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Designing and Developing a Meat Traceability System: A Case Study for the Greek Meat Industry

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Abstract: This research paper investigates the importance of traceability in the meat industry. It explains that the global market's intense competition and consumers' increased expectations have forced companies to implement electronic traceability systems to improve efficiency, reduce errors, and mitigate incidents and fraud. The meat industry is facing increased consumer awareness and concern about food quality and safety. Consumers are extremely sensitive to food production conditions, and traceability can help companies increase consumers' trust. This work describes the design and implementation of a customized traceability system, developed using the Agile method, for the local meat industry. For the needs of the project, advanced and innovative information and communication technologies and tools, such as cloud computing and the Internet of Things, were also used. The main problem that this research aims to address is the lack of transparency in three phases: transparency within the industry's internal processes, transparency in the life of the animal from the moment of its birth, and transparency towards the consumer. The objectives of this research are twofold. First, we aim to digitize the Greek meat industry. Concurrently, we intend to create a traceability system that will generate important data, thereby providing valuable information for all stakeholders.

Keywords: meat traceability; Greek meat industry; Agile; food safety; ICT technologies; transparency; sustainability

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1. Introduction

In the last decades, traceability has rapidly become an essential tool for the food industry and "sustainability skeptic" consumers [1,2]. The term "traceability" is "*necessarily broad*" [3] and refers to a tool that has the ability "*to track the source of a food product at any point in production*" [4], "*to find product and process information again at a later date*" [5], to equip companies to deal with potential food safety problems or poor-quality foods, to capture the currently evolving situation, and to implement national and European legislation. In practice, traceability is involved in the food manufacturing process and systematically follows the physical flow of "*a food, feed, food-producing animal or substance intended to be, or expected to be, incorporated into a food or feed, through all stages of production, processing and distribution*" [6], thereby recording all relative information. The organization of information on products, processes, or raw materials and the link to the product is achieved with the implementation of traceability systems.

Traceability systems have been developed worldwide in response to the strong interest in safety, quality, transparency, and regulatory, social, and economic requirements [7]. The global nature of the markets, the intense competition, and the increased expectations of consumers have forced companies to turn their attention to their relationships with customers and suppliers. At the same time, there is an increasing need for efficiency in business operations [8], the reduction of errors due to the human factor, and the mitigation of incidents and fraudulence cases [9].

According to the literature, traceability is vital for the meat industry as it serves as a useful tool for both controlling and improving production [10], which, in turn, enhances crisis management [7]. It also plays a significant role in livestock identification and management, involving the recording and maintenance of information regarding the origin, rearing, and slaughter of animals [11]. This ensures the "*preservation of the product's identity*" [12]. The term "*identity preservation*" refers to those attributes that add value for the consumer, such as safety, farming methods/conditions, animal welfare, and more [13].

Equally important is the application of traceability to protect and enhance the reputation of products for their quality attributes [14], to safeguard the brand, and to prevent adulteration and fraud [15,16]. Traceability is the mechanism that guarantees the safety, quality, and authenticity of meat products reaching the end consumer [3,17–19].

Although the value of traceability for consumers varies by geographic region, it is sought after in many countries worldwide [20]. Notably, Greek consumers show great interest and consider the traceability of pork to be of "*high importance*" [2]. According to Kassaun et al. [21], traceability builds consumer confidence and simultaneously informs and educates consumers about the quality characteristics of meat products.

Taking the importance of traceability into consideration, in certain food sectors, such as meat companies, there is concern about what systems to use and how to integrate such systems into the production process. Traceability in the meat industry starts with the delivery of the animals and includes the stages of breeding and growth, slaughter, cutting, preparation/processing, packaging, and distribution for consumption. The effective implementation and application of traceability require compliance with the legislation, directives, and regulations laid down by the European Union and the state concerning the production and handling of meat products or by-products. Therefore, the operator must systematically collect and maintain information by applying established practices for archiving and storing it for future use. The large volume of data, the requirement to anticipate and avoid errors, and the need for rapid access to information (e.g., in case of a recall) lead to the choice of solutions based on modern information and communication technologies (cloud [22], IoT) that allow organized archiving, storage of information, rapid and accurate recall, and reasonable costs.

In the last decades, traceability systems have advanced following technological evolution and innovations to overcome various problems, such as reduced recall costs, information tampering, food safety and quality, food wasting, a diversity of materials and multiplicity of processes, and a lack of cost-effective techniques for analyzing risk factors [20,23–26].

The application of traceability in the meat supply chain has attracted the interest of researchers who are exploring different aspects of the issue and contributing their solutions. Many of the studies focus on specific issues, such as data collection, or are limited to a theoretical approach to the issue. Today, in a dynamically changing environment due to social, economic, technological, and climate changes, meat management remains a challenge that requires an integrated (end-to-end) approach.

Experts concur, and firms have recognized, that digital technologies are essential for the responsible, successful, responsive, cost-effective, and sustainable development of a meat traceability system [27,28]. The complexity of the traceability system, as well as the involvement of a large number of stakeholders (businesses, producers, retailers, consumers, government agencies, organizations, etc.) justify this approach [29]. While there is a strong desire for efficient, effective, and robust traceability in the meat industry, there is a noticeable lack of empirical studies and practical guidance.

Our study attempts to bridge this gap by presenting the implementation of an integrated, ready-to-use, and sustainable meat traceability system. The aim is to provide a framework for strategic resource management oriented towards the circular economy [28], i.e., improving livelihoods as a consequence of environmental protection. The adoption of digital transformation contributes to this direction by extending the shelf life of products, offering solutions for resource reuse, and reducing food spoilage and waste.

