nutritional advice to diabetic patients.

3.3.3.2 Food ontologies for specific area of the food domain

Currently food ontologies have been only designed for specific “County Food”, such as the Korean Food Ontology proposed by Kim (2012), and only for representing the knowledge related to specific food area. Several authors, in fact, have focused their attention on the definition of taxonomies and ontologies for particular areas of the food domain such as fruit and vegetables (Wang et al., 2012; Yue et al., 2005), meat (Chifi et al., 2007), pepper (Easwaran, S. and Thottupuram, R., 2011), wine (Graça et al., 2005; Noy and McGuinness, 2001), beer (Heflin, 2000), pizza (Drummond et al., 2007). The above-mentioned ontologies deal with small area of the food sector and are focused on a specific product or on a particular class of products, such as beverages or food. In addition, several authors tried to model the knowledge related to particular vegetables or animals supply chain.

On one hand, the use of an ontology for knowledge expressing of vegetable SC has been discussed in Yue et al. (2005), in which authors put forward a process to build a vegetable SC Ontology and gave to the vegetable SC a knowledge-expressing frame that was used to express concepts and their relationships in the domain of vegetable supply chain. In addition, a traceability system for fruit and vegetable products based on ontology has been proposed also in Wang et al., (2012) for improving the quality and safety of agriculture products. In their work, authors pay attention on the agricultural chain and define a sematic model for the traceability of fruit and vegetables dividing this domain into a set of sub-systems, each of one is used to model to planting system, the gaining system, the transportation system and the sale system. Nevertheless, in this work there is no a clear expression of how terms are organized in classes and how concepts are related. From the cultivation point of view, an ontology for modeling the domain of crop production (the CROPonto Ontology) have been proposed by Bansal and Malik (2011). The CROPonto Ontology serves as a building block for an ontology driven by the Agriculture Information System Framework. It has been developed using the AGROVOC thesaurus as base vocabulary. The ontology pointed out the most important classes for modeling the world of crop production such as soil, plant, cultivation method, cultivation stage, and fertilizer. Relevant domain concepts (crops, fertilizers, chemicals) within the agriculture domain have been also included in Shoaib and Basharat (2010) for the definition of the Centralized Agriculture Resource Ontology as part of the Integrated Agriculture Information Framework.

On the other hand, from the point of view of traceability of food from animal origin, the ontological model proposed by Chifi et al. (2007) for maintaining the traceability in the meat industry can been used as a base for the successive modeling of the agricultural domain for livestock production. In particular, the core ontology implemented by Chifi et al. (2007) in the framework of the Food Trace Project describes participants involved in the traceability chains, services and products they offer/uses and the main features of the products. The Food-Trace system represents a solution to assure the traceability in the domain of food industry even if it refers to the meat processing industry only. Nevertheless it represents a good reference for the implementation of a traceability ontological model for the meat industry. Detailed analysis must be carried out for modeling the different subsystems, which are at the base of the meat processing industry, such as for the livestock production.

3.3.3.3 Food ontologies for the traceability domain

There are various sources of knowledge and concepts on the food domain like the AGROVOC thesaurus , the USDA National Nutrient Database for Standard Reference, or the

LanguaL thesaurus which comprise thousands of food items. These terms and these concepts can be integrated and combined taking into account the above mentioned food ontologies for defining a complete Food ontology for traceability purposes. The obtained ontology can be used for solving the main traceability issues and, at the same time, for solving nutritional and healthcare problems. Salampasis et al. (2008) tried to solve the problem of developing traceability systems from a Semantic Web (SW) perspective and present a traceability solution that consider food traceability as a complex integration of a business process problem which demands information sharing. They propose a generic framework for traceability applications which consists of three basic components: (i) an ontology management component based on OWL; (ii) an annotation component for "connecting" a traceable unit with traceability information using RDF; (iii) Traceability core services & applications. In Salampasis et al.(2012) the authors describe the TraceALL framework and provide a set of core services for storing, processing and retrieving traceability information in a scalable way. In addition, they uniquely identify a Traceability Resource Unit (TRU) using a Uniform Resource Locator (URL) code.

The fundamental concepts that should be considered during the formulation of an ontology for traceability of products, have been defined for the first time by Kim et al. (1995) and they consist in Traceable Resource Unit (TRU) and primitive activity. A TRU is the representation of a resource that must be traceable. In the batch processes, a TRU represents a unique unit, meaning that no other unit can have exactly the same, or comparable, characteristics from the point of view of traceability. On the other hand, a primitive activity is the representation of the activity that must be traceable; a primitive activity is not formed by sub-activities, and it is also not an abstraction of other activity-like entities. Unique identification and the size of the TRU are the keys for a successful traceability system implementation.

3.3.3.4 Methodologies for representing the knowledge related to food traceability domains

In a typical supply chain mass information and knowledge spread out in various format among different enterprise systems. In addition, especially in Small and Medium Enterprises, data are generally stored in relational databases and actors normally use the same terms with different meanings. Current enterprise informative systems usually do not contain information about the meaning of concepts and about the relations existing between different terms and these conditions lead to semantic interoperability issues. In such a context a new ontology should be developed for providing a structure for developing knowledge and unifying the metadata model of the current systems.

The need of a global ontology is supported by the analysis of the state of the art that highlights that ontologies are future trends in the maintenance of food traceability.

The food ontologies which are at the base of the Food-Oriented Ontology-Driven Systems (FOODS) (Snae and Bruckner, 2008)and of the PIPS project (Cantais et al., 2005) should be considered as guide for the development of a more completed ontology for the traceability of food products. The new ontology, considering the main elements defined by Kim et al. (1995) and looking at the traceability as a complex integration of a business process problem which demands information sharing, as defined by Salampasis et al. (2008), should include not only products and activities as most important elements, but should consider all the actor involved in the food supply chain, from the raw ingredient producer to the final retailer, passing through transporters, wholesalers, manufacturing companies, and company involved in the distribution channel. For the detailed definition of the food taxonomy important consideration can be provided by the contemplation of the main works carried out for the definition of particular ontologies devoted to the modeling of specific food domain (Chifi et al., 2007; Drummond et al., 2007; Easwaran, S. and Thottupuram, R., 2011; Graça et al., 2005; Heflin, 2000; Noy and McGuinness, 2001; Wang et al., 2012; Yue et al., 2005). While the afore mentioned ontologies deal with some smaller area of the food sector, these ontologies could be integrated and combined with each other with the main aim of defining a new complete food taxonomy, which includes food and beverages under the same main class. For the definition of the beverage taxonomy, the beer ontology (Heflin, 2000) and the wine ontology (Graça et al., 2005; Noy and McGuinness, 2001) can be reused. On the other hand, the taxonomy of food can be defined classifying aliments on the base of their origin. Food, in fact, may originate from plants or from animals. In addition, the cooking ontology presented in Batista et al. (2006) and in Ribeiro et al. (2006) can be useful for the definition of the taxonomy for processed food, since recipes concepts introduced in the ontology interconnect food concepts with each other.

Some ontology has been proposed in the food domain, moreover there is no ontology that connects food products with the elements involved in their transformation process. There is the need of new ontology in the domain of food traceability in which information on ingredients, receipts, and food processes and actors involved in the supply chain are combined all together to facilitate the knowledge sharing.

The above-mentioned ontologies can be reused and correctly implemented for the definition of the Global Food Track &Trace (FTTO) Ontology for traceability purposes. The new ontology should combine the main elements of the previous works and should include the main elements fundamentals for representing the knowledge related to the food world with the main goal of modeling the domain of food traceability. Additional information to represent in the new ontology, in a simple and understandable way, is data related to products, actors and processes involved in the food supply chain.

3.4 Discussions

The analysis of the state of the art underlines that, over the last decades, the development of traceability systems has received growing attention and several models have been developed for the management of food traceability, at the industry and scientific level. In addition several countries have developed different traceability programs in many food sectors, from meat to fish, along with eggs and olive oil. Nevertheless, more than often these programs do not provide information to the consumer about raw material management, processing, storage and distribution practices.

Despite the numerous efforts made to develop effective traceability systems, current deployments results reveal some critical limitation of existing traceability systems (Bechini et al., 2005). Successful implementation of traceability systems requires high investment costs, staff training and global legal requirements. The recent food safety incidents have further demonstrated that traceability systems have shown to be weak or absent and hence slow or unable to assure consumers of food safety. In such case, food recalls or warnings have been applied to all suppliers, even to the supplier of products that do not contribute to the contamination.

From a regulatory point of view, one of the main problem related with the maintenance of food traceability is that information recorded on food labels only refers to the last actor involved in the transformation process and, in general, the link with the other actors involved in the supply chain which concurred to the manipulation of the food products is loss. As a consequence, even if today a variety of lot code markings and systems exist for products identification and these have merit, they do not link across the entire product’s life cycle.

In order to solve this issue important technologies, such as the Internet and the new generation of products identification technologies, have been developed for supporting new traceability application. In literature, important considerations have been done on the evaluation of the different technologies that can be used for recording, managing and transferring information. Some works carried out in this specific area highlight the importance of RFID systems for products traceability, even if this technology requires high investments costs if compared with the value of food products. Furthermore, some researchers state that web application can be useful tool for providing additional information to consumer and they can be used as valuable instruments for reducing the information asymmetry between producers and consumers, with the main aim of guarantying producers’ responsibility and liability.

From a managerial point of view, the development of a traceability system requires a thorough knowledge of the product flow and information flow along the food supply chain. In literature, different techniques have been used for modeling business processes and information exchanged in the food supply chain. Bevilacqua et al. (2009), for example, use the business process reengineering (BPR) approach to create a computer-based system for the management of the supply chain traceability information flows. They present a computer-based system for the traceability of fourth range vegetables. They use the Event-Driven Process Chains (EPCs) technique to model the business processes. To ensure the traceability, each single unit or lot of the food products has been uniquely identified combining global trade item number GTIN (GS1 traceability, 2006) and the lot code. The business processes database generate follows the Entity Relationship Model (ERM). In the paper, moreover, the data model is not presented, and the front-and generated using the software ARIS is only discussed. Ruiz-Garcia et al. (2010) presented a web-based system to process, save and transfer data for tracking and tracing agricultural batch products along the supply chain. The development of the prototype involved the integration of several information technologies and protocols. The tracking system is based on a service-oriented architecture (SOA) and the communication is through messages in XML.

At the present time there are no works that completely integrate the process flow chart model of the SC with the data model for managing the data required for traceability and automatically generate a web application useful for data track and trace. Nevertheless, those papers where a web model is presented are limited.

New traceability systems can be developed integrating the advantages of the previous works, in order to obtain a better solution at lower cost.

The analysis of the previous works carried out in the traceability domain highlight that the degree of coordination between the different actors of the supply chain is fundamental in the implementation of a traceability system. Also Álvarez et al. (2006) state that particular importance must be devoted to the degree of coordination between buyers and suppliers. To this and, important consideration must be made on the introduction of appropriate rules and sector agreements in order to govern and efficiently manage the relationships between the different actors in the chain.

In a typical supply chain mass information and knowledge spread out in various format among different enterprise systems. In addition, especially in Small and Medium Enterprises, data are generally stored in relational databases and actors normally use the same terms with different meanings. Current enterprise informative systems usually do not contain information about the meaning of concepts and about the relations existing between different terms and these conditions lead to semantic interoperability issues. Ontologies can be used for integrating heterogeneous databases and enabling inter-operability among different systems, since consistent vocabulary is needed for unambiguous querying and unifying information from multiple sources (Jagadish, 1990). There is the need of new ontology in the domain of food traceability in which information on ingredients, recipes, and food processes and actors involved in the supply chain are combined all together to facilitate the knowledge sharing. Some ontology has been proposed in the food domain, moreover there is no ontology that connects food products with the elements involved in their transformation process.

The above-mentioned ontologies can be reused and correctly implemented for the definition of a new ontology for traceability purposes. Since consistent vocabulary is needed for unambiguous querying and unifying information from multiple sources, the proposed ontology can be defined as a standard devoted to the maintenance of food traceability, mainly obtained by enabling interoperability among the different systems and integrating the heterogeneous databases adopted by each actor of the Food Supply Chain.

Starting from the analysis of the state of the art, a SWOT analysis has been carried out for describing strengths, weakness, opportunities and threats related with the introduction of effective traceability systems at the company levels (Table 4).

Table 4 - SWOT Analysis

Strength	**Weakness**
Consumers Demands for food quality and safety, Prevention of food contamination, Quality reputation of certified products Most advanced technologies available, Greater internal efficiency, Overall costs reduction	Lack of global legal requirement, High investment costs Lack of global standards for information encoding and information exchange Staff Training Lack of rules and supply chain agreements
Opportunity	**Threat**
Potential to apply direct consumer tracking, Potential to facilitate the obtaining of appropriate certifications (product, process, environmental and safety certifications), Decrease in the possibility of food fraud, Increased speed of intervention in case of food recall, Targeted recalls Improvement in the company brand, Optimization of products dispatches, Improvements in the consumers trust	Loss of data, Privacy requirements, Eventual obsolescence in the wake of improved technologies, Reluctance to change

Chapter 4

Effective Traceability Management: The Global Track&Trace System for Food

4.1 Introduction

This Chapter describes the design and development of the Global Track&Trace System for Food. As mentioned in Chapter 1, the Global Track&Trace System for Food is obtained through the combination an informative system for food Traceability and the Food Track&Trace Ontology (FTTO), which represents a standard for information encoding and transmission.

The business process modeling and the related data modeling required for modeling the informative system for the traceability maintenance highlighted the huge number of data involved in a typical Food Supply Chain.

In the first part of the work a complex database was implemented for managing data. Moreover databases impose several restrictions to ensure efficient information access and management Hence, in order to model more complex processes, in which several entities are involved (such as food transformation), more expressive systems and techniques are required for reducing the risk of loose the correct meaning related with database.

To solve this issue in the recent years a huge number of other computer science fields and technologies have been used in developing intelligent systems, starting from traditional information systems and databases. In particular, knowledge-modeling techniques have received most attention. A successful new approach in this area to model knowledge has been defined in the last decade: Ontologies.

The solution adopted for the information management to support traceability is generally applicable, which means that it meets requirements from various kinds of industries. This model can be applied in real-life situations that might benefits from traceability solutions. The work, in fact, aims to contribute to the development of a reference model in food traceability and it presents the result of the first part of a complex research work.

4.2 The Global Track&Trace (T&T) System for Food

In this section the Food Track&Trace General Framework is described in its entirety. In the first subsection, the methodological approach followed for the design and development of the Track and Trace Information System is described with a particular focus on the general architecture that characterize the system.

A particular suite has been used for supporting the process modeling and the management of the information flow along the supply chain. The use of software for modeling and managing processes either directly or through web services is a valuable tool for implementing a traceability system.

The Global Track and Trace System for storing, managing and transmitting data includes software for the modeling of the food supply chain, a data server for the storage of information and the generation of a web application that makes data accessible simultaneously from multiple locations.

4.2.1 The Food Track&Trace Building Process

The methodology followed for the development of the Global Track and Trace Information System can be divided into five different steps that are respectively:

- **STEP 1**: Food Supply chain analysis;
- **STEP 2**: Food Supply chain modeling;
- **STEP 3**: Data Collection;
- **STEP 4**: Data modeling;
- **STEP 5**: Generation and Customization of the web-based application for the traceability management.

The food supply chain has been initially studied and analyzed in order to identify actors, elementary processes and resources involved in the supply chain, including food and service product required in the phase of food manipulation. Taking into account the Supply Chain Operations Reference (SCOR) model of the Supply Chain Council (Supply Chain

Council, 2010), for each agent belonging to the food supply chain the most important operations have been identified.

In the second step, business requirements have been conceptualized in a business process model at a high level of abstraction. Process models represent specific ordering of work activities across time and place, including clearly identified inputs and outputs (Davenport, 1993). They represent the sequence of activities, events and control decisions. In this PhD thesis, the Business Process Modeling Notation BPMN was used for modeling the whole food supply chain. In general BPMN is used for representing two different operating configurations. The first configuration refers to processes that take entirely place in a company. In this case, processes are private and the internal activities are not directly visible from the outside. The second configuration refers to collaborative processes that take place between two or more business entities, more specifically between two different companies, organizations, units, etc. The first configuration has been adopted for modelling the internal traceability system required for guarantee the *internal traceability* and for following the path of each single product internally to the company, from the beginning, when it is bought from a supplier, to the end, when it is sold to a client. Each actor of the supply chain, in fact, must develop its own internal traceability system. Moreover, there is the need to connect the internal system of every company with the internal systems of the other actors of the supply chain or of the actors belonging to the same sector. This connection is particularly important for controlling the exchange of information and guarantees the information transmission that takes place when a product moves from one operator to another actor of the supply chain. In such cases, in fact, it is important to keep track of all the transitions that take place between the different actors of the supply chain and maintain the *external or supply chain traceability*.

The supply chain analysis carried out for defining the main elements of the systems and modeling the food supply chain, led to the collection of data generated and manipulated at each level of the supply chain. Data involved in the traceability process and required for the correct management of the supply chain have been identified and analyzed during the third step.

Collected data were modeled using the Entity-relationship technique and, in the fourth step, a relational database was generated.

Finally, the supply chain process model developed using the BPMN standard was enhanced and enriched introducing process parameters and data. The connection required for assigning data to processes was obtained using such java connectors. A particular Business Process Management Suite was used in order to integrate the supply chain model with the data model. In addition, the BPM Suite adopted in the modeling phase was successively used for automatically generate a web based application using the HTML code.

The steps of data modeling, data integration and web application's generation were supported by the use of the tool Bonita BPM Studio, which is a graphical environment for creating processes. Bonita BPM Studio contains two major design tools:

- the whiteboard, for drawing a process flow diagram and defining the detail of steps, transitions, decision points and other process elements
- the form builder, which is used to create forms used in process web applications.

Bonita BPM Studio contains a Bonita BPM Platform (Tomcat, Bonita BPM Portal, Bonita BPM Engine, and an h2 database), suitable for testing processes that is in development.

The methodological approach used for generating the Global Track&Trace System is showed in Figure 15.

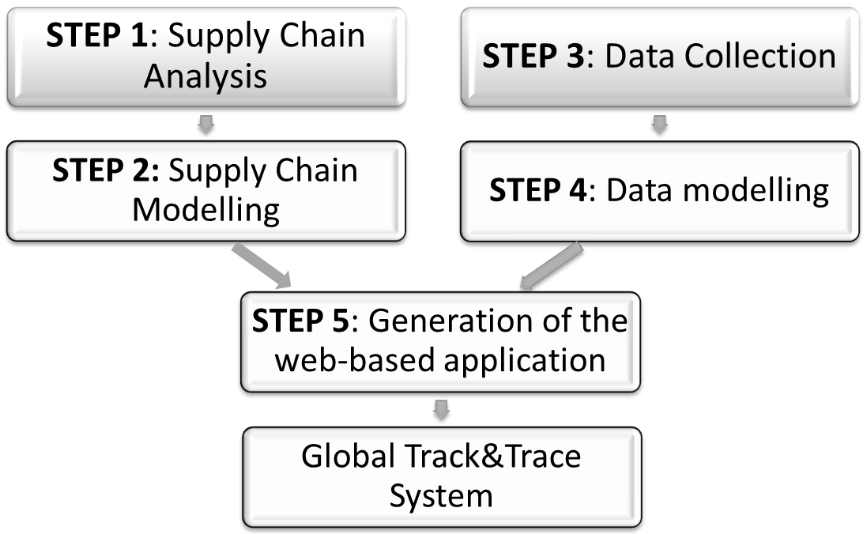


Figure 15 - Methodological approach used for the Global Track&Trace System Development

The main concepts used for the development of the Global Track&Trace System are described in the following subsections, focusing on each single step of the above-mentioned methodology. In particular, in the first Subsection, the first to step are detailed and a brief introduction to the Business Process Modeling notation is provided. In the second subsection, the phase of data modeling is described emphasizing on the use of the Entity-Relationship technique. Finally, the web-based system is presented.

4.2.1.1 STEP 1: Food Supply Chain analysis

The term "Food Chain" is usually reserved for an understanding of the total supply process from agricultural production, harvest/slaughter, through primary production and/or manufacturing, to storage and distribution to retail sale or use in catering and consumer practice (Stringer et al., 2007). From the point of view of traceability, two main entities must be identified in order to maintain product's traceability: processes executed on products and actors who executed these processes. In this step the Food Supply Chain is analyzed in order to identify **actors** and **processes** involved in the traceability processes.

Actors:

The Food Supply Chain (FSC) is a complex structure in which are involved several actor that contribute to the production, distribution, marketing and supply of food products. A Food Supply chain can assume different configuration depending on the number of actors who participate in the chain and on the transformations (physical, temporal, spatial, etc.) that a product undergoes before reaching the final consumer (Source: ISMEA).

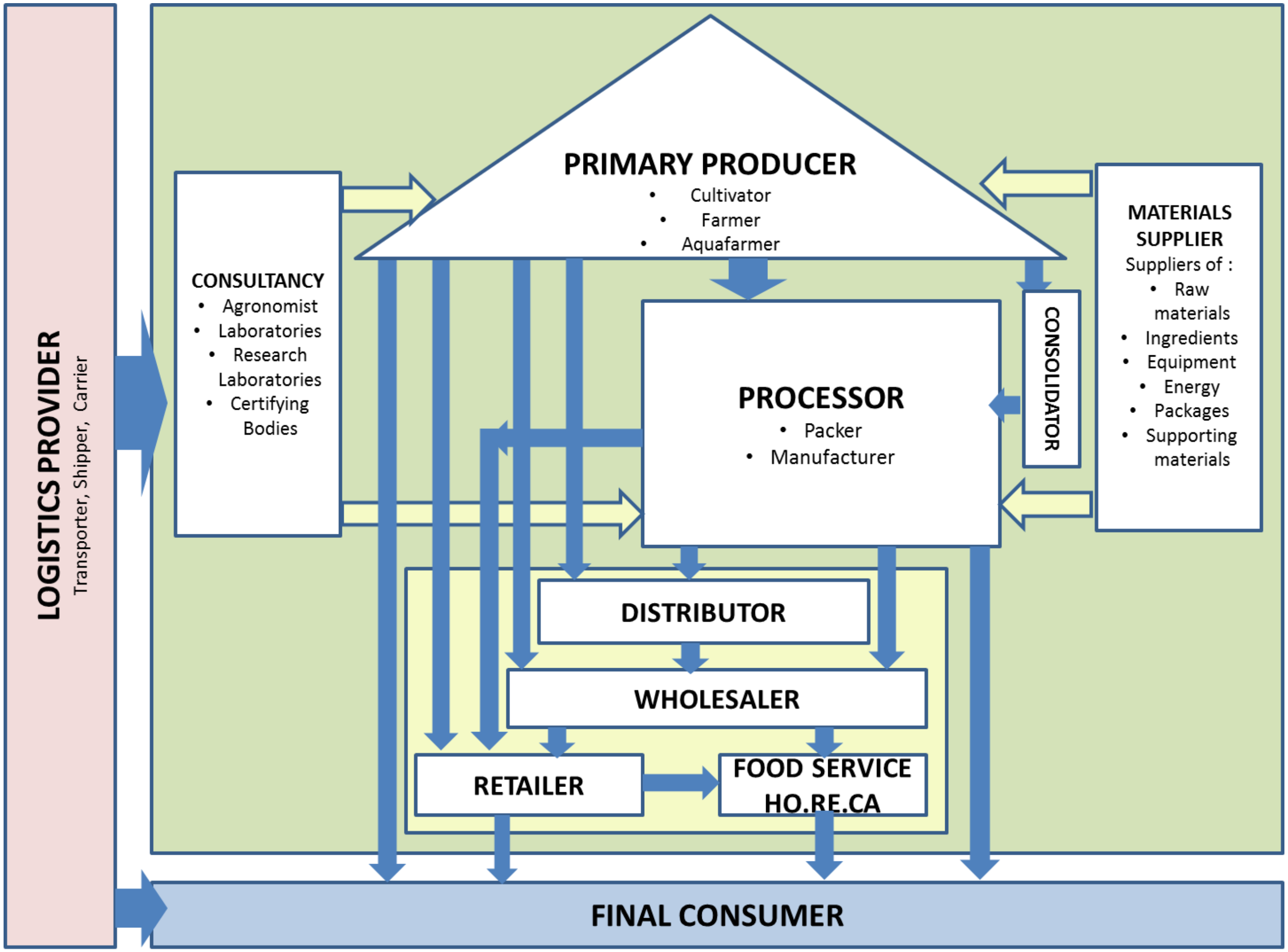


Figure 16 - Actors involved in a Food Supply Chain

Actor involved in a typical food supply chain can be numerous, but they refer to the following categories:

- Agricultural producers or primary producers (farmers, cooperative or organizations of producers);
- Processors (packers or manufacturers),
- Logistic companies (Shippers, transporters, or third part carriers);
- Commercial organizations (buying groups, wholesalers, distributors, department stores, retailers, restaurants, hospitals, etc.),
- Final consumers

The presence of another actor is significantly important in a food supply chain for the consolidation of food products. Consolidators are generally located between primary producers and processors. The buy large quantities of products from different primary producer store them and resell them to the processors in large quantities.

The general schema of a food supply chain, along with the actors involved, is showed in Figure 16.

In general, two main actors are always present in the chain: the primary producer and the final consumer. When the activities of production, processing and sales are carried out directly from the farmers, the organizational system refers to the so-called short food supply chain (SFSC). Farmers and cooperatives of farmers that cultivate or produce primary food commodities such as fruits and vegetables or animals, and directly sell them to the final customers in bulk or packaged forms, without involving any commercial intermediary, represent typical examples of short supply chains. On the other hand, long food supply chains refer to more complex agro-industrial systems in which food, before reaching the consumer, passes through different stages of processing, transport and distribution that are usually managed and controlled by different actors. An example of long food supply chain is the chain of tomato sauce that is obtained through the execution of several unit operation of food processing and they can be sold using different commercial channels.

Figure 17 represents a food supply chain distinguishing highlighting the flow of products in a long and in a short supply chain.

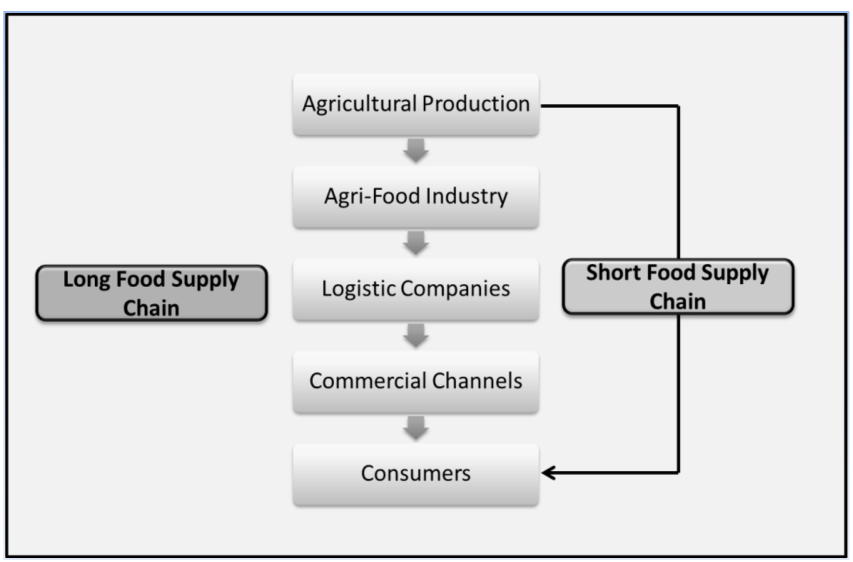


Figure 17 – Schema of a Typical Food Supply Chain

There is a large variety of types of short food supply throughout the EU and nearly each type is present in every part of the EU (Kneafsey et al., 2013). Products mainly traded are, first, fruit and vegetables (mainly fresh, particularly vegetables in the now well present 'veg boxes'), followed by animal products, principally meat, fresh and prepared, and dairy products as well as beverages.

In literature, Marsden et al., 2000 identified three main types of SFSC:

- ✓ Face-to-face, in which consumer purchases a product direct from the producer/processor on a face-to-face basis. Authenticity and trust are mediated through personal interaction. The Internet also now presents opportunities for a variant of face-to-face contact through on-line trading and web pages.
- ✓ Spatial proximity: products are produced and retailed in the specific region (or place) of production, and consumers are made aware of the ‘local’ nature of the product at the point of retail.
- ✓ Spatially extended: where value and meaning laden information about the place of production and those producing the food is translated to consumers who are outside of the region of production itself and who may have no personal experience of that region.

An overview of the different types of SFSC in Europe have been provided by Kneafsey et al. (2013) (Table 4). It excludes the separate category of 'face to face' sales identified by Marsden et al., and groups these instead within 'sales in proximity'.

According to Volpentesta et al.,(2013), the most important forms of SFSC are described as follows:

- ➢ Direct (on farm) sale: It consists in a kind of direct selling that enables producer–consumer face to face relations, offering consumers the chance to procure food with visible provenance. It includes roadside stands where a grower establishes a selling stand (a place located on a farm or orchard) for agri-food products grown exclusively on the farm.
- ➢ Pick your own or U-pick (PYO). This is a form of direct selling where consumers gather products by their own directly from the field. PYO is addressed to consumers who look for fresh and quality products;
- ➢ Box schemes. These types of SFSCs are usually run on a subscription basis where customers sign up in advance to purchase what the scheme makes available (Chiffoleau, 2009). This form of SFSC refers to famers’ cooperatives and local consumption groups ensure a regular procurement of seasonal food grown up in a sustainable way in the local community or its close surroundings ((Sánchez Hernández, 2009).
- ➢ Farmers’ markets. Markets, generally placed in urban areas and with periodic frequency, where a group of farmers meets and where each producer direct sells his own agro-food product to single customers, represent them. Farmer markets are characterized by two main features: (i) sold products are ‘local’ (that means that they are usually produced within 50 km from the market place); second, manufacturers are directly involved in sales (Rossi et al., 2008; Sánchez Hernández, J., 2009)
- ➢ Collective farmer shops. Farmers act together to set up and jointly manage a shop in a market town or a suburban or urban areas where selling their local products. Operatively, products are sold (usually every day) by qualified and

trusted third organizations or by some of the farmers themselves. In this SAFSC form there is no direct contact among consumers and food producer, the trusted third organization acts as intermediaries

- Collective buying groups. Organized consumers that choose to commonly buy directly from selected producers form them. Acting in a collective buying group (CBG), consumer is not only a purchaser of goods, but becomes an active participant of the SAFSC;
- Community-supported agriculture. They involve consumers and local farmers participating to a common agreement. Consumers agree to buy seasonal food from producers who are responsible to delivery periodically at the consumers' home (Sánchez Hernández, J., 2009)

Table 5 - Types of Short Food Supply Chain in Europe

Short Food Supply Chain	
Sales proximity	CSA (Community Supported Agriculture) On Farm Sales: • Farm Shops • Farm based hospitality (e.g.B&B) • Roadside sales • Pick-Your-Own Off Farm Sales-commercial sector: • Farmers' markets and other markets • Farmer owned retailer outlet • Food Festivals/tourism events • Sales directly to consumer co-operatives/buying groups • Sales to retailers who source from local farmers and who make clear the identity of the farmers • Sales to HoCaRe as long as the identity of the farmer is made clear to the end consumer Off-farm sales –catering sector: • Sales to hospitals, schools, etc. The catering sector institution in this case is understood as the "consumer" Farm Direct Deliveries: • Delivery schemes (e.g. Veg box)
Sales at a distance	Farm Direct Deliveries: • Delivery schemes • Internet sales • Specialty Retailers

Source:Kneafsey et al., (2013)

By the time that a product moves from the raw material producer to the retailer store level, that product has gone through a number a transformation. Each transformation will have involved a number of different role players belonging to one of the primary participants of the supply chain. In general, seven primary participants can be identified in a supply chain:

1. **Primary producer**: The primary producer is responsible for the production of raw material and ingredient that can be sold in their original form (fruit and

vegetables, eggs, milk) or can be manipulate and transformed in order to obtain processed food such as bakeries, confectioneries, products of animal origin, processed food of vegetable origin, beverages, etc. Products in their original form are called primary food commodities, whereas food obtained through such a manipulation process are called processed foods. Primary producers can be devoted to the production of primary food commodities or raw materials of vegetable origin (nurseries, cultivators, famers) or to the production of animals, fish or shellfish.

2. **Processor**: The processor is responsible for food manipulation and transformation. A processor can be a packer or a manufacturer. Typically raw materials in input are received from a Primary Producer and transformed by a Processor. A transformation process is every process operated on a particular raw ingredient that leads to a modification in the final composition of food or to the generation of a new product (for example, milk can be used for obtaining butter, and meat can be used for obtain sausages).
3. **Transporter or Carrier**. The carrier is responsible for handling and/or delivery products. The transportation mode can involve differed parts or actors, such as in the case of intermodal transport. To this end, a single transporter can include several means of transportations and can be performed by different carriers.
4. **Wholesaler/Distributor.** The Wholesaler buys large quantity of goods from various producers or vendors, warehouses them, and resells them to the retailers. Wholesalers who carry only non-competing goods or lines are called distributors. Wholesalers provide raw or finished product such as fresh fruit, fish or meat to the retailer. On the other hand, a distributor buys noncompeting products or product lines, warehouses them, and resells them to retailers or direct to the end users or customers.
5. **Retailer/ Store/ Food Service Operator**. The retailer is responsible for the distribution of goods to individual stores. A store and a food service operator have the final relationship with the consumer. The foodservice operator may be an individual restaurant, an extended care facility, healthcare provider or hospitality service such as a hotel chain.
6. **Consumer**.

Individual firms, agricultural associations or cooperatives of producers can represent primary producers. In addition, processing companies can be distinguished according to the type of production and to the transformation processes operated on food. In particular, we refer to ***agricultural food productions*** when food commodities undergo transformation processes that not modify their original composition. In case of agricultural food production primary food commodities are subjected, for example, to the unit operations of sifting, sorting and packing generally operated by a packer. On the other hand, we refer to ***agro-industrial production*** when food is manipulated and transformed, and primary food commodities are characterized by a modification in their original shape and composition. Outputs of agro-industrial productions are, for examples, jams, juices, creams, jellies, purees obtained from the processing of fruit.

According to the logistics infrastructure, logistic business networks can be classified into short and long also. The former refers to the direct transfer of food from producers to consumers. In this case we can distinguish between direct channels and ultra-short supply chain. A direct distribution channel is represented by “collective buying groups” (or “gruppi di acquisto collettivo" in Italian) that sourcing from small companies and/or cooperatives and provide delivery services of type door-to-door or on-line booking. The second form of logistics network is characterized by the presence of multiple actors that can be represented by logistical and commercial facilities that operate in the steps between producers and consumers. The main actors involved in logistics and commercial operation are wholesalers, retailers and distributors. In the Large Scale Distribution ("Grande Distribuzione Organizzata, GDO" in Italian) and Modern Detail ("Dettaglio Moderno, MO" in Italian), the logistic organization is divided into central purchasing companies; platforms or distribution centers ("Centri di Distribuzione, CeDi" in Italian) associated or affiliated point of sales. Purchasing companies, acting on behalf of all the members, buy the products directly from farms or by organizations of producers in large quantities. The products, which are included in the logistic platforms, are then sorted and delivered directly to the points of sale.

Figure 18 shows the different path that a food products can following in a food supply chain. The link between each actor represents a transportation activity that is generally executed by a logistic company, which is identified by a transporter or carried.

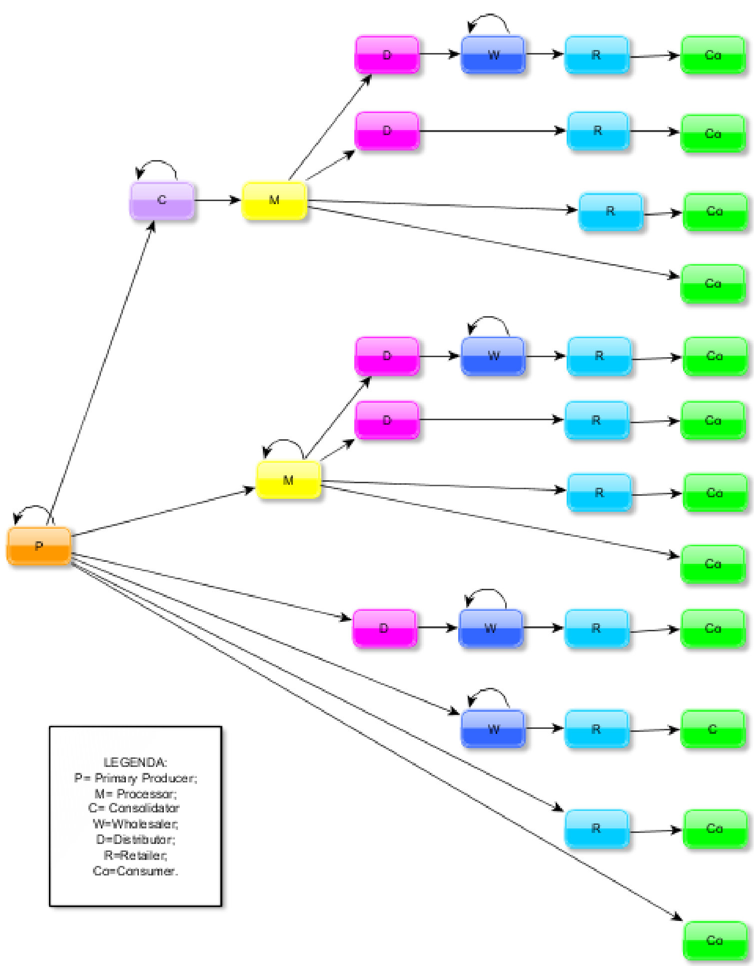


Figure 18 – Possible Product Flows in the Food Supply Chain

Analyzing the graph proposed in Figure 18, a short food supply chain can be seen as a specialization of a long food supply chain, which is characterized by a direct connection between primary producers and consumers or and in which any form of intermediation is present.

Processes:

Following a top down approach, different types of ***processes*** can be identified for each actor of the food supply chain. A short description of the processes operated by each actor is provided as follows.

Depending on the raw materials produced, the agricultural processes operated by a Primary Producer can be distinguished into crop cultivation processes, aquaculture, livestock or poultry production processes. These processes refer to the more general agricultural process. Agriculture, in fact, is the science of producing animals, plants and fungi for food.

Important operations executed at the cultivation stage are seed selection, land or soil preparation, crop establishment (including seedling and transplanting), irrigation or water management, nutrient management and pest management (or crop health management), harvesting and post harvesting. In order to facilitate good record keeping during the crop cultivation phase, growers must fill a logbook in which annotate, for each lot of cultivation, pre-planting actions and in-crop activities such as herbicide and nutrients applications, with a clear definition of the service product utilized, the explanation or motivation of the cause which led to its usage, the amount of service product utilized and the date of the application along with information of the person responsible for the different operations.