This research focuses on the meat industry. We analyze, design, and develop an efficient traceability system based on cutting-edge technologies. Our work investigates and presents the effectiveness, efficiency, and usability of the developed traceability system for the local meat industry. It also argues that the implementation of the traceability system has many beneficial impacts on business operations, such as inventory management, minimizing errors, and reducing handling costs. This research focuses on achieving familiarity of the company's employees with the traceability system and the clarification of its advantages by making it more constructive for improving information and knowledge sharing.

2. Literature Review

2.1. Traceability

In the 1980s, traceability systems were introduced in the food industry to increase food safety [4]. Demand combined with technological advances determined their development. Initially, simple product-related information was recorded on paper or electronic media, following the relevant food traceability legislation. The introduction of IoT technologies in traceability systems in 2008 marked a new era for traceability. At that time, electronic integration of information was introduced at every stage of the supply chain. Today, there is a new requirement for intelligent decision making in traceability systems, and modern technologies, such as artificial intelligence, are contributing to this.

Implementing a traceability system is a complex and complicated issue with a great number of challenges. These include limitations on the availability of resources, information, standards, and awareness [7], interoperability, a lack of knowledge on how to integrate and use new technologies, and data management [30]. A lot of companies, especially in the agri-food sector, have introduced traceability processes themselves that support the collection, archiving, and maintenance of information in electronic or paper format. This is because most SMEs are unable to adopt and implement modern technologies, such as ERP systems.

According to Aung and Chang [3], who present the conceptual framework of traceability, the electronic traceability system supports tracing and tracking processes along the supply chain from the source (e.g., from the animal to the farm) to the final product in the store, where it is purchased and consumed by a consumer. The information flow parallels the path of the raw materials/products, and forward and backward step-by-step transitions are possible. Researchers have provided general solutions and basic principles that can guide the implementation of a traceability system [10,31] for meat or meat products.

Researchers have argued that each recorded observation includes the following fields: location, time, product identity, condition, and quality [32,33]. The location refers to the logistical processes that occur in the physical path of the product and defines the place, exact time, and condition of the product within the supply chain. The condition refers to the processing and procedures that take place in the physical path of the product and defines the processing conditions in the various stages that the product undergoes during its production and transportation. The quality refers to the set of properties and characteristics a product carries or acquires along its route in the supply chain. It is a dimension that is particularly important for traceability systems for fresh products, such as meat, and the quality of these products changes dynamically as the products move. For fresh food products, it is extremely important to define quality attributes and corresponding indicators that track changes in product quality from the beginning to the end of the supply chain [34]. In addition, each entity (product or process) is assigned a set of key attributes, such as the type, quantity, processing time, etc., and each attribute includes a multitude of traits. The traceability system records all variables and their values at all stages of production and/or distribution of a product at the location at which the operation took place. The set of input variables affects the quality of the operation's results [35]. Input operation information may include environmental conditions, drug or husbandry information, animal species and breeds, etc. Traceability should record all variables and their values at all stages of production and/or distribution of a product at the location at which the operation took place.

2.2. Research Studies on Traceability

Today, there are a large number of specialized studies on traceability systems available in the international literature. The three primary research directions on food traceability systems are: (a) traceability as a tool for ensuring food quality and governing other food issues; (b) traceability as a tool to differentiate and add value to a company's products; and (c) the efficient and effective development of such a mechanism [36].

2.2.1. Traceability as a Useful Tool

According to Monteiro et al. [37], consumers associate the traceability of meat with its quality characteristics and seek assurances about food safety and animal welfare, even if this means paying more. The need for quality and safety is recognized as a key aspect of a traceability system [3,13]. Hobbs et al. [38] identified three essential functions of traceability, which are: the ability to effectively trace products or raw materials in unforeseen situations (e.g., recalls), reliability, and the motivation to produce safe products.

To ensure consumers' safety, quality, and trust in meat products, meat supply chains must be transparent in terms of openly sharing data and providing easily understandable actions [39]. Traceability and transparency could be enhanced by digital transformation, thereby offering a competitive advantage. Architectures designed to enhance transparency along the supply chain have been implemented for beef and pork [20,40] and can be applied to other types of meat (e.g., poultry).

Yan et al. [41] described an information model based on Petri Nets and how the use of UML could lead to a well-structured and efficient traceability system that is suitable for the safe and high-quality management of meat products. The vertices of a UML graph indicated the different states, while directed arrows depicted the possible transitions. The synergy of IoT and Petri Nets achieved cost and complexity reduction and process automation and enhanced the effectiveness of traceability compared to other techniques (e.g., K-means and SOM methods) [42].

Golan et al. [34] suggested that an effective traceability system should be characterized by:

- *Breadth* (e.g., the amount of information it can collect);
- *Depth* (e.g., how far back or forward the system can detect the relevant information);
- *Accuracy* (e.g., the assurance of detecting a specific movement of a food item).

Bhatt and Zhang [43] emphasized the importance and need for interoperability to improve the safety of the global food system. Interoperability is the ability of different information technology systems to communicate seamlessly to share and use data [44].

2.2.2. Traceability as a Differentiation and Added Value Tool

A key benefit of traceability systems is the product value added [45], and for many countries, the motivation for implementing traceability is to enhance the value of products [46] achieved by online control of food quality and freshness. According to Hallak and Tacsir [47], traceability systems have two key differentiating features: (a) they can fulfill latent requirements (e.g., environmental footprint) that are not mandatory but are a criterion for differentiation; and (b) they can meet the ever-increasing demands of consumers. It is the consumer, as the final recipient of the products, who will decide whether to choose a product or not. For Qian et al. [20], consumer perception should be taken into account in the design of a traceability system. The enhancement of the value added may not only concern the product but the company as a whole. The appropriate use of technology with an emphasis on emerging technologies (e.g., IoT) can contribute to this direction and enhance the effectiveness of the food traceability system by making use of the value stream mapping method [40].