Similarly to its application in the cultivation phase, the logbook can be also used for keeping records on aquaculture and livestock or poultry activities.

Farming practices for animals rising are different depending on the type of animals and breading farm. Livestock, in fact, can be kept in an enclosure and fed by human-provided food, or can be not kept in an enclosure and fed by access to natural food, or are allowed to breed frees or any combination of thereof. On the other hand, aquaculture, also known as aqua farming, is the farming of aquatic organisms such as fish, crustaceans, mollusks and aquatic plants.

For the phase of livestock management and aquaculture, fundamental information to track refers to the establishment of the location where a specific animal has been kept in each phase of its lifecycle. Important information to record are the location and date at which animal were born, raised, transported, information of feed used for its alimentation or on treatment done with pharmacological substances or medicated feed. The logbook management can be facilitating by the use of such informative system.

Beside the operational processes operated on food, a series of business processes not directly related with traceability requirements, but able to support the main traceability activities, must be considered and modeled. Especially for ingredients and raw materials, important information to record is information on suppliers, inventory conditions, material used for contain the products during their stay in the company and during the transportation phase.

A food product can be sold in the form of fresh products or can be manipulated and transformed into a complex or derived product. Food that can be eaten right after harvesting or that do not need any manipulation are defined ***primary food commodities*** and, before to be sell, they require just some process of cleaning and/or packaging executed by the primary producer itself of by a packer. Food such as fruit and vegetable and meat, which are included in the category of primary food commodities, are minimally processed and they undergone only simple processes of cleaning, sorting, grading, packing and labeling. On the other hand, ***processed food*** generally goes through different processes before reaching the tables of the consumers. Some of the processes used in food processing change the way food looks, feels and tastes. Food processes may seem bewildering in their diversity, but careful analysis has showed that these complicated and different processes can be broken down into a small number of unit operations. Food unit operations are governed by specific conditions and are characterized by different environmental and process parameters. Important unit operations in the food industry are fluid flow, heat transfer, drying, evaporation, contact equilibrium processes (which include distillation, extraction, gas absorption, crystallization, and membrane processes), mechanical separations (which include filtration, centrifugation, sedimentation and sieving), size reduction and mixing.

Transportation activities play an important role in the food supply chain management. Food products are extremely time critical and, by their nature, they are characterized by a short shelf. Their shelf life can be conditioned by the harvesting means, the transformation processes, the way of transportation, and the storage and handling conditions. Transportation can be done in different ways and using several means of transportation. To this end, the actor Transporter play an important role in the general framework, due to his responsibility in moving food through the different actors involved in the FSC. The main processes operated by the Transporter are Process of Taking Delivery, Transportation Management and Delivery. The holding and movement of materials can occur at several points in the food chain within and across several stages.

A central role is played also by the distribution channel that includes retailer, wholesalers and the distributors that buys large quantity of goods from various producers or vendors, warehouses them, and resells to retailers. The main processes operated by these actors are Buying, Warehousing and Selling. During the storage phase, in the warehouse some operations such as mixing, cleaning or packaging can be executed. Transformations and logistics operation such as procurement and delivery can be considered for each actor.

Each of the above mentioned roles in the Supply Chain needs to keep or share the mandatory elements and, depending on the requirements of their sector, may need to keep and share some of the optional element required for food traceability.

4.3.1.2 STEP 2: Food Supply chain modeling

The modeling of a food supply chain is a complex task because of the different features and which characterizes each single product and because of the different processes required for obtaining a food.
A classification of the different food supply chain can be obtained considering food products from a technological point of view and, consequently, considering the unit operations required for its obtainment.
As mentioned in the previous paragraph, food products can be classified into:

1. Primary food commodities;
2. Processed Foods, which includes derived products, manufactured products.

A primary food commodity is generally sent to a factory where it undergone a series of processes, which can be different on the base of the final products that is required. In such a case, the operation executed on fresh products is different from the operations executed on transformed products. There is, in fact, a wide range of food products. These products can be classified into five different typologies depending on the transformation process.
In particular, eight different type of food supply chain can be identified depending on the food sector:

1) Fruit and Vegetables supply chain;
2) Cereal supply chain;
3) Supply chain of oil and protein crops;
4) Wine Supply Chain;
5) Oil Supply Chain;
6) Supply Chain of milk and dairy products;
7) Supply Chain of meat and meat products;
8) Supply Chain of fish and fish products.

In the context of the proposed PhD thesis, we focused the attention on the analysis of three different supply chains that is described in the next Chapter 5. Each analyzed food supply chain has been modeled at a high level of abstraction, including main actors and processes.

Processes and actors involved in the supply chain, and the relations existing between them, can be modeled using different techniques including Petri nets, the Structured Analysis and Design Technique (SADT), techniques for Integration Definition (IDEF) and Event-driven process chain (EPC). These techniques, along with other methodologies for process modeling (UML Activity Diagram, UML EDOC Business Processes, IDEF, ebXML BPSS, Activity- Decision Flow (ADF) Diagram, Rosetta Net, Loveme, and Event-Process Chains (EPCs)), were revised in 2001 by the Business Process Management Initiative (BPMI), which defined a new standard notation, the Business Process Model and Notation (BPMN). BPMN allows reconstructing the process diagrams (BPD - Business Process Diagram) by means of graphs or networks of "objects". These objects represent the activities of the process and are linked by control flows, which define the logical relationships, dependencies and order of execution

In the proposed research work, process and actors involved in the supply chain and the relationships between them have been modeled using the BPMN technique.

The choice of the BPMN as standard for the modelling of process flow is directly connected with the possibility of integrating actors, tasks and data in a single model. The main advantage related with the use of the BPMN standard deals, in fact, with the model dynamicity since the transition from one version to another one can be obtained without the necessity of reprogramming the application using a specific language, but simply editing the model, adding or deleting a particular element.

According with BPMN, actors involved in the supply chain can classify into pools and external traceability is obtained through the flow of messages between two or more processes.

Following, a brief introduction to the BPMN standard is provided in order to make easier the model comprehension. Then, the model is presented.

4.3.1.2.1 Background: Business Process Modelling Notation

The Business Process Modelling Notation (BPMN) is a new standard used for modeling business process flows and web services. It consists in a graphical notation mainly devoted to depict the different steps, which deal with the execution of a business process.

The primary goal of BPMN is to provide a notation that is readily understandable by all business users, from the business analysts that create the initial drafts of the processes, to the technical developers responsible for implementing the technology that will perform those processes, and finally, to the business people who will manage and monitor those processes. BPMN aims at bridging the gap between business process design and process implementation. It allows the automatic translation from a graphical process diagram to a BPEL process representation that may be then executed using a Web services technology.

Another goal, but no less important, is to ensure that the XML language designed for the execution of business processes, such as WSBPEL (Web Services Business Process Execution Language), can be visualized with a business-oriented notation. The Business Process Modelling Notation, in fact, is especially used in Service Oriented Architecture (Object Management Group, 2010). In a Service Oriented Architecture (SOA) approach, business processes models are leading in routing event data among multiple software components that are packaged as interoperable services (Erl, 2005; Papazoglou et al., 2007).

The BPMN notation has been specifically designed to coordinate the sequence of processes and the messages that flow between different process participants in a related set of activities (Object Management Group, 2010). BPMN defines a Business Process Model as a network of graphical objects, which are activities, and the flow controls that define their order of performance(Chinosi and Trombetta, 2012).

There is no standard definition of a business process, so we define it as the temporal and logical sequence of those activities performed by one or more business participants in order to deliver value to the business.

This definition emphasized the following points:

- ✓ The process can be broken down into a sequence of simpler activities
- ✓ These activities have to be performed by someone or something (a participant)
- ✓ The ultimate goal is to deliver value to the business whether directly or indirectly.

BPMN notation is best used for low level Process step modelling. This low level is the detailed level where you start to know the roles, applications, and information databases involved.

To model a business process flow, it is require to simply modeling the events that occur to start process, the processes that get performed, and the end results of the process flow. Business decisions and branching of flows is modeled using gateways. A gateway is similar to a decision symbol in a flowchart. Furthermore, a process in the flow can contain sub-processes, which can be graphically shown by another Business Process Diagram connected via a hyperlink to a process symbol.

A Business Process Diagram is a simple diagram made up of a set of graphical elements that depicts a business process. There are five basic categories of elements that can be used in order to depict a BPD using BPMN:

- ➢ Flow Objects (Events, activities, gateways)

- Connecting Objects (Sequence flow, message flow, association)
- Swimlanes (Pool, lane)
- Artifacts (Data object, group, annotation)
- Data

The main elements of BPMN are showed in Figure 19.

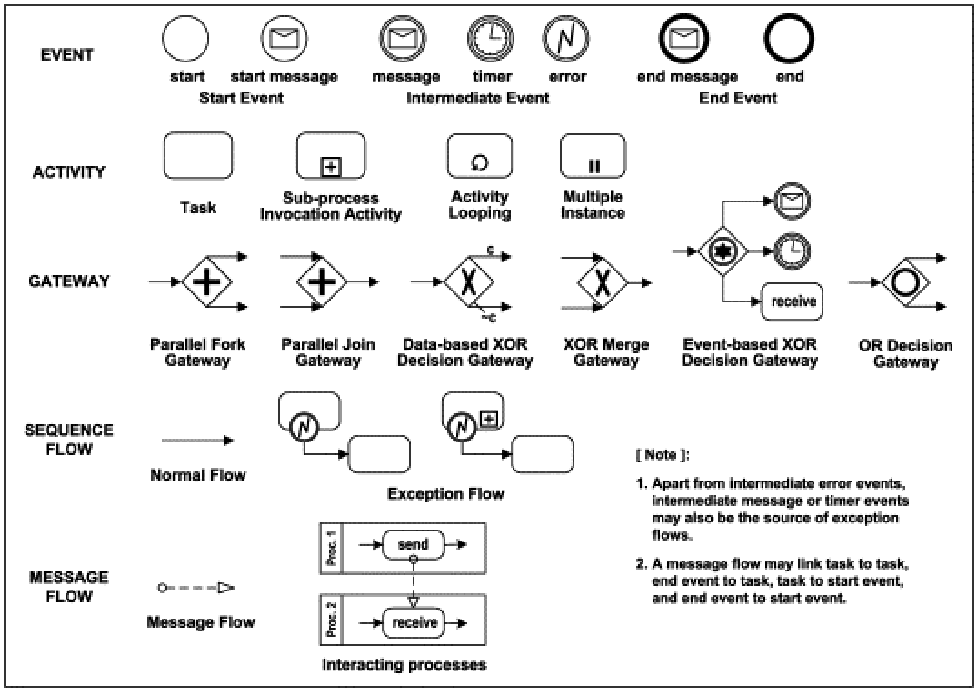


Figure 19- Core Element of BPMN
Source: Remco et al. (2008)

Flow objects are the main graphical elements used to define the behavior of a Business Process and they consist in:

- Events;
- Activities;
- Gateways.

An event is something of note that happens during the course of a process. The events affect the flow of a model and usually have a cause (trigger) or impact (result). There are three main types of events in an "event-driven" process:

- Start events;
- End events;
- Intermediate Events

A start event signs the start of a process, an end event indicates where a path of a process will end, while an intermediate event indicated where something happens somewhere between the start and end of a process.

Particular types of events are:

- Message events, used to send or receive a message;

- Timer event, which indicate that a given time instant has been reached;
- Error event, which sign a fault or exception rose during the process.

There are other types of events in BPMN, namely link events, rule events, terminate events, and compensation events.

Events come in two flows:

- Events that catch a trigger;
- Events that throw a result.

An activity is a piece of work performed in a business process. An activity can be a task or a sub-process. A task is an atomic activity, standing for work to be performed. A task is used when the work in the process cannot be broken down to a finer level of detail. There are seven task types: service, receive, send, user, manual, business rule, script. A service task is a task that uses some sort of service, which could be a web service or an automated application. A send task is a simple task that is designed to send a message to an external participant. Once the message has been sent, the task is complete. Similarly a receive task is designed to wait for a message send from an external participant relative to the process and once the message is received the task is completed. A user task is a typical "workflow" task where a human performer performs the task with the assistance of a software application. On the contrary, a manual task is expected to be performed without the aid of any business processes execution engine or any application. It can be considered as an unmanaged task in the sense that the business process engine doesn't track the start and completion of such a task. A business rule task provides a mechanism for the Process to provide input to a business engine and to get the output of calculations that the business rule engine might provide. A business process engine executes a script task. The modeler or implanter defines a script in a language that can be interpreted by the engine itself. When the task is ready to start, the engine will execute the script and the task will be completed when the script is completed.

A sub-process is a compound activity defined as a flow of other activities. A call activity identifies a point in the process where a global process or global task is used.

Gateways are used to control the flow through the business process and in particular to control the divergence and convergence of Sequence Flows in a process. Gateways can define all the types of business process sequence flow behavior: decisions/branching (exclusive, inclusive and complex), merging, forking and joining. A gateway is defined as a routing construct: the gateway controls the flow of both diverging and converging. There are: parallel fork gateways (AND-split) for creating concurrent (sequence) flows, parallel join gateways (AND-join) for synchronizing concurrent flows, data/event-based XOR decision gateways for selecting one out of a set of mutually exclusive alternative flows where the choice is based on either the process data (data-based, i.e., XOR-split) or external event (event-based, i.e., deferred choice), XOR merge gateways (XOR-join) for joining a set of mutually exclusive alternative flows into one flow, and inclusive OR decision gateways (OR-split) for selecting any number of branches among all its outgoing flows.

There are four ways of connecting the Flow objects to each other or other information. There are four connecting Objects:

- Sequence Flows
- Message Flows;
- Associations;
- Data Associations;

A sequence flow is used to show the order that Activities will be performed in a Process.

A message flow is used to show transmission of messages between two interacting processes. In particular, a message flow is used to show the flow of messages between to participants that are prepared to send and receive them. The two processes are located, respectively, within two separate pools. In BPMN, two separate Pools will represent two participants.

An Association is used to link information and Artifact such as text annotations.

There are two ways of grouping the primary modelling elements through swimlanes:

- Pools;
- Lanes.

A Pool is a graphical Representation of a Participant in a Collaboration. A Participant is often responsible for the execution of the Process enclosed in a Pool and it can be a specific Partner Entity (e.g. a company) or can be a more general Partner Role (e.g. buyer, seller or manufacturer). A Pool acts as the container for the Sequence Flow between activities. A process is fully contained in a Pool: the Sequence Flow of the Process is therefore contained within the Pool and cannot cross the boundaries of the Pool. The interaction between Pools is shown through Message Flows. Message Flow, in fact, can cross the Pool boundary to show the interactions that exist between separate private business processes.

A lane is a sub-partition within a process. Lanes are used to organize and categorize activities.

A process describes a sequence or flow of Activities in an organization with the objective of carry out work. In BPMN a process is depicted as a graph of flow elements (activities, events, gateways and sequence flows). Processes can be defined at any level; low-level processes can be grouped together to achieve a common business role. There are three main basic types of BPMNP Processes:

- Private Non-executable (internal) business processes,
- Private Executable (internal) Business Processes;
- Public Processes.

In general, BPMN is used for two different operating configurations. The first refers to processes that take entirely place in a company. In this case, processes are private and the internal activities are not directly visible from the outside (internal tracking). The latter refers to "collaborative" processes between two or more business entities (companies, organizations, units, etc.).

Private business processes are those internal to a specific organization and are the type of processes that have been generally called workflow or BPM processes. There are two types of business processes: executable and non-executable. An executable Process is a Process modeled with the aim to be executed, while a non-executable Process is a Private Process that has been model exclusively for documenting the Process behavior.

A public process represents the interactions between a private business process and another process or participant. Only those activities that communicate outside the private business process are included in the public process. All other “internal” activities of the private business process are not shown in the public process. A public process shows to the outside world the sequence of messages that are required to interact with that business process.

A collaboration process depicts the interactions between two or more business entities.

Private business process can be modeled in other to manage the internal traceability in each company, while collaborative or business-to-business processes can be modeled to show the interaction between the different actor of the supply chain and for model the supply chain traceability process.

The choice of the BPMN as standard to model the process flow is directly connected with the advantage of integrating actors, tasks and data in a single model. The flow of products lots along the supply chain is associated with information exchanges among responsible actors and possibly third-party organizations. The main advantage related with the use of the BPMN standard deals with the model dynamicity: in fact, the transition from one version to another one permits to add or cancel some elements of the model without the necessity of reprogramming the application using a specific language.

According with BPMN, the actors involved in the supply chain have been classified into pools and external traceability is obtained through the flow of messages between different processes.

4.3.1.3 STEP 3: Data Collection

The core of the data collection step is to identify common data and parameters that will be used for the construction of a data model enough flexible to be adapted to different supply chains. One of the main issues in the design of an efficient traceability system is the identification and classification of the appropriate traceability data to record and make available to the different actors of the supply chain. At this point, a series of data were collected in order to identify the most important information to be recorded in order to guarantee the traceability maintenance.

Some authors, such as Folinas et al., (2006) tried to classify traceability data distinguishing them between static and dynamic data. The former refers to product features that cannot change, such as retirement/catch date, country of origin, expiry date, size, etc. On the other hand, dynamic data refer to dynamic features that change over time while product is changing ownership while moving along the supply chain, such as lot/batch number, order ID, dispatch date, taste, content of chemical components, etc.

According to the statement of by Bertolini et al.,(2006), data collection and reconstruction must include the entire food supply chain, starting from the origin of the raw materials, moving on the production processes, and ending with the distribution of the final product to the customer. A set of detailed information must be collected and linked to each specific phase of the process, above all for both handling and production processes, in order to track the material flow through the production and distribution process.

Some regulations have been introduced in order to define mandatory data to be recorded. In Europe, Regulation EC 178/2002 states that each operator belonging to the food supply chain must record a series of information in order to demonstrate the origin of the products in input to their companies. This information is:

- Name of the supplier;
- Type and amount of the supplied products;
- date of receipt;
- indications for the correct identification of the packaging unit (lot, pallet, box).

In addition, some information must be recorded in order to easily identify the supply customers. This information is:

- name and address of the client;
- type and amount of the products sold;
- date of delivery.

The analysis of the regulatory framework highlights that, from a regulatory point of view, traceability is a requirement limited to ensure the ability for businesses to identify at least the direct supplier of a product as well as the immediate client, with the exemption for retailers (European Commission, 2004, 2002). Notwithstanding, other requirements should be satisfied to ensure food security and to improve food quality (Food Standards Agency, 2002). Additional information should be collected at each stage of the SC to ensure the availability of data for the production analysis and optimization (Thompson et al., 2005). Optional data could be useful to be collected and shared, even if they are not essential for the efficient operation of a traceability system.

For the question of what it is possible to trace in order to improve the supply chain management and to guarantee the correct traceability of the product along the whole supply chain, in the context of this research work we were inspired by the traceability ontology proposed in the TOVE project, which define the essential entities to be traced: Traceability resource units (TRU) and primitive activities (Kim et al. 1995). Traceable resource unit is the resource representation that must be traceable, such as primitive activity is the activity representation that must be traceable.

A series of attributes must be traced for each traceable resource units and primitive activities.

Information on the actor who operated the primary activity on the TRU are fundamental for identify products responsibility and liability.

From the point of view of the TRU, information must be recorded at each step of the supply chain every time that a particular activity is performed. In such a context we believe that information on time and periods must be recorded every time that an activity is performed, especially when the execution of the activity results in a change in the total composition of the TRU.

Additional information to be traced is related to the numerous resources involved in the transformation process, fundamental for correctly performing each single activity. In the context of the Global Track and Trace System, these resources are called service product. For more information on service products see Section 4.3.1.3.4 “Service Product Module”. The information on service products includes data on packaging products, machineries and utensils, food additive, fertilizer. Particularly in the agricultural phase, information to be recorder is related with phitosanitary products and plant treatments products involved in the cultivation process. For transportation and transformation processes, information on materials for packaging is essential for maintaining the connection between products and relative containers.

4.3.1.4 STEP 4: Data modeling

An extended data model should be generated in order to facilitate the information exchange and management. In the context of the Global Track and Trace System, data has been modeled following the Entity-Relationship (ER) modeling technique (Hoffer et al., 2010). An ER model is a detailed, logical representation of data for an organization or for a business area. . The ER model is represented in terms of entities in the business environment, the relationships among those entities, and the attributes of both the entities and their relationships (Hoffer et al., 2006).

The main elements of the data model are entities, or containers of data elements, and relationships, defined as semantic connections between entities. An entity, represented by a table, consists in an element that can be uniquely identified and characterized by its attributes. On the other hand, relationships represent the associations among different entities. Attributes represent information about an entity and relationship types by mapping them into value sets (Patig, S., 2006). A particular type of attribute is the primary key, which consist in an attribute or combination of attributes that uniquely identify an instance in a database. A foreign key, instead, uniquely identify an instance obtained by linking two different tables. Typically, a primary key from one table (entity) is inserted into another table (entity), and it then becomes a foreign key.

Relationships between two entities are obtained by matching a primary key (that provides a unique row/instance) from one table to a foreign key instance in another table.

It is important to note that at this point a series of rules need to be identified for the definition of the different identifiers used for uniquely identify a product or a lot of products. As defined by the Revision Committee on the Handbook for Introduction of Food Traceability Systems (2007), different ID should be defined for the identification of:

- Received traceable unit and shipped traceable unit;
- Traceable unit of raw materials and product’s traceable unit (generally stored in a warehouse)
- Combination and division of raw materials or products.

To this end a series of registers can be introduced in order to maintain the links between raw materials and supplier, delivered products and clients, stored materials and warehouses, operations of transformation, which requires different products in input for the production of particular products in output.

By using information from the production environment it is possible to provide relevant details on local environmental conditions that contribute to the particular uniqueness of the products, as soil, landscapes and climatic conditions, and to certify the origin of a particular product. In addition, the indication of origin (soil, region, country) becomes objective data with special regards to the new requirements of food safety and environmental protection.

4.3.1.5 STEP 5: Generation and Customization of the web-based application for the traceability management.

Process model and data model need to be integrated in order to assign data to the related processes and maintain the connection links with products in each stage of the Supply Chain. At this step the process model needs to be enhanced with the introduction of process parameters and data. The integration of the business process model and data model led to the generation of such web application model aimed at facilitating the management of the whole supply chain.

In the first part of this step, variables need to be introduced in the business process model. Variables can be global or local. Global variables are accessible to all elements in a process. Thus, they can be used anywhere in the process. Local data is available only to the task where it is defined, and to its output transitions. Thus, they can be used only in a single task, and in conditions on the task's output transitions. For each variable, it is possible specify a datatype and consequently the format used for its definition.

Different software can be used for integrating process models and data models. For the development of the Global Track&Trace System we opted for the adoption of Bonita Open Solution, an open source that provides the process modeling through the use of the BPMN technique. In addition the BPM Suite provides the so-called connectors for connecting a task (activity) or a process (pool) to different external information systems. In our case, data have been stored in an external MySQL database and connects have been used for querying the external database, introducing, editing or deleting data. In particular, connectors take specified input (directly as a value from the end user or carried over / built into an expression) and execute a MySQL Query. The working condition of connectors is showed in Figure 20.

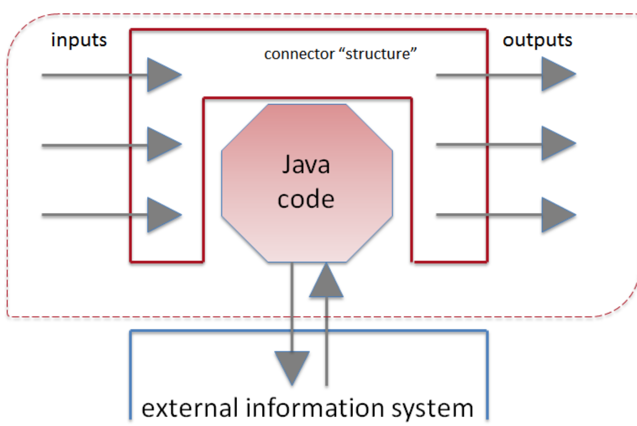


Figure 20- Working condition of a connector

Source: Bonita Soft

Bonita Open Solution connectors accept embedded code, take inputs, communicate with external services, and return outputs.

After introducing data in each process, particular forms can be modeled for creating the web pages related to each particular task. This will automatically generate a web application that can be used for processes and information management.

4.3 The Food Track and Trace Ontology (FTTO)

When agents collaborate in a supply chain they should agree on the same use of word and adopt the same standard or notation. Moreover, the lack of common standards for information encoding and transmission is one of the main issues related with food traceability. In order to solve this problem, we believe that ontological models can be used to increase interoperability between multiple representation systems and to maintain products traceability along the food supply chain. The need of global food ontology is directly related with the main goal of ensuring that all the terms used for coding food in the supply chain are agreed from all the users belonging to the systems. Each company of the supply chain, in fact, should adapt its language to this that is expected for the agent involved in the system.

To this end, in the second part of the PhD research work a new ontology, the Food Track and Trace Ontology (FTTO), is proposed for supporting the process of information extraction and unification in compliance with legal and quality requirements. The main goal of the proposed FTTO Ontology is to include the most representative food concepts involved in a SC all together in a single ordered hierarchy, able to integrate and connect the main features of the food traceability domain (Pizzuti et al., 2014). FTTO have been particularly designed in order to be connected with the Global Traceability Information System proposed in the previous section.

Since consistent vocabulary is needed for unambiguous querying and unifying information from multiple sources, the proposed ontology can be defined as a standard mainly devoted to the maintenance of food traceability, capable of enabling interoperability among the different systems and integrating the heterogeneous databases adopted by each actor of the Food Supply Chain.

The Global Track&Trace System (Pizzuti, 2012), which is at the base of the FTTO Ontology, can be configured as system in which different agent collaborated among them in order to obtain a particular food product. In such a context, the FTTO ontology is used as reference and standard for communication.

The knowledge model has been formalized using Protégé (Stanford Center for Biomedical Informatics Research, 2013), which was also used to automatically generate the ontology code.

The consistency if the FTTO ontology was continuously checked during the entire development phase. The ontology consistency is of fundamental importance, especially when autonomous software agents are to use ontologies in their reasoning (Baclawski et al., n.d.). Reasoning with inconsistent ontologies may lead to erroneous conclusions. The Pellet reasoner supported the validation phase. Pellet is a complete OWL-DL consistency checker Bernardo Cuenca Grau, (2007). The OWL Test Case document (Carroll and De Roo, 2004) provide a useful definition of a OWL consistency checker: “An OWL consistency checker takes a document as input, and returns one word begin Consistent, Inconsistent or Unknown”. Pellet supports standard set of inference services (consistency, satiability, classification and realization), the ones suggested by the W3C recommendations (consistency, entailment and conjunctive query answering) and introduces various nonstandard services. In addition, Pellet is also an OWL syntax checker.

4.3.1Background: Ontologies and OWL

Different notions of the term ontology are provide in literature. Gruber (Gruber, T. R., 1993) defines an ontology as “a formal, explicit specification of a shared conceptualization”. However, the most-cited definition of “specification of conceptualization” should be reconsidered and replaced by the definition provide by Guarino, N. and Giaretta, P., (1995) because an ontology can only mostly approximate the intended meaning of a conceptual meaning.

The aim of an ontology is to capture knowledge in related field, provide share understanding to conceptual knowledge, define common vocabulary in this field and give clear definition to relationships (Heijst et al., 1995).

Ontology consists of a set of objects that are divided into classes, concepts, properties and the restrictions of the roles (Noy and McGuinness, 2001). In other words, the key ingredients that make up ontology are a vocabulary of basic terms, semantic interconnections, simple rules of inference and some logic for a particular topic. Ontology is the key enabling technology for the semantic web. The main purpose of ontology is to enable communication between computer systems in a way that is independent of the individual system technologies, information architectures and application domain.

Based on the notion provided by Noy et al. (Noy and McGuinness, 2001), an ontology defines a common vocabulary for researchers who need to share information in a domain". By relating main and more specialized classes to ontology, a hierarchy can be created. Additionally, individual objects of the selected domain can be represented by the so-called instances of the classes.

Ontologies can be built using a number of possible languages, including general logic programming languages such as Prolog. Information included in an ontology can be queried and manipulated using different standard, such as the W3C standards (Antoniou and Harmelen, 2009).

Web Ontology Language (OWL) (Smith et al., 2004) is a language for defining and instantiating Web ontologies. OWL ontology may include descriptions of classes, properties and their in- stances. The OWL has been created to enlarge web sites with semantic information and to make the Internet usable as a structured information source. The OWL language provides three increasingly expressive sub-languages designed for use by specific communities of implementers and users: OWL Lite, OWL DL and OWL Full.

4.3.2Ontology description

This section describes how FTTO has been defined to set up a traceability semantic model with the scope of reusing the available information resources involved in the process of tracing and promoting the accuracy, reliability and efficiency of the information management system.

As before mentioned, the need of containing all the information related to the food traceability domain in a unique ontology is directly related with the need of enabling information sharing along the food supply chain. Each company of the supply chain should adopt the same language for describing the same entities and all the agents involved in the system should agree this language. To enable information sharing, in fact, data and the way they are organized should be standardized.

In the first part of this section the development process of the ontology prototype is explained. Then, additional information on the conceptualization phase is provided. Finally, a description of the main features of the developed ontology is introduced .The ontology is proposed as a combination of separated modules covering the key concepts of the traceability domain. Both food and processes are key components or core entities of the developed ontology. Additional information is provided on the different features of the FTTO ontology, focusing on the different modules generated. Each module has been developed considering the main elements involved in a general food supply chain. These elements or, key components, are required for keeping the traceability.

4.3.2.1 FTTO Building process

In the recent past a growing number of methodologies that specifically address the issue of development and maintenance of ontologies have been defined. As an example, Methontology (Fernández-López et al., 1997) represents a general methodology that can be used as guide in the phase of ontology development. Methontology is quite general and includes a life cycle based on the continuous evolution of prototypes in which are involved the following activities:

- ✓ Specification. In this step the purpose of the ontology is identified along with its scope including the set of terms to be represented, their characteristics and the required granularity.
- ✓ Knowledge acquisition. This activity generally occurs in parallel with the specification phase. Knowledge acquisition is a long process of working with domain experts. It comprises the use of various knowledge acquisition techniques, in order to create a preliminary version of the ontology specification document, as well as all of the intermediate representations resulting from the conceptualization phase.
- ✓ Conceptualization. In this phase, domain terms are identified as concepts, instances, verbs relations or properties and each one is represented using an applicable informal representation.
- ✓ Integration. In order to obtain some uniformity across ontologies, definitions from other ontologies should be incorporated.
- ✓ Implementation. The ontology is formally represented in a language, such as OWL, generally obtained using an ontology development environment.
- ✓ Evaluation. In this activity a series of techniques are used to evaluate incompleteness, inconsistencies and redundancies.
- ✓ Documentation. A set of documents is collected resulting from other activities.

Following this life cycle, ontology goes through a series of states, which correspond to some of the activities above identified that are respectively specification, conceptualization, formalization, integration and implementation. Finally, the ontology enters into the maintenance state where knowledge acquisition, evaluation and documentation are carried during the entire life cycle (Fernández-López et al., 1997).

Because of the general approach adopted by Methontology, the ontology development process for FTTO has been extended and integrated also being inspired by the ontology building process proposed by (Noy and McGuinness, 2001).

The FTTO building process is presented in Table 2.

Table 6 - FTTO Building Process

Step 1	Analysis of the existing ontology in the food domain for reusing.
Step 2	Extraction of the relevant information for the food traceability domain.
Step 3	Collection of the nouns related to the food and to the agro-food processes (Identification of concepts).
Step 4	Definition of modules.
Step 5	Definition of classes' hierarchy.
Step 6	Definition of Data Properties to describe classes.
Step 7	Definition of Object Properties to describe the internal structure of concepts.
Step 8	Definition of Individuals.
Step 9	Definition of cardinality constraints and values restrictions.
Step 10	Connection of the different modules to the top-level ontology.
Step 11	Performing of the reasoning.
Step 12	Translation of the ontology schema in OWL language.

The FFTO building process was supported by the use of Protégé (SCBIR, 2013), a popular tool able to edit and save the terms of an ontology, providing also a graphical representation of it. Protégé was developed at the Stanford University and has already been through a number of versions and modifications. It facilitates the definition of concepts or classes, properties, taxonomies, and restrictions, as well as class instances. Protégé supports several ontology representation languages, including OWL and RDF (S), and provides translation functionalities for graphical ontology. The Web Ontology Language (OWL) (Smith et al., 2004) is used as the reference representation language for the FTTO. An important feature of the OWL vocabulary is its extreme richness for describing relations among classes, properties, and individuals. For example, it is possible to specify in OWL that a property is *Symmetric*, the *InverseOf* another one, an *equivalentProperty* of another one, and Transitive; that a certain property has some specific cardinality, or *minCardinality*, or *maxCardinality*; and that a class is defined to be an *intersectionOf* or a *unionOf* some other classes, and that it is a complementOf another class.

Similarly, a class instance can be the *sameIndividualAs* another instance, or it can be required to be differentFrom some other instance.

The FTTO evaluation phase has been supported by the Pellet reasoner (B. Cuenca Grau, 2007) included as external plug-in in Protégé. Pellet is an open-source Java based OWL-DL (Description Logic) reasoner. Pellet API provides functionalities to verify the species validation, check consistency of ontology, classify the taxonomy, check entailments and answer a subset of queries. The core of the system is the tableaux reasoner that checks the consistency of a knowledge base. The datatype reasoner is responsible for checking if the intersection of datatypes is consistent or not.

The different elements of the ontology and the related properties are described in Section 4.3.3.2.3 Ontology basic elements.

4.3.2.2FTTO conceptualization

The representation of a body of knowledge is based on the specification of its conceptualization. A conceptualization is a simplified view of the world to be represented for some purpose. The main activities of the conceptualization required for the development of each module were:

- Identification of class and their classification
- Identification and description of data properties
- Identification and description of object properties.
- Identification of instances and their description.
- Validation of the previous step

The concept identification phase was a prerequisite for the definition of the FTTO in the OWL language. At this step, a large list of nouns of the food and agro-food processes domain was identified and classified in hierarchical form. The representation of things in a hierarchical form is the backbone of ontology and it is known as taxonomy.

More deeply, the main components of OWL ontology are Classes, Individuals, and Properties. OWL classes are interpreted as sets that contain individuals. Individuals represent objects in the domain of interest. Individuals are also known as instances and can be referred to as being “instances of classes”. Properties are binary relations on individuals. Taxonomy of properties can be defined as well. The basic elements of the FTTO are described in the Section 3.2, along with a description of some type terms used, type of relationship used and examples.

The need to cover the whole traceability domain, for a general food supply chain, led the authors to define the FTTO ontology as combination of four separated modules covering the key concepts of the traceability domain (actors, food, process, and traceability elements). The FTTO ontology consists of the following main classes:

- ***Agent.*** An agent represents an entity (or actor) involved in the process of food manipulation. This class includes companies and actors operating at each company
- ***Food Product.*** This class includes ingredients such as salt, sugar, oil, and vinegar and food products in the form of raw material or manipulated products.
- ***Service Product.*** It includes products used during the manipulation of raw material or unprocessed food, such as phitosanitary products used in the agricultural phase, or during the transformation phase, such as food coloring or food additives. It includes also material for packaging and container of products.
- ***Process***. It includes business processes and agro-food processes.

Another class has been used in order to define parameter and measurement unit for processes and products.

Several datatype properties were defined to describe relationships between individuals and data values. In addition, numerous object properties have been introduced for defining the relationships between two objects, well known as individuals. However, the need to add knowledge about the world, not limiting ontology to simple definitions of taxonomic hierarchies of classes and terminologies, led to the introduction of several axioms that constraint the possible interpretations for the defined terms. As consequence, a series of restriction were introduced to describe class of individuals on the base of the relationships that members of the class participate in.

4.3.2.3 Ontology basic elements

Four different types of classes have been and combined in the design of the FTTO. A short description for each module is provided in the following paragraphs.

4.3.2.3.1 Agent Module

The Agent Module has to represent the information included in the definition of the actors modeled in the BPMN Model of the food supply chain. The main actors involved in the food supply chain are:

- ✓ Primary producer. It represents the roles of seeder, nursery and cultivator.
- ✓ Processor, which manipulate food products.
- ✓ Distribution channel. It represents the roles of wholesaler, retailer and distributor.
- ✓ Transporter, which physically moves products among different actors.

Along the food supply chain these actors can be present in the role of Client or Supplier. In case health problems due to food contamination or degradation, a key role in the supply chain management is covered the additional actor Observatory, which is responsible for the management of the traceability system and the recall activities. Each agent communicates with the rest of the SC providing to the Observatory actor, the information required for the traceability management. The Agent Module is presented in Figure 21.

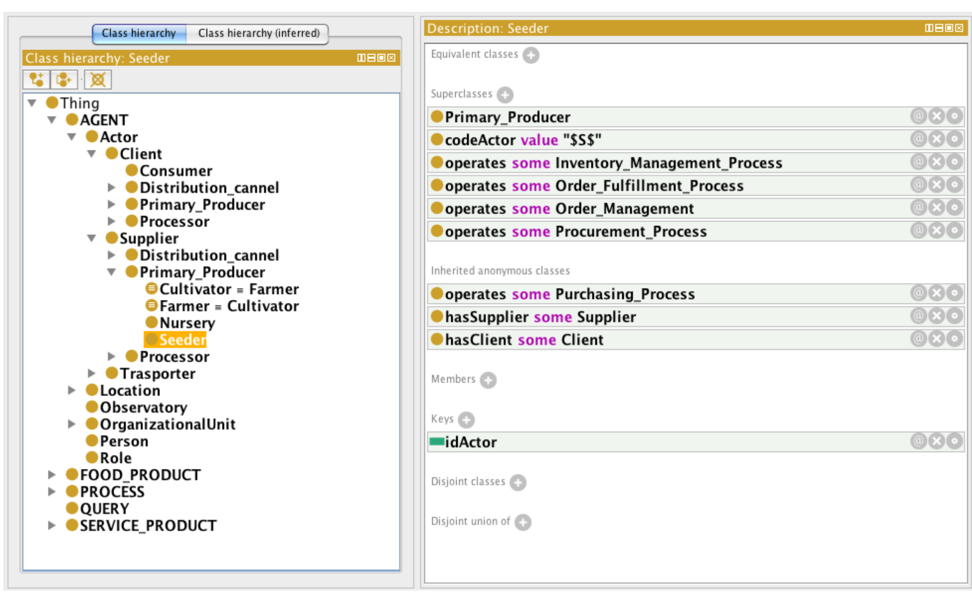


Figure 21 - Agent Module

Figure 21 shows that each actor is uniquely identified by the datatype *idActor*, present in the Keys section, and that it is characterized by a *codeActor* datatype that specifies its role in the supply chain. In particular, in the proposed figure, the *codeActor* with value *S* correspond to the seeder. In addition, general information on processes operated is provided as restriction. These means that the seeder can involve different persons in the role of sales responsible, warehouse responsible, operator or manager.