2.2.3. Traceability Implementation Issues

According to Bougdira et al. [48], the implementation of a traceability system is the result of the contribution of three components: (a) descriptive, i.e., the modeling of the particular case that conforms with the requirements; (b) engineering, which refers to the set of methods, technologies, and tools used to develop and support it; and (c) executive, which focuses on the design and development of the system as a sequential step-by-step process. These aspects set the foundation to build the sophisticated, efficient, and more intelligent traceability systems necessary to meet business requirements.

Brent Whittaker, the Global Account Executive of Infinity QS [49], mentioned that the tools that will help to comply with the law cost effectively while maintaining high-quality standards are: a centralized data repository (collected data), cloud-based quality management (easy, rapid access), and real-time statistical process monitoring (predicting and optimizing applied practices). The implementation of the traceability system includes the definition of data selection/collection/processing processes, the identification of points of interest for data collection, management, and communication.

Olsen and Borit [31] suggested that the key building blocks of a traceability system should include mechanisms for:

1. Identifying traceable resource units (TRUs);
2. Documenting transformations, e.g., links between TRUs;
3. Recording the characteristics of TRUs;
4. Communicating data between the operating units of the system.

The implementation of traceability is best achieved by adopting modern information and telecommunication technologies. Alfian et al. [50] noted that the utilization of WSNs and RFID, along with data mining technologies, ensures the safety and quality of food products. However, there are cases where special conditions prevail at the product production stage, as is often the case in meat production and processing lines (e.g., humidity in the slaughterhouse), and care should be taken with the means and technologies to be used. Bai et al. [51] pointed out that animal identification mechanisms (e.g., RFID tags) and ways to identify products derived from animals (e.g., barcodes, 2D barcodes, and QR codes) are needed.

The application of a pilot traceability system in Tanzania showed that it is possible to identify the origin of the animal(s) even if labeling (e.g., ear tags) is performed at an early stage (before sale) [52]. Various technologies, such as IoT, blockchains, and cloud computing, are capable of exploiting, processing, and properly displaying collected data to make them useful for the traceability system. Thanks to a wide variety of ways to connect data transmission to any physical object or "thing" at any time, the IoT is widely used to implement food traceability systems. Moreover, in combination with other technologies, IoT allows safer and more efficient data management in the food supply chain [53]. The proposed solutions include the integration of the traceability system into the supply chain and describing the development of an advanced pork traceability system based on RFID technology [54–56].

Several food traceability solutions (e.g., for meat, fish, and milk) are based on IoT technologies [57]. Mutua et al. [52] found that animal identification using IoT technologies is the most reliable method that can be applied, and it is considered to be the most suitable technique in harsh environments (e.g., animal husbandry and meat product processing) [57,58]. An IoT-based food traceability system can be used to remove low-quality products, identify counterfeits, or feed data to machine learning models for prediction and decision making [58]. To manage data collected from IoT devices, various technologies, such as fog computing and cloud computing, are used [59]. Researchers have proposed cloud-based solutions for beef [20] or mobile-based solutions for pork [40]. BovChain is an information management application for the beef supply chain from the farm to the slaughterhouse based on cloud/edge computing technologies [60].

Unlike the work mentioned above, our study is a pilot application specifically designed and implemented to meet the needs of small businesses operating in the meat industry.

Because digital transformation, traceability, and transparency are the key elements of sustainable development, we strive to incorporate these elements into our implementation.

3. Materials and Methods

This section presents the design methodology utilized in the development of the integrated digital traceability system, taking into consideration a comprehensive set of requirements that encompass the system, hardware, and software needs. The proposed traceability system follows a widely accepted methodology regarding the traceability process, the critical dimensions of the system, the available technologies, and the considered internal and external factors. In particular, the needs of the company were identified in accordance with national and EU legislation. The traceability processes (identification, data recording, data exchange, and data management) were defined, and the means of managing the digital system and the IT infrastructure, as well as the enabling technologies, were selected to ensure the effectiveness of the system.

The system was designed and developed using the Agile methodology, a flexible and iterative approach to project management [61]. Consistent with the Agile methodology, the design and development phases of the system necessitated ongoing collaboration among stakeholders to derive a comprehensive solution based on predefined requirements [62]. The aim was to design and develop a customized and efficient system capable of providing a reliable and robust end-to-end traceability solution while meeting both the company's and the regulatory authority's requirements.

3.1. System Architecture

A well-structured traceability system should monitor the flow of information along the supply chain and collect the necessary data from the various stages that a product goes through before consumption [63]. The key to an effective traceability system is the collection of the correct information at the right time, which necessitates excellent cooperation between people and technology. Figure 1 depicts the general organization of the traceability system, highlighting the interaction between the technology and human resources. The system's main focus is to monitor the complete traceability process from the birth of the animal on the farm to the delivery of the processed product to the consumer.

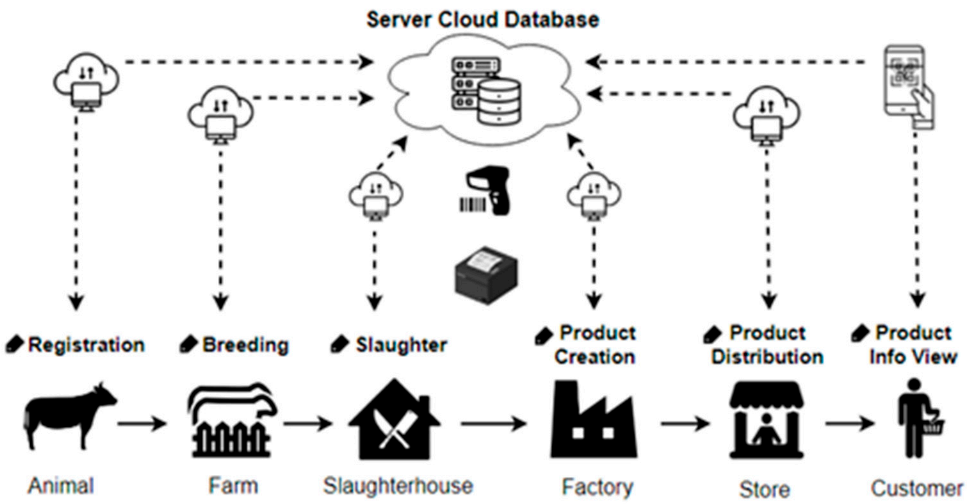


Figure 1. Traceability system architecture overview.

The system is divided into multiple phases, with relevant information collected using a software platform. These data are then inputted into a specially designed and developed database hosted on a cloud server, ensuring efficient storage and retrieval. In addition, hardware tools, such as barcode scanners and printers, are utilized at different stages of the process, significantly contributing to the direct and rapid management of information. All traceability phases are connected via the software platform, which serves as the heart of the traceability system, enabling accurate and efficient data exchange between the human and technological resources involved in the process.

3.2. System Requirements

Traceability systems have specific requirements to ensure product tracking, such as the implementation of data collection, the efficiency of data management, compatibility with other existing systems of the company, and safety and transparency of the process.

Specifically, this requires gathering accurate and thorough information about the product, including its source, handling, and delivery. In addition, the system should manage and monitor a large volume of data that are current and accessible in real time. The traceability system must be compatible with the existing supply chain systems that producers, processors, and retailers use. In addition, it must provide clear and transparent details concerning the product's origin, handling, and distribution. The system must be safe, provide safeguards against unwanted access, and ensure the confidentiality of any data. The system must comply with all relevant standards and regulations set by food safety authorities or industry organizations. Meeting these requirements is essential for ensuring the success of a traceability system in tracking products effectively and efficiently.

3.3. Hardware Requirements

The integrated tracking path relies heavily on the use of information and communication technology. At each stage of the food chain, the staff is required to use a variety of hardware devices (mobile devices, desktop computers, a server, barcode scanners, and printers) to create or update product data. Table 1 summarizes all of the technological means used and their roles in the traceability system. The selection of the devices that support the tracking process is based on the experience and relationship of the company's employees with technology.

Table 1. The technology used and its role in our traceability system.

Hardware	Description	Role
Zebra Thermal Printer	Printing of unique QR and barcodes (GS1 Data bar)	Printing QR and barcodes
Zebra Barcode Scanner	Decode the data contained in the barcode	Reading barcodes
Mobile and desktop devices	A complete recording of the animal's available information in real time through the software platform	Information acquisition/transmission/ tracking/tracing
Server	Store, retrieve, and process data in a remote cloud-based database	Data processing and management

3.4. Software Requirements

Software requirements are crucial for ensuring the proper functionality of the traceability system. The software components manage and process data while providing a user-friendly interface for accessing information and generating reports. Additionally, all collected information is synchronized in the cloud and remains accessible throughout end-to-end communication. The developed software is built on web technologies and consists of two main components: the front-end and the back-end. It is essential to maintain effective communication and cooperation between both sides to achieve a high-speed response, scalability, user friendliness, and overall functionality [64].

3.4.1. Front-End Development

The front-end refers to the portion of a web application that a user interacts with and can access via a desktop, mobile phone, or tablet. In this work, it was designed and developed through a desktop and mobile application with a cross-platform approach. Cross-platform applications are based on only one code base that supports multiple platforms [65]. One of the most popular solutions in front-end development for cross-platform applications is the Angular framework [66,67].

The developed applications' purpose is to interact with the company's employees to collect and manage traceability data. The developed applications utilize forms to enable users to perform data entry and data management tasks. The Angular framework provides reactive forms that have great extensibility and reusability inside the software application. The design of the applications was carried out so as to be easily used by the employees. Especially in the design of the mobile app devices, the interactive elements, like the buttons, are large enough because workers wear gloves during their shifts.

3.4.2. Back-End Development

The back-end refers to the environment where all server operations are performed, but it is not accessed by a user. The back-end system includes all database operations and the execution of server-side scripts. One of the key responsibilities of the back-end is the security it provides to the system, as it incorporates strong security measures, such as two-factor authentication and Advanced Encryption Standard (AES), to protect sensitive data from unauthorized access. Furthermore, it regularly performs backups to minimize the risk of data loss. The developed system is based on a cloud environment and includes a server and a database.

Server: The server is based on the Representational State Transfer (REST) architectural style for developing web services, and it uses an Application Programming Interface (API) to interact with the web services and to support the transmission of data between the back-end and the front-end (client–server communication) properly. The REST API runs in a NodeJS environment, a server-side platform that uses the Express framework to handle incoming requests from the front-end.

Database: The back-end uses MongoDB, a NoSQL database, for traceability, data storage, and retrieval. Today, NoSQL databases are widely used and can store, manage, and index large datasets. They provide high accessibility and adaptability to the circulated frameworks compared to traditional relational database management systems (RDBMS). Also, these types of databases support multiple concurrent users and offer strong consistency in not altering the data [68].