Each agent of the model represent a company in which is involved different persons who have been assigned a specific role in a specific department. The connection among persons of the class agent is obtained through the definition of the object property *hasMember*, which connect the domain Actor with the range Person. The list of object properties used to define connections among persons, departments and actors are showed in Figure 22.

Each actor is characterized by some data properties such as fiscalCode, codeActor, nameActor, etc.

Furthermore, information on actor's location is modeled through the use of the object property hasLocation, which connect the Actor domain with the Location range.

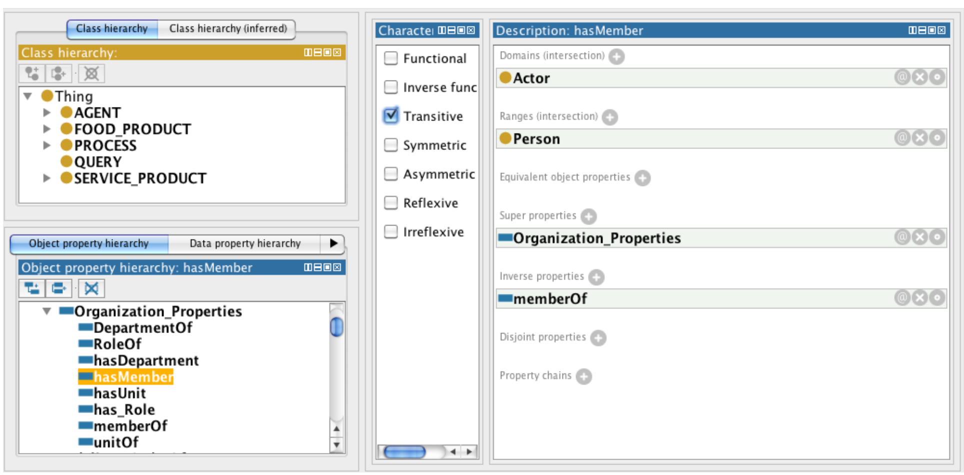


Figure 22 - Organization data properties

4.3.2.3.2 Food Module

The aim of the Food class is to represent an abstract model of the different types of foods available to the users, together with the information about its ingredients. There are a huge number of existing coding systems that have been used in order to classify food and several databases developed with the same purpose. However, very few ontological resources that describe food exist.

The food taxonomy used in the Food class is based on the Codex Classification of Foods and Animal Feeds (Joint FAO/WHO Food Standards Program CODEX ALIMENTARIUS COMMISSION, 1993). Other taxonomies were considered an used in order to complete the food hierarchy such as Eurocode2 food Categories (Unwin and Møller,

1999) and CIAA Food Categorization (Confederation of the Food and Drink Industries of the EEC, 1995).

The terms modeled in the Codex Classification of Foods and Animal Feeds, the Eurocode2 and the CIAA Food Categorization have been integrated with several food databases. More specifically, the vocabulary of food products, used for referring the terms for food traceability, come from the integration of information contained in the AGROVOC metathesaurus (Liang et al., 2006), the LanguaL Thesaurus (Møller and Ireland, 2008) and other databases, such as the USDA National Nutrient Database for Standard Reference (U.S. Department of Agriculture, 2012), the Food Composition database of EUROFIR (Church, 2009), the Molecular Biology Database of the TRACE project ("TRACE - Molecular Biology Database") and the Italian Food Composition Database for Epidemiological Studies in Italy ("Food Composition Database for Epidemiological Studies in Italy," 1998).

AGROVOC is a multi-lingual thesaurus developed by the Food and Agriculture Organization of the United Nations (FAO) in 1982 that includes about 17,000 concepts and 3 types of relations (FAO, 2012). The USDA National Nutrient Database for Standard Reference is a database developed by the United Stated Department of Agriculture to be the major source of food composition data in the United States. Its eighteenth release (SR18) comprehends 7,146 food items and up to 136 food components (U.S. Department of Agriculture, Agricultural Research Service, Food Surveys Research Group, 2010).

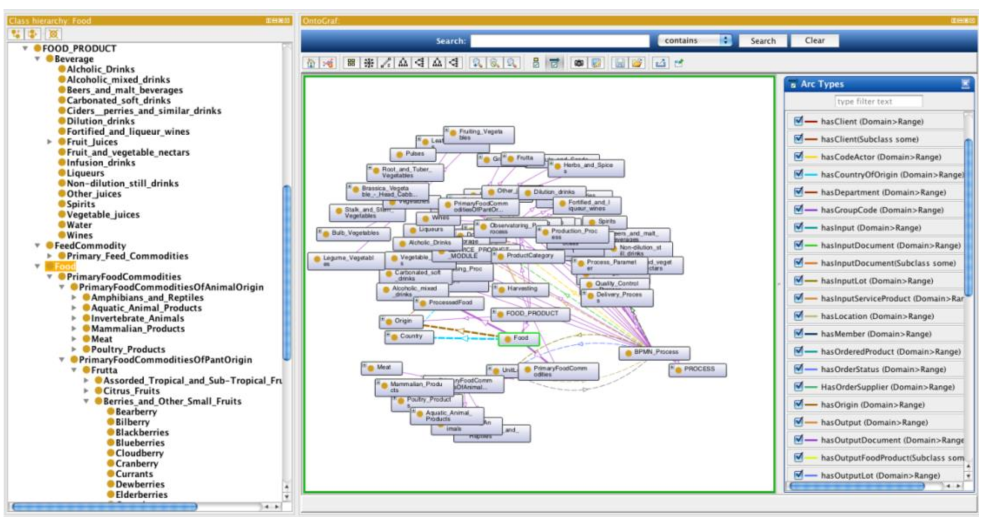


Figure 23 - Food Product Ontology

Figure 23 shows the taxonomy of the Food class in which food products are classified according to their origin and on the base of processes executed on them. According to their origin, food products can have animal or plant origin, even though most food has its origin in plants. Food taxonomy initially identifies the categories of "primary food commodities" and "processed foods". The term "primary food commodity" means the product in or nearly its natural state. The category of primary food commodities of animal origin includes irradiated primary food commodities and products after removal of certain parts of the animal tissue, e.g. bones. Food commodities of animal origin are parts of domesticated or wild animals, including their eggs and mammary secretions. The category of "processed foods" includes products that have been handled and transformed by the execution of some unit operation of food processing. These products have been classified in "derived products", "manufactured foods" and "secondary food commodities". The term "secondary food commodity" means a "primary food commodity" which has undergone simple processing, such as removal of certain portions, drying, and combination, which do not basically alter the composition or identity of the commodity. "Secondary food commodities" may be processed further or used as ingredients in the manufacture of food or sold directly to the consumer. "Processed foods" prepared from these primary food commodities are again separated into those of plant origin and of animal origin. Multi-ingredient "manufactured foods" containing ingredients of both plant and animal origin are listed as plant or animal origin depending upon the main ingredients.

During the development phase of the FTTO ontology, the main difficulty found in the conceptualization of the food class was to consider and model the concept that a food item may be part of another one (Ribeiro et al., 2006) in case of processed foods. This issue was solved specifying the objet property *hasIngredient*, which links each food item with the primary commodities and the processed food used to obtain it, and that has as inverse property the relationship *isIngredientOf*. As example, the food item "minestrone", is an individual of the class Vegetables Mix, which is a sub-class of Manufactured Foods of Plant Origin, that contains has ingredients carrot, tomato, onion, bean, potato, spinach (Figure 24)

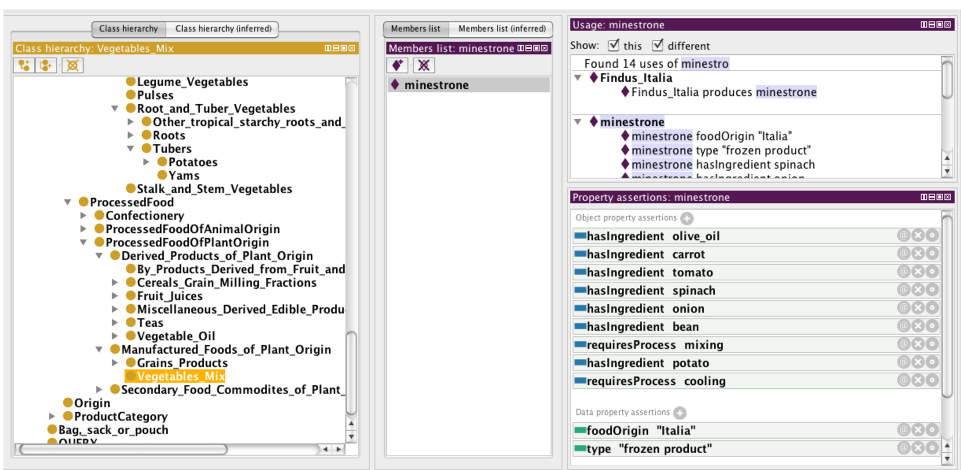


Figure 24 - An example of individual

4.3.2.3.3 Process Module

The Process Module conceptualizes the knowledge related to the process domain in the field of the food processes. The need to connect the FTTO ontology to the General Track&Trace framework introduces taxonomy of the all processes modeled in the BPMN model of the food supply chain in the Process Module. The classification of the processes operated in the food supply chain is particularly important to standardize the internal traceability systems of each company involve di in the SC and to reuse the same terms in order to specify or refer to particular activity operated on food, independently by the actor who manipulated the product.

A detailed analysis of a generic food supply chain has been initially carried-out in order to identify the main terms and concepts to be included in the FTTO ontology. The supply chain analysis leads to the development of the Global Track and Trace System described in detail in section 4.2. Taking into account the modeled food supply chain, a classification of the processes has been obtained. As shown in Figure 25, the Process class includes a classification of business processes, agro-food processes and food transformation processes operated by the different agents involved in the supply chain.

The class of Business processes includes processes related to traceability, such as distribution, labeling, purchasing, order fulfillment, storage, packaging and labeling. For the definition of the taxonomy of the business process class, important consideration have been done taking into account the Supply Chain Operations Reference (SCOR) model proposed by the Supply Chain Council (Supply Chain Council, 2010). Business processes, in fact, have been classified considering their main goals. Moreover, as mentioned before, the business processes classification has been mainly defined considering the business process models proposed by Pizzuti et al. (2012).

The class of ***agricultural process*** includes crop cultivation processes, livestock production processes and aqua farming processes. In order to maintain internal traceability, important information must be recorded for each process depending on the specific activity operated on food. To this end, for each process, the most important activities have been classified. For example, the crop cultivation process includes the activities of sowing or transplanting, irrigation, fertilization, weeding, plant protection treatments and harvesting. On the other hand, the livestock and poultry production process includes feeding processes and watering, along with the pharmacological treatments processes. Further considerations can be done also for the aqua farming process.

The taxonomy for the ***processes of food transformation*** was collected based on the *unit operation of food processing* (Earle, 1983). Food processing refers to the transformation of raw ingredients into food or food into other forms. The main processes operated for food transformation have been defined under the class Food Transformation processes. As previously defined, the processes used by the food industry can be divided into common operations, called unit operation. Examples of common operations for many food products include cleaning, drying, separation, and material handling, heating and cooling. Unit operation operations may include different types of activities (Potter, N.N. and Hotchkiss, J.H., 1998). The unit operation of mixing, for example, includes the activities of emulsifying, blending, agitating or stirring.

Some object properties have been introduced for representing the knowledge related to the processes operated in a food SC. Important information to store for each activity operated in a unit operation is information on process parameters, such as environmental parameters like temperature, humidity and pressure, or technical parameters like speed, capacity or processing time. Process parameters are defined for each process using the objects properties of *hasProcessPameter*, which connect the Process class with the Parameter class.

Furthermore, the starting time for each process is defined by the relationship *hasStartTime*. The information on the date and the time in which a process is operated is fundamental for traceability purposes because it permits to identify critical control points to keep in consideration in case of food crises or food outbreak diseases.

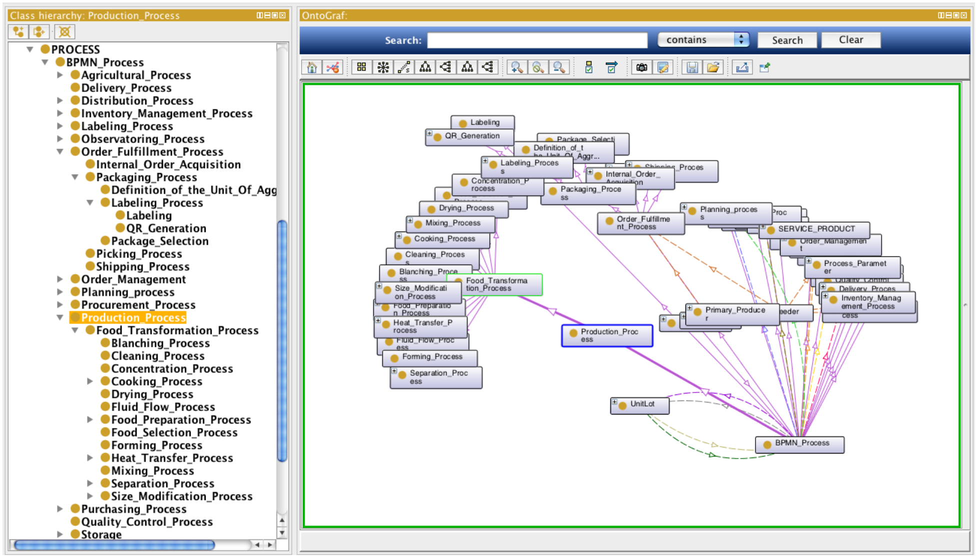


Figure 25 - Representation of the Process class hierarchy

4.3.2.3.4 Service Product Module

The Service Produce Module models the knowledge of the products related with the production processes. The Service Product class includes products for packaging and for food treatments at each stage of the supply chain. For e.g., phitosanitary product are involved in the agricultural processes operated by the nursery and cultivator (farmer). Food additives, however, are substances used in the food industry during the phases of preparation, storage and marketing of foodstuffs. Another sub-class includes machineries and utensil used in each stage of the supply chain. The class hierarchy is showed in Figure 26.

Figure 26 - Service Product Class Hierarchy

The importance of the Service Product Class in the FTTO ontology is a consequence of the legal requirements on materials and products used for managing food. In particular the sub-class of the Packaging Products is fundamental for the traceability of materials used to package food, as these can contaminate food or lead to their deterioration.

4.3.3. Ontology querying

Every agent has its own knowledge base, and only information that can be expressed using ontology can be stored and used in the knowledge base. When an agent wants to communicate to another agent in the food supply chain, he uses the construct from the FTTO ontology. The Global Food Track&Trace Systems, which is at the base of the FTTO ontology, can be configured as a multi-agent system in which agents cooperate and communicate delivering and receiving messages. In this context, the FTTO ontology is used as a standard reference for communication. However, the final aim of the FTTO is to help authorities and food agents to solve problems in case of food crises, when analysis and elaboration of common data available in the food supply chain is required.

To demonstrate the FTTO validity, different scenarios have been studied and analyzed. This paragraph provides a short description of one of this scenario. When a food crisis occurs, authorities or government agencies elaborate data available querying the FTTO ontology and make a series of assertions in a consistent way. In the proposed scenario a series of persons present symptoms food poisoning. For each person, information on food eaten is available. Due to the complexity of food composition and to the huge number of information on products, the problem of identifying the source of a food outbreak disease is a complex problem. In the analyzed scenario patients have eaten different food. Different foods can be obtained combining several primary food commodities or processed foods that can have some ingredients in common. Through the ontology querying, information on common ingredients can be easily obtained. For example, patients can have eaten different products such as vegetable mixes, tomato sausage, and lasagna. All these products have a common ingredient that is the tomato and that can be the source of the food outbreak disease. Figure 27 shows the result of a query expressed in Description Language, which requires the selection of all foods that contains tomato as an ingredient. In particular tomato is contained in juices or sauces that are used for the production of complex foods such as ready meals and pizzas. In addition, tomatoes can be dried and pickled in oil or cut and used in vegetable mixes.

The querying of the FTTO ontology permits to elaborate information and to return information of ingredients, processes or service products that are common for elements for the different foods under analysis.

Different food products can be characterized not only by the presence of the same ingredients but also by the use of similar processes operated along the food supply chain, which can requires the same service product. In addition the same actor can manipulate different food products using the same service product and materials. On the base of these statements, another possible scenario to analyze can be characterized by the presence of patients who ate different products that do not share any ingredients, but that can be characterized by the use of some service product in a particular phase of the supply chain. This is the case in which water, for example, is used as common source for irrigating a parcel used for the growth of a particular vegetable and for watering the animal in a herd. The water, which is characterized by the presence of a particular contaminant, can lead to the contamination of the vegetables produces in that parcel and of the meat of the caw that drank the same water used for the irrigation.

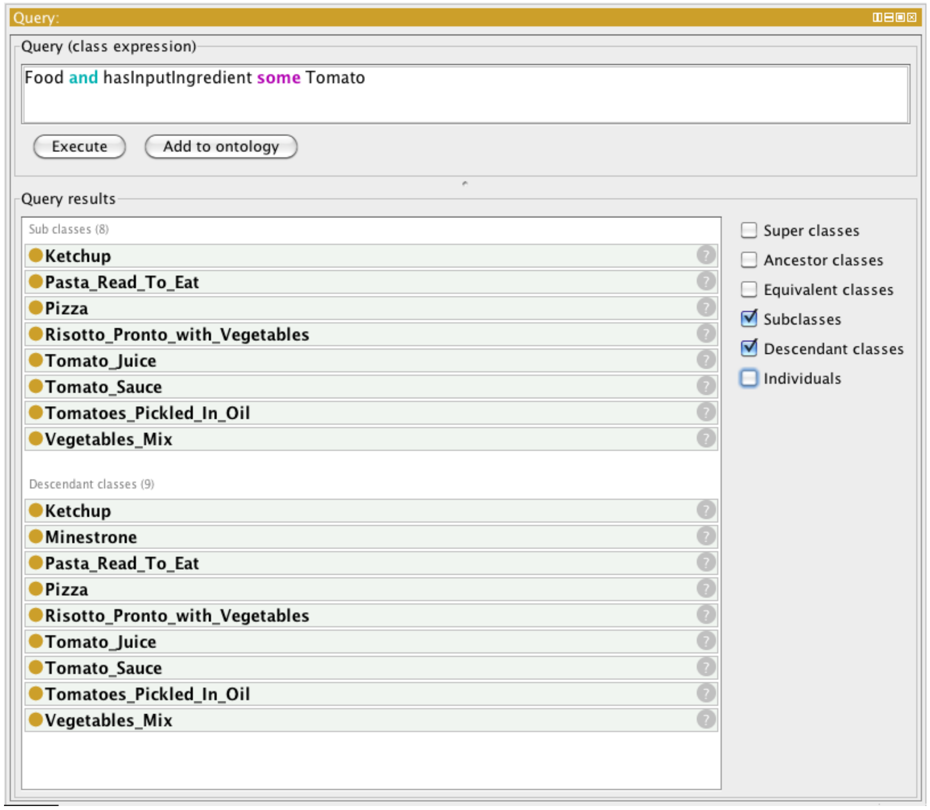


Figure 27 - DL Query expression and Results

The solution of the problem presented in the proposed scenarios can be easily obtained querying the FTTO ontology, and correlating the information conceptualize in the ontology with the information recorder in the database of each actor belonging to the supply chain. The results of a query on the use of water in the different processes that can be operated along the food supply chain are showed in Figure 28.

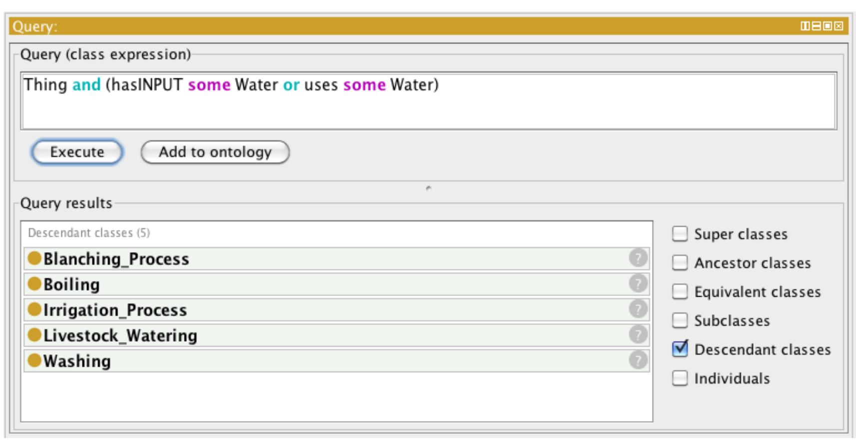


Figure 28 - Query expression and Results

At this step, it is important to pointing out that the FTTO ontology has been developed with the main aim of containing all the information related to the food traceability domain in a single hierarchy. FTTO, and the general framework in which it is involved, have been designed in order to define a traceability prototype able to assist in solving some exiting problems which deal with food traceability, such has the need to connect information on food, processes, products and actor involved during the manipulation of a particular products, and to identify the causes which lead to the definition of a particular problem of food origin.

Chapter 5

Effective Traceability Management: Functioning Principles and Case Studies

This chapter presents some case studies related to the application and adaptation of the Global Track& Trace Framework. Practical examples allow understanding the use of the methodologies followed for the Global Track and Trace System. In particular, in the first part of this Chapter, the working principles of the Global Track&Trace System are explained. In order to demonstrate the validity of the Global Track and Trace System, in the second part of the chapter the general framework developed for the maintenance of food traceability has been adapted to two different supply chain: the supply chain of Fruits and Vegetables and the supply chain of meat and meat products. Starting from the analysis of the Fruit and Vegetable supply chain, two different cases have been modeled, focusing the attention respectively on the traceability process in the supply chain of fresh fruits and of processed vegetables.

5.1 Global Track & Trace System Working Principles

Because of the different features that characterize a typical food supply chain; we considered the need of developing a general framework for the traceability management. In particular we focused on common processes required for food traceability and defined mandatory data to be recorded. In addition a series of encoding rules were defined on the base of the developed FTTO ontology.

A general data model is proposed enough flexible for developing the strategy of traceability and open to incorporate new future features to be taken into account.

In addition a MySQL database is generated for each actor involved in the supply chain in order to record information about products and processes operated on products. In particular, the traceability data model was developed using MySQL Workbench. MySQL Workbench provides DBAs and developers an integrated tools environment for Database Design & Modeling. MySQL Workbench enables a database administrator, developer, or data architect to visually design, model, generate, and manage databases. It includes everything a data modeler needs for creating complex ER models, forward and reverse engineering, and also delivers key features for performing difficult change management and documentation tasks that normally require much time and effort.

Information on products are identified and stored essentially in four different stages of the supply chain: when receiving a shipment lot, when a lot is moved internally to the company, when a lot is manipulated or transformed and finally when a lot is shipped or delivered. In particular:

- ***when receiving a shipment lot*** it is important to check the incoming lot and the related information such as the lot ID, generally included in the label or in the invoice provided by the supplier. Them it is required to link the Id of the incoming lot with the Id of the supplier which provided it and record additional the information on the time of arrival
- ***when moving a lot internally to the company*** it is important to maintain the linkage between the old and the new location in which the lot is temporary stored. Consequently information to be recorder is location of origin and destination, date and time of movement, optional information on the operator who moved the lot.
- ***when such a kind of operation is executed on the product***, information on the type of operation needs to be registered, along with information on the date of processing and on possible changes that can happen on the lot weight or lot composition. In addition, the linkage with ingredients or service products used for the execution of that particular operation should be maintained to facilitate the identification of possible sources of contamination in case of food outbreak diseases.

  Such a kind of operations can lead to some modification in the lots composition. This is the case in which different lots are integrated into a unique combined lot or a single lot is divided into several lots. When two or more lots are combined into a new lot it is important to assign a new Id to the new obtained lot, maintaining the linkage with the information of each single lot used for obtaining it, and to record information on the date of combination. On the other hand, when a single lot is divided into one or more lots it is convenient to assign a new Id to the new generated lots and maintain the linkage with the lot that originated them. Other information to be recorded includes information on the date of division, the weight of the lot before and after the division, the form of package used.

- ***when a lot is shipped or needs to be delivered to another*** actor of the supply chain it is fundamental to link the information on the shipped lot with the information about its buyer. In particular, the Id of the shipped lot should be linked with the Id of its Buyer and information on date and time of the delivery operation should be recorder.

Starting from the above considerations, the process of traceability of incoming lots, the process of traceability of movements within the company, the process of traceability of operation executed on lot and the process of traceability of shipped lots have been analyzed and modeled in order to identify data to be recorded and modeled for the generation of a series of web applications useful for assisting in the traceability management process of all the different types of food supply chain.

The main processes modeled are showed in the following subsection, describing for each one data collected and their modeling processes.

Particular attention has been devoted also to the traceability of the processes of ***storage*** that are fundamental for the maintenance of food quality and safety.

5.1.1 Traceability of Incomings Lots

When a company receives a shipping lot, the first operation required for product traceability is the identification of the lot and the registration of the incoming Lot in the Global Track and Trace System (Figure 29).

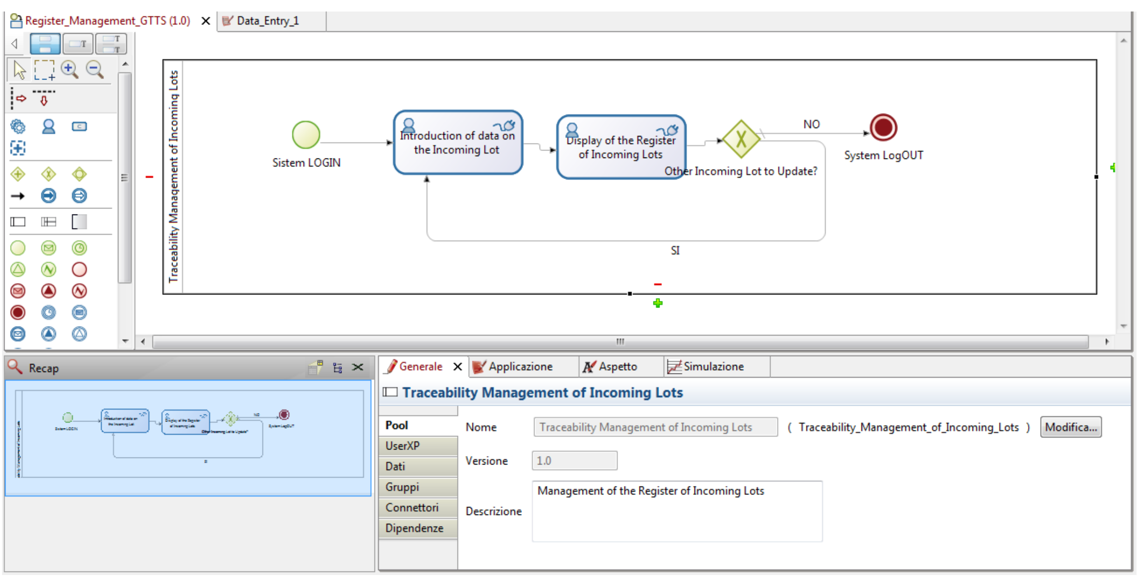


Figure 29 – Process of Registration of Incoming Lots

The different Lots of incoming materials can be recorded using a particular register, the MP Register or register of raw materials. The Register of incoming lots is particularly important for maintaining the ***backward traceability*** (to the supplier).

Data required for the traceability of Incoming Lots are showed in the table proposed in Figure 30. Information recorded on every incoming lot or lot of raw material is:

- ✓ Id of the Actor responsible for uploading the register;
- ✓ Id of the lot of incoming material;
- ✓ Id of the contained material;
- ✓ Description of the contained material;
- ✓ Quantity of the lot;
- ✓ Unit of measure of the lot;
- ✓ Id of the supplier which provided the incoming lot;
- ✓ Id of the lot provided by the supplier;
- ✓ Date of arrival of the incoming lot.

localhost ▸ gtts_db ▸ mp_register

Mostra | Struttura | SQL | Cerca | Inserisci | Esporta | Importa | Operazioni

#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
1	**idActor**	varchar(8)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
2	**idMP**	int(10)			No	*Nessuno*		Modifica Elimina Più
3	**MPDescription**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
4	**idLotMP**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
5	**lotQuantity**	int(10)			No	*Nessuno*		Modifica Elimina Più
6	**unitOfMeasure**	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
7	**idSupplier**	varchar(7)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
8	**idLotSupplier**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
9	**dateArrival**	varchar(8)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più

Figure 30 - Register of Incoming Lots

A devoted web application has been generated for the management of the Process of Traceability of incoming lots. The Web Application has been obtained integrating the process model with data and information required for food traceability. Figure 31 shows how data are introduced in the process model.

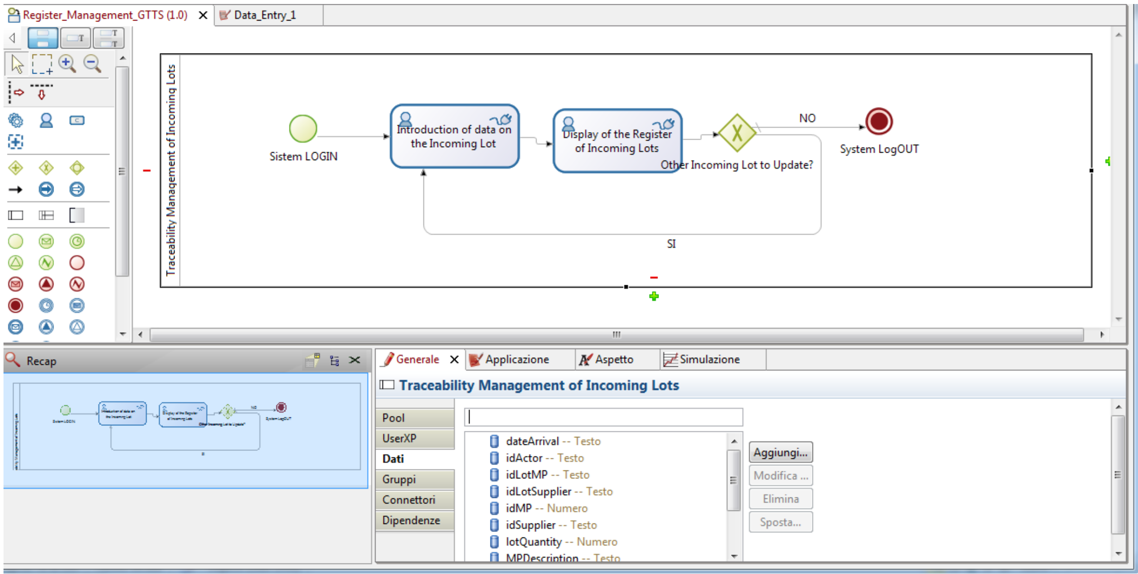


Figure 31 - Data integration

Data introduced in the process model are useful for connecting the process model itself with the data model developed following the entity-relationship approach.

A series of connectors have been introduced in the process model for querying the related database. Figure 32 shows the query introduced in the process model for uploading the incoming lots and inserting all the related data, while Figure 33 shows the query introduced for displaying the uploaded register. The connector executes the query on the MySQL database and returns as output the uploaded register of incoming lot.

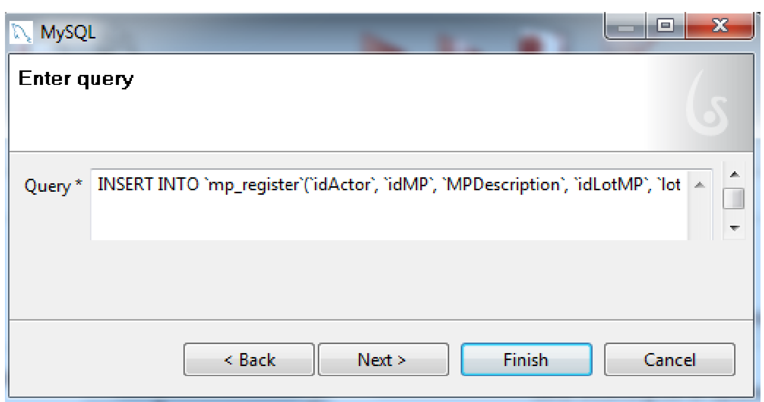


Figure 32 – Database Connector with related Query for the upload of the Register of Raw Materials

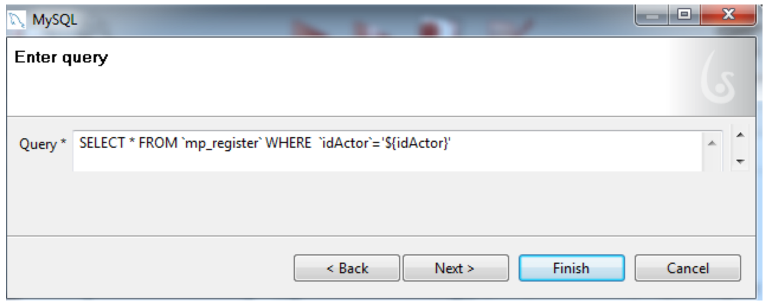


Figure 33 - Database Connector with related Query for displaying the register of Raw Materials

In the developed web application, each actor registered in the Global Track and Trace System, after entering the identification code of its company is able to easily register all the information on every single Incoming lot using a simple front-end (Figure 34).

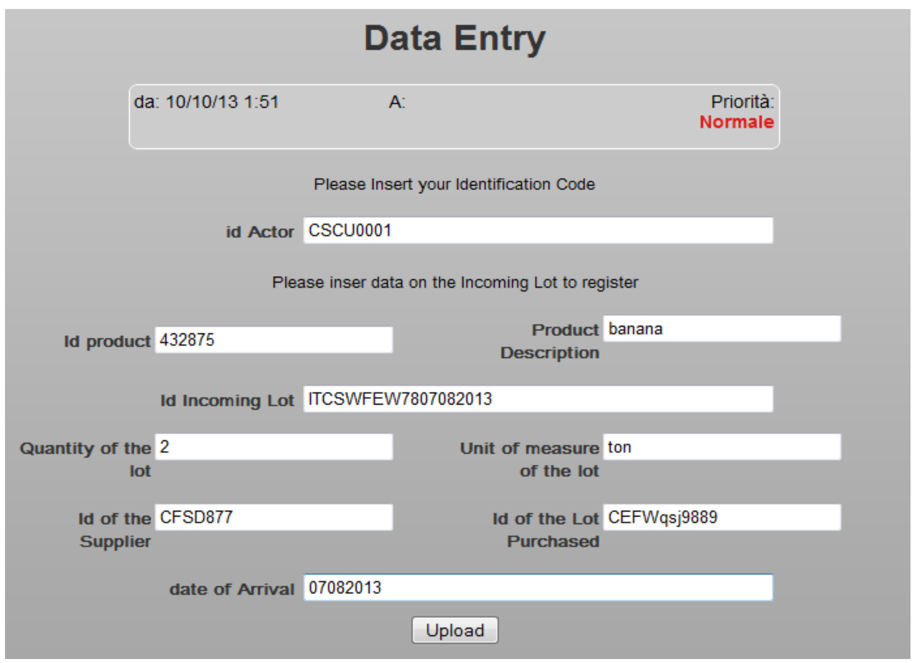


Figure 34 - Front end of the Web based Application

Once data are entered into the system, the uploaded register is displayed (Figure 35) and the user is asked if there are more incoming lots to be registered in the system.

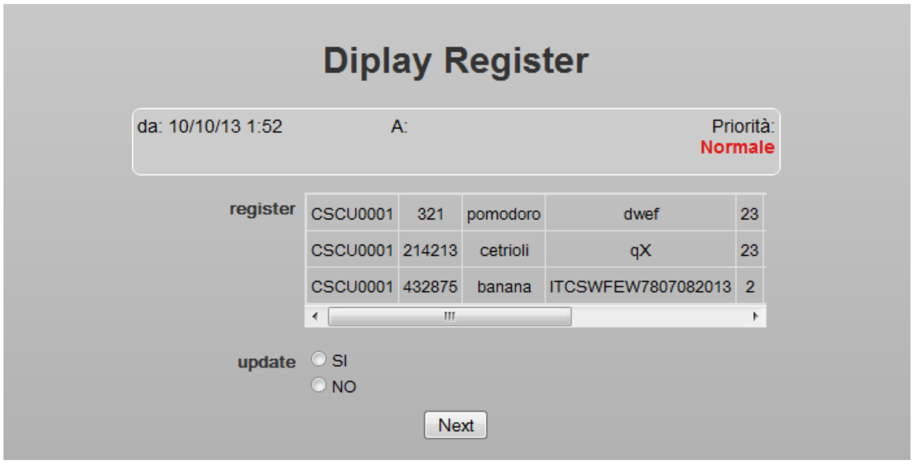


Figure 35 -Displaying of the uploaded register

5.1.2 Traceability of Storage

Once information on Incoming Lot is recorded in the system, products must be allocate in the company and stored in internal or external warehouses. During their flowing in the company, products can be stored in three different moments:

- at their arrival to the company, when they need to wait for their entry in the production process (in this case the storage is in INPUT).
- during the transformation process when they need to wait in order to be processed in a second time (in this case the storage is in LINE)
- at the end of the production process when they are packaged and need to wait before to be delivered (in this case the storage is in OUPUT)

Each warehouse is characterized by a series of environmental conditions that are required for the maintenance of quality and safety of food products. Generally, the temperature necessary for food preservation depends on the storage time required and the type of product. In general, there are three groups of products, foods that are alive (e.g. fruits and vegetables), foods that are no longer alive and have been processed in some form (e.g. meat and fish products), and commodities that benefit from storage at controlled temperature (e.g. beer, tobacco). Cold storage preserves agricultural products. Refrigerated storage helps in eliminating sprouting, rotting and insect damage. Several perishable products require a storage temperature as low as -25°C. In addition,

Information on storage and storage conditions are fundamental in food supply chains because of their perishability feature. In addition, edible products generally cannot be stored for more than one year or can be stored only for a certain period. To this and, the maintenance of a storage register is a fundamental process of a company belonging to the food supply chain for the transparency of the chain and the maintenance of the ***internal traceability***.

A particular process has been modeled for representing the storage process in a company (Figure 36).