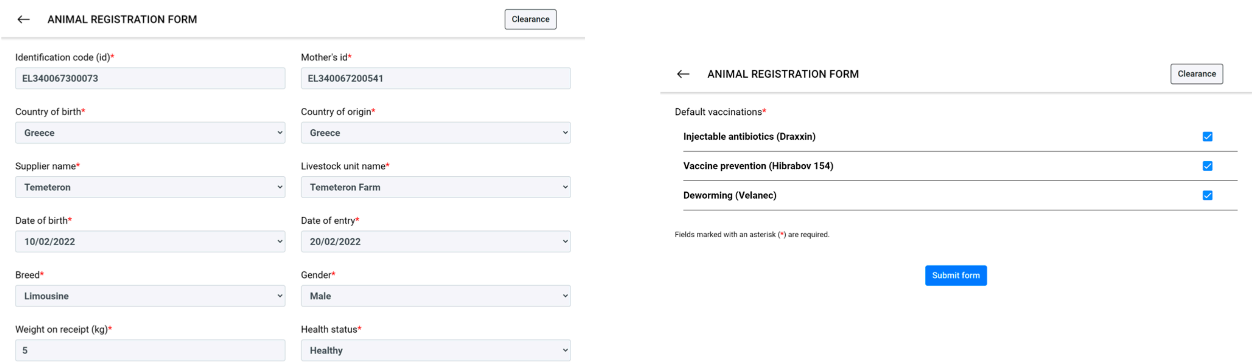
4. Results

This section presents the results of our efforts to develop a robust traceability system. It provides an overview of the collected data and the procedures implemented to establish a comprehensive pathway for animals from the farm to the store. It also highlights the successful integration of various technological means within the tracking system's multiple stages, including a user-friendly software platform used by workers through mobile and desktop devices, a barcode printing machine adhering to GS1 Databar standards, a barcode reader, and a centralized database running on a remote server. The presentation of the results follows the sequential progression of the developed traceability system through its key stages: animal registration, animal breeding, animal slaughter, product manufacturing, product distribution and recall, and product traceability by the consumer. The system developed as a result of our work empowers us to drive efficiency in supply chain management, enhance transparency, and bridge the research gap through the digitization of supply chain data.

4.1. Animal Registration Stage

The first stage of traceability takes place when the animal is introduced to the undertaking farm and its data are entered into the tracking platform's database. When each animal has arrived from the supplier, its passport is provided, which contains the essential information required by regulations. The administrator of the tracking platform digitizes the animal's data and stores them in the system database. The information recorded in the animal's passport includes the identification code, the mother's identification code, the country of birth, the country of origin, the name of the supplier and the livestock unit, the date of birth, the date of entry on the farm, the breed, the gender, the weight on receipt, and the health status.

As shown in Figure 2a,b, the registration of a new animal on the company's farm is carried out through the "animal registration form," where the system administrator enters, in addition to the passport details, certain vaccinations (e.g., injectable antibiotics—Draxxin; vaccine prevention—Hibrabov 154; and worming—Velanec) that have been carried out on the animal. It is worth noting that the identification code of the animal is used as the main means of identification for the traceability of the individual stages. This code, obtained after the animal's birth, ensures the uniqueness of each animal and enables seamless tracking throughout its life cycle.



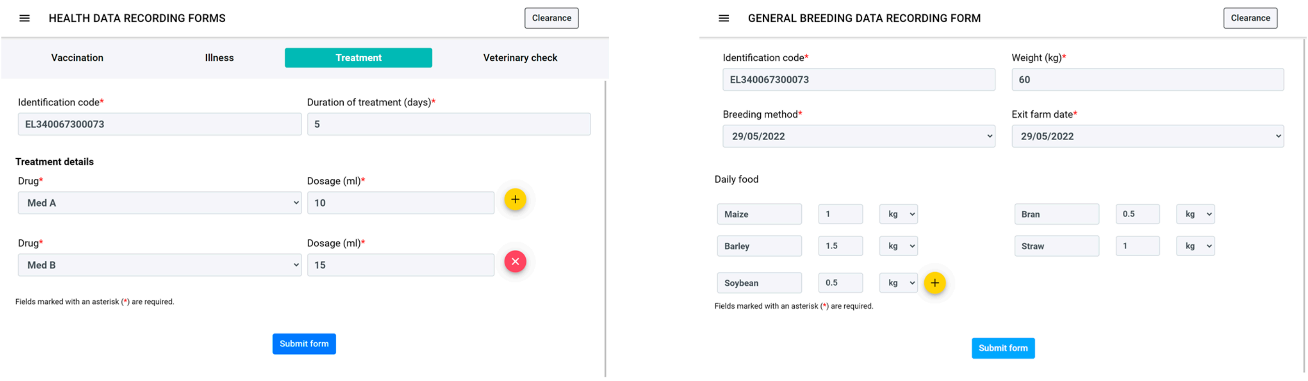
(**a**) (**b**)

Figure 2. Input of animal data into the traceability system: (**a**) passport data and (**b**) vaccination data.

4.2. Animal Breeding Stage

Building upon the standards of animal breeding, the second stage involves recording the data added during the animal's stay on the farm. In compliance with Regulation (EU) No 98/58/EC, thorough inspections are conducted on all animals at least once a day to ensure their welfare. Adequate and constant lighting is provided to facilitate comprehensive inspections, and the construction materials of the lairage prioritize animal safety and cleanliness. The animals receive appropriate and sufficient feed, tailored to their age and species, along with access to clean water. To further ensure the well-being of the animals, maintenance of optimal conditions, such as air circulation, temperature, humidity, and gas concentrations, is a priority [69].