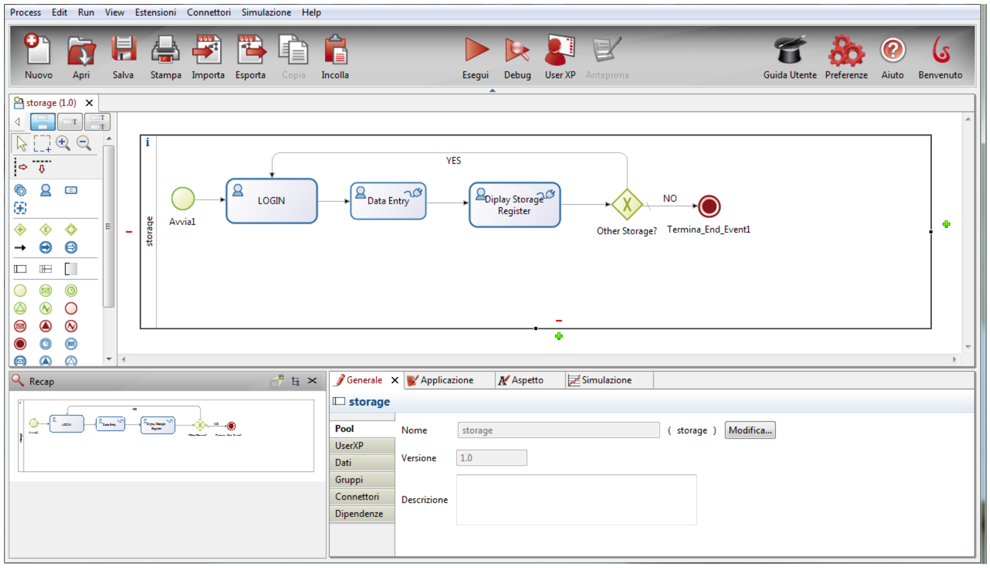


Figure 36 - Process of Storage

In particular the operator devoted to the warehouse's management, after introducing the identification code of the company in which operates, he is able to select from the list of the company in which is involved the interested one and to introduce the information on the product or lot of products that need to be stored in a particular date.

At this step it is important to note also that the process of storage is important not only for food, but even for the definition of the locations in which a particular fruit or plant has been cultivated and for the definition of the location in which a cow or an animal has been bred and raised. Analogous processes have been modeled for the management of the cadastral parcels in which cultivation processes and/or processes on livestock are carried out. These processes are well described in the next sections.

For each company involved in the Global Track and Trace System information on warehouses and storage conditions have been collected.

During the phase of data modeling, a particular register has been generated for maintain the link between products and storage conditions. The "storage register" contains information about products lots and warehouses in which they are located, along with information on the date of storage (Figure 37). In particular, for each Lot of material stored in a particular warehouse, information recorder is:

- ✓ id of the Actor owner of the process;
- ✓ id of the lot stored;
- ✓ description of the lot stored;
- ✓ id of the warehouse in which the lot is stored;
- ✓ date of storage.

localhost ▸ gtts_db ▸ storage_register

Mostra | Struttura | SQL | Cerca | Inserisci | Esporta | Importa | Operazioni

#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
1	**idActor**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
2	**idLotMaterial**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
3	**lotDescription**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
4	**dateStorage**	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
5	**idWarehouse**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più

Figure 37 - Table for the Registration of Storage Locations

In addition, the list of warehouses present in the organization is available for each actor (Figure 38).

The list of warehouses for each actor contains the following information:

- ✓ id of the Actor owner of the warehouse;
- ✓ id of the warehouse;
- ✓ description of the warehouse;
- ✓ warehouse type.

The field "warehouse description" is used to record the information on the warehouse, in particular for defining the environmental condition of the warehouse, that's to say if the warehouse is at room temperature or at a controlled temperature. On the other hand, the field "warehouse type" is used to define the typology of the warehouse, that is to determine whether the magazine is incoming (for lots in input), in line (for semi-finished products which need to wait along the production line in order to be or outgoing (for lots in output).

localhost ▸ gtts_db ▸ warehouse

Mostra | Struttura | SQL | Cerca | Inserisci | Esporta | Importa | Operazioni

#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
1	**idActor**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
2	**idWarehouse**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
3	**warehouseDescription**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
4	**warehouseType**	varchar(6)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più

Figure 38 - Table for the tracking information on warehouses' conditions

In order to generate the web application, the process model has been enriched of data and variable (Figure 39)

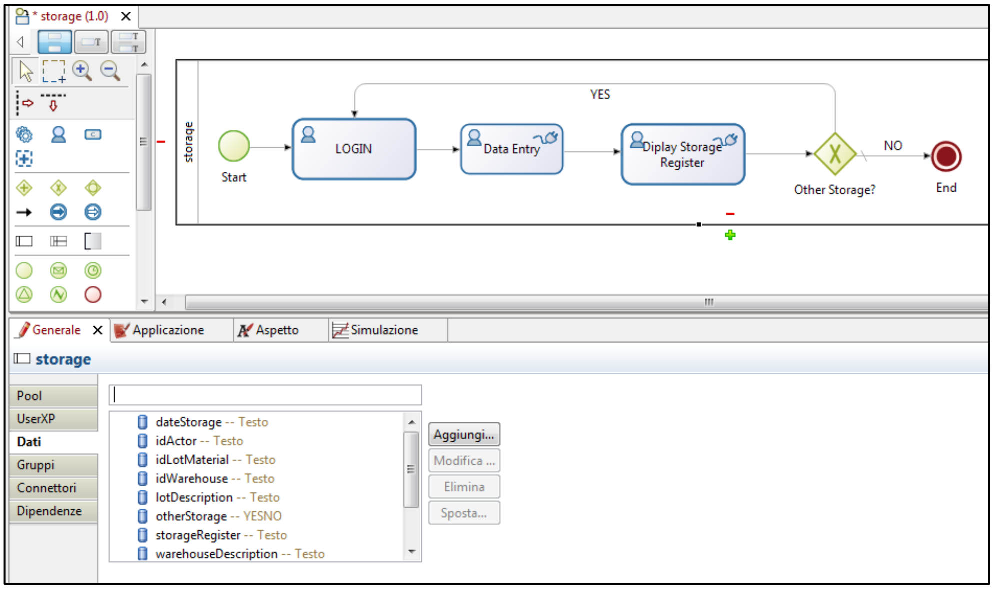


Figure 39 – Introduction of data and variables in the Process Model

In addition, a series of connectors have been introduced for querying the related database. An example of connector is showed in Figure 40 and Figure 41. In this case the connector "showLISTWarehouses" is used to query the Warehouses' register in order to obtain exclusively the warehouses related to a particular actor (Figure 42).

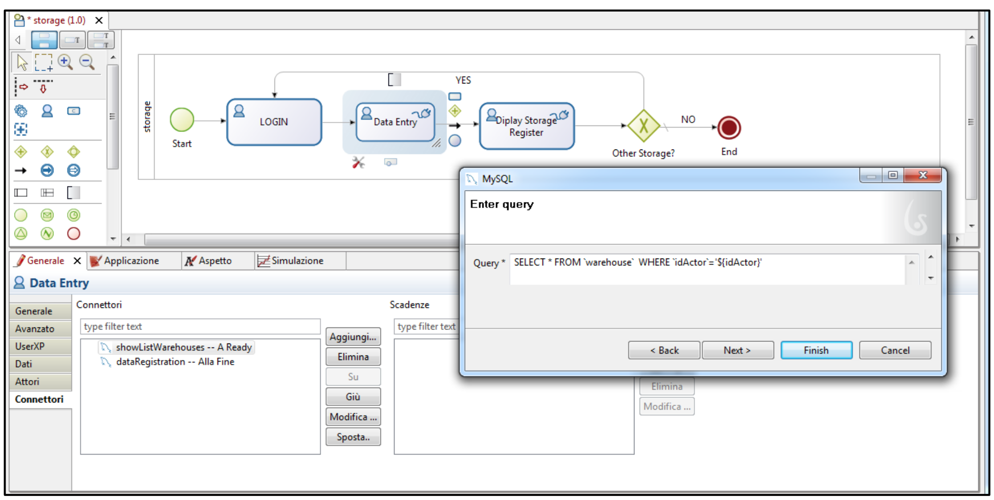


Figure 40- Enter Query

The connector executes the query on the MySQL database and returns as output the warehouseList (Figure 43).

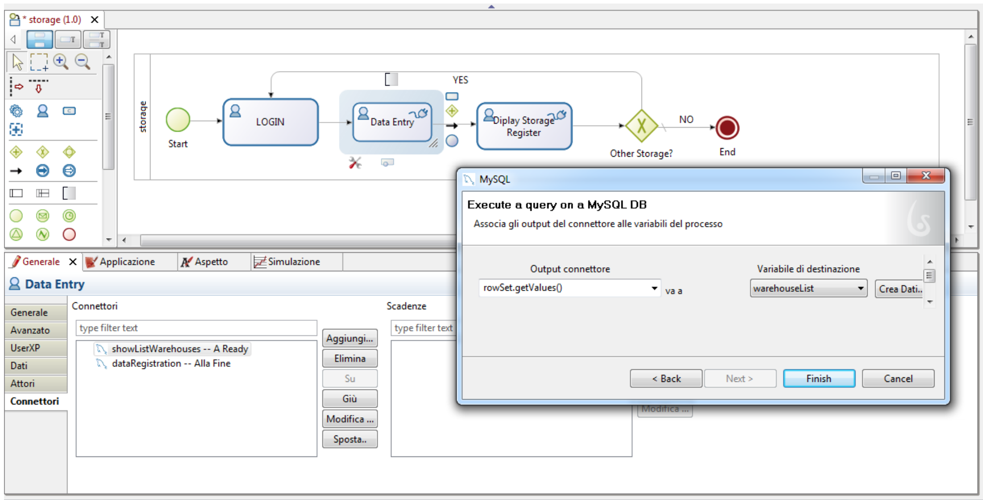


Figure 41 - Query execution and answering

The integration of the process model with the data model leads to the generation of a web application.

The web-based application generated for assisting in the uploading of the storage register, is showed in Figure 42, 43 and 44.

Initially the process requires the entry of the identification code of the Actor involved in the storage process in order to facilitate the selection the proper warehouse to be used (Figure 42).

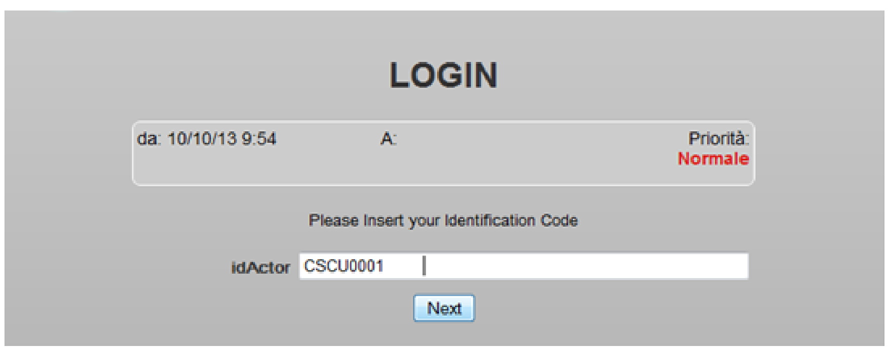


Figure 42 - Company Identification

Consequently, the list of warehouses associated to a particular actor is showed and information on products or lot to store is required. Figure 43 shows that the product "Fico Dottato di Cosenza" is stored in the Warehouse W001 of the Actor identified by the code "CSCU0001".

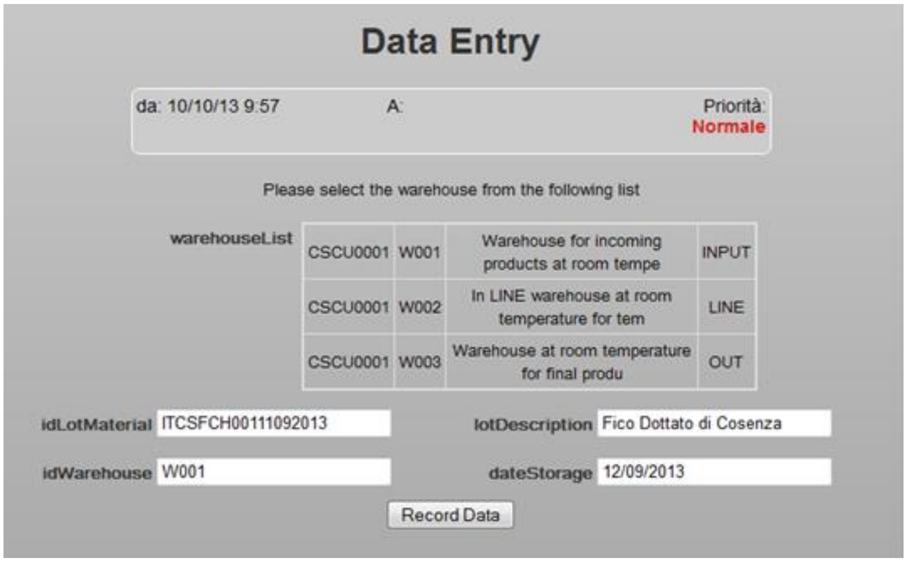


Figure 43 - Introduction of information on lots and warehouses

Finally the system displays the storage register with the uploaded product (Figure 44).

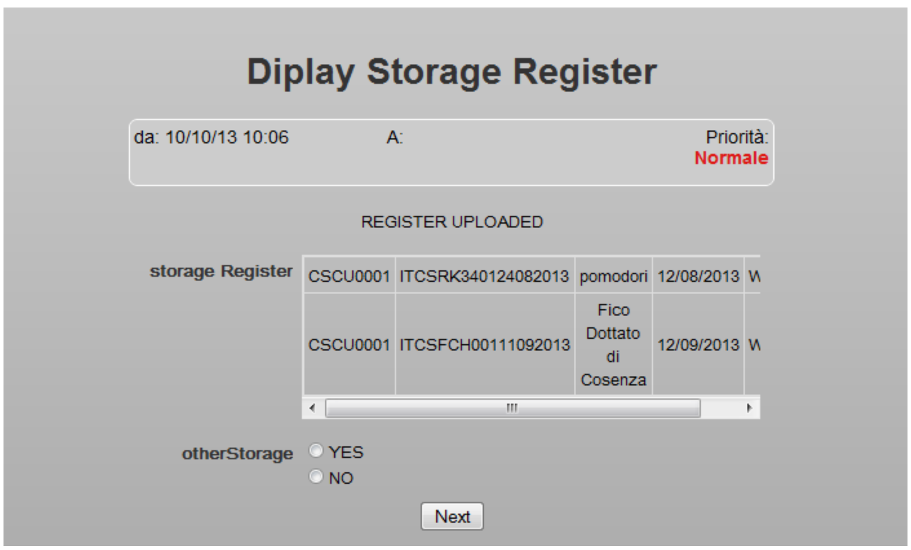


Figure 44- Displaying of the storage register

5.1.3 Traceability of Operations executed on Lots

Each process executed along the food supply chain can be seen as a slot in which inputs are represented by Food Products that are manipulated or transformed by some Actors of the supply chain with the use of some Service Products (Figure 45). The output of a process is a final food product that have undergone some operations, that has been manipulated or just moved from one site to another or from one actor to another.

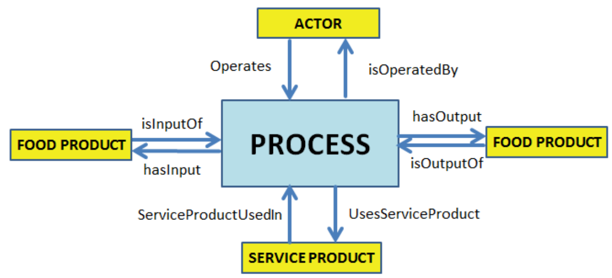


Figure 45 - Graphical Representation of a Process

During the agricultural phase, as well as during a transformation process, a single lot can be subjected to different treatments or operations. For example, when the agricultural phase refers to the process of crop cultivation, information on operations of sowing, irrigation, phitosanitary treatments and harvesting must be recorded for each lot of cultivation. On the other hand, when the agricultural phase refers to aquaculture, livestock or poultry production processes, information to be recorded generally deals with feed used for animals' alimentation or treatments done with pharmacological substances or medicated feed. In additions, information on involved service products and materials used should be also recorder.

This information can be easily stored in a Register of Operations (Figure 46), which can be filled with the information regarding each lot of products that flows in the supply chain.

localhost ▸ gtts_db ▸ operations_register

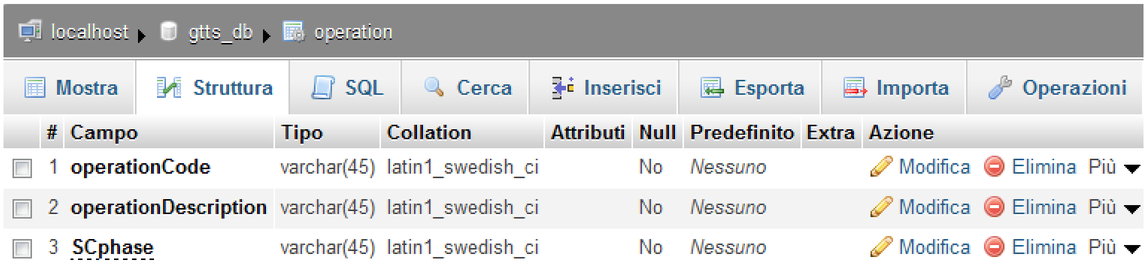
Mostra | Struttura | SQL | Cerca | Inserisci | Esporta | Importa | Operazioni

#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
1	idRegister	int(11)			No	Nessuno	AUTO_INCREMENT	Modifica Elimina Più
2	idLot	varchar(20)	latin1_swedish_ci		No	Nessuno		Modifica Elimina Più
3	operationCode	varchar(20)	latin1_swedish_ci		No	Nessuno		Modifica Elimina Più
4	operationDescription	varchar(45)	latin1_swedish_ci		Sì	NULL		Modifica Elimina Più
5	date	varchar(10)	latin1_swedish_ci		No	Nessuno		Modifica Elimina Più
6	usedMaterial	varchar(45)	latin1_swedish_ci		No	Nessuno		Modifica Elimina Più
7	quantityUsed	int(10)			No	Nessuno		Modifica Elimina Più
8	uniOfMeasure	varchar(10)	latin1_swedish_ci		No	Nessuno		Modifica Elimina Più
9	idLotMaterial	varchar(20)	latin1_swedish_ci		No	Nessuno		Modifica Elimina Più
10	idOperator	varchar(10)	latin1_swedish_ci		No	Nessuno		Modifica Elimina Più
11	idLocation	varchar(20)	latin1_swedish_ci		No	Nessuno		Modifica Elimina Più
12	note	varchar(45)	latin1_swedish_ci		Sì	NULL		Modifica Elimina Più

Figure 46 Register of Operations

The taxonomy of the operations executed in a Food Supply Chain is well described in the "Process" module of the FTTO ontology. In particular, the primary producers execute agricultural processes and they are related to the phase of crop cultivation or livestock production (farming) or fish farming. Every operation have been codified and registered in an "Operation Table" (Figure 47). For each operation, information recorder is:

- ✓ id of the operation;
- ✓ description of the operation;
- ✓ phase of the supply chain in which the operation is executed.



localhost ▸ gtts_db ▸ operation

Mostra | Struttura | SQL | Cerca | Inserisci | Esporta | Importa | Operazioni

	#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
☐	1	operationCode	varchar(45)	latin1_swedish_ci		No	Nessuno		Modifica Elimina Più
☐	2	operationDescription	varchar(45)	latin1_swedish_ci		No	Nessuno		Modifica Elimina Più
☐	3	SCphase	varchar(45)	latin1_swedish_ci		No	Nessuno		Modifica Elimina Più

Figure 47 – Representation of the Operation Table

In order to maintain the internal traceability, every Actor in the supply chain should record information on operation executed on each product in an Operations Register in which are recorded the following information:

- ✓ id of the lot of products on which a particular operation is performed;
- ✓ code of the operation executed;
- ✓ description of the operation executed;
- ✓ date of execution;
- ✓ description of the service material used for performing the operation;
- ✓ quantity of the service material used for performing the operation;
- ✓ unit of measure of the quantity of service material used for performing the operation;
- ✓ id of the lot of origin of the service material used for performing the operation;
- ✓ id of the operator who performed the operation;
- ✓ id of the place or location in which the operation has been performed, which can be an open space, a warehouse, a particular department of the company;
- ✓ note with additional information.

A similar register must be recorded for maintain the connection between an exit lot to a process and the lots in input necessary for its realization during an operation of transformation. Transformations occur when products move from upstream to downstream through the supply chain. Lot transformations can occur when different lots are mixed, joined, split-up, added or converted into another TRU within the company or between companies in a value chain.

When an operation leads to the modification of the structure of a TRU o traceable lot, it is important to record the information on the lots of origin and the lots of destination. This behavior can be traced by adapting the Register of Operation by introducing the id of the lot of origin, with all the related information.

Especially for the *transformation processes* it is possible to adapt the operation register for defining a ***register of the lot in output*** (Figure 48) that includes the following information:

- ✓ id of the register;
- ✓ id of the Actor;
- ✓ id of the operation;
- ✓ description of the operation;

- ✓ starting time of the operation;
- ✓ ending time of the operation;
- ✓ id of the location or production line;
- ✓ id of the output lot;
- ✓ description of the output lot;
- ✓ quantity of the output lot;
- ✓ unit of measure of the quantity of the output lot.

localhost ▸ gtts_db ▸ outputlot_register

Mostra | Struttura | SQL | Cerca | Inserisci | Esporta | Importa | Operazioni

	#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
☐	1	idRegister	int(11)			No	*Nessuno*	AUTO_INCREMENT	Modifica Elimina Più
☐	2	**idActor**	varchar(8)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	3	**operationCode**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	4	**operationDescription**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	5	**startingTime**	varchar(12)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	6	**endingTime**	varchar(12)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	7	**idLocation**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	8	**idOutputLot**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	9	**outputLotDescription**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	10	**outputLotQuantity**	int(10)			No	*Nessuno*		Modifica Elimina Più
☐	11	**unitOfMeasure**	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più

Figure 48 - Register of Lots in Output to a process or operation

The id of location is fundamental when a production system is formed by more than one department which executes the same operation or more than one production line. In this case it is important to identify the production line. In these cases, the lot in output will be uniquely determined on the basis of the production line or department in which it was obtained.

localhost ▸ gtts_db ▸ log_processing

Mostra | Struttura | SQL | Cerca | Inserisci | Esporta | Importa | Operazioni

	#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
☐	1	idRegister	int(11)			No	*Nessuno*		Modifica Elimina Più
☐	2	**idActor**	varchar(8)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	3	**idOperation**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	4	**startingTime**	varchar(12)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	5	**idLocation**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	6	**idInputMaterial**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	7	**materialDescription**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	8	**idLotInputMaterial**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	9	**quantityInputMaterial**	int(10)			No	*Nessuno*		Modifica Elimina Più
☐	10	**unitOfMeasure**	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	11	**idOutputLot**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più

Figure 49 - Register of ingredients or log processing

For each Lot in output to a particular operation it is important to define such a ***register of ingredients*** or "***log processing***" for each output lot (Figure 49). This register will contain the information required for identify the materials in input to each process and maintain the link between a lot in output and the required lots in input to the process:

- ✓ id of the register;
- ✓ id of the Actor;
- ✓ id of the Operation;
- ✓ description of the operation;
- ✓ starting time;
- ✓ id of the location or production line;
- ✓ id of the product (x) in input;
- ✓ description of the product (x) in input;
- ✓ Id of the Lot of origin on the product (x) in input;
- ✓ Quantity of the product (x) involved in the process;
- ✓ Unit of measure of the quantity of product (x) involved in the process;
- ✓ Id of the Lot of Output to the operation;

This information will be recorded for each material in input to the process. For example, if we consider the process of mix of ingredients needed to make bread, for each lot of bread in output to the process of mixing under consideration it is possible to record the raw materials involved in the process, along with the amount used, and clearly define their lot of origin. In case of operations that lead to the integration of two or more ingredients, the link between output lot and the combined lot in input is easily maintained. Operations of combination and division are particular operations that be managed as particular cases of the traceability process of operations.

5.1.4 Traceability of Shipped lots

When a lot is shipped and delivered to client, information on Buyers and date of shipping are fundamental in order to maintain the ***forward traceability*** (to the client). To this end, a particular register has been modeled for the management of the Traceability of shipped lot and a web application was generated.

Data required for the traceability of shipped Lots are contained in the sales register. The structure of the sales register is showed in the Figure 50. Information recorded on every shipped lot is:

- ✓ Id of the sold product;
- ✓ Description of the sold product;
- ✓ Id of the packaging lot of the sold product;
- ✓ Quantity sold;
- ✓ Unit of measure of the quantity sold;
- ✓ Id of the Client;
- ✓ Date of Delivery

localhost ▸ gtts_db ▸ sales_register

Mostra | Struttura | SQL | Cerca | Inserisci | Esporta | Importa | Operazioni

	#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
☐	1	idRegister	int(11)			No	*Nessuno*	AUTO_INCREMENT	Modifica Elimina Più
☐	2	idProduct	int(10)			No	*Nessuno*		Modifica Elimina Più
☐	3	productDescription	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	4	idPackagingLot	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	5	quantitySold	int(10)			No	*Nessuno*		Modifica Elimina Più
☐	6	unitOfMeasure	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	7	idClient	varchar(7)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	8	dateDelivery	varchar(11)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più

Figure 50 - Sales Register for the Traceability of shipped lots

5.2 Adaptation of the general framework

This Section demonstrates how the general framework can be easily adapted to the different types of food supply chain (De Cindio et al., 2012b; Mirabelli et al., 2012b; Pizzuti et al., 2012). In this context, three different food supply chains have been analyzed and modeled in order to facilitate the adaptation of the Global Food Track&Trace System: (i) the supply chain of fresh fruits, (i) the supply chain of pre-cooked and frozen vegetables belonging to the class of fifth range vegetables, and (iii) the supply chain of meat and meat products.

5.2.1 Traceability of Fruit and Vegetables

Italy is the sixth largest fruit and vegetable producer in the world, and it holds the first position in Europe for production, with the southern regions leader in the production of many sectors (ISTAT, 2013) The Italian fruit and vegetable sector produces almost 34.2 million tons (down to 2009) of product, with a production of 11 billion and a turnover of 22 billion, virtually unchanged from 2009 (ANSA 2011, http://www.conipiediperterra.com/italia-sesto-produttore-al-mondo-di-frutta-1005.html). The fruit and vegetable supply chain is very complex because of both the enormous variety of species that can be cultivated in different geographical areas and the different operations that are required for each stage of the supply chain, from the production to the consumption.

The cultivation companies or farmers are involved in the first phase of the fruit and vegetables supply chain. Farmers perform all the operations necessary for the successful completion of cultivation, by tilling the soil and executing the first operations of land fertilization, sowing or transplanting, executing the plant protection interventions and the collection phase.

Harvested fruits and vegetables are collected, cleaned, graded, sorted and packaged. Thus, they can be sold in form of fresh fruits or processed food. Fruits and vegetable that require some transformation process before reaching consumers, are sent to the processing center where, after being washed, they undergoes a series of processes that are different depending the features of the final that they intend to be. Depending on the operations that can be executed at the processing center, fruits and vegetables can be classified in the following categories:

- ✓ First Range products: which include fresh fruit and vegetable, in their original form;
- ✓ Second Range products: which includes canned and binned fruits and vegetables;
- ✓ Third Range Products: which includes frozen vegetables;
- ✓ Fourth Range Products: This includes ready to eat food that is preserved in their fresh and natural form, without the addition of any additive.
- ✓ Fifth Range Products, which includes pre-cooked vegetables.

According to this classification, four main categories of fruit and vegetable supply chains can be identified:

1) Supply chain of fresh fruits and vegetables.
2) Supply chain of third range fruits and vegetables;
3) Supply chain of fourth range fruits and vegetables;
4) Supply chain of processed fruits and vegetables, which includes the categories of second and fifth range fruits and vegetables that requires complex industrial processes.

Fresh products belonging to the First Range category are cleaned, sorted and graded, but they do not undergone any transformations and, therefore, they are sold in the form of fresh products that can bought packaged or in bulk. The products of the Third Range are those of the cold chain, where the original product, opportunely cleaned, is immediately packaged and frozen without undergo other manipulations. Fourth Range products are meticulously cleaned and cut and successively packaged. Typical Fourth Range products are salad already washed and ready for consumption or fruit cut into pieces and ready for fruit salads. In case of Second Range products and Fifth Range products more complex operations are required for obtaining the final food. In particular, Second Range products, such as tomato and jams, are obtained submitting the original food product to complex processes such as removal of parts, boiling, mixing, and cooking, with the final phase that is represented by canning or binning and labeling of the final product. On the other hand, products belonging to the Fifth Range are generally cleaned, cut, pre-cooked, grilled or steamed, without the addition of preservatives or seasonings and they only need to be heated before eating.

In the next paragraphs, some of the supply chain above mentioned will be analyzed and modeled. In particular we will focus on the traceability of fresh fruits and frozen vegetables, belonging respectively to the First Range products and Fifth Range Products.

The idea of focusing on the traceability of the supply chain of fruits and vegetables mainly depends on the analysis of the European food production. The market analysis highlighted, in fact, that Italy is the largest producer of fruits and vegetables in Europe: the Italian fruit and vegetables is one of the most significant sectors of the primary sector, with a total turnover of just over € 22 billion of euro per year. Inside the Italian fruit and vegetable sector the largest contributions come from vegetables and potatoes (6,9 billion of euro in total) (ENEA, 2011).

The final aim of this section is to demonstrate how the general framework, which is at the base of the Global Track and Trace System, can be easily adapted to every food supply chain.

5.2.1.1 Traceability of fresh fruit

STEP 1: Analysis of the supply chain of fresh fruit and vegetable

The Supply chain of fresh products can be divided into (i) supply chain of fresh products under own production and (ii) supply chain of fresh products under contract farming. A simple representation of the product flow in both the supply chain is showed in Figure 51 and Figure 52. The Figures reported also the list of the processes executed by every actor.

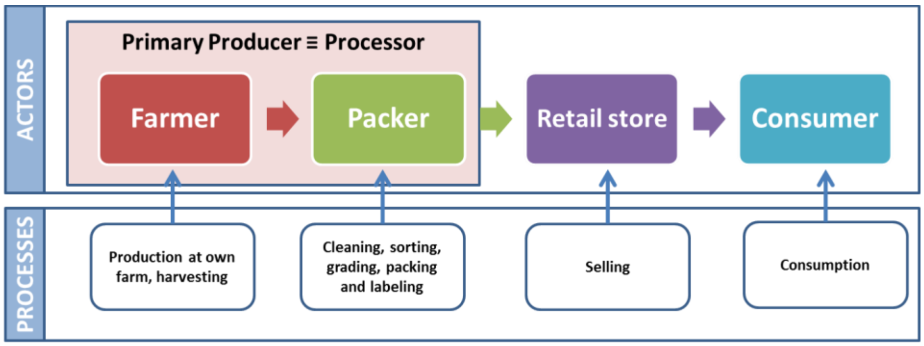


Figure 51 - Supply Chain of fresh fruits and vegetables under own production

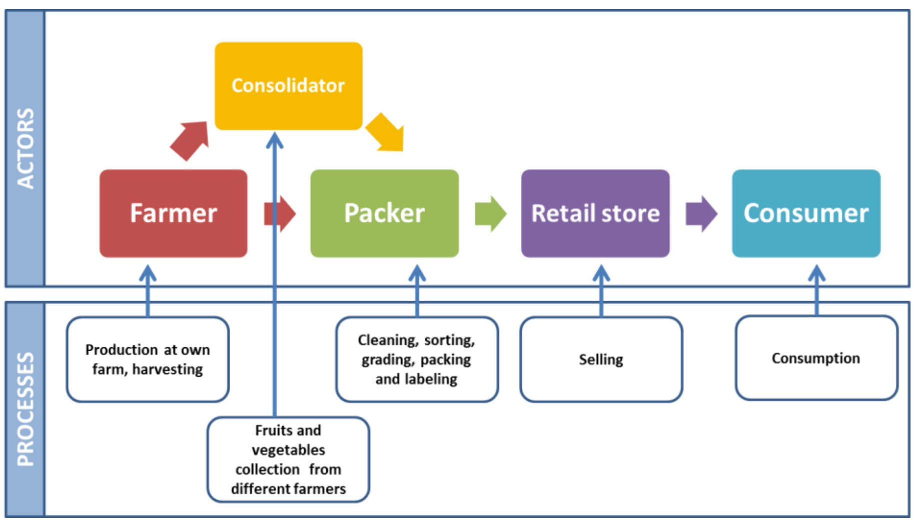


Figure 52-Supply Chain of fruits and vegetables under contract

In the supply chain of fresh products under own production the primary producer invests also the role of packer and, besides the agricultural processes, it is also devoted to the execution of the operations of cleaning, sorting, grading, packing and labeling.

In case of supply chain under contract farming, the primary producer is different from the packer, which can buy fruits or vegetables directly from farmers or from agent devoted to their collection, such as consolidators.

At the farming level, the farmer is responsible for the agricultural production of fruits and vegetables. After selecting the place in which the fruits and vegetables will be cultivated, important operations executed at the cultivation stage are seed selection, land or soil preparation, crop establishment (including seedling and transplanting), irrigation or water management, nutrient management and pest management (or crop health management), harvesting and post harvesting.

Harvested fruits or vegetables are collected, and cleaned, graded, sorted and packaged and labeled at the pack house. Then they are sold to the retail stores or directly to the customers.

In this contest, we will focus the attention on the modelling of a short supply chain of fresh fruits and we will demonstrate how the Global Track&Trace System can be adapted to this sector.

STEP 2: Modeling of the supply chain of fresh fruits and vegetables under own production

The short supply Chain of fresh fruits and vegetables can be modeled focusing the attention on each single step operated by every single actor. Figure 53 shows the main operation executed at the cultivation level. In particular, referring to the BPMN notation, *Crop Establishment* and *Cultivation Management* tasks are calling activity because their execution requires the processing of several subtasks. In case of crop establishment, for example, type of establishment of the crop must be defined, specifying if the crop is established by sowing seeds or by transplanting seedlings. On the other hand, during the cultivation process, plants are irrigated and they are submitted to a series of plant treatments that requires the addition of some nutrients or pesticides.

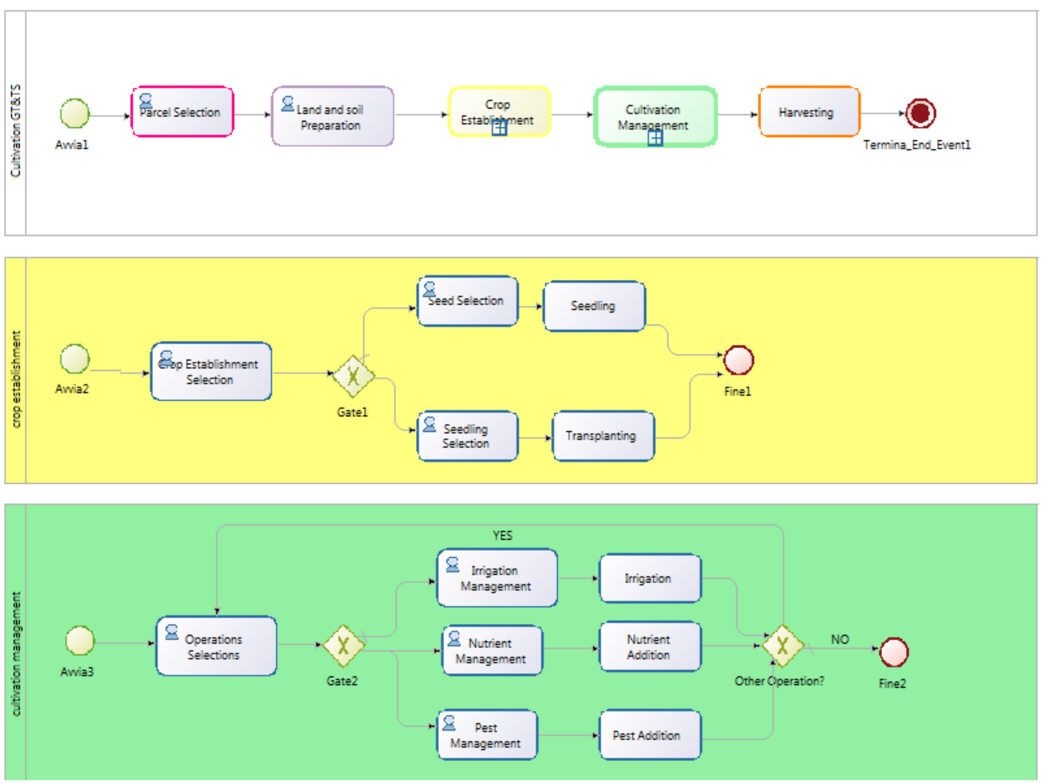


Figure 53 -Modelling of the cultivation process

Harvested products are successively sent to the pack house. Figure 54 shows the modeling of the operations executed at the pack house, where fruits and/or vegetables are initially cleaned, sorted and grade and successively packaged and labeled. Then packaged fruits and vegetables are temporary stored in order to be shipped, though the distribution channel, to the final consumer.

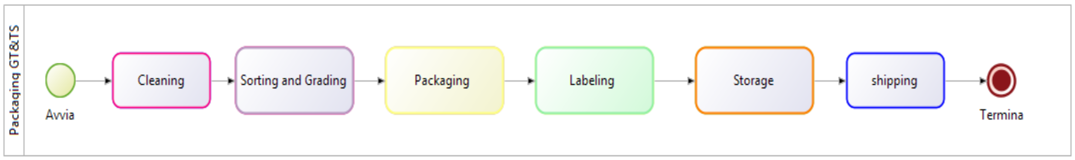


Figure 54 - Modelling of the Packaging Process

STEP 3: Data collection

During the phase of analysis of the supply chain, the most important information to be traced has been identified. In particular, important information is related with the cultivation land in which fruits and vegetables grown. *A general assumption we made is that a cultivation lot is defined for each parcel containing a collection of plants or trees with similar characteristics, i.e. belonging to the same variety of plant.*

From a regulatory point of view, a cultivation lot is defined as “a production of a crop species with similar characteristics by period of sowing/transplanting, cultivation and plant-health control” at the agricultural company. Consequently, each ***lot of cultivation*** is obtained by combining the information on the parcel in which the seeds are sowing or the plant are transplanted and the identification of the lot of origin, such as the lot of seeds sowed or the lot of plants planted. Required information at this step is:

1. information on the place in which the lot is cultivated:
   - ✓ Id of the Municipality in which the cultivation lot is located;
   - ✓ Parcel number;
   - ✓ sheet number;
2. information on the lot of seeds or plants sowed or transplanted in the cultivation land:
   - ✓ id of the seeds or plants;
   - ✓ description of the seeds or plants;
   - ✓ Variety plant;
   - ✓ Id of the lot of seeds or plants;
   - ✓ Date of purchase;
   - ✓ Id of the Supplier;

During the **cultivation process**, in order to maintain the traceability of the operations executed on each cultivation lot, a particular register, the ***register of cultivation*** must be filled every time that a particular operation is executed on a specific cultivation lot. The register of cultivation is also required from a regulatory point of view and it is generally called logbook or “Quaderno di Campagna”. More in detail, for each lot of cultivation on the register of cultivation will be recorded information on the executed operation of plant protection and irrigation must be registered. For each operation of plant protection, important data to record are:

- Id of the plant protection product;
- Description of the plant protection product;
- Id of the lot of origin of the plant protection product used;
- Id of the supplier who provided the plant protection product;
- Date of the treatment;
- Quantity of the product used during the treatment;
- Unit of measure of the quantity used;
- Name of the operator making the treatment;
- Cause of the treatment (for answering to the following question: "why the treatment is required?")