Health data include information about the animals, such as vaccinations, illnesses, treatments, and veterinary checks, as shown in Figure 3a. The second type of data concerns how the animal was bred during its stay on the farm. It also includes some information regarding the preparation of the animal for leaving the farm and going to the next stage. Overall, as shown in Figure 3b, general breeding data refer to the breeding method, the feed consumed by the animal daily (type of feed and quantity), the animal's weight (before farm exit), and the farm exit date. Recordings of both types of data are performed similarly. Using the animal's identification code, the system administrator enters that animal's new data (health and general breeding) into the database via the "health data recording form" and the "general breed data recording form" of the software platform.



(**a**) (**b**)

Figure 3. Recording of the animal's data on (**a**) treatment during the animal's stay on the holding and (**b**) breeding before the animal exits the farm.

4.3. Animal Slaughter Stage

Slaughter occurs after the animal leaves the farm and before entering the factory. This stage consists of three distinct phases. Firstly, there is the phase of moving the animals, where they are transported from the farm to the slaughterhouse. Secondly, there is the phase of arrival at the slaughterhouse, where the animals are received and prepared for the slaughter process. Lastly, there is the phase of slaughtering the animals and separating them into quarters.

According to Regulation (EU) No 1/2005/EC, which refers to legislation on the welfare of animals, the first phase of moving animals requires a movement permit obtained from the veterinary office, along with accompanying movement documents, such as health certificates. The transportation of animals must be conducted using a suitable truck that meets the required standards and is assigned a code by the veterinary service to ensure its suitability for transport. Furthermore, all animals must be in good physical condition and fit for transport. The transport of sick, injured, or weak animals is strictly prohibited to ensure their well-being during the journey. The truck used for transport is equipped with appropriate features, such as a roof, dividers, and ventilation, to ensure the smooth and safe transportation of the animals [70].

In the second phase, governed by Regulation (EU) No 1099/2009/EC, animal welfare at the slaughterhouse is prioritized. The animals are transported to the slaughterhouses the day before. Upon arrival, careful procedures must be followed to unload the animals correctly. The slaughterhouse provides adequate and sufficient space, in the form of boxes, for the animals to stay until the time of slaughter. During this waiting period, the animals are provided with food, water, and protection from adverse weather conditions. Efforts are made to create a calm environment with minimal handling, noise, intimidation, or stress, thereby ensuring their well-being before the slaughter process [71].

Within this context, the system administrator enters the data of the animal to be slaughtered into the system's database with its identification code. As shown in Figure 4, the slaughter data also include the slaughterhouse number, the date of slaughter, the animal's weight before slaughter, the movement permit, the accompanying movement documents, the truck code, and the day of arrival at the slaughterhouse.

After slaughter, the animal is divided into four quarters. These quarters are then used to create processed and unprocessed products. For each quarter, a new unique identifier (barcode) is automatically generated from the database using the EAN-13 standard (the barcode number starts with '30'). EAN-13 is the most widely used barcode for processed consumable products [72]. Then, as shown in Figure 5, the software platform asks the administrator to enter the necessary information for each quarter into the database. The information relates to each quarter's entry date, expiration date, and weight. Also, the platform enables printing each quarter's barcode via a thermal printer. Finally, the administrator marks each quarter with the corresponding barcode before they are transferred to the cooling chambers of the slaughterhouse, where they are cooled at temperatures from 0 °C to 3 °C in accordance with Regulation (EU) No 853/2004 [73].

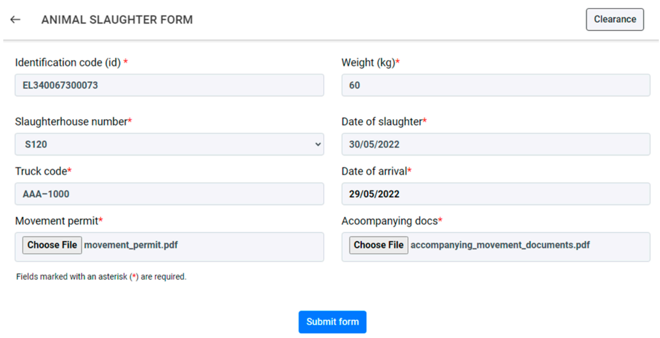


Figure 4. Recording of the animal's data on the animal slaughter stage.

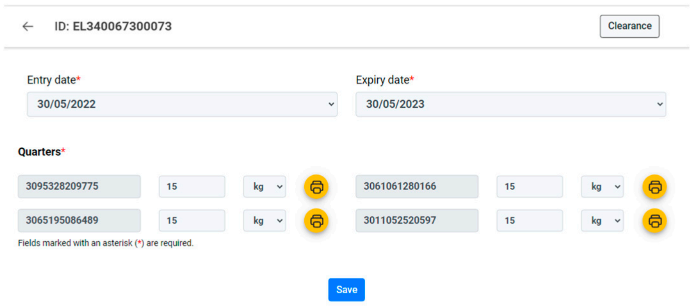


Figure 5. Form for entering necessary information for the generated quarters.

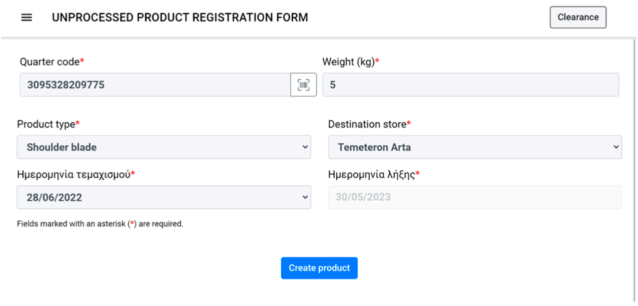
4.4. Product Manufacturing Stage

The final products, which are (a) processed and (b) unprocessed, are created at this stage before being sent to a store for sale. Processed meat products are meat products that are created from one or more quarters and standardized, such as country sausages, pork rolls, and others. On the other hand, unprocessed products represent meat taken from only one quarter and that are not standardized, such as steaks, shoulder blades, and generally unchanged pieces of meat.

In both cases, products are securely packaged in co-extruded vacuum bags using PA/PE multilayer film. The outer layer (80 microns), which does not come into contact with food, is made from PA polyamide, while the inner layer (180 microns), intended for food contact, is made from low-density polyethylene (LDPE). All raw materials used for the production of the packaging product meet the relevant requirements laid down in Regulations (EC) No 10/2011 [74] and (EC) No 1935/2004 [75]. Furthermore, these bags are produced following the Good Manufacturing Practice (GMP) standards recommended by Regulation (EC) No 2023/2006 [76] and are covered by a traceability system complying with Regulation (EC) No 1935/2004.

Also, detailed information is recorded for any other materials or articles, such as kitchen tools and food machinery, that are used in the food processing and production phases, following the broad definition of EU Regulation No 1935/2004. Information relative to the packaged products is then entered into the database by the system administrator via the software platform. The database creates a new barcode using the EAN-13 template for each one. The barcodes of unprocessed products start with the number '40,' while those of processed products start with the number '50.'

The product registration forms are similar in both cases, with the only difference being that when creating a processed product, the administrator can add multiple quarters. As shown in Figure 6a, additional fields include the product type, weight, destination store, and packing and expiration dates. The fields relating to the quarters are completed via a barcode reader on a desktop device and through the camera via an Angular Framework plugin (Figure 6b) on a mobile one.



(**a**)

(**b**)

Figure 6. (**a**) Forms for creating an unprocessed product; (**b**) Quarter barcode reading via a camera from a mobile device.

After the product is registered, the administrator can print and mark the product with the corresponding QR code and barcode for identification purposes. Barcodes are used for product tracking between businesses and stores, while QR codes are used for product tracking on the consumer side. The product is then prepared for storage in the factory's cooling chambers and maintained at temperatures between 0 °C and 3 °C before being shipped to the store.

4.5. Product Distribution and Recall Stage

The products are transported to the stores by refrigerated trucks that maintain optimal temperatures between 0 °C and 3 °C. The previous steps ensure the traceability of each product through the use of unique barcodes, ensuring effective tracking and identification of each item. This process enables upstream and downstream tracking of a product between the company and store and its eventual withdrawal/recall from the company if deemed necessary.

In particular, in the case of a defective product in both upstream (store to company) and downstream (company to store) tracking, the product is traced through the unique barcode. As shown in Figure 7, the developed traceability platform enables the administrator to search for a product by its barcode and obtain all the information related to it and the animal it came from.

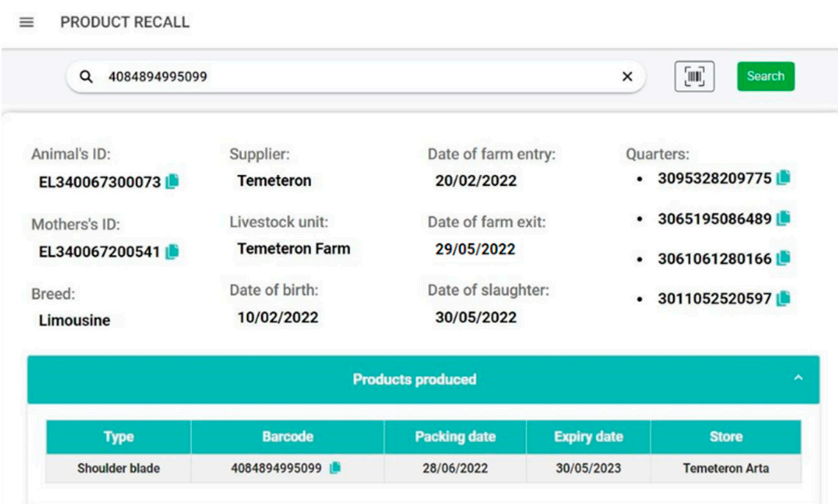


Figure 7. Detailed information about a product from its entry to the farm to its distribution in a shop.

4.6. Product Traceability by the Consumer

If the product is not defective and stays in the store of sale, scanning the QR code gives consumers peace of mind that they are purchasing a safe, high-quality product. By scanning the QR code on the meat product, consumers can track the origin of the product and its journey through the supply chain. As shown in Figure 8, the QR code leads to a digital platform that displays information about the product, the animal's farm, the date of birth and slaughter, the feed of the animal, etc.

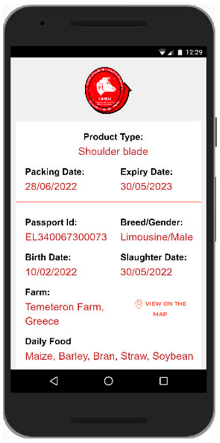


Figure 8. The alternative version of the traceability app for mobile.

5. Discussion

The proposed traceability system has been analyzed, designed, implemented, and presented. It is an "Integrated Advanced Traceability System" that has been piloted and applied in two small and medium enterprises operating in the meat production sector in Greece [77,78]. In order to meet the traceability requirements and improve the traceability system, it is essential to gain a better understanding of business practices and the behaviors of the employees who use them.

This work highlights the importance of traceability systems in the food industry, specifically in the meat sector. There is a wide demand for safe, nutritious, and sustainable food; nowadays, consumers are more aware and conscious of any product they purchase. This awareness has led to an increase in demand for transparency in the food supply chain, and our proposed traceability system offers a solution to this need. The implementation of traceability systems not only ensures the quality and safety of food but also provides economic benefits for companies, including added value, reduced labor costs, inventory decrease, anti-counterfeit practices, administrative efficiency, and operational improvement.