Referring to the irrigation process, important data to record is:

- Date of irrigation;
- Source of the water (internal shaft or connection to water network);
- Name of the operator who activated the process of irrigation.

Fruits and vegetable that reach a sufficient state of maturity are subsequently harvested. During the **harvesting phase**, important information to be collected is:

- Id of the lot of cultivation;
- Data of harvesting;
- Id of the operator who collected the products;
- Id of the lot of harvesting;
- Quantity of the lot harvested;
- Unit of measure of the lot harvested.
- Numbers of containers or bins in which the harvesting lot is collected.

A simple rule has been introduced for maintain product's traceability during the harvesting phase. In particular, *a lot of harvesting is composed by the bins or containers filled with products belonging to the same parcel and harvested in a defined time window*. In order to make the process more understandable, a simple schema of the phases of cultivation and harvesting is showed in Figure 55.

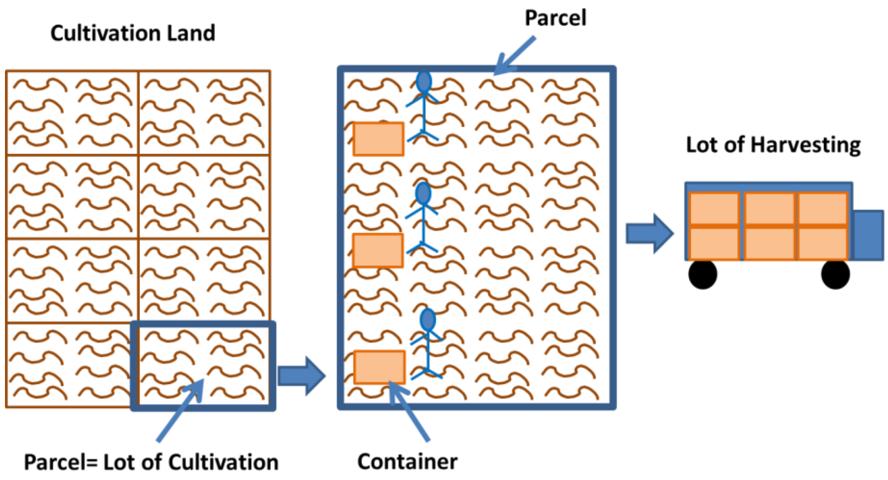


Figure 55 - Cultivation and Harvesting Process's Schema

Once harvested, fruits and vegetable are moved to the pack house where they are cleaned, sorted, graded and packaged. At the **pack house**, in order to maintain the link between the different lot in input, that in this case are lot of harvesting, and the output lot, which is represented by the packaging lot, it is convenient to record all the information on a ***log processing or register of packaging***

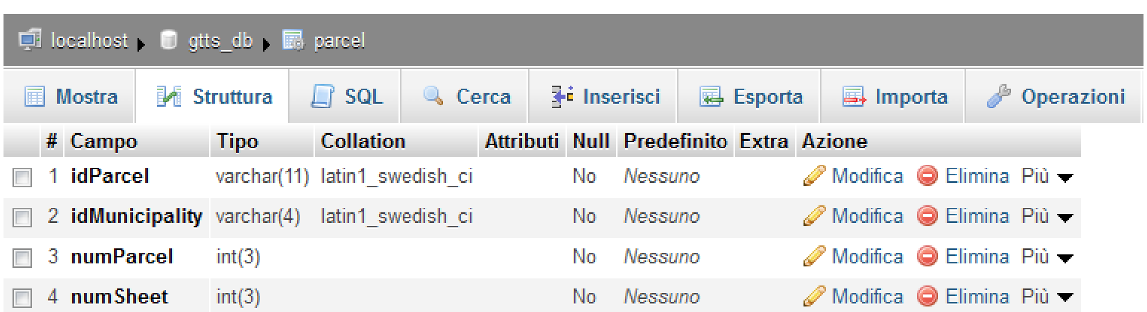
In particular, the register of packaging will contain the information required for maintain the link between the lots in input and the lot in output. Each lot of packaging can be defined on the base of a particular time window of reference that can be an hour or a day in case of small productions. Information contained in the register of packaging is:

- ✓ Id of the operation (packaging)
- ✓ starting time of the operation;
- ✓ ending time of the operation;
- ✓ id of the location or production line;
- ✓ Id of the lot in input;
- ✓ description of the lot in input;
- ✓ Quantity of the lot in input;
- ✓ Unit of measure of the lot in input;
- ✓ Id of the Lot in Output (packaging lot)
- ✓ Quantity of the lot in output;
- ✓ Unit of measure of the lot in output;

In addition, different traceable units form each packaging lot. In case of fresh fruits and vegetable, the smallest traceable unit can be referred to a box or to bag, as in the case of potatoes. Each traceable unit is characterized by the Id of the lot of origin and a sequential number that represent a progressive number for each traceable unit belonging to the same packaging lot.

STEP 4: Data modeling

Focusing the attention on the cultivation process, as mentioned in the previous section, a ***cultivation lot*** is defined for each cadastral parcel. A cadastral parcel is identified on the base of the id of the Municipality in which is located, the number of the parcel and the number of the cadastral sheet (Figure 56) and it refers to the lot of land in which are cultivated the products belonging to the same lot under the same conditions.

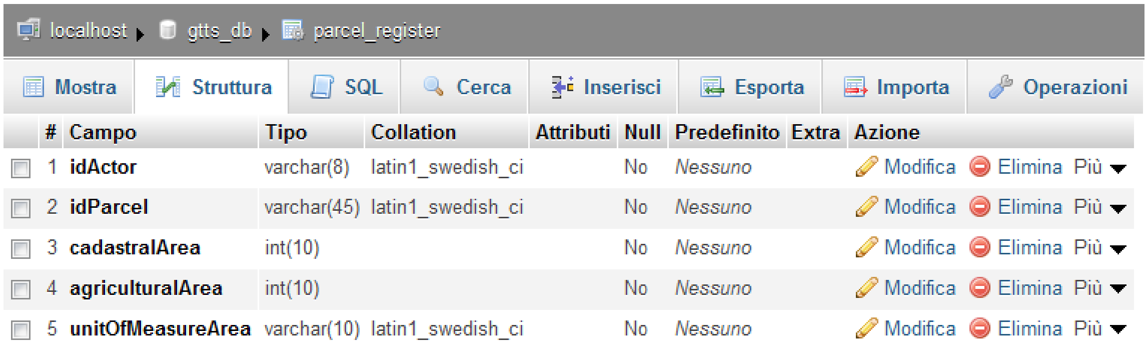

localhost ▸ gtts_db ▸ parcel

Mostra | Struttura | SQL | Cerca | Inserisci | Esporta | Importa | Operazioni

#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
1	**idParcel**	varchar(11)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
2	**idMunicipality**	varchar(4)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
3	**numParcel**	int(3)			No	*Nessuno*		Modifica Elimina Più
4	**numSheet**	int(3)			No	*Nessuno*		Modifica Elimina Più

Figure 56 – Parcel structure

In addition, the list of the cadastral parcels associated with each Actor involve in the supply chain is recorded in the system (Figure 57).



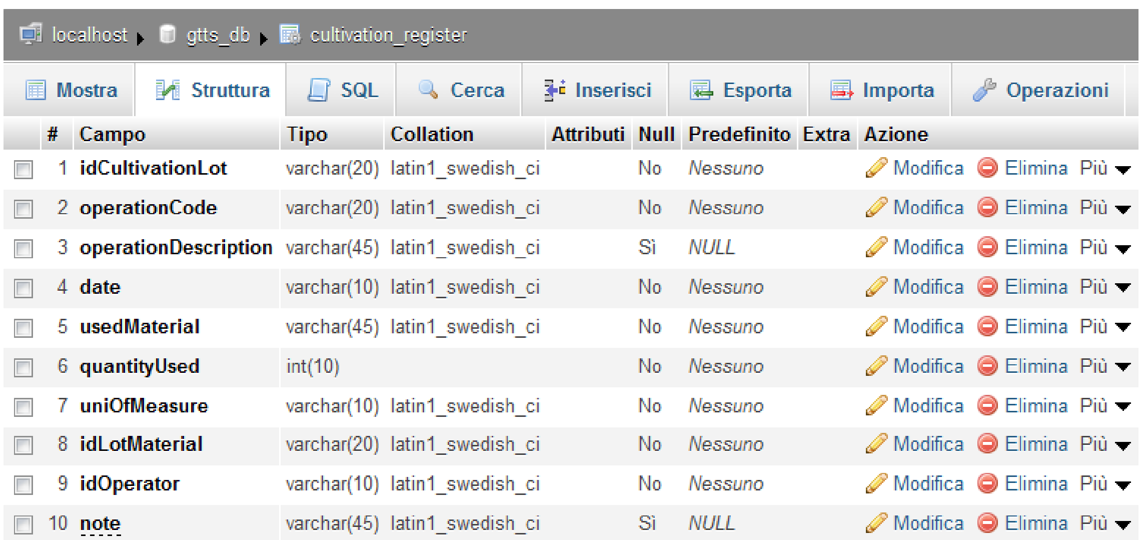
localhost ▸ gtts_db ▸ parcel_register

Mostra | Struttura | SQL | Cerca | Inserisci | Esporta | Importa | Operazioni

	#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
☐	1	**idActor**	varchar(8)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	2	**idParcel**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	3	**cadastralArea**	int(10)			No	*Nessuno*		Modifica Elimina Più
☐	4	**agriculturalArea**	int(10)			No	*Nessuno*		Modifica Elimina Più
☐	5	**unitOfMeasureArea**	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più

Figure 57- Register of Cadastral Parcels

A register with the operations executed on each cadastral parcel is introduced in order to order to contain all the information related to the cultivation process (Figure 58). In particular, the ***cultivation register*** contains data required from a regulatory point of view on the treatments executed on plants or vegetables and additional data on operations of irrigation or removal of grass.



localhost ▸ gtts_db ▸ cultivation_register

Mostra | Struttura | SQL | Cerca | Inserisci | Esporta | Importa | Operazioni

	#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
☐	1	**idCultivationLot**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	2	**operationCode**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	3	**operationDescription**	varchar(45)	latin1_swedish_ci		Sì	*NULL*		Modifica Elimina Più
☐	4	**date**	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	5	**usedMaterial**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	6	**quantityUsed**	int(10)			No	*Nessuno*		Modifica Elimina Più
☐	7	**uniOfMeasure**	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	8	**idLotMaterial**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	9	**idOperator**	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	10	**note**	varchar(45)	latin1_swedish_ci		Sì	*NULL*		Modifica Elimina Più

Figure 58 - Cultivation Register

In order assist the traceability in the harvesting phase, the ***harvesting register*** have been modeled has showed in Figure 59. Data recorded refers to the total amount of products harvested in a particular date from the same lot of cultivation or parcel and the number of container in which products harvested are located.

	#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
☐	1	idRegister	int(11)			No	Nessuno	AUTO_INCREMENT	Modifica Elimina Più
☐	2	idActor	varchar(8)	latin1_swedish_ci		No	Nessuno		Modifica Elimina Più
☐	3	dateHarvesting	varchar(12)	latin1_swedish_ci		No	Nessuno		Modifica Elimina Più
☐	4	idParcel	varchar(45)	latin1_swedish_ci		No	Nessuno		Modifica Elimina Più
☐	5	numContainer	int(5)			No	Nessuno		Modifica Elimina Più
☐	6	quantityHarvested	varchar(5)	latin1_swedish_ci		No	Nessuno		Modifica Elimina Più
☐	7	unitOfMeasure	varchar(10)	latin1_swedish_ci		No	Nessuno		Modifica Elimina Più

Figure 59 - Harvesting Register

Once harvested products reach the pack house, the register of load is filled for maintain the connection with the incoming lot and its supplier.

STEP 5: Generation of the web application

In order to facilitate the identification of the different lot of cultivation and harvesting, some rules have been defined for the definition of their identification codes.

In particular, every actor involved in the Global Track and Trace System is uniquely identified combining the information on the state, the municipal and the province in which he is located. Following the regulatory standard already defined for the traceability of meat products, the structure of the identification code of the actor is showed in Figure 60.

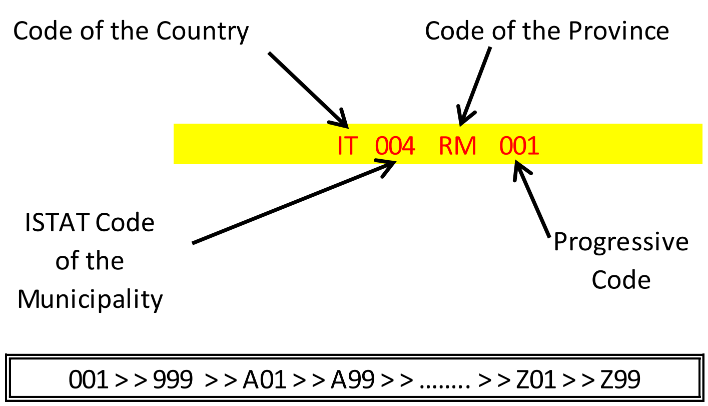


Figure 60 - Attribution of the actor code

In particular, the actor code is formed by the combination of the following information:

- ✓ Abbreviation of the Nation in which the company is located.
- ✓ ISTAT code of the City (three digits),
- ✓ Abbreviation of the Province (two digits)
- ✓ sequence number assigned to the company on a municipality basis (three digits)

Some rules have been defined also for the definition of the identification code of a parcel of land and consequently for the definition of a cultivation lot.

Every parcel is uniquely identified by a code obtained combing the information of the municipality in which it is located, the number of the parcel and the cadastral sheet.

On the base of the above-mentioned rules for the definition of the encoding system, every lot of harvesting is uniquely identified by the information on the actor, the parcel, the date of harvesting. In addition, the lot of harvesting is formed by the complexity of the products harvested in the same day that can be located in different containers. A container can be a bin or a box. In order to identify every single container, a progressive number is assigned to every bin. An example of code for the identification of the harvesting lot for a container is showed in Figure 61.

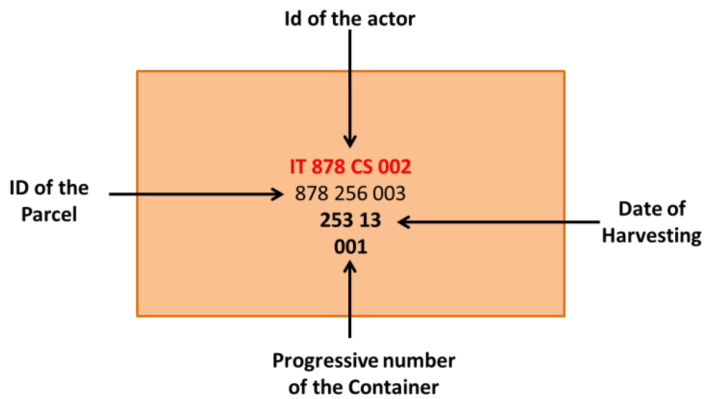


Figure 61 – Identification code of a harvesting container

Starting from the definition of these rules, a web application for the traceability of fresh fruits and vegetables have been obtained introducing data on the process model and connectors for executing queries on the generated database.

The operator, after selecting the operation to execute (Figure 62), will be supported in the registration of the most important information for each sub-process.

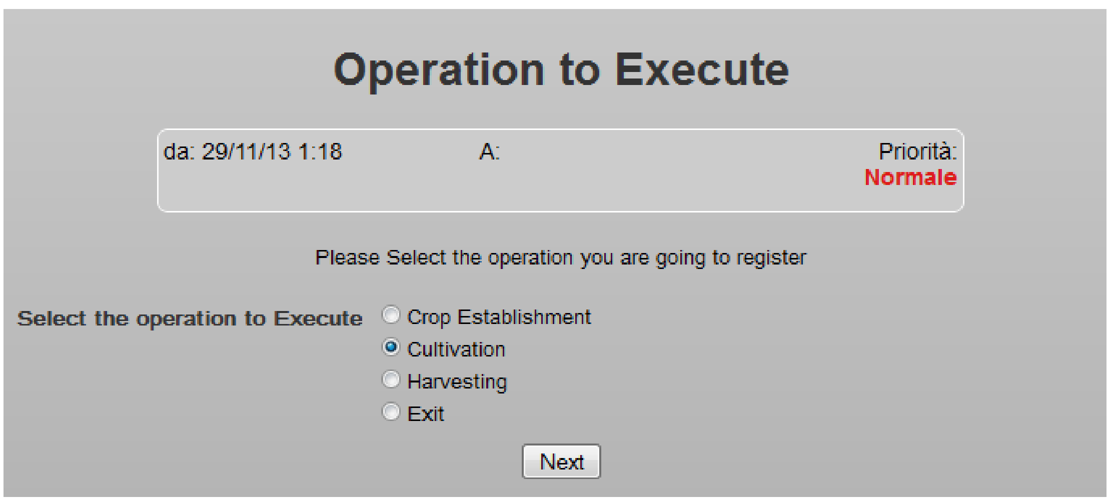


Figure 62 - Selection of the Operation to Register

For example, during the phase of crop establisment, the operator defines if the crop establishment is obtained by sowing some type of seed or transplanting the seedlings bought from a nursery (Figure 63). For both the type of crop establishment , information on the used product are recorded (Figure 64).

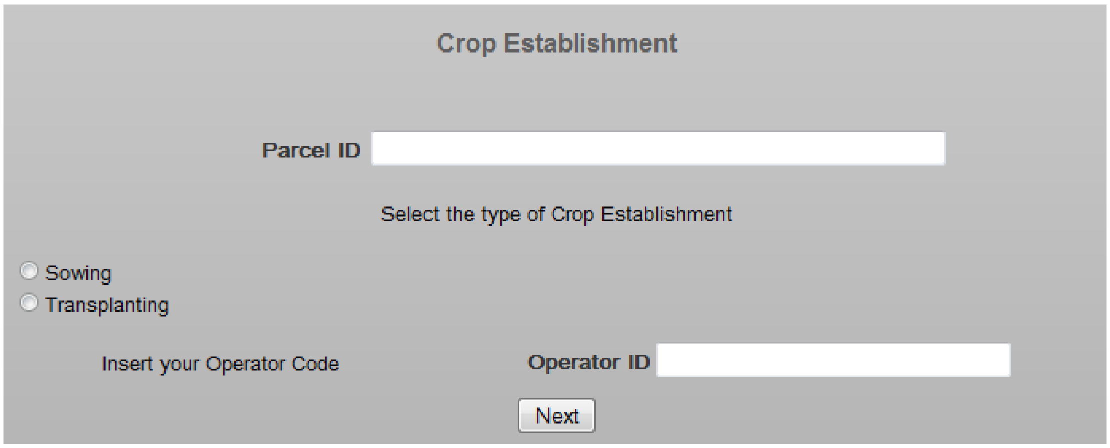


Figure 63 - Webpage for supporting the registration of data during the phase of crop establishment

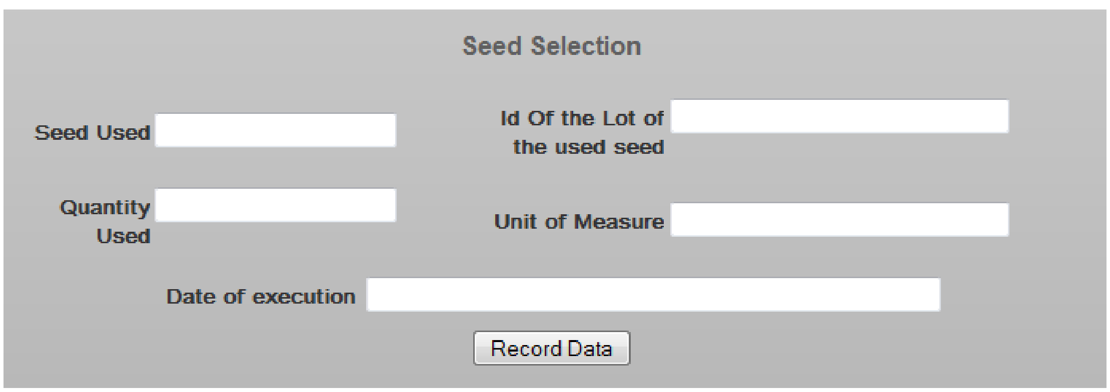


Figure 64 - Webpage for supporting in the registration of data during the phase of sowing

Figure 65 shows the web-page developed for supporting the registration of data on the treatments executed during the cultivation process, while the web-page for supporting in the registration of data during the process of harvesting is showed in Figure 66.

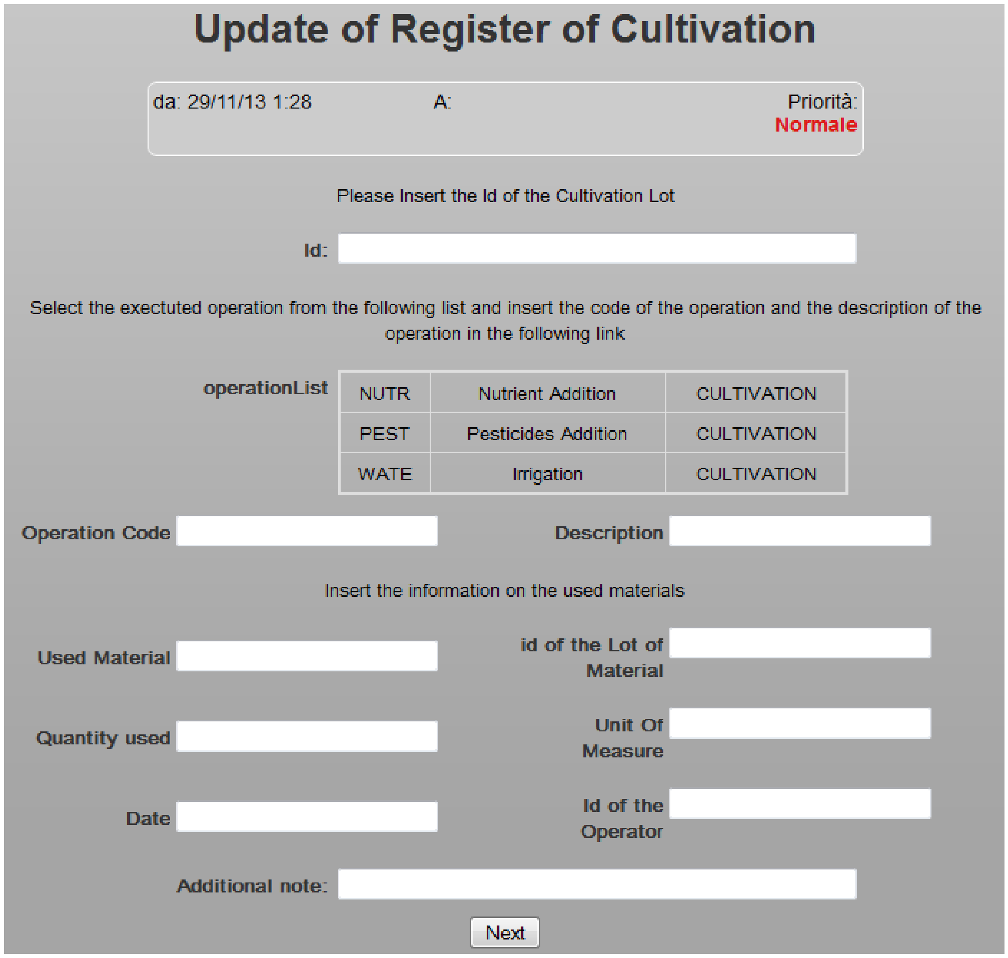


Figure 65- Web page for supporting in the registration of data during the process of cultivation

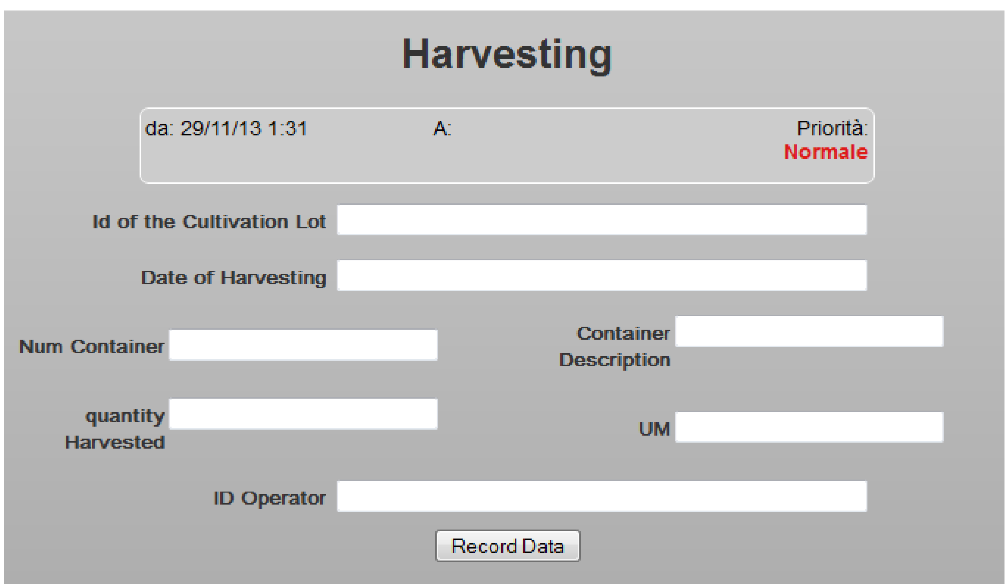


Figure 66- Web page for supporting in the registration of data during the process of harvesting

5.2.2. Traceability of frozen vegetables

In order to demonstrate the validity of the Global Track and Trace System, in this Section the general framework developed for the maintenance of food traceability has been adapted for the traceability of frozen vegetables. The frozen food sector is among the top ten more innovative sectors in Europe (Figure 67).

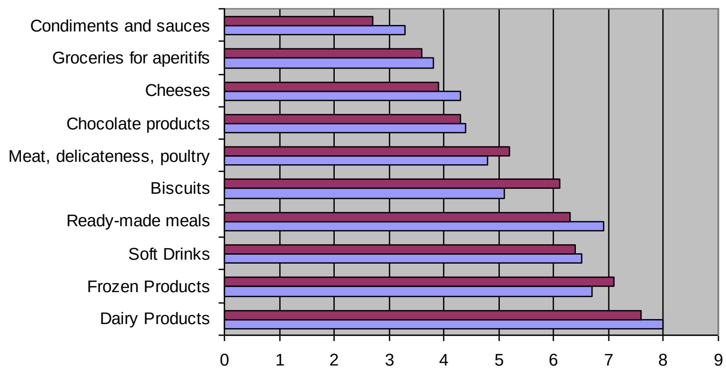


Figure 67 - The ten most innovative food sectors in Europe (Source: ISMEA)

This context and the large amount of companies working in the fruit and vegetable industry, has attracted our attention and led to the analysis of the frozen vegetable industry in order to identify advanced solutions for traceability.

The application example proposed in this section is based on the adaptation of the Global Track and Trace System to a specific company operating in the sector of frozen vegetables and located in South Italy. The whole supply chain in which the company is involved has been deeply analyzed in order to identify processes and data involved in the traceability process. Successively the vegetables supply chain has been modeled according to the BPMN standard. Fundamental data have been classified for internal and external traceability of products and a general data model has been generated. Consequently data and processes have been integrated in a unique BPMN model in order to generate the Web Application useful for the supply chain optimization and traceability management. The generated front-end helps the user in the process of data management.

STEP 1: Supply Chain Analysis of Frozen Vegetable for the Company under study

The company under study is devoted to the production of frozen foods. The business activities of the company include the cultivation, harvesting, processing, packaging and marketing of a wide assortment of frozen vegetables. The company directly controls the entire production chain, from sowing to harvesting. All operations are scrupulously monitored and controlled: this allows achieving the best results not only from the organoleptic but also from a bacteriological and health point of view. The company delivers many products for prestigious multinational and important companies belonging to large retailer and large organizations both national and international of catering and restaurants, representing its main clients. It keeps in its portfolio a wide range of products, from ready meals to soups, from grilled vegetables to natural plant, from legumes to prepared cereals. The variety of finished products is extremely wide. From the suppliers point of view it has established supply agreements with more than 50 companies and two big cooperatives of agricultural producers that provide about 90% of the vegetable products it needed.

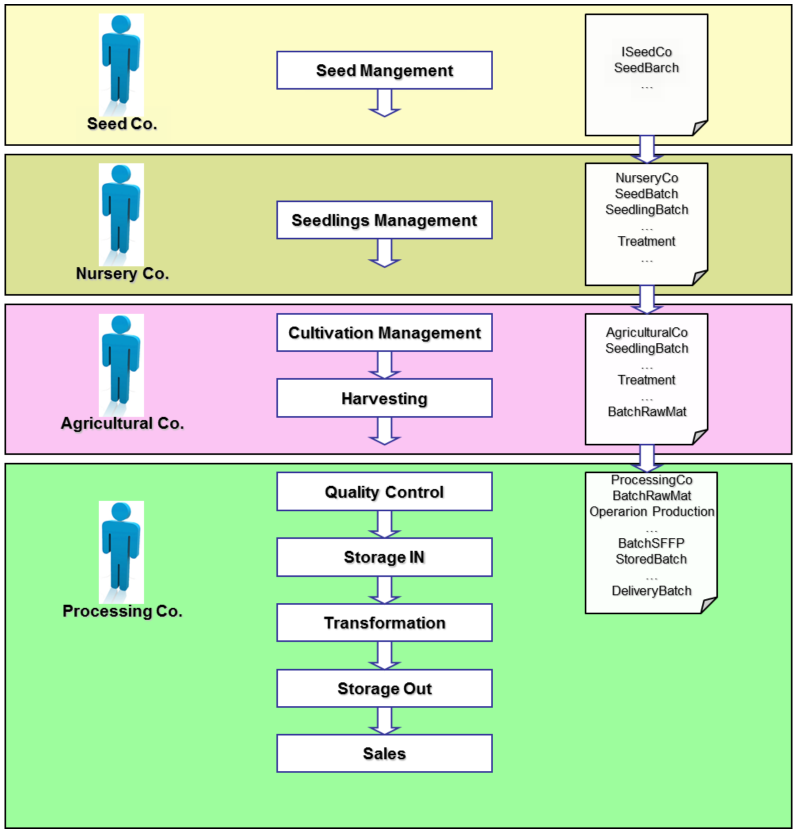


Figure 68 - Process Flow of fruit and vegetable industry, actors and data required.

Figure 68 shows the main processes involved in supply chain and the main data flow and information. The column in the middle of figure 68 shows the processes in a logical sequence. On the left side of this column the actors involved in the proposed activities are represented. Finally on the right side of the column all the information needed to maintain the product traceability is represented.

The main actors involved in the supply chain of the company under study are (1) the seed company, (2) the nursery company, (3) the agricultural company and (4) the processing company. The seed company provides the processing company with the seeds needed for the production of plants and vegetables. The processing company receives seeds and stock in form of batch. These batches are then sent to the nursery companies, which are interested in the growing of the seedlings and are involved in all the stages of the seedlings growing, from the germination to the production of batches of seedlings. All batches of seedlings are then delivered to the agricultural companies responsible for the production of the needed vegetables. The processing company adopts a particular policy for the management of seed: periodically it determines the number of seeds to be delivered to the nurseries and communicates to each nursery company the conferring agricultural company to which provide with a particular batch of seedlings. The first controlling phase is done when the unprocessed vegetables batches income into the processing company. They unprocessed vegetables batches are administered in form of input bins and each bin is coded and labeled. The controlling phase is followed by a transformation phase. At the beginning of this phase, each bin of raw material, depending on the type of the scheduled destination, is subjected to particular manufacturing processes. Common operations executed are: washing and cutting, cooking and/or freezing and packaging. The last phase includes the labeling phase.

In the context of this PhD Thesis, the focus has been oriented to the modeling of the operation that are executed at the level of the transformation company, where products are temporary stored at environmental condition in order to be successively cleaned, sorted and graded, cut, cooked, and finally packaged. Packaged products are then stored and maintained at low temperatures also during the transportation phase.

STEP 2: Supply Chain Modeling

The general model developed for representing the fruit and vegetable supply chain under study shows the different processes operated by each actor along with the information flow (Figure 69). Actors involved in the supply chain are classified into pools and lanes are used to differentiate the different executors of a process. Each actor records data of products and processes and collaborated with other operators in the industry by making available all the information necessary for traceability. The main agents modeled are the Seed Company, the Nursery, the Cultivation Company or Cultivator and the Processing Company or Factory.

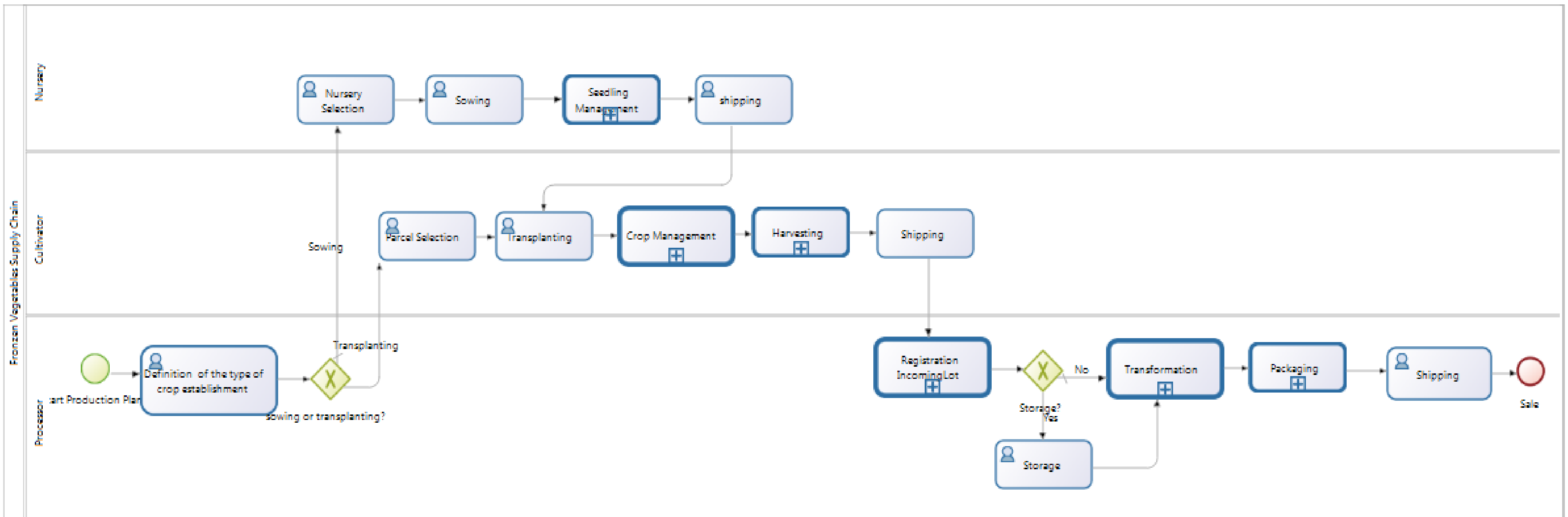
The modelling of the cultivation and harvesting process is similar to the model proposed for the traceability of fresh fruits and vegetables. For the management of seedlings at the nursery is used the same working principles used for the management of the cultivation lot. The cultivation process along with the harvesting process of this particular supply chain is managed equally to the cultivation process executed for the supply chain of fresh fruits and vegetables. The main difference is in the transformation process. Once harvested, in fact, vegetables are sent to the processing company where they are cleaned, selected and transformed in order to obtain more complex food.

The first operation executed at the transformation company is the control of compliance of products and the consequently filling of the load register. Vegetable are then stored in order to be transformed. In the transformation line, products are washed, graded and sorted, and cut.

A general assumption made at this step is that the order of entry in the transformation line is governed by the following rule:

1. containers belonging to the same lot of harvesting must be introduced together in the production line;
2. when the quantity of the lot of harvesting is not sufficient to cover the capacity of the production line, two or more that harvesting lot are combined in the same production lot. This operation refers to the integration pattern discussed in the section 2.3.2 “Unique Identification of Lot”.

During its flow in the production line, the same lot of production can be divided in two or more lot because of the execution of some operation of selection or grading. In this case the production lot will be divided into different part. This operation refers to the division pattern described in section 2.3.2 “Unique Identification of Lot”.



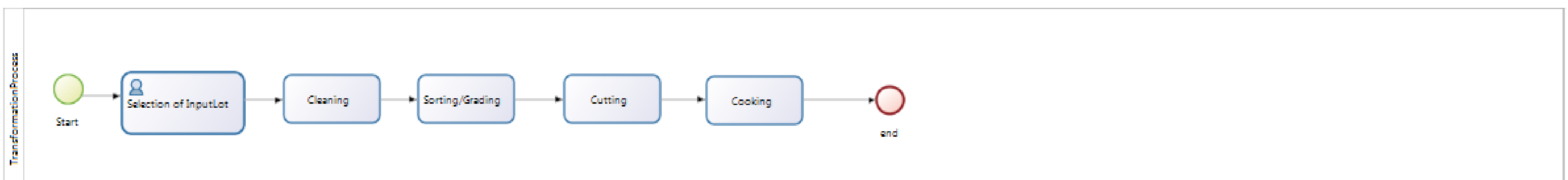


Figure 69 - Frozen Vegetable Supply Model

A simplified schema of the lot behavior during the transformation process is showed in Figure 70. In particular, every container of incoming lot can be divided into different lot depending on the processes of sorting and grading. Every lot is identified with the information on date and time of the operation that led to its generation. According to the example showed in Figure 67, the lot of potatoes, cultivated on the parcel "878 256 003" and harvested the 252nd day of the year 2013 by the actor with id "IT 878 CS 002" is provided to the actor "IT 500 CS 001" the 255th day of the year 2013. The actor who buys the lot of potatoes, which is represented in this case by the transformation company, must register the incoming lot the load register of the company. During the registration phase and internal id is assigned to the incoming lot. The internal Id is obtained combining the Id of the transformation company with the date and time of registration. In the example showed in Figure 70, the new id for the incoming lot is "IT 500 CS 001 255 13 0830 001".