Here, we emphasize the meat industry, which is a vital sector for food production that must adhere to strict regulations and directives to ensure food safety and quality. Traceability in the meat industry starts at the birth of the animals and includes the stages of breeding and growth, slaughter, cutting, preparation/processing, packaging, and distribution for consumption. The use of modern information and communication technologies, such as cloud-based systems and IoT, supports any company's ability to organize archiving, storage, and rapid recall of information.

With the integration of the digital traceability system in small businesses producing and distributing state products, a new operational framework is created that enhances the building of trust, reliability, sustainability, and transparency between the links of the supply chain. Specifically, the design and development of the system are expected to ensure food safety and quality, underpinning sustainability and future research challenges.

5.1. Food Safety and Quality

Traceability is a tool to ensure the reliability and transparency of the food chain because it prevents the emergence of risks that could potentially affect food safety. According to researchers [79], the use of modern technologies (e.g., cloud, IoT, and the Internet) is important to improve the safety and quality of perishable products, and there are numerous ways of implementing them [15]. The traceability system is a complex system characterized by dynamic evolution that needs to be reshaped and redefined in terms of technological integration in order to provide food safety and quality.

The proposed implementation utilizes Internet, cloud, and IoT technologies for the identification, tracking, and real-time monitoring of the production processes of products at all stages and for all processes. The benefit is twofold, as: (a) the volume of data is not a problem and the information collection, retrieval, and storage processes are easier to manage, and (b) the possibility of human error is reduced. This leads to faster and more efficient decision making. The use of smart devices reduces costs, and flexible technology can be widely used. For example, consumers using their mobile devices have access to information about the product. Modern technologies also provide the ability to visualize information. This helps to understand the relationships between entities in the food chain and can help to set priorities and address potential issues or challenges.

5.2. Sustainability

The systematic monitoring of the food chain leads to the collection of a large amount of data that can help in decision making and in the development of optimal policies for livestock production oriented towards sustainability and food safety. Modern technologies, such as AI and Big Data virtualization, can contribute to this by making the system more efficient, thereby indicating processes that waste resources or cause increased greenhouse gas emissions [80].

Our solution involves producers and is in constant collaboration with them, pursuing social sustainability as it is defined by Gosnells et al. [81] and as it concerns human health, animal welfare, antibiotic use, learning and adaptation, and technology use. The main objective was to ensure food safety and quality, and to achieve this, we worked in two directions: first, we implemented the regulations and legislation, and, second, we ensured that the traceability system records in detail the information at each critical stage/point of the production process, providing transparency on tracking and tracing information. This methodology was followed to achieve safety and quality [3], elements that constitute the third pillar of environmental sustainability [82]. The use of new technologies helps reduce the time needed to complete the production processes, thus increasing the shelf life of the final product as it becomes available to consumers earlier. At the same time, consumers have more time to consume it, thus reducing the likelihood of throwing the food away. Food waste is accompanied by water waste, and its potential reduction is a benefit to society, the economy, and the environment.

The traceability system provides a large amount of data for which the analysis will guide the planning of investments in the acquisition of raw materials and other goods in order to achieve sustainable performance.

5.3. Challenges and Feature Improvements

This work highlights the digital traceability system as a useful tool that can improve productivity, help save resources, and build and establish a framework of trust with the consumer. Our effort includes the integration of technologies to create an integrated system that shares information with all stakeholders (operators, farmers, businesses, and consumers). After all, systematic monitoring of the food chain leads to the collection of a large amount of data that can help in decision making and in the formulation of optimal policies for livestock farming oriented towards sustainability and food safety. Modern technologies that are “positively related” to food traceability, such as AI [29] and Big Data [17], can contribute to this by indicating processes that waste resources or cause increased GHG emissions. Driven by “Meat 4.0 enablers” [17], such as Big Data, IoT, augmented reality, and machine learning, the firms could move towards digital transformation and harvest its benefits. In this respect, a specific focus will be given to the meat production process, meat preservation methods, and quality and safety analysis in line with the principles and requirements of sustainability.

Recent studies have revealed the interest of consumers [83] in how the meat products they put on their tables are produced and processed. Their perceptions are differentiated according to their specific characteristics (dietary, social, religious culture, etc.) and are influenced by the degree of consumer awareness of the safety of meat, the origin of meat, animal welfare, and the sustainability of the environment. Towards this aim, the mobile app can enhance and ensure traceability. The implementation system supports the collection of data from the user app, such as how many users downloaded the app on their device, how they used it, etc. This analysis will lead to formulating recommendations for the consumer, the farmer, and the business, forecasting demand, predicting yield by correlating the animals' breeding and weight, and creating new products.

6. Conclusions

In conclusion, the meat industry is characterized as a complex and dynamic multi-process that requires a well-functioning traceability system to ensure food safety and quality. Our research focuses on analyzing, designing, and developing an appropriate traceability system for the meat industry. The main outcome is the establishment of an integrated meat traceability information system. Consequently, we have successfully accomplished both objectives of this research endeavor. Initially, we digitalized the complete process, starting from the point when the animal enters the farm to its transportation to the slaughterhouse. Simultaneously, the entire process can now be digitally monitored at every phase.

The implemented traceability system was subjected to testing in two local meat industries within the region. The adoption of such systems holds the potential to yield substantial advantages for both consumers and businesses, thereby fostering the overall growth and development of the industry. Presently, we are actively engaged in the data collection process from these meat industries. The purpose