In conclusion, the id of every lot is obtained combining the id of the lot of origin with the information on date and time of the executed operation.

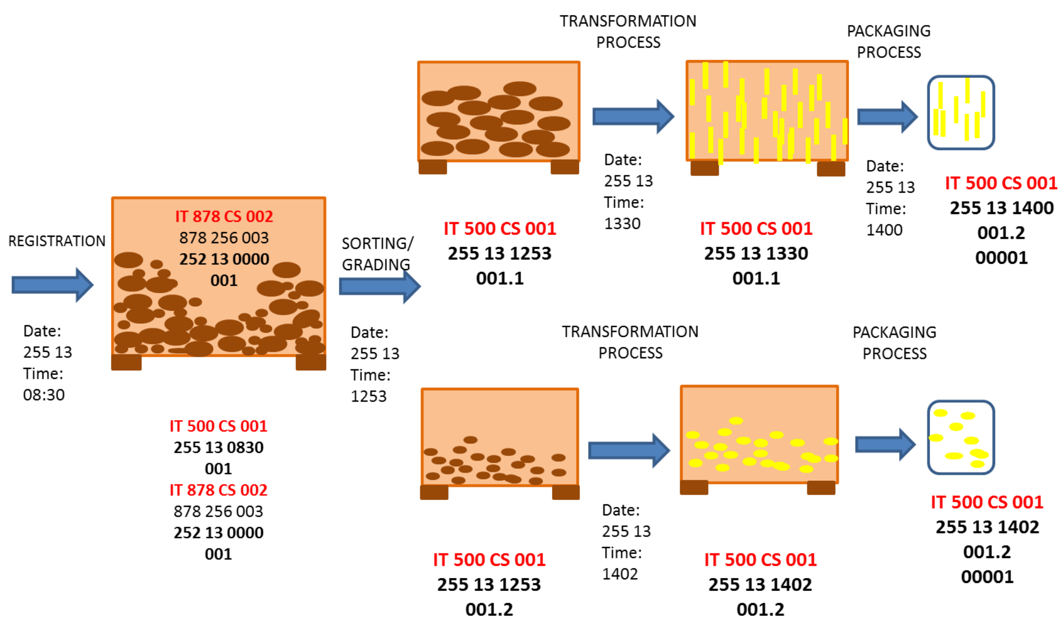


Figure 70 - Lot behavior during the transformation process

Generally, different lot can be integrated in order to obtain a combined lot generated for assuring the compliance with the particular characteristics of the production line (e.g. capacity of the production line). Also in this case the new lot obtained as combined lot will be uniquely identified combining the information on the actor and the information on the executed information (Figure 71).

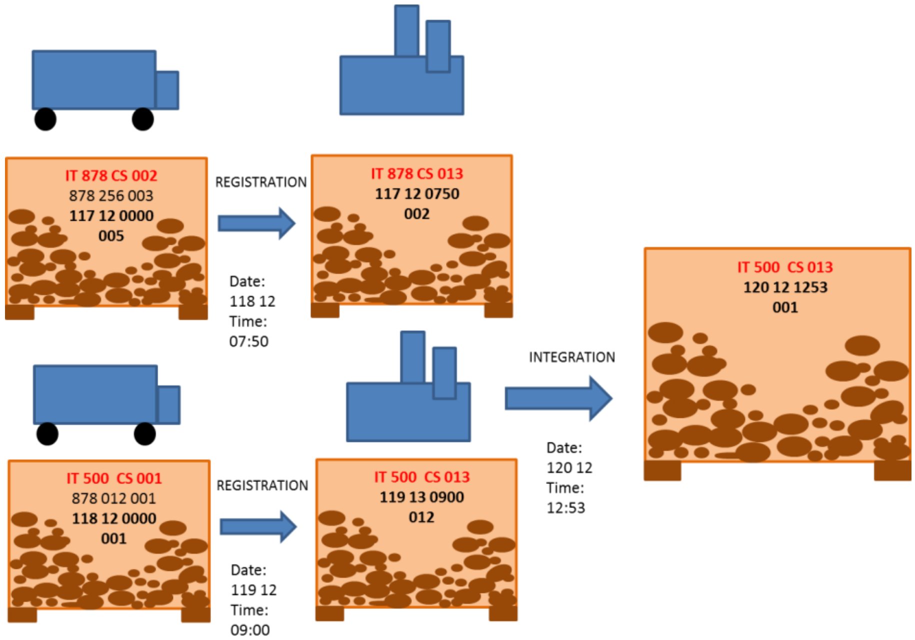


Figure 71 - Integration Pattern

In order to avoid the problem of having to lot with the same identification code into two different production lines, the additional information on the location can be added (Figure 71).

STEP 3: Data collection

During the data collection step, the first phase a register with the list of actors involved in the supply chain was generated. For each actor the following information has been collected:

- ✓ Name;
- ✓ Address;
- ✓ Type (seeder, nursery, cultivator, processor, transporter)
- ✓ Date of approval

In the second phase, different types of lots were defined for each actor in the supply chain. The identification of lot and elements to trace, in fact, depends on the different processing stages under analysis. Notwithstanding each batch is characterized by the identification of products obtained under homogeneous conditions by location, type and date of treatments.

We identified different batches types for the phases of seeds production, seedlings production and cultivation. These batches are described as follows.

During the process of seed production and management, the ***Seeds lot*** is defined through the recording of the following information:

- ✓ Species of the seed;
- ✓ Variety of the seed;

- ✓ Category of the seed;
- ✓ Size/caliber;
- ✓ Nation of origin;
- ✓ quantity of the lot (in a specified unit of measure)
- ✓ Id of the supplier;
- ✓ Date of production/packaging;
- ✓ Usability period.

Information on seed is recorded on the seed register of the nursery or of the cultivator when seed are sowing directly on the land by the cultivator without the necessity of refers to the nursery for the production of the different seedling required.

Seed can be sown directly on the land by the cultivator or used by the nurseries for obtain the seedlings that will be successively sell to the cultivators, which will transplant them. The Seedling lot or batch identifies the individual batch of seedlings on the stage of growing at the nursery. In Italy, a ***seedling batch***, also called "partita", is defined as a number of elements that can be identified by its homogeneity of composition and origin". Information required for the definition of a seedling batch is regulated by DM 14/04/97 and they consist in:

- ✓ Cultivated species;
- ✓ Variety produced;
- ✓ Id of the seed lot of origin;
- ✓ Data of sowing;
- ✓ Method or cultivation (conventional, integrated or organic)
- ✓ Data of packaging;
- ✓ Date of delivery.

In addition to this information, other information recorded at this step is:

- ✓ Information on the location in which the seedling grown (identification of the parcel);
- ✓ Information on the type of cultivation (cultivation on open land or greenhouses cultivation)
- ✓ Information on the operations executed on each seedling lot.

The operations executed by the nursery are equal to the operation executed by cultivators. The only difference consists in the time of processing which is reduced if compared to the time of cultivation at the cultivation company.

For each nursery, the cultivation register is used for recording information on the date of sowing and on the operations executed on the different seedling lots. The cultivation register and the register of unload for the nursery is equal to the registers used for the cultivation phase for the production of fresh fruit.

On the other hand, for each cultivator, two different types of lots were defined: the ***cultivation lot*** and the ***harvesting lot***. As before mentioned, the logbook is used to register all the operations executed on each cultivation lot are recorded. For each operation important information to be recorded is:

- ✓ Information on the operation (sowing, irrigation, phitosanitary treatment);
- ✓ Information on the material or product used;
- ✓ Quantity of the material used;

- ✓ Motivation or cause of the operation;
- ✓ Execution date;
- ✓ Information on the operator who performed the operation.

The harvesting lot is identified during the harvesting time. Each harvesting lot is defined in order to contain only products belonging to the same parcel or cultivation lot. In case of products belonging to different parcel a clear definition of the lot of origin must be maintained.

Harvested goods are successively sent to the Factories, which will transform them in order to obtain a series of processed food products. At the factory, different types of lots are defined.

In this context, a lot of incoming raw material identifies the raw materials delivered from a specific cultivator or wholesaler and it is characterized by the amount of bins supplied in a defined date or time, containing a fixed quantity of vegetables divided by caliber, as well as all the characteristics of the plant batch of origin.

Raw materials are registered in the load register and for each lot of raw materials data collected is:

- ✓ Id of the supplier;
- ✓ Date/Time of delivery;
- ✓ Vegetables type;
- ✓ Vegetables caliber;
- ✓ Origin (id of the cultivation lot or of the parcel)

Incoming raw materials can be stored until their entry in the production process. In this case, several lots of storage can be defined. A Lot of storage can consist in a bin, in a pallet or in a container identified by the following information:

- ✓ information on the lot of origin;
- ✓ information on the supplier;
- ✓ information about storage conditions;
- ✓ identification of the storage cell or the warehouse;
- ✓ final destination (optional).

Data on storage condition can be stored on a register similar to the storage register modeled in the general framework.

During the transformation process, products processed under similar condition refer to the same lot of transformation or processing lot. For each processing lot information to be recorder refers to:

- ✓ Lot of incoming raw material (or lot of storage in case of temporary storage of the raw material before their entry in the production process);
- ✓ Date and starting time of the transformation process;
- ✓ Processing condition.

A Lot of semi-finished/finished products, usually called packaging lot, is defined at the end of the transformation process and it contains the products belonging to the same processing lot and packaged at the same time or in a prefixed time window. Information contained in the lot of semi-finished/finished products is:

- ✓ Packaging Type (bottle, box, bin, etc.);

- ✓ Material used for packaging;
- ✓ Amount/quantity of goods in the packaging unit;
- ✓ Date and time of packaging;
- ✓ Expiration Date.

After the transformation process, products can be temporary stored. Even in this case a lot of storage is defined and all the related information is collected.

Each entity of the supply chain has been uniquely identified using specific Identification Codes. Consequently a series or registers have been generated for containing all the information related to actors and lots.

STEP 4: Data modeling

In particular, a ***seed register*** has been modeled for recording information on seed bought and sent to nurseries and cultivators. The seed register has been modeled by adapting the mp_register modeled in the general framework (Figure 72).

#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
1	**idActor**	varchar(8)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
2	**idseed**	int(10)			No	*Nessuno*		Modifica Elimina Più
3	**seedDescription**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
4	**specie**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
5	**variety**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
6	**category**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
7	**sizeCaliber**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
8	**origin**	varchar(2)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
9	**idLotSeed**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
10	**lotQuantity**	int(10)			No	*Nessuno*		Modifica Elimina Più
11	**unitOfMeasure**	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
12	**idSupplier**	varchar(7)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
13	**idLotSupplier**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
14	**dateArrival**	varchar(8)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
15	**dateProduction**	varchar(15)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
16	**usabilityPeriod**	varchar(15)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più

Figure 72 - Seed Register

The packaging register has been defined generally enough to be adapted for the registration of consumer units and trade unit. Different units of aggregation are defined according to the GS1 Global Traceability Standard (GS1 Standards Document, 2010). In particular:

- ✓ A Consumer Unit (CU) represents a single products, bags, and packages with a certain amount, volume or weight of goods.

- ✓ Cartons, boxes, pallets or bulk lots (in weight or volume) represent a Trade Unit (TU).
- ✓ Pallets and containers generally represent a Logistic Unit (LU).

The packaging register is showed in Figure 73.

	#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
☐	1	numRegister	int(11)			No	*Nessuno*	AUTO_INCREMENT	Modifica Elimina Più
☐	2	IdLotPackaging	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	3	idPackaging	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	4	lotQuantity	int(10)			No	*Nessuno*		Modifica Elimina Più
☐	5	unitOfMeasure	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	6	datePackaging	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	7	idLotOrigin	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più

Figure 73 - Packaging Register

For each consumer unit, which represent a single product, is generated a QR code including the following information:

- ✓ Id of the Country in which is located the last agent who operated on the product (Packer)
- ✓ Id of the Actor;
- ✓ Id of the structure that packaged the product;
- ✓ Id of the product;
- ✓ Id of the packaging
- ✓ Quantity contained in the packaging;
- ✓ Unit of measure of the quantity;
- ✓ Date/Time of packaging;
- ✓ Due date of the product

The information on the packaging lot can be obtained joining the information contained in the packaging register with the information contained in the table lot (Figure 74). The packaging lot is a particular lot of type "packaging" formed by a certain quantity of products contained in one or more consumer units or containers.

	#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
☐	1	idLot	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	2	lotDescription	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	3	quantity	int(10)			No	*Nessuno*		Modifica Elimina Più
☐	4	unitOfMeasure	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	5	typeofLot	varchar(10)	latin1_swedish_ci		Sì	*NULL*		Modifica Elimina Più
☐	6	dueDate	varchar(15)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	7	numContainers	int(10)			No	*Nessuno*		Modifica Elimina Più

Figure 74 - Lot Table

In the case under study, the consumer unit is represented by a bag of frozen vegetables. The bags of vegetables obtained packaging the same production lot in a defined time window belong to the same packaging lot. Consequently, a packaging lot is formed the bags of vegetables belonging to the same production lot and packaged in a well-defined time window.

Different bags of vegetables are successively packaged in several boxes in order to be sold. Every box represents a trade unit. In order to make the process more understandable, an example of consumer unit, logistic unit and pallet is showed in Figure 75.

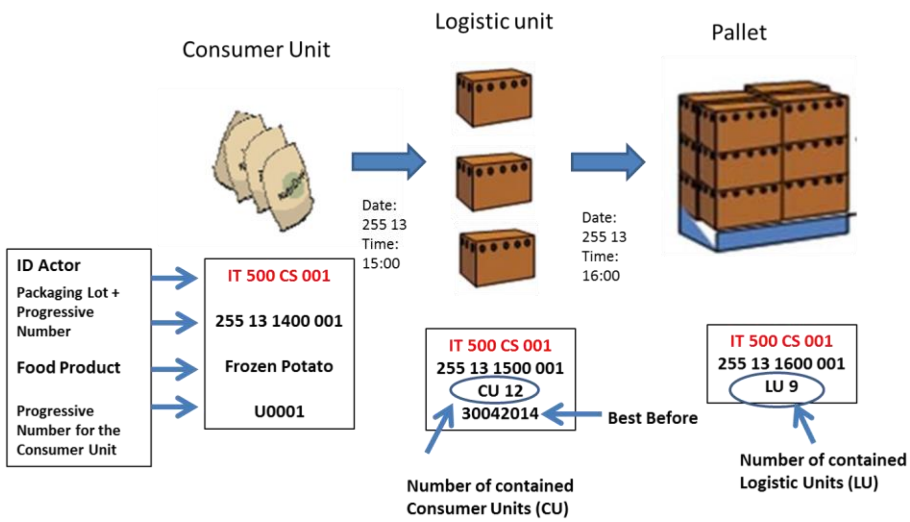


Figure 75 - Consumer Unit, Logistic Unit and Pallet

In order to maintain the traceability of each single Traceability resource unit, a QR code is generated each time that a Traceability Resource Unit is formed. The QR-code, which was developed by Denso Wave (http://www.qrcode.com), is known as a kind of 2D barcode.

The choice of the QR code is directly related with the low costs connected with its application and the possibility of recording a large amount of information. The main features of this code symbol are, in fact, large capacity, small printout size and high speed scanning. A QR code is generated each time that a traceability unit is generate, moved, or manipulated.

A streamlined data model of the database that support the traceability management in the traceability supply chain of frozen products under study is showed in Figure 76. In the model each batch is identified by an ID (batch ID), which is unique within the SC. Each actor is uniquely identified by an identifier actor (actorID). The batchID contains the actorID. Typically batchID is attached as a bar code on the batch of seed, batch of seedling and batch of package.

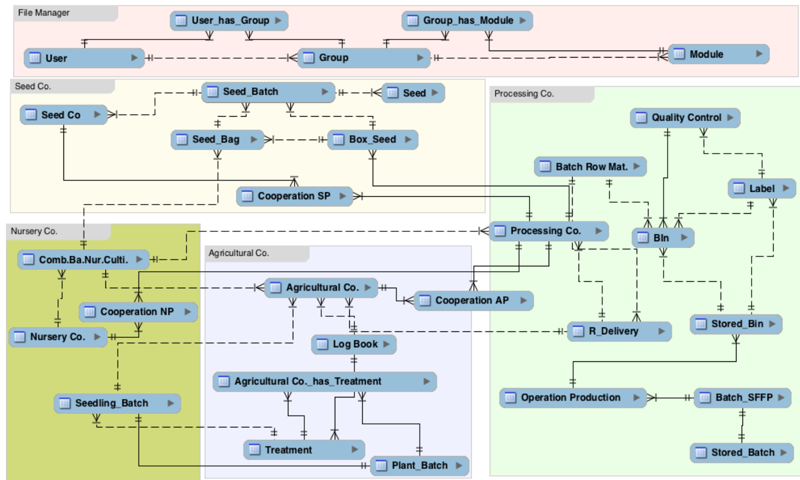


Figure 76 - Streamlined Data Model for the Fruit and Vegetables Supply Chain

STEP 5: Generation of the web application

In case of seedling, some rules have been introduced for the maintenance of products traceability. In particular, the nursery can be dived in different part, where are located the seedlings obtained from the sowing of the seed belonging to the same lot of seed provided by the same seeder.

Each nursery is identified by the combination of the id of the parcel in which is located and a progressive code for each nursery located in the same parcel. A nursery can grow seedling in an open space on a greenhouse. In addition, every lot of seedlings is located in a particular area of the nursery which is identified by the combination of the nursery code and a progressive number for the specific area of the nursery. Consequently, a lot of seedling is formed by the different box of seedling located a particular area of the nursery (Figure 77).

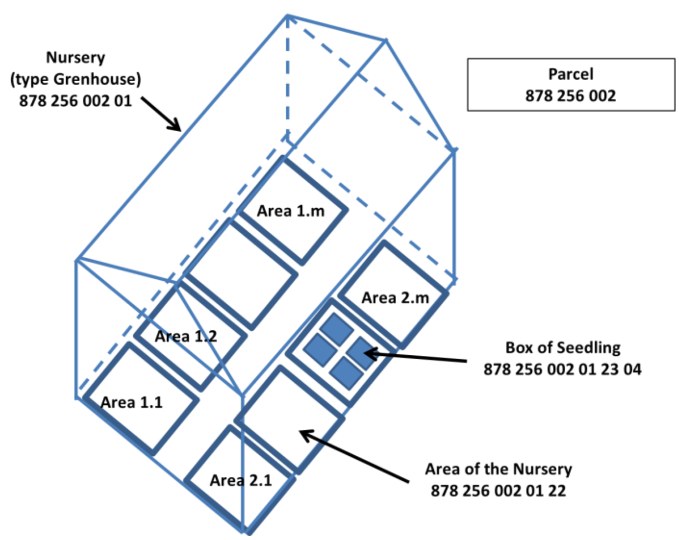


Figure 77- Seedling's box allocation

Similarly to the cultivation process, the sales register is filled every time that a lot of seedling is sent to the cultivator.

According to the transformation company, one of the most important operations to execute is to register the incoming lot in order to maintain the connection with the id of the lot provided by the different supplier. The web-page developed for supporting this phase is showed in Figure 78.

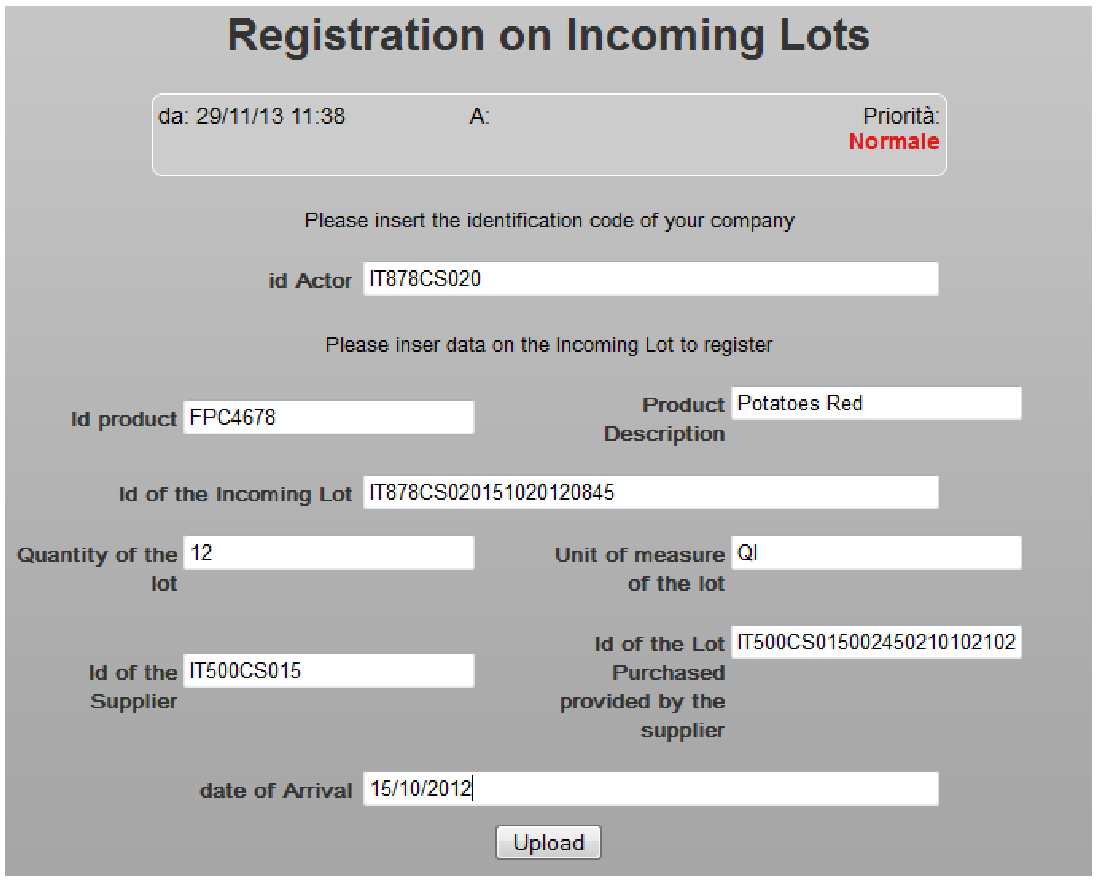


Figure 78 - Registration of Incoming Lots

Particular importance has been given to the packaging process and a particular web application has been created for supporting the packaging process (Figure 79)

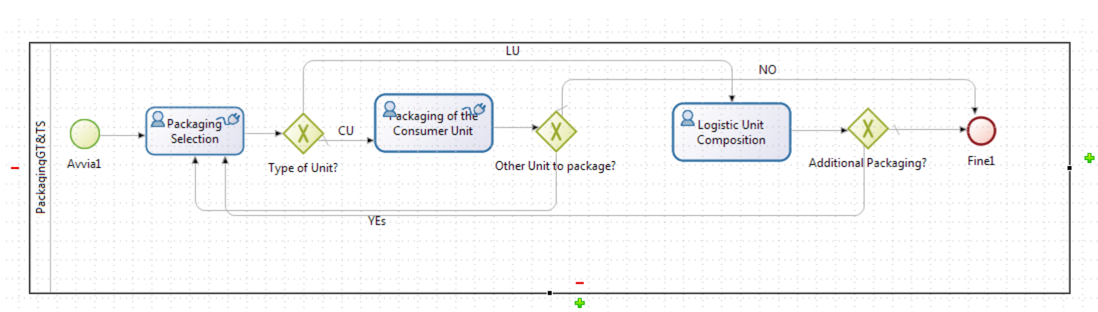


Figure 79 - Packaging Process

A web application has been developed for supporting the registration of data and its transmission (Figure 80, 81, 82).

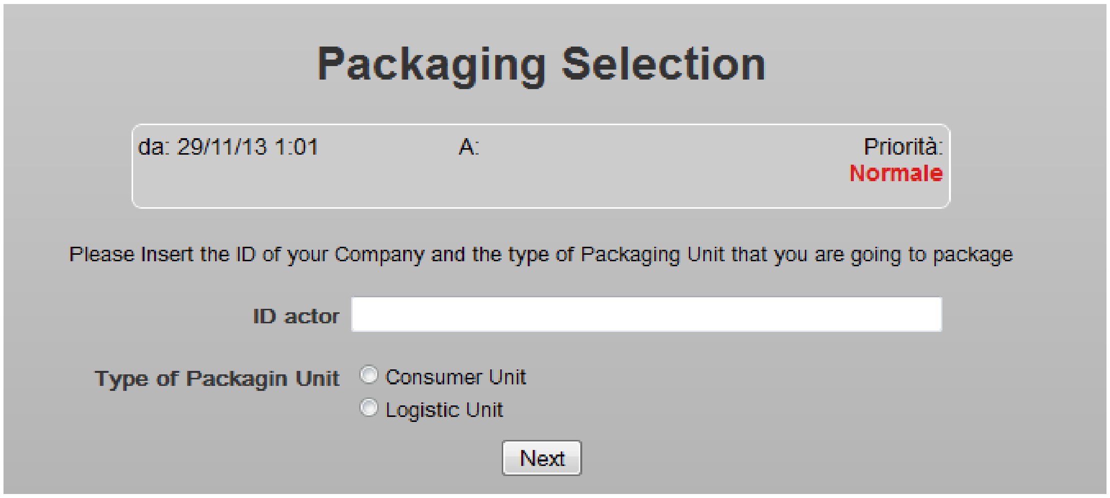


Figure 80 - Web page supporting the packaging process

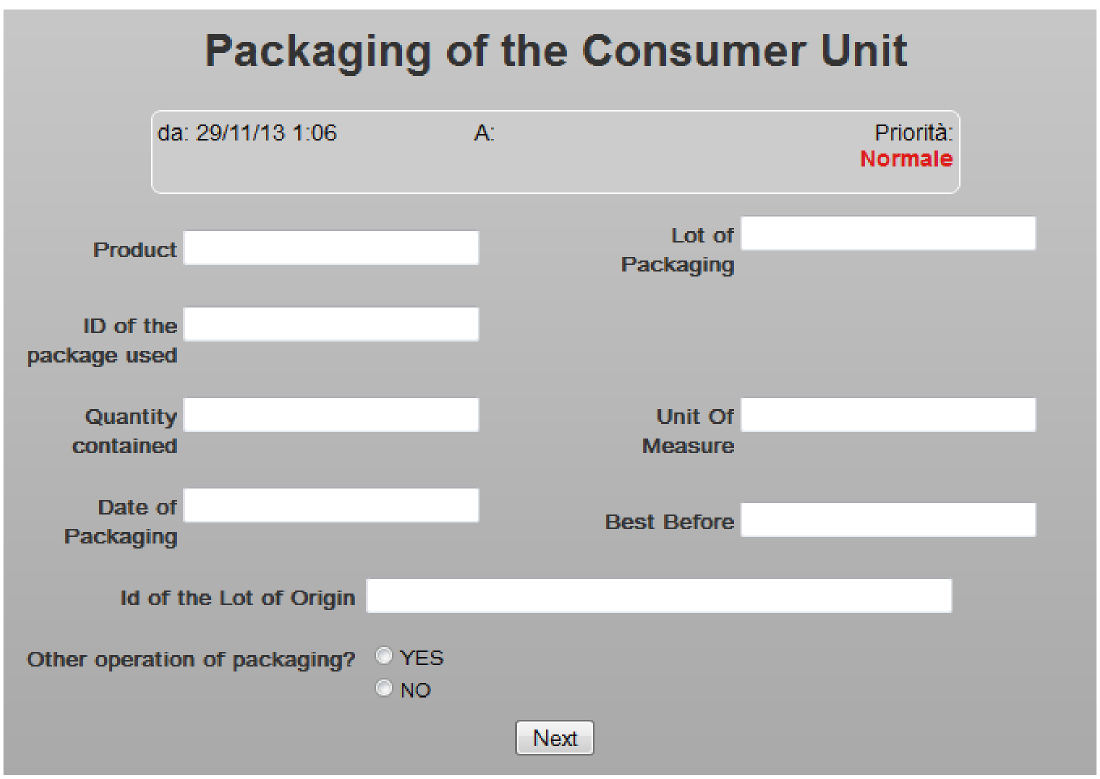


Figure 81 - Web page for the registration of data on Consumer Units

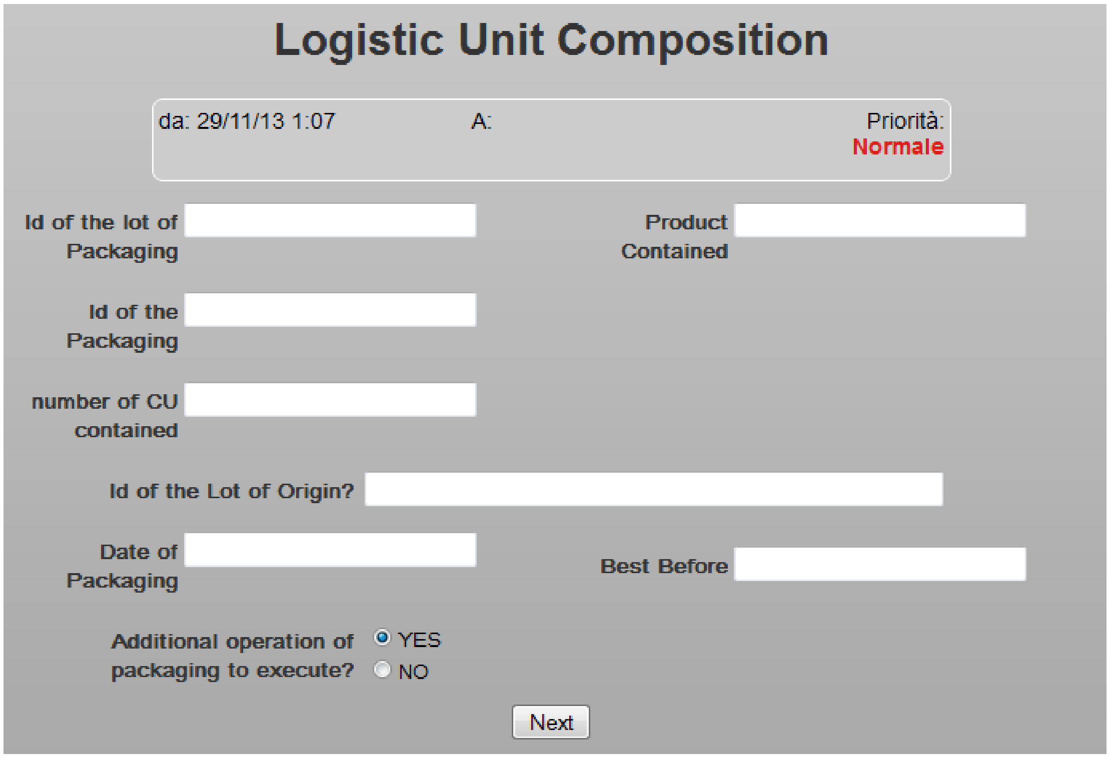


Figure 82 - Web page for the registration of data on Logistic Units

5.2.2 Traceability of meat and meat products

STEP 1: Analysis of the meat supply chain

The meat supply chain refers to all the stages of meat production and processing which, starting from the farming of animals that are slaughtered and cut, lead to the production of fresh meat that can be successively manufactured for producing different meat products.

The main actors involved in a meat supply chain are: breeders, farmers, slaughterhouses, meat products manufacturers, distribution center, supermarket or retailer, food services and consumer. Meat production is projected to double by 2020 due to increase per capita global consumption of meat and population growth (M. Rosegrant, M. Agcaoili, N.D. Perez, 2005).

In the context of this PhD Thesis the attention has been focused on the analysis of the supply chain of meat and meat products of pork origin. Pork production is an important socioeconomic factor in the European Union (EU) as more than 20% of the world pork production is produced here (Figure 83). Pork and pork products represent an important part of the diet in the EU. In several of the member states the proportion of pork exceeds 50 % of all meat consumed (Q-PorkChains final report, 2012. Availableat: http://www.q-porkchains.org/~/media/Qpork/docs/pdf/leaflets/final_report_QPC_september2012_web.ashx

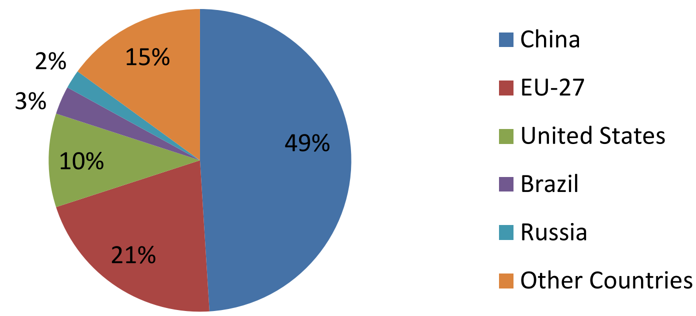


Figure 83 - Pork Production in 2010
Source: United States Department of Agriculture.

Pork is the culinary name for meat from the domestic pig. Pork meat represents the most commonly consumed meat worldwide.

Pork can be used for the production of fresh meat that can be sold to the final consumer or for the production of meat products such as ham and bacon. On the market fresh pork is available in a wide variety of cuts (head, neck, blade, hand, loin, belly, leg, hock, trotters and other cuts of lesser importance) that have different composition and which are characterized by different characteristics.

A simplified version of the supply chain of meat from pork is shown in Figure 84.

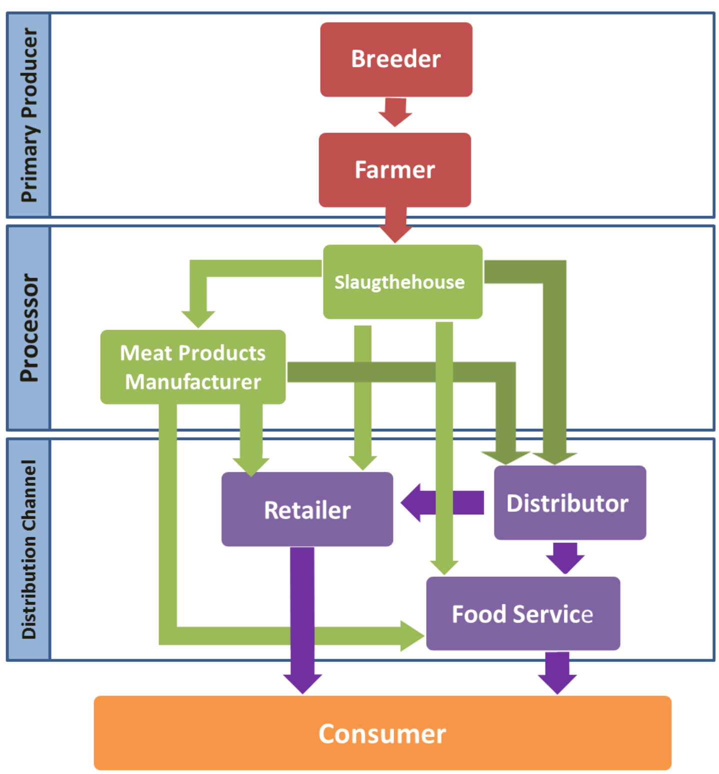


Figure 84 - Pork meat supply chain

The process required for the production of meat products can be divided in four main steps:

- ✓ Farming;
- ✓ Slaughtering;
- ✓ Meat products production
- ✓ Packaging.

Farmer can buy pigs from breeder or can provide by themselves to the breeding of the animals.

After the reproductive phase, pigs are weaned and fattened. Pigs are fed until they reach the expected slaughter weight of about 100 kg. Once they reach the required weight they are moved to the slaughterhouse. The main operations executed at the slaughterhouse are pigs culling, cleaning, cutting, boning, packing and storage. The different meat cuts obtained at the slaughterhouse can be sold directly to the clients through the distribution channel or to the meat manufactures, which can produce different type of meat products from the main cuts.

As mentioned in the Preface, the research work carried out has been mainly oriented by the analysis of the Calabria region. In the context of this PhD thesis, we focused the attention on the traceability process of the most important meat supply chain in Calabria: the “Salsiccia di Calabria”, which obtained the ODP certification (Origin of Denomination Protected) along with other products of meat origin such as the “Soppressata”, the “Capocollo” and the “Pancetta”. The “Salsiccia di Calabria” is obtained through the mixing of milled meat of pork origin and other ingredients such as salt and black or red pepper.

STEP 2: Modeling of the meat supply chain

The supply chain of the “Salsiccia di Calabria” can be divided in 3 main steps: in the first step pigs are reproduced and fattened at the farm level. Then, they are send to the slaughterhouse where pigs are killed, cleaned and dissection for obtain the half-carcasses which are send to the transformation company. The transformation companies or “salumifici” process, milled the meat selected from the main cuts that is mixed with other ingredients and filled in a particular film, which generally consists in the guts of the pigs. Fresh “Salciccia di Calabria” are dried for 30 days and successively packaged.

The supply chain of the “Salsiccia di Calabria” has been modeled identifying the main processes executed at the farm level, at the slaughterhouse and at the transformation company.

Figure 85 shows the modeled obtained for the meat supply chain at a high level of abstraction. In particular the product flow can follow two different paths depending on the market destination of the main cuts obtained from the pork meat. The main cuts, in fact, can be sold as fresh meat or can be manufactured for obtaining different meats products.

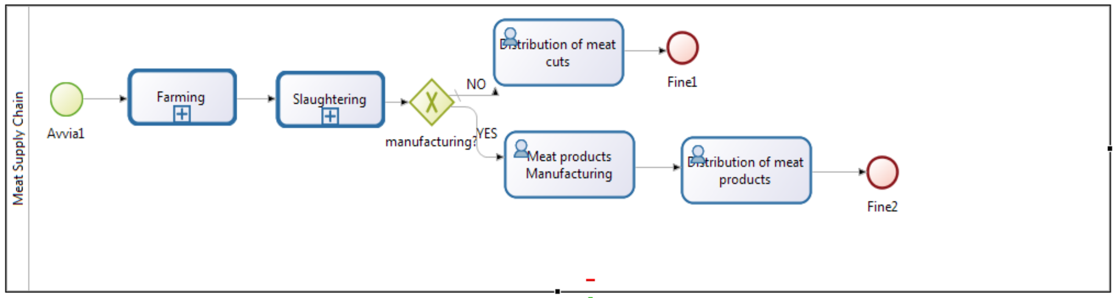


Figure 85 - Meat Supply chain

At the farm level, pig are weaned and fattened. Because of the regulatory framework, every time that a pig born in the factory or is bough from a third company, and it is introduces in the company, a particular register, the unload register must be filled recording all the information required from identifying its origin. Figure 86 shows the pig's flow at the farm level.

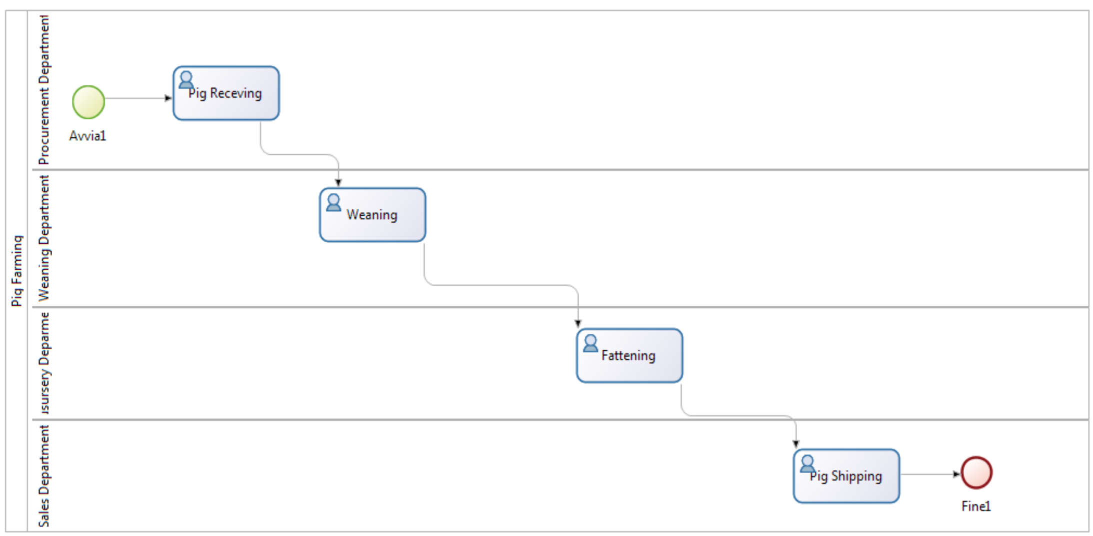


Figure 86 - Pig's Flow at the farm level.

Pigs sent at the slaughterhouse are killed and dissection (Figure 87). Half-carcasses are then send to the transformation company, where they are cut, boned and degreased and nerves are removed. The Transformation process is showed in Figure 88.

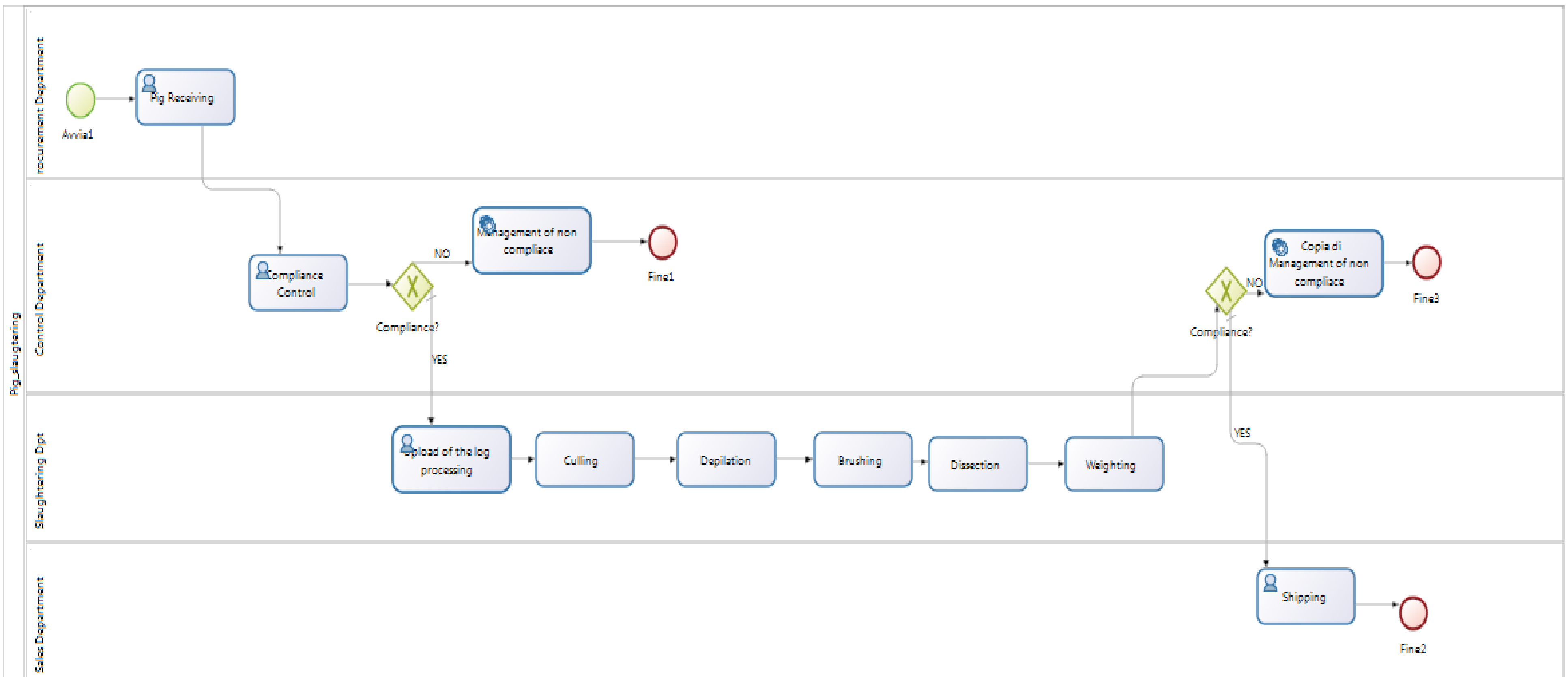


Figure 87 - Modell of the Slaughtering process

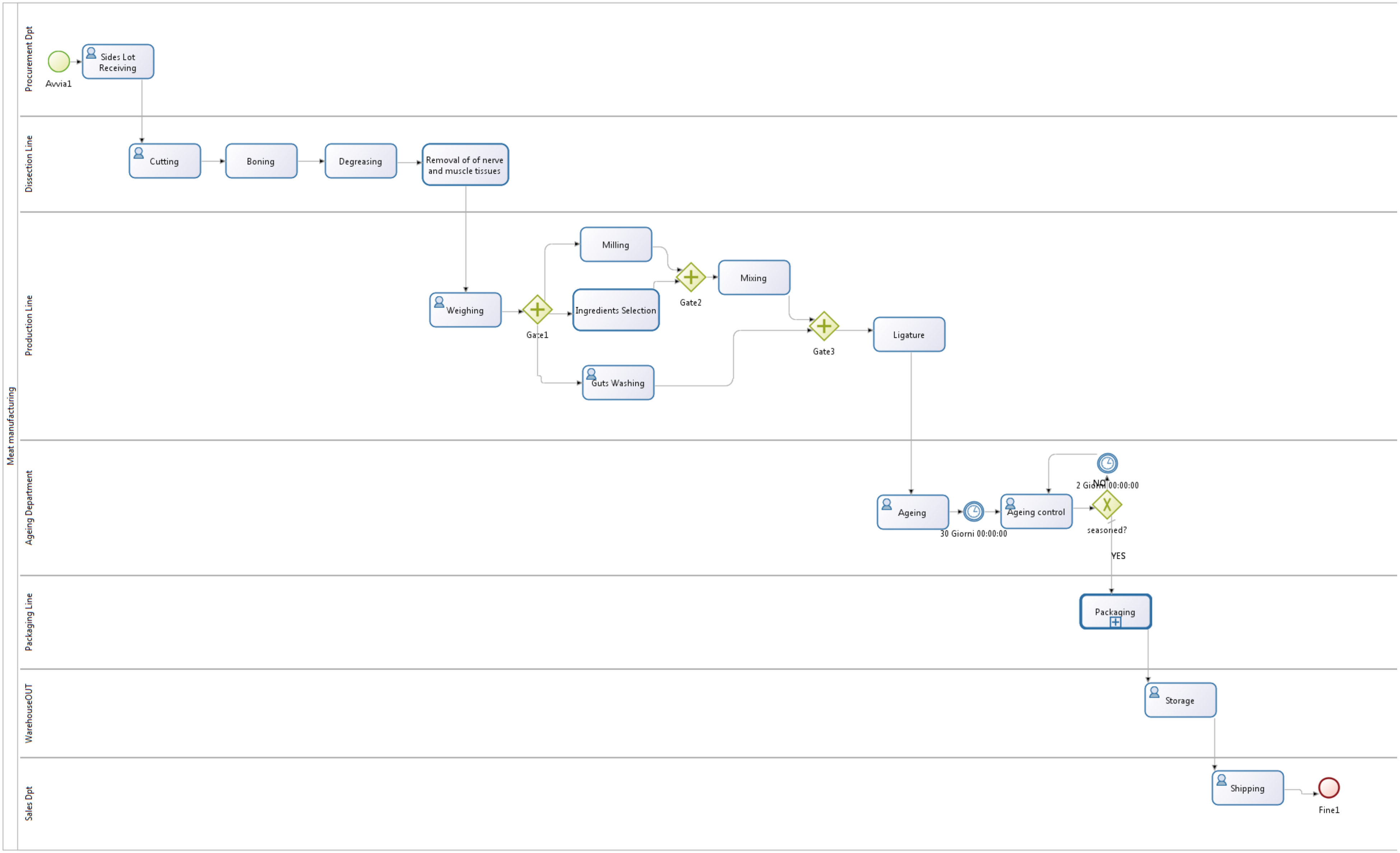


Figure 88 - Model of the Transformation Process

STEP 3: Data analysis

The phase of data analysis has been carried out for identifying mandatory and voluntary data to store for the traceability maintenance.

In Italy, the regulatory framework for pig traceability at the farm level is governed by the Legislative Decree no. 26 October 2010, n. 200 (Gazzetta Ufficiale N. 282 del 2 Dicembre 2010), which implements the Directive 2008/71/EC laying down the minimum requirements for the identification and registration of pigs. Companies, defined as any agricultural establishment, building or other place where animals are kept, bred or sold are recorded by the Veterinary Service of the Local Health Authority responsible for the area in a computerized list.

Every ***company devoted to the breeding, wearing and fattening of animals*** (or, in simple words, the farmer) is uniquely identified by the veterinary service responsible for the area by the attribution of a company code, which is formed by the combination of the following information:

- ✓ ISTAT code of the City (three digits),
- ✓ Identification of the Province (two digits)
- ✓ sequence number assigned to the company on a municipal basis (three digits)

The company code uniquely identifies the place where animals were bred and/or marketed. The company is of the type showed in Figure 89.

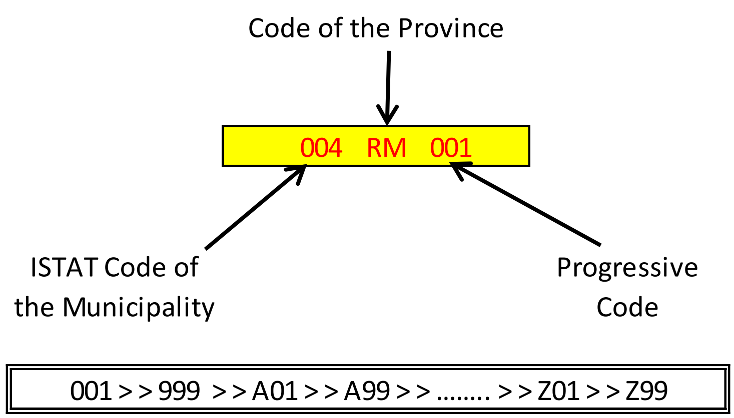


Figure 89 - Attribution of the company code
Source: http://www.salute.gov.it/imgs/C_17_pagineAree_2273_listaFile_itemName_0_file.pdf

The veterinary service must register in the National Database a series of information for each company, such as the company code, the address and its geographical coordinates.

If the same farmer owns several companies in different locations, it will be assigned more company codes, one for each company located in the different places each of which must also take the appropriate registry loading and unloading of animals.

From the regulatory point of view, the ***animal identification*** must be made before the seventieth day of life and in any case before that the animal leaves the company. The animal identification is generally made through the execution of a tattoo in the left ear. In some cases, the tattoo can be carried on the outside of the thighs. The tattoo and, where present, the ear tag bearing the identification code of the structure of birth or of the structure of first destination when the animal is imported from third countries and intended to remain in the national territory (http://www.salute.gov.it/imgs/C_17_pagineAree_2273_listaFile_itemName_0_file.pdf).

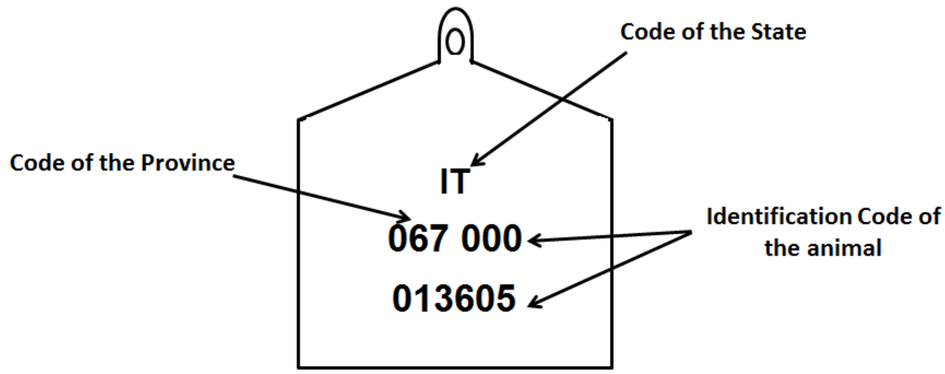


Figure 90- An example of ear tag

An example of ear tag is showed in Figure 90, along with the description of the information that must be recorded for each animal to be uniquely identified:

- ✓ Identification of the State of Origin (2 digits);
- ✓ Abbreviation of the Province (3 digits);
- ✓ a sequence number assigned to each individual animal (9 digits).

In Italy, the National Service Center is devoted to the assignment of the individual identification code for each animal.

Every animal is additionally accompanied by a passport, which contains the following information:

- ✓ the identification code;
- ✓ the type (cattle, sheep, pig, goat)
- ✓ the race (frisona, bruna alpine, romagnola, incrocio, large white, landrace, etc.);
- ✓ the category (calf, heifer, cow, piglet, sow, pig fattening, boar, etc.);
- ✓ sex (male, female);
- ✓ the identification code of the mother;
- ✓ location of birth (N if the animal is born in the Company, E if the animal is born in another Country);
- ✓ date of birth;
- ✓ the date of admission or entry in the company (which coincides with that of birth in case of reproduction within the company).

When an animal moves from a structure to another (for instance from farm to slaughterhouse, or internally to the same company) some information has to be recorded in both of the structures by using a ***register of loading and unloading***:

- ✓ Information on the actors involved in the moving process, including the address of the holdings from and to which the pigs are being moved;
- ✓ the date of the movement;
- ✓ the number of pigs being moved;

- ✓ the identification mark of each pig moved.

For the phase of livestock management, fundamental information to track refers to the establishment of the location where a specific animal has been kept in each phase of its lifecycle. Important information to record are the location and date at which animal were born, raised, transported, information of feed used for its alimentation or on treatment done with pharmacological substances or medicated feed. Similarly to the logbook used in the cultivation phase for recording the information on all the operation executed on a particular lot of cultivation, a logbook or ***farm register*** is obtained by adapting the <u>operation register</u> for recording all the information on the operation executed on a particular lot of animals at the farm level. The farm register is useful for storing the information on the daily operations of feeding and watering. A similar register can be modeled for recording the information on the pharmacological treatments executed on the animals, along with the cause, which lead to the pharmacological treatment. This register is called ***pharms register***.

Once animals reach the appropriate age and/or weight they are selected for slaughter, where they are killed and then divided into half-carcasses or quarters. Half-carcasses and quarters are then portioned, resulting in the characteristic meat cuts. Depending on the type of the final product, different processing lines can be identified for:

- ✓ fresh meat
- ✓ frozen meat;
- ✓ canned meat;
- ✓ hams (cooked and raw);
- ✓ sausages.

In accordance with Reg. 1249/2008 and the Ministerial Decree of 8 May 2009, after grading, carcasses shall be marked with capital letters indicating the weight category (H, that is, heavy, or L, i.e., light) and the class of fleshiness (E, U, R, O, P) or, alternatively, with the letter indicating the category of weight followed by the percentage of lean meat (a class of fleshiness (% lean meat on the carcass weight): E (+55), U (50 - 55), R (45 - 50), O (40 - 45), P (- 40) and S (+ 60 pigs weighing less than 110 kg)).

Half-carcass are stored for a certain time and then they are moved to the transformation company. At the transformation company, the main cuts are obtained from the half-carcass they are milled and mixed with other ingredients in order to obtain the final sausage.

At this level is important recording information on the executed operation. The ***log processing register*** is used to maintain the connection between a lot of sausage and the ingredients involved in the production process.

An ***ageing register*** is defined for maintain information on the ageing process. In particular "Salsiccia di Calabria" is matured for a period of 30 days. Once dried, sausages are packaged and successively stored in order to be shipped and sold. During the packaging process, the ***packaging register*** is generated for maintaining the connection between the product and its packaging, and the lot of sausages of origin.

STEP 4: Data modeling

The analysis of the regulatory framework highlighted the presence the lack of some information in the process of animal's identification. In order to contain all the information in the ear tag of the animal, the coding system defined at the regulatory level for the animals' identification has been opportunely integrated with the introduction of other information. In particular, every animal traced in the Global Track and Trace System is uniquely identified by a code obtained combining the identification code of the company where the animal was born, the number of the day of the year in which the animal is born, followed by the reference to the year of birth and an incremental number for every animal born in the same year in the same structure. An example of animal's identification code is provided in Figure 91.

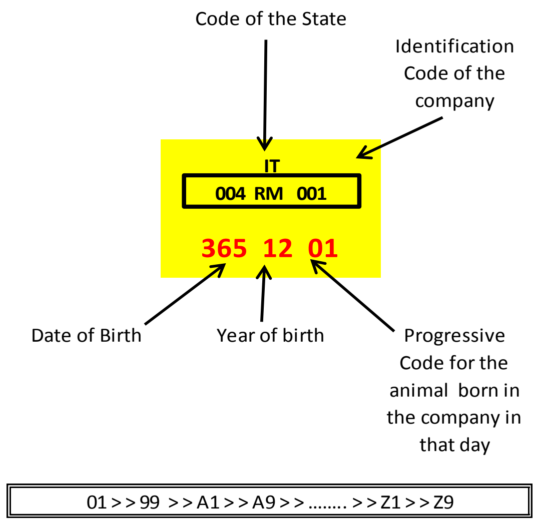


Figure 91 - GT&TS Animal Identification Code

In addition, when an animal moves from an actor to another, for example from a breeder to a farmer, the code of the actor will the added to the previous code (Figure 92). For example, if an animal is reproduced in the company with code IT 004 RM 001 and it is successively sold to the farmer IT 005 CS 004, the code of the second actor is added to the first string. This way of operating facilitates the identification of all the actor that were involved the in growing of an animal.

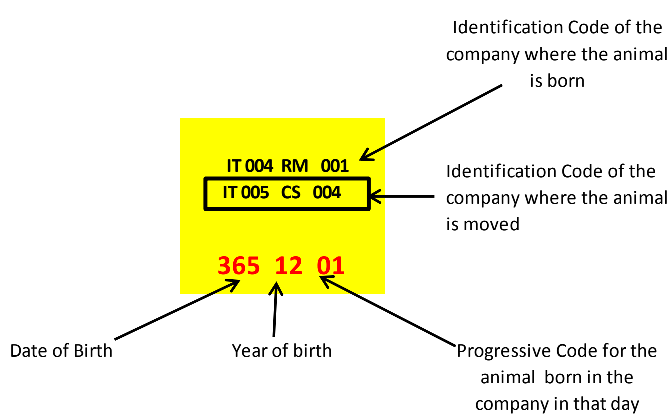


Figure 92 - GT&TS Animal Identification Code

The specification of the encoding system is followed by the definition of the data model required for the management of the traceability process in the meat supply chain. In particular the data model can be analyzed from the farm point of view or from the transformation point of view.

FARM LEVEL

Every animal is characterized by its passport. The passport has been modeled using the animal table, which contains information on race, category, gender, date and place of birth, id of its mother (Figure 93).

	#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
☐	1	idAnimal	varchar(14)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	2	type	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	3	race	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	4	category	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	5	gender	varchar(1)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	6	motherId	varchar(14)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	7	dateOfBirth	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	8	placeOfBirth	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più

Figure 93 - Animal passport

At the time of their joining the company, each animal is considered as a single Traceable Resource Unit (TRU).

A ***load register*** is then created for maintain the link between each single animal incoming in the company and its supplier. Because an animal can be reproduced on the farm or can be purchased from the outside, the load register is uploaded every time that a new animal born in the farm or that it is bought from a third party. If the animal is born in the same farm, the date of load will be the same of the date of birth. The structure of the modeled data register is showed in Figure 94.

	#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
☐	1	idActor	varchar(8)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	2	dateLoad	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	3	idSupplier	varchar(16)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	4	idAnimal	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più

Figure 94 - Load Register

When an animal is located in the farm, a lot of animal is formed for every nursery which contains the animals. A nursery is a particular space in the farm which contains the animals characterized by the same features or that requires the same treatments. For each nursery is created a particular register, the ***nursery register***, obtained by adapting the *storage register* defined in the Global Track and Trace General Framework. The definition of the nursery register is fundamental for recording the information about the different types of farming and the medical treatment carried out on the animals located in the same area. In this case, the nursery table (Figure 95) is obtained by adapting the warehouse table developed in the Global Track and Trace general framework. The field nurseryType is used for describing the final use of the nursery, in other world if the nursery is devoted to the animals' weaning or fattening.

	#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
☐	1	**idActor**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	2	**idNursery**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	3	**nurseryDescription**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	4	**nurseryType**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più

Figure 95 - Nursery Table

When an animal is moved from a nursery to another, the ***nursery register*** is uploaded (Figure 96). In this way, every time is possible to know the current location of an animal in the farm.

	#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
☐	1	**idActor**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	2	**idAnimal**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	3	**dateEntry**	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	4	**idNursery**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più

Figure 96 - Nursery Register

For each nursery, which represents a lot of animal located in a well-defined space, a register of breeding or **farm register** is created for maintaining the connection between the animal and feeds eaten during its life cycle (Figure 97). The farm register is obtained by adapting the operations register developed in the general framework. The operation executed at the farm level refers exclusively to the feeding process.

	#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
☐	1	**idRegister**	int(11)			No	*Nessuno*	AUTO_INCREMENT	Modifica Elimina Più
☐	2	**idNursery**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	3	**idAnimalLot**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	4	**operationCode**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	5	**operationDescription**	varchar(45)	latin1_swedish_ci		Sì	*NULL*		Modifica Elimina Più
☐	6	**date**	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	7	**idUsedFeed**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	8	**quantityUsed**	int(10)			No	*Nessuno*		Modifica Elimina Più
☐	9	**uniOfMeasure**	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	10	**idLotFeed**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	11	**idOperator**	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	12	**note**	varchar(45)	latin1_swedish_ci		Sì	*NULL*		Modifica Elimina Più

Figure 97 - Farm Register

A particular table has been modeled for describing the feed used in the feeding process and its features (Figure 98). The typology of feed for the feeding process is specified in the field typeFeed. In particular, feed can be divided into two main categories: forage and concentrated feed.

Forage can be fresh or preserved. Fresh forage mainly consists in freshly cut grass or grazed. The preserved forages differ in the type of conservation. The techniques used for the forage conservation are basically three:

1. Haying or drying in the field and subsequent collection with packaging.
2. Drying with artificial completion of the dehydration of the packed product in the drying machine of the company.
3. Silage (as in the case of the silo maize) with preservation of the product finely crushed and pressed in covered trenches, where in the absence of oxygen it produces lactic acid, which blocks all fermentations and negative allows the fodder stacked to preserve itself.

Concentrated feed includes:

- ✓ protein crops (soybean, sunflower)
- ✓ cereals (barley, oats, corn)
- ✓ flour;
- ✓ balanced mixtures of products of different types often supplemented with vitamins and minerals

For each feed it is important to register the type of cultivation used for their production that means if they are cultivated following a biological production, a conventional production or a conversion production. This information is recorded in the field provenience of the table Feed (Figure 98).

#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
1	idFeed	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
2	typeFeed	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
3	feedDescritpion	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
4	nutritionalValue	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
5	proteinComponent	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
6	provenience	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più

Figure 98 -Feed Description

Similarly to the farm register, a **pharma register** is created in order to keep track of the health operation performed on each animal and for recording the information on the pharmaceutical product used for that particular treatment (Figure 99). Products used for animals' health treatments include physiotherapy, homeopathy, trace elements and products in compliance with the Regulation EC 889/08. For each product used during the health treatment, important information to store is the quantity of product used in that particular treatment.

#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
1	idRegister	int(11)			No	*Nessuno*	AUTO_INCREMENT	Modifica Elimina Più
2	idAnimal	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
3	date	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
4	idUsedPharma	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
5	typeUsedPharma	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
6	quantityUsed	int(10)			No	*Nessuno*		Modifica Elimina Più
7	uniOfMeasure	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
8	idLotPharm	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
9	idSupplier	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
10	idOperator	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
11	note	varchar(45)	latin1_swedish_ci		Sì	*NULL*		Modifica Elimina Più

Figure 99 - Pharma register

At a top level, a Register of Incoming Lot has been defined for maintaining the connection between materials purchased and suppliers. The product register (Figure 100) has been obtained adapting the *mp_register* modeled in the general framework.

#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
1	idActor	varchar(8)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
2	idProduct	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
3	productDescription	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
4	idLotProduct	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
5	lotQuantity	int(10)			No	*Nessuno*		Modifica Elimina Più
6	unitOfMeasure	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
7	idSupplier	varchar(7)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
8	idLotSupplier	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
9	dateArrival	varchar(8)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più

Figure 100 - Product Register

On the other hand, a ***register of unload*** is generated for storing the information on the sale of the animals or their death (Figure 101). The cause of unload (sale or death) is specified in the field motivation.

#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
1	idRegister	int(11)			No	*Nessuno*	AUTO_INCREMENT	Modifica Elimina Più
2	idAnimal	int(10)			No	*Nessuno*		Modifica Elimina Più
3	motivation	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
4	idClient	varchar(7)	latin1_swedish_ci		Sì	*NULL*		Modifica Elimina Più
5	date	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più

Figure 101 - Unload Register

TRANSFORMATION LEVEL

As mentioned in the previous paragraph, once animals reach the appropriate age and/or weight they are selected for slaughter, where they are killed and then divided into half-carcasses or quarters.

In the Global Track and Trace system every half-carcass is uniquely identified by a label containing the information required from the regulatory point of view, such as the weight category and the class of freshness, along with information on the pig origin and, consequently, along with information recorded during its whole lifecycle (Figure 102). The combination of the two progressive numbers that characterize the register is related to the same animal.

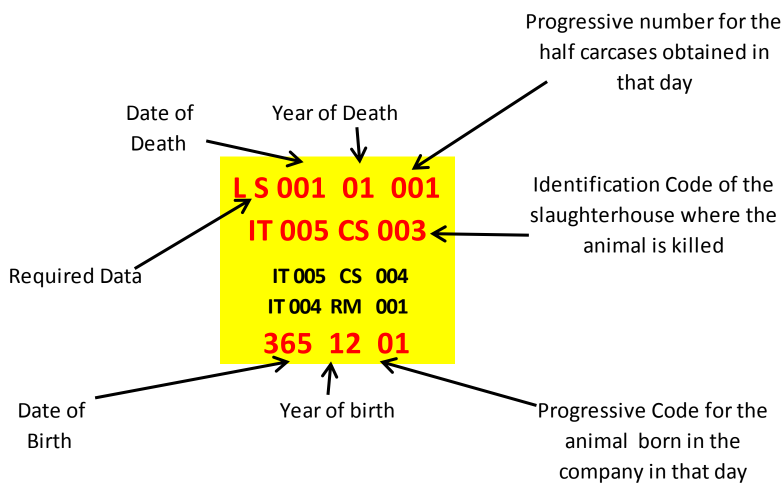


Figure 102 - Identification code for the half-carcass

In order to maintain the traceability at the slaughterhouse level, the following registers have been modeled:

- the register of animal incoming;
- the register of compliance for animals and quarters;
- the register of processing;
- the register of half-carcass;

Half-carcass are stored for a certain time and then they are moved to the transformation company. At the transformation company, the main cuts are obtained from the half-carcass they are milled and mixed with other ingredients in order to obtain the final sausage.

At this level is important recording information on the executed operation. The ***log processing register*** is used for maintain the connection between a lot of milled meat and the pork of origin (Figure 103). A lot of milled meat is obtained every time that the meat cuts belonging to the same pig are milled. The log processing register is used also for recording data on mixing, filling. A lot of sausages is consequently obtained from the same lot of milled meat. Only operating in this way the traceability can be maintained at the level of the transformation company.

	#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
☐	1	idRegister	int(11)			No	*Nessuno*		Modifica Elimina Più
☐	2	**idActor**	varchar(8)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	3	**idOperation**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	4	**startingTime**	varchar(12)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	5	**idLocation**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	6	**idInputProduct**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	7	**productDescription**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	8	**idLotInputProduct**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	9	**quantityUsed**	int(10)			No	*Nessuno*		Modifica Elimina Più
☐	10	**unitOfMeasure**	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	11	**idOutputLot**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più

Figure 103 - Log processing register

An ***ageing register*** is defined for maintain information on the ageing process. In particular the ageing register is obtained by adapting the storage register (Figure 104). In case of ageing, the location refers to the particular cart where the "Salsiccia di Calabria" is hanged up and that are located in a particular area of the company or warehouse (Figure 105). The ageing process can be executed outdoors or in drying chambers. In case of drying chambers, the warehouse identifies the cell in which sausages are dried and it is a warehouse of type "in line". Warehouses can be at environmental temperature or at controlled temperature. In order to maintain product traceability it is important at this step ageing the same lot of sausage in the same warehouse in order to respect the definition of traceable resource unit. In addition every lot of sausage must be dried on the same cart or in adjacent carts.

	#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
☐	1	**idActor**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	2	**idLotSausage**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	3	**lotDescription**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	4	**dateStorage**	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	5	**idWarehouse**	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
☐	6	**idCart**	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più

Figure 104- Ageing register

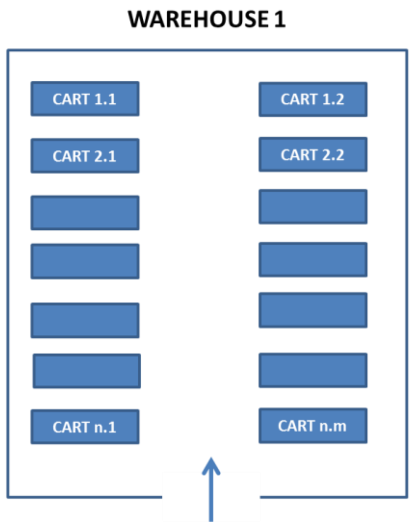


Figure 105 - Warehouse Lay-out

Once dried, sausages are packaged and successively stored in order to be shipped and sold. During the packaging process, the ***packaging register*** is generated for maintaining the connection between the product and its packaging, and the lot of sausages of origin (Figure 106). The packaging register can be easily obtained by adapting the operation register generated in the general framework. Each sausage, or packaged product, is uniquely identified by the id of its lot and a sequential number.

#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
1	numRegister	int(11)			No	*Nessuno*	AUTO_INCREMENT	Modifica Elimina Più
2	idSausageLot	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
3	idPackagedProduct	varchar(20)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
4	idpackaging	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
5	quantity	int(10)			No	*Nessuno*		Modifica Elimina Più
6	unitOfMeasure	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
7	numPieces	int(6)			Sì	*NULL*		Modifica Elimina Più
8	dateTimePackaging	varchar(16)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
9	packagingType	int(11)			No	*Nessuno*		Modifica Elimina Più

Figure 106 - Packaging Register

Every time that a lot of sausage is sold to a client, the ***sales register*** is filled for maintain the connection between the sold lot and the client who bought the lot (Figure 107).

#	Campo	Tipo	Collation	Attributi	Null	Predefinito	Extra	Azione
1	idRegister	int(11)			No	*Nessuno*	AUTO_INCREMENT	Modifica Elimina Più
2	idProduct	int(10)			No	*Nessuno*		Modifica Elimina Più
3	productDescription	varchar(45)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
4	quantitySold	int(10)			No	*Nessuno*		Modifica Elimina Più
5	unitOfMeasure	varchar(10)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
6	idClient	varchar(7)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più
7	dateDelivery	varchar(11)	latin1_swedish_ci		No	*Nessuno*		Modifica Elimina Più

Figure 107- Sales Register

STEP5: Traceability of Meat Supply Chain Web Application

A series of registers and modules have been generated for facilitating the processes of information registration, management and transmission. Figure 108 shows the web-page generated for recording data on pigs that born in a breeder.

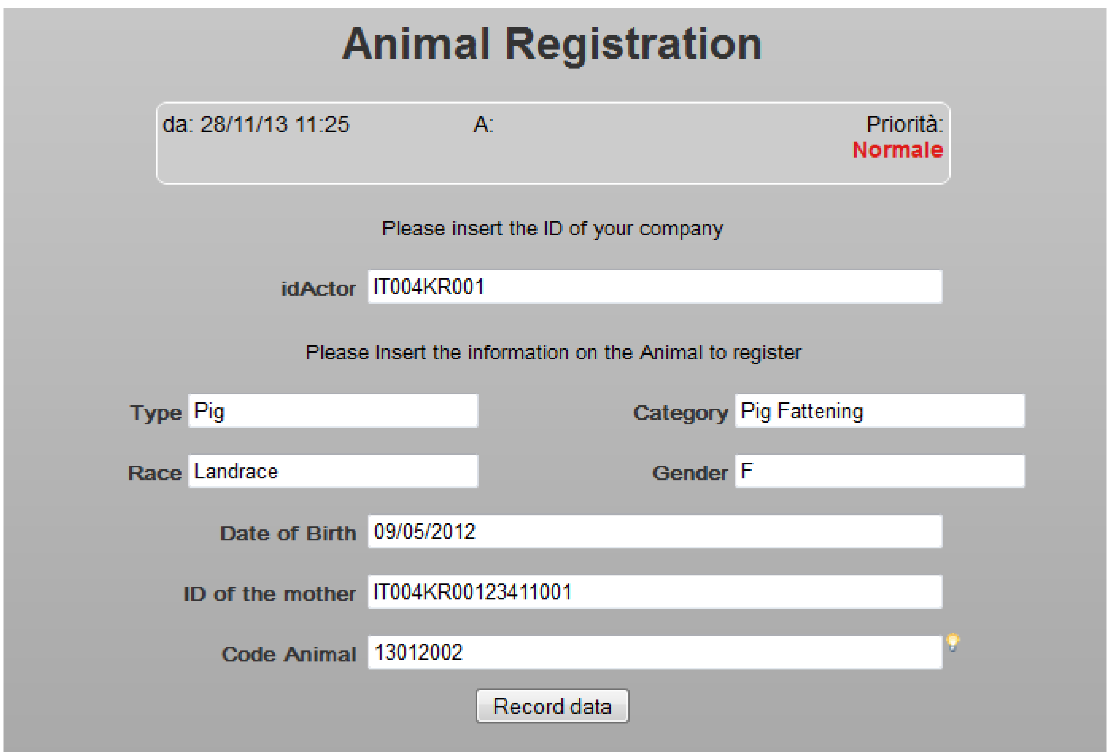


Figure 108 - Web page for supporting the process of animals' registration

Once animals reach a particular weight or a particular age they are transferred to the farmers. When pigs arrive to the farmer, information on the different animals is recorded on the load register showed in Figure 109. On the other hand, Figure 110 show the register with the list of animals loaded in the register.

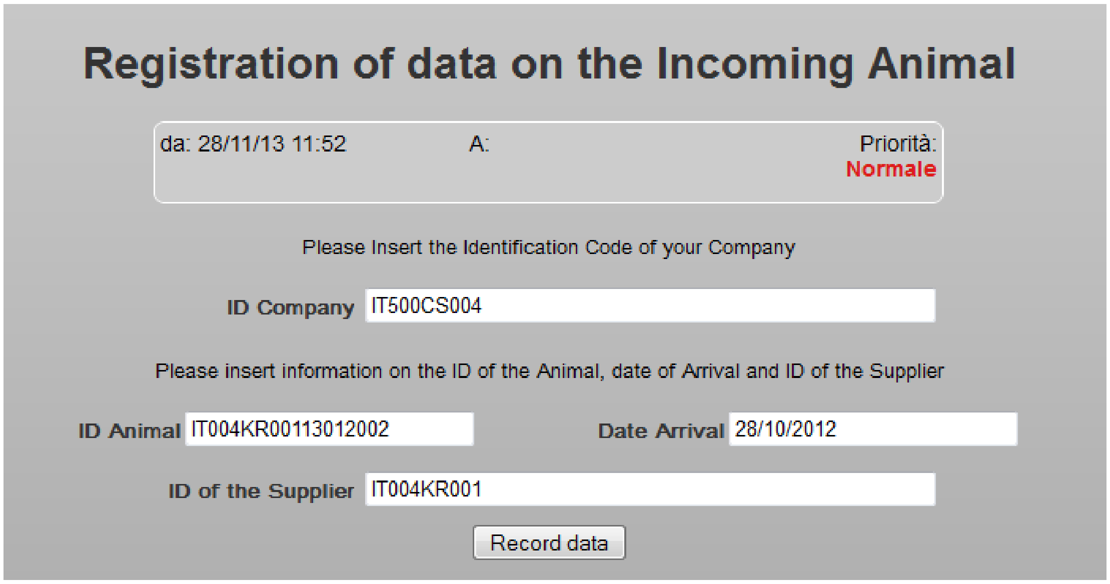


Figure 109 -Web page for supporting the process of updating the load register

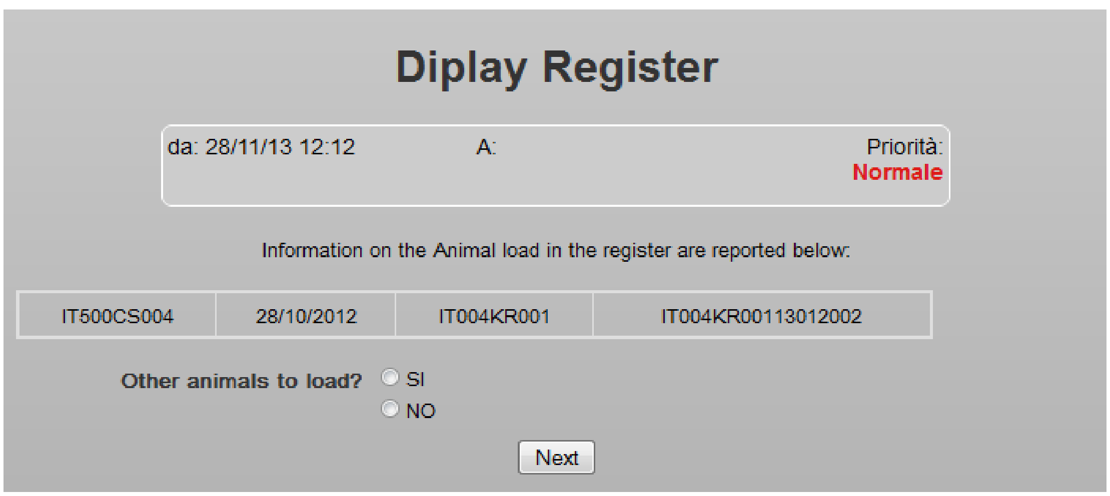


Figure 110 - Display of the register of load

A similar web page has been generated for supporting the process of unload that takes place when the pig dead or they are sold. Figure 111 shows the webpage for supporting in the process of updating the unload register, while Figure 112 shows the register with the unloaded animals.

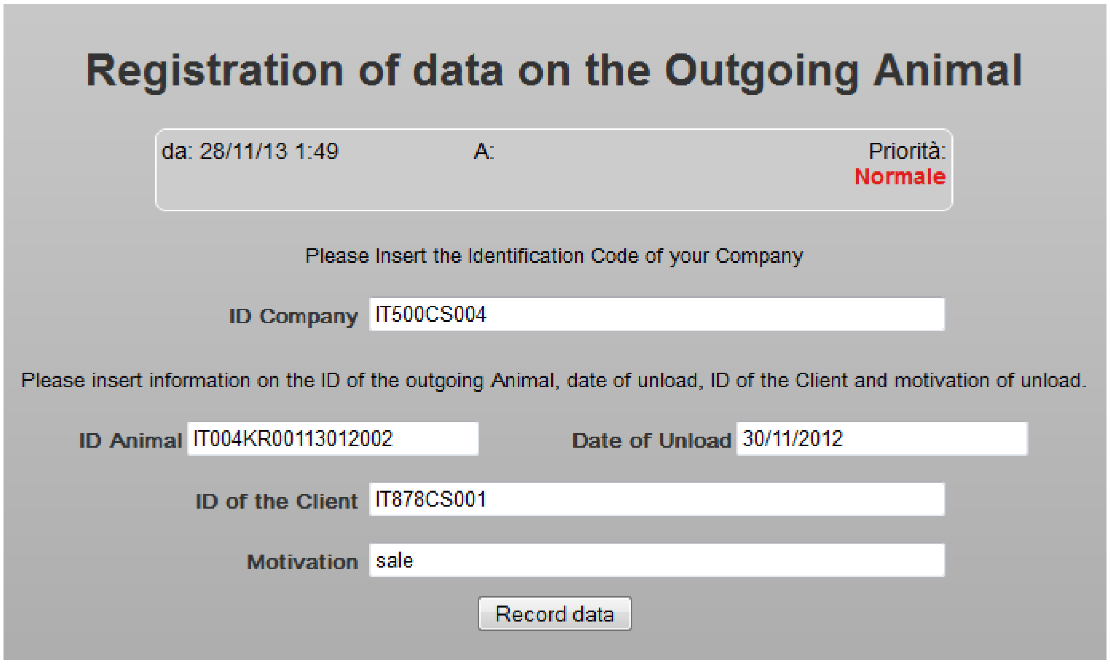


Figure 111 - Web page for supporting the process of updating the unload register

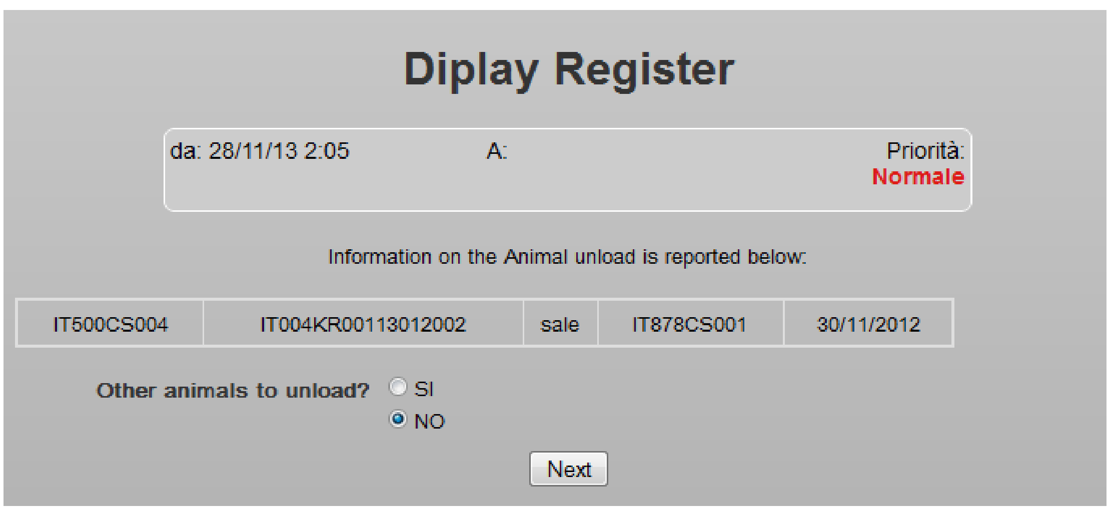


Figure 112 - Display of the register of unload

The same logic has been used for the construction of the other registers. Important information need to be stored during the transformation process. Figure 113 shows the web page generated for supporting the registration of data during the process of meat cutting.

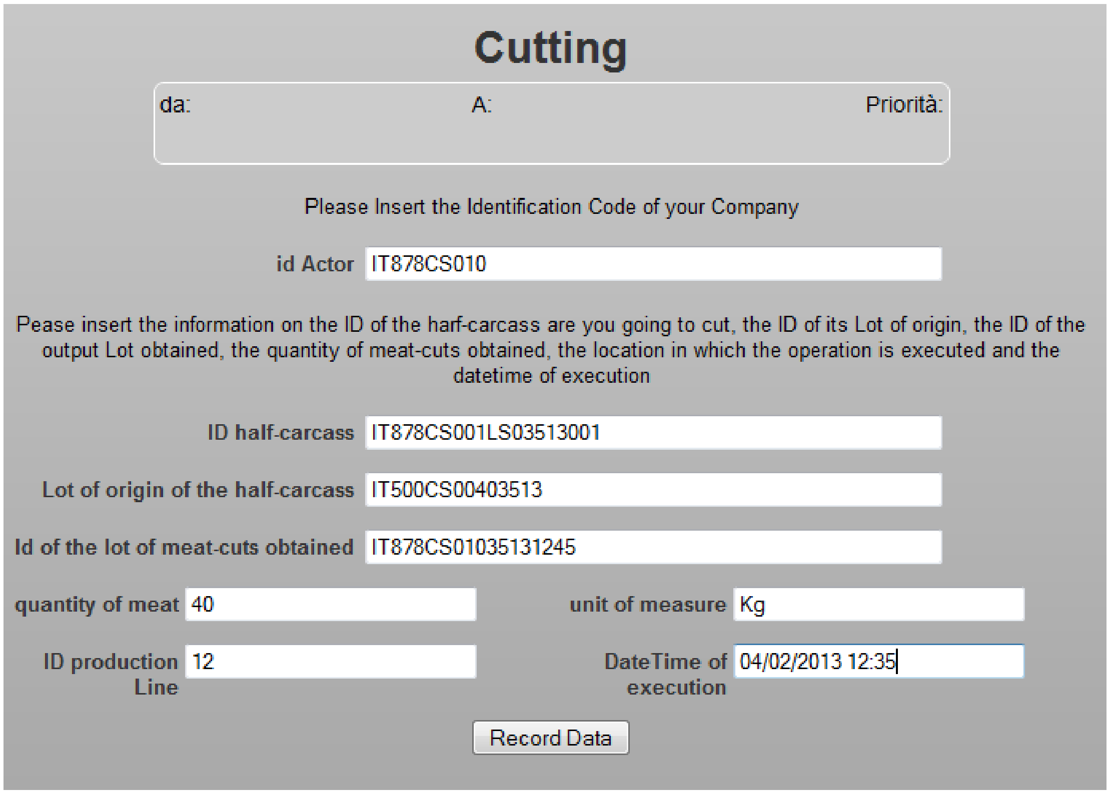


Figure 113 - Web page for supporting the registration of data during the process of meat cutting

Results and Conclusions

The outbreak food diseases of the past years show as more information is necessary and that a global traceability system is fundamental in a global market. In addition to systematically storing information that must be made available to inspection authorities on demand, a traceability system should take also food safety and quality improvement into account. To take into account the current requirements on food quality for health care, additional data that is not strictly necessary for traceability must be stored. For instance, for a cooking activity, oven temperature and humidity can be considered important parameters in case of hazard. For a cultivation activity, operations on the parcel are fundamental to trace the proximity of the land for cultivation to a source of pollution.

Starting from the analysis of the state of the art, in which the current traceability systems where studied and analyzed from the regulatory and scientific point of view, we stated that new traceability systems can be developed integrating the advantages of the previous works in order to remedy the deficiencies of certain systems. In such a context, ontologies have been used to support the integration of heterogeneous databases and facilitate the interoperability of different systems through the introduction of a common standard for all the actors involved in the food supply chain.

This goal has been reached through the modeling of a traceability system which supports the business processes executed in a typical food supply chain obtained with the modeling of the business processes, the definition of a data model for supporting the supply chain, a web application generated in order to facilitate the recording, editing, tracing and transmission of information through the Internet, the definition of rules for the correct management of the system.

The Global Track and Trace System for Food have been obtained through the combination of an informative system for food tracking and tracing, the Global Track and Trace Informative System, and of an ontology devoted to the modeling of the knowledge related to the food traceability, the Food Track and Trace Ontology, which consists also in a standard for information encoding and transmission.

The Global Track and Trace Informative System consists in a system for the storage, management and transmission of data that includes: (i) a process model of the supply chain, (ii) a data server for the storage of information, (iii) a web application generated to facilitate the information management. The Global Track and Trace Informative System has been developed through the execution of a methodological approach that is formed by five different steps that are respectively:

- **STEP 1**: Food Supply chain analysis;
- **STEP 2**: Food Supply chain modeling;
- **STEP 3**: Data Collection;
- **STEP 4**: Data modeling;
- **STEP 5**: Generation and Customization of the web-based application for the traceability management.

The Food Supply Chain have been modeled using the Business Process Model and Notation (BPMN) Standard, which consists in a graphical notation that allows to build the process diagrams using a series of graphs or network of objects. An extended data model has been generated in order to facilitate the management and transmission of information. Data has been modeled using the Entity-relationship technique.

On the other hand, the Food Track and Trace Ontology (FTTO) has been developed for modeling the knowledge related to the traceability domain for food products and to overcome the problem of the lack of a standard for encoding information. The FTTO building process has been inspired by the ontology building process proposed by Noy and McGuinness (2001) that has been extended and integrated considering also the fundamental steps adopted in the Methontology proposed by Fernández-López et al. (1997). The ontology model is based on four different modules each of one devoted to the modeling of the knowledge related to the main entities involved in typical food supply chain, such as Actor, Food Product, Service Product and Process. FTTO intends to be a reference ontological model for future works in the development of food ontologies with traceability purpose. The main goal of FTTO is to include the most representative concepts involved in a food supply chain all together in a single ordered hierarchy. In case of food outbreak disease FTTO can be easily queried to obtain essential information fundamental to connect data available in the food supply chain. It is a valuable tool for supporting quality and safety control. The OWL-DL language based on description logics is used to describe the food traceability domain. The ontology reasoning is conducted proposing a series of competency questions and checking is the questions were being correctly answered. The queries are formulated in Description language (DL-QUERY). The Pellet plug-in is used as reasoner.

Information on products have been identified and recorded essentially in four different phases of the supply chain: when receiving a shipment lot, when moving a lot internally to the company, when such a kind of operation is executed on the product/lot, when a lot is shipped or need to be delivered to another actor. The working principles of the system are well described and different food supply chains have been additionally analyzed and modeled in order to demonstrate how the general framework can be easily adapted to every type of food supply chain.

The traceability system prototype presented in this PhD Thesis is designed under a flexible and open perspective in order to facilitate integration of information across the entire supply chain, ensuring consumer trust and compliance with legal and quality standard. The system can be easily adapted to every type of food supply chain. The same system can be used for modeling the supply chain of primary food commodities and of processed food.

The general framework includes a set of process models that are understandable by business manager in a notation that can be interpreted by SOA-based Information System (BPMN).

The main features of the general proposed framework are:

(i) high flexibility,
(ii) reduced development time,
(iii) reduced implementation costs,
(iv) high usability,
(v) management and control of actors, processes and data,
(vi) easy information exchange between the different actors of the supply chain,
(vii) appropriate level of integration with the data system.

Any actor belonging to the Food Supply Chain can use the Global Track and Trace system in order to:

(i) guarantee the origin and the quality of a food product;
(ii) assure the compliance with regulation;
(iii) improve logistics;
(iv) improve the inventory management;
(v) management of the whole products lifecycle.

Furthermore, information recorded at each production step will help identifying non-compliance in the case of storage. The system, in fact, can be used in order to avoid food fraud such as off-season sales and certify the total quality of the product. In addition, recorded data in the system can be used for several analyses such as the definition of:

(i) type and quantity of cultivation (plant, animals or fresh) per locality or region;
(ii) type and quantity of cultivation per period or year;
(iii) land surface availability to be allocated to a particular product;
(iv) level of activities of a particular locality/region/country;
(vi) previsions;
(vii) recommendations.

Finally, the system is able to certify the maintenance of the cold chain and it consists in a valid support for avoiding food fraud. In addition, the system represent a valid tool for facilitating the obtaining of particular denominations and guaranteeing the Origin and Location of particular food.

Currently, the Global Track and Trace System is a prototype but, according to several tests performed, it is possible to put it in practice in a real SC.

According to the Food Track and Trace Ontology, which is general for the food domain, it can be specialized and adapted to specific areas and domains in order to conceptualize it in a complete manner. In addition more facts can be added about food and processes. The ontology querying can be formulated for several purposes, and in particular, for identifying the causes of cases of food outbreak diseases. The structure proposed is able to solve some existing problems related to food traceability

List of Figures

List of Tables

Bibliography

Abad, E., Palacio, F., Nuin, M., Zárate, A.G. de, Juarros, A., Gómez, J.M., Marco, S., 2009. RFID smart tag for traceability and cold chain monitoring of foods: Demonstration in an intercontinental fresh fish logistic chain. J. Food Eng. 93, 394–399.

Amador, C., Emond, J.-P., Nunes, M., 2009. Application of RFID technologies in the temperature mapping of the pineapple supply chain. Sens. Instrum. Food Qual. Saf. 3, 26–33.

Antoniou, G., Harmelen, F. van, 2009. Web ontology language: Owl. Handb. Ontol. 91–110.

Baclawski, K., Kokar, M.M., Waldinger, R., n.d. Consistency Checking of Semantic Web Ontologies Kenneth Baclawski1, Mieczyslaw M. Kokar2, Richard Waldinger4, and Paul A. Kogut3 1 College of Computer Science, Northeastern University.

Bansal, N., Malik, S.K., 2011. A Framework for Agriculture Ontology Development in Semantic Web. Presented at the International Conference on Communication Systems and Network Technologies, IEEE, pp. 283–286.

Batista, F., Paulo, J., Mamede, N., Vaz, H., Ribeiro, R., 2006. Ontology construction: cooking domain. Artif. Intell. Methodol. Syst. Appl. 4183, 213–221.

Bechini, A., Cimino, M.G.C.A., Marcelloni, F., Tomasi, A., 2008. Patterns and technologies for enabling supply chain traceability through collaborative e-business. Inf. Softw. Technol. 50, 342–359.

Bechini, Cimino, M.G.C.A., Lazzerini, B., Marcelloni, F., Tomasi, A., 2005. A General Framework for Food Traceability, in: SAINT 2005 Workshops. Presented at the Symposium on Applications and the Internet Workshops, pp. 366–369.

Beers, G., Beulens, A.J.M., Trienekens, J.H., 1994. Global reference information models for product chains in agri-culture: a case of apples and pears, in: Management Studies, Wageningen Universiteit. pp. 205–215.

Bertolini, M., Bevilacqua, M., Massini, R., 2006. FMECA approach to product traceability in the food industry. Food Control 17, 137–145.

Bevilacqua, M., Ciarapica, F.E., Giacchetta, G., 2009. Business process reengineering of a supply chain and a traceability system: A case study. J. Food Eng. 93, 13–22.

Bo, Y., Haiyan, F., Caijiang, Z., 2008. Application of RFID technology in meat circulation management, in: Control Conference, 2008. CCC 2008. 27th Chinese. Presented at the Control Conference, 2008. CCC 2008. 27th Chinese, pp. 808 –812.

Bollen, A.F., Riden, C.P., Cox, N.R., 2007. Agricultural supply system traceability, Part I: Role of packing procedures and effects of fruit mixing. Biosyst. Eng. 98, 391–400.

Cantais, J., Dominguez, D., Gigante, V., Laera, L., Tamma, V., 2005. An example of food ontology for diabetes control, in: Working Notes of the ISWC 2005. Presented at the Workshop on Ontology Patterns for the Semantic Web.

Carroll, J.J., De Roo, J., 2004. OWL Web Ontology Language Test Cases, W3C Recommendation [WWW Document]. URL http://www.w3.org/TR/owl-test/

Charlier, C., Valceschini, E., 2007. Coordination for traceability in the food chain. A critical appraisal of European regulation. Eur. J. Law Econ. 25, 1–15.

Chiffoleau, Y., 2009. From politics to co-operation: The dynamics of embeddedness in alternative food supply chains. Sociol. Rural. 49, 218–235.

Chifi, V.R., Salomie, I., Chifu, E.S., 2007. Ontology-enhanced description of traceability services. Presented at the IEEE International Conference on Intelligent Computer Communication and Processing, pp. 1–8.

Chinosi, M., Trombetta, A., 2012. BPMN: An introduction to the standard. Comput. Stand. Interfaces 34, 124–134.

Church, S.M., 2009. EuroFIR Synthesis report No 7: Food composition explained. Br. Nutr. Found. Nutr. Bull. 34, 250–272.

Confederation of the Food and Drink Industries of the EEC, J., 1995. The CIAA Food Categorization System: a Tool for the Allocation of Food Additives. Food Addit. Contam.

Cuenca Grau, B., 2007. Pellet: A Practical OWL DL Reasoner. J. Web Semant. 5.

Cuenca Grau, B., 2007. Pellet: A Practical OWL DL Reasoner. J. Web Semant. 5.

D.Lgs 193/07, 2007.

Davenport, T.H., 1993. Process Innovation: Reengineering Work through Information Technology. Harvard Business School Press, Boston, Massachusset.

De Cindio, B., Longo, F., Mirabelli, G., Pizzuti, T., 2011a. Modelling a Traceability System for a Food Supply Chain: Standards, Technologies and Software Tools, in: MAS2011. Presented at the 10th International Conference on Modeling and Applied Simulation, Rome, Italy, pp. 488–494.

De Cindio, B., Longo, F., Mirabelli, G., Pizzuti, T., 2011b. Tracciabilità e rintracciabilità nel settore alimentare: analisi delle opportunità e vantaggi competitivi. Ind. Aliment. 7–19.

De Cindio, B., Longo, F., Mirabelli, G., Pizzuti, T., 2012a. La filiera ortofrutticola: aspetti critici nell'adozione di un sistema di tracciabilità. Ind. Aliment. 51, 9–21.

De Cindio, B., Seta, L., Mirabelli, G., Pizzuti, T., 2012b. Nuovi sistemi informativi per la tracciabilità dei prodotti alimentari (New innovative systems for food traceability). Ind. Aliment. 51, 47–53.

Diogo, M.S., Julie, A.C., 2004. The Economics of Implementing Traceability in Beef Supply Chains: Trends in Major Producing and Trading Countries.

Donnelly, K.A.M., Roest, J., Höskuldsson, S.T., Olsen, P., Karlsen, K.M., 2009. Improving information exchange in the chicken processing sector using standardised data lists. Metadata Semantic Res. 312–321.

Drummond, N., Horridge, M., Stevens, R., Wroe, C., Sampaio, S., 2007. Pizza Ontology v 1.5.

Dupuy, C., Botta-genoulaz, V., Guinet, A., 2002. Traceability analysis and optimization method in food industry, in: Systems, Man and Cybernetics, 2002 IEEE International Conference On. pp. 494 –499.

Dupuy, C., Botta-Genoulaz, V., Guinet, A., 2005. Batch dispersion model to optimise traceability in food industry. J. Food Eng. 70, 333–339.

Earle, R.L., 1983. Unit Operations in Food Processing - the Web Edition.

Easwaran, S., Thottupuram, R., 2011. Farm-Agro Ontology formation: A black pepper model. Int. J. Res. Rev. Inf. Technol. 1.

Erl, T., 2005. Service-Oriented Architecture: Concepts, Technology and Design. Prentice-Hall PTR, Englewood Cliffs.

European Commission, 2002. REGULATION EC No 178_2002 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food SafetyAuthorityand laying down procedures in matters of food safety.

European Commission, 2004. GUIDANCE ON THE IMPLEMENTATION OF ARTICLES 11, 12, 16, 17, 18, 19 AND 20 OF REGULATION (EC) N° 178/2002 ON GENERAL FOOD LAW: CONCLUSIONS OF THE STANDING COMMITTEE ON THE FOOD CHAIN AND ANIMAL HEALTH.

FAO, 2012. Agrovoc [WWW Document]. URL http://aims.fao.org/standards/agrovoc/about
Fernández-López, M., Gómez-Pérez, A., Juristo, N., 1997. Methontology: from ontological art towards ontological engineering. Aaai Tech. Rep. 33–40.
Folinas, D., Manikas, I., Manos, B., 2006. Traceability data management for food chains. Br. Food J. 108, 622–633.
Food Composition Database for Epidemiological Studies in Italy [WWW Document], 1998. URL http://www.ieo.it/bda2008/uk/bda.aspx
Food Standards Agency, 2002. Traceability in the Food Chain: A preliminary study.
Gandino, F., Montrucchio, B., Rebaudengo, M., Sanchez, E.R., 2009. On improving automation by integrating RFID in the traceability management of the agri-food sector. Ind. Electron. Ieee Trans. 56, 2357–2365.
Golan, E., Krissoff, B., Kuchler, F., 2004. Food traceability: One ingredient in a safe and efficient food supply.
Graça, J., Mourao, M., Anunciação, O., Monteiro, P., Pinto, H.S., Loureiro, V., 2005. Ontology building process: the wine domain. Presented at the 5th Conference of EFITA.
Gruber, T. R., 1993. A translation approach to portable ontology specifications. Knowl. Acquis. 5, 199–220.
GS1 Standards Document, 2010. GS1 Global Traceability Standard: Business Process and System Requirements for Full Supply Chain Traceability.
Guarino, N., Giaretta, P., 1995. Ontologies and knowledge bases towards a terminological clarification. Very Large Knowl. Bases Knowl. Build. Knowl. Shar. 25–32.
Gutiérrez-Villarias, L., 2004. Ontology-based semantic querying of the Web with respect to food recipes. Technical University of Denmark Informatics and Mathematical Modelling.
Heflin, J., 2000. Beer Ontology 1.0 (draft).
Heijst, G. van, Falasconi, S., Abu-Hanna, A., Schreiber, G., Stefanelli, M., 1995. A Case Study in Ontology Library Construction. Artif. Intell. Med. 7, 227–255.
Hobbs, J.E., Bailey, D., Dickinson, D.L., Haghiri, M., 2005. Traceability in the Canadian Red Meat Sector: Do Consumers Care? Can. J. Agric. Econ. Can. Agroeconomie 53, 47–65.
Hobbs, J.E., Fearne, A., Spriggs, J., 2002. Incentive structures for food safety and quality assurance: an international comparison. Food Control 13, 77–81.
Hoffer, J.A., Prescott, M., McFadden, F., 2006. Modern Database Management. Prentice Hall, New Jersey.
Hoffer, J.A., Venkataraman, R., Topi, H., 2010. Modern Database Management. Prentice Hall.
Hsu, Y.-C., Chen, A.-P., Wang, C.-H., 2008. A RFID-enabled traceability system for the supply chain of live fish, in: IEEE International Conference on Automation and Logistics, 2008. ICAL 2008. Presented at the IEEE International Conference on Automation and Logistics, 2008. ICAL 2008, pp. 81 –86.
Hu, Z., Jian, Z., Ping, S., Xiaoshuan, Z., Weisong, M., 2009. Modeling Method of Traceability System based on Information Flow in Meat Food Supply Chain. Wseas Trans. Inf. Sci. Appl. 6.
Jagadish, H.V., 1990. A compressed transitive closure technique for efficient fixed-point query processing. Acm Trans. Database Syst. 15, 558–598.
Jansen-Vullers, M.., van Dorp, C.., Beulens, A.J.., 2003. Managing traceability information in manufacture. Int. J. Inf. Manag. 23, 395–413.

Jedermann, R., Ruiz-Garcia, L., Lang, W., 2009. Spatial temperature profiling by semi-passive RFID loggers for perishable food transportation. Comput Electron Agric 65, 145–154.

Joint FAO/WHO Food Standards Program CODEX ALIMENTARIUS COMMISSION, 1993. Codex Classification of Foods and Animal Feeds.

Juels, A., 2006. RFID security and privacy a research survey. Iee Transcaction Ind. Electron. 24, 382–394.

Kim, E., 2012. The Korean Ontology, in: FOIS 2012. Presented at the Poster of Seventh International Conference on Formal Ontology in Information Systems, Graz, Austria.

Kim, H.M., Fox, M.S., Gruninger, M., 1995. An Ontology of Quality for Enterprise Modelling, in: WET ICE 95. Presented at the Enabling Technologies: Infrastructure for Collaborative Enterprises, pp. 105–116.

Kneafsey, M., Venn, L., Schmutz, U., Balázs, B., Trenchard, L., Eyden-Wood, T., Bos, E., Sutton, G., Blackett, M., 2013. Short Food Supply Chains and Local Food Systems in the EU. A State of Play of their Socio-Economic Characteristics.

Liang, A.C., Lauser, B., Sini, M., Keizer, J., Katz, S., 2006. From AGROVOC to the Agricultural Ontology Service/Concept Server: An OWL model for creating ontologies in the agricultural domain, in: DCMI'06. Presented at the International Conference on Dublin Core and Metadata Applications, pp. 76–88.

LiWei, G., DongPing, Q., ChunHui, Z., 2009. Cow identification technology system based on radio frequency. Trans. Chin. Soc. Agric. Eng. 25, 137–141.

Lo Bello, L., Mirabella, O., Torrisi, N., 2005. A general approach to model traceability systems in food manufacturing chains, in: ETFA 2005. Presented at the 10th IEEE Conference on Emerging Technologies and Factory Automation, p. 8–pp.

Marsden, T., Banks, J., Bristow, G., 2000. Food supply chain approaches: exploring their role in rural development. Sociol. Rural. 40, 424–438.

Martínez-Sala, A.S., Egea-López, E., García-Sánchez, F., García-Haro, J., 2009. Tracking of Returnable Packaging and Transport Units with active RFID in the grocery supply chain. Comput. Ind. 60, 161–171.

Ministry of Agriculture, Forestry and Fisheries of Japan, 2003. Guidelines for Introduction of Food Traceability Systems [WWW Document]. URL http://www.maff.-go.jp/trace/guide_en.pdfù

Ministry ofn Agriculture, Forestry and Fisheries (MAFF), 2004. What You Need To Know about Traceability Systems.

Mirabelli, G., Pizzuti, T., Goméz-González, F., Sanz-Bobi, M.A., 2012a. Food Traceability models: an overview of the state of the art, in: MAS2012. Presented at the 11th International Conference on Modeling and Applied Simulation, Vienna, Austria.

Mirabelli, G., Pizzuti, T., Goméz-González, F., Sanz-Bobi, M.A., 2012b. Modelling a traceability system for the agro-food industry: the case of frozen vegetables, in: IEOM 2012. Presented at the 3rd International Conference on Industrial Engineering and Operations Management, Istanbul, Turkey, pp. 1065–1074.

Moe, T., 1998. Perspectives on traceability in food manufacture. Trends Food Sci. Technol. 9, 211–214.

Møller, A., Ireland, J., 2008. LanguaL 2008 Multilingual Thesaurus.

Nishantha, G.G.D., Wanniarachchige, M.K., Jehan, S.N., 2010. A pragmatic approach to traceability in food supply chains, in: Advanced Communication Technology (ICACT), 2010 The 12th International Conference On. pp. 1445–1450.

Noy, N.F., McGuinness, D.L., 2001. Ontology development 101: A guide to creating your first ontology. Stanford knowledge systems laboratory technical report KSL-01-05 and Stanford medical informatics technical report SMI-2001-0880.
Object Management Group, 2010. Business Process Model and Notation (BPMN) Version 2.0.
Olivier, R., Fourie, L.C.H., Evans, A., 2009. Effective information access and automated traceability in fruit export chains in South Africa. Sa J. Inf. Manag. 8.
Opara, L.U., 2003. Traceability in agriculture and food supply chain: a review of basic concepts, technological implications, and future prospects. J. Food Agric. Environ. 1, 101–106.
Papazoglou, M.P., Traverso, P., Dustdar, S., Leymann, F., 2007. Service-oriented computing: State of the art and research challenges. Computer 40, 38–45.
Patig, S., 2006. Evolution of entity-relationship modeling. Data Knowl. Eng. 56, 122–138.
Pizzuti, T., 2012. Global Track and Trace (T&T) Framework for Food, in: PALM-DSW 2012. Presented at the Doctoral Spring Workshop "Product and Asset Lifecycle Management," Taormina, Italy.
Pizzuti, T., Mirabelli, G., Goméz-González, F., Sanz-Bobi, M.A., 2012. A BPMN general framework for managing traceability in a Food Supply Chain, in: MAS2012. Presented at the 11th International Conference on Modeling and Applied Simulation, Vienna, Austria.
Pizzuti, T., Mirabelli, G., Sanz-Bobi, M.A., Goméz-González, F., 2014. Food Track&Trace Ontology for helping the food traceability control. J. Food Eng. 120, 17–30.
Potter, N.N., Hotchkiss, J.H., 1998. Unit Operations in Food Processing, in: Food Science. Springer US, pp. 69–89.
Pouliot, S., Sumner, D.A., 2009. Traceability, food safety and industry reputation.
Puddu, E., Mari, L., 2011. Un'introduzione ai sistemi Rfid. Principali caratteristiche tecnologiche e funzionali. Tutto Misure 1.
Regattieri, A., Gamberi, M., Manzini, R., 2007. Traceability of food products: General framework and experimental evidence. J. Food Eng. 81, 347–356.
Reiners, K., Hegger, A., Hessel, E.F., Böck, S., Wendl, G., Van den Weghe, H.F.A., 2009. Application of RFID technology using passive HF transponders for the individual identification of weaned piglets at the feed trough. Comput. Electron. Agric. 68, 178–184.
Remco, M.D., Marlon, D., Chun, O., 2008. Semantics and analysis of business process models in BPMN. Inf. Softw. Technol. 50, 1281–1294.
Revision Committee on the Hanbook for Introduction of Food Traceability Systems, 2007. Handbook for Introduction of Food Traceability Systems (Guidelines for Food Traceability).
Ribeiro, R., Batista, F., Pardal, J., Mamede, N., Pinto, H., 2006. Cooking an ontology. Artif. Intell. Methodol. Syst. Appl. 213–221.
Riden, C.P., Bollen, A.F., 2007. Agricultural supply system traceability, Part II: Implications of packhouse processing transformations. Biosyst. Eng. 98, 401–410.
Rossi, A., Brunori, G., Guidi, F., 2008. I mercati contadini: un'esperienza di innovazione di fronte ai dilemmi della crescita. Riv. Dirit. Aliment. 3, 1–11.
Ruiz-Garcia, L., Steinberger, G., Rothmund, M., 2010. A model and prototype implementation for tracking and tracing agricultural batch products along the food chain. Food Control 21, 112–121.
Salampasis, Tektonidis, Dimitrios, Kalogianni, Eleni P., 2012. TraceALL: a semantic web framework for food traceability systems. J. Syst. Inf. Technol. 14, 302–317.

Salampasis, M., Kalogianni, E.P., Ocak, S., Lantzos, T., Kouroupetroglo, C., 2008. Demands and Technology Pushes for Building ICT Infrastructure for Food Traceability, in: AWICTSAE 2008. Presented at the International Advanced Workshop on Information and Communication Technologies for Sustainable Agri-production and Environment, Alexandroupolis.

Sanchez, E.R., Gandino, F., Rebaudengo, M., 2009. Public-Key in RFIDs: Appeal for Asymmetry. Security in RFID and sensory networks. Crc Press 195–216.

Sánchez Hernández, J., 2009. Alternative food networks: Concept, typology and adaptation to the Spanish context. Boletín Asoc. Geógrafos Españoles 49, 375–380.

Schwägele, F., 2005. Traceability from a European perspective. Meat Sci. 71, 164–173.

Shanahan, C., Kernan, B., Ayalew, G., McDonnell, K., Butler, F., Ward, S., 2009. A framework for beef traceability from farm to slaughter using global standards: An Irish perspective. Comput. Electron. Agric. 66, 62–69.

Shoaib, M., Basharat, A., 2010. Semantic Web Based Integrated Agriculture Information Framework. Presented at the Second International Conference on Computer Research and Development, IEEE, pp. 285–289.

Smith, M.K., Welty, C., McGuinness, D.L., 2004. OWL Web Ontology Language Guide.

Snae, C., Bruckner, M., 2008. FOODS: A Food-Oriented Ontology-Driven System, in: DEST 2008. Presented at the 2nd IEEE International Conference on Digital Ecosystems and Technologies, pp. 168–176.

Sparling, D.H., Laughland, P., Sterling, B.T., 2011. White Paper. An Appetite on Traceability. Results from OnTraceability 2011 Conference.

Stanford Center for Biomedical Informatics Research, 2013. Protégé [WWW Document]. URL http://protege.stanford.edu/

Stringer, M.F., Hall, M.N., The Breakdowns in Food Safety Group, 2007. A generic model of the integrated food supply chain to aid the investigation of food safety breakdowns. Food Control 18, 755–765.

Supply Chain Council, 2010. Supply Chain Operations Reference (SCOR®) modelOverview - Version 10.0.

Tamayo, S., Monteiro, T., Sauer, N., 2009. Deliveries optimization by exploiting production traceability information. Eng. Appl. Artif. Intell. 22, 557–568.

Thakur, M., Donnelly, K.A.M., 2010. Modeling traceability information in soybean value chains. J. Food Eng. 99, 98–105.

Thakur, M., Hurburgh, C.R., 2009. Framework for implementing traceability system in the bulk grain supply chain. J. Food Eng. 95, 617–626.

Thakur, M., Martens, B.J., Hurburgh, C.R., 2011a. Data modeling to facilitate internal traceability at a grain elevator. Comput. Electron. Agric. 75, 327–336.

Thakur, M., Sørensen, C.-F., Bjørnson, F.O., Forås, E., Hurburgh, C.R., 2011b. Managing food traceability information using EPCIS framework. J. Food Eng. 103, 417–433.

Thompson, M., Sylvia, G., Morrissey, M.T., 2005. Seafood Traceability in the United States: Current Trends, System Design, and Potential Applications. Compr. Rev. Food Sci. Food Saf. 4, 1–7.

TRACE - Molecular Biology Database [WWW Document], n.d. URL http://www.trace.eu.org/mbdb/

U.S. Department of Agriculture, 2012. Composition of Foods Raw, Processed, Prepared USDA National Nutrient Database for Standard Reference, Release 25.

U.S. Department of Agriculture, Agricultural Research Service, Food Surveys Research Group, 2010. The USDA Food and Nutrient Database for Dietary Studies, 4.1.

UNI CEI EN 45011, 1999.

UNI EN ISO 14001, 2004.
UNI EN ISO 8402: Sistemi Qualità. Gestione per la Qualità ed assicurazione della Qualità - Termini e definizioni, 1995.
UNI EN ISO 9001, 2008.
Unwin, I., Møller, A., 1999. Eurocode 2 Food Cooding System: The classification systems for recording food consumption data [WWW Document]. URL http://www.ianunwin.demon.co.uk/eurocode/index.htm
Van Dorp, C.A., 2003. A TRACEABILITY APPLICATION BASED ON GOZINTO GRAPHS. Presented at the EFITA 2003 Conference, Debrecen, Hungary.
Volpentesta, A.P., Ammirato, S., Della Gala, M., 2013. Classifying short agrifood supply chains under a knowledge and social learning perspective. Rural Soc. 22, 217–229.
Wang, F., Cao, R., Ding, W., Qian, H., Gao, Y., 2011. Incentives to enable food traceability and its implication on food traceability system design, in: SOLI'11. Presented at the IEEE International Conference on Service Operations, Logistics and Informatics, pp. 32–37.
Wang, X., Li, D., O'brien, C., Li, Y., 2010. A production planning model to reduce risk and improve operations management. Int. J. Prod. Econ. 124, 463–474.
Wang, Y., Yang, Y., Gu, Y., 2012. Research on Quality and Safety Traceability System of Fruit and Vegetable Products Based on Ontology. J. Converg. Inf. Technol. Jcit 7, 86–93.
Yue, J., Wen, H., Zhang, X., Fu, Z., 2005. Ontology Based Vegetable Supply Chain Knowledge Expressing, in: SKG'05. Presented at the First International Conference on Semantics, Knowledge and Grid, pp. 130–130.

"La presente tesi è cofinanziata con il sostegno della Commissione Europea, Fondo Sociale Europeo e della Regione Calabria. L'autore è il solo responsabile di questa tesi e la Commissione Europea e la Regione Calabria declinano ogni responsabilità sull'uso che potrà essere fatto delle informazioni in essa contenute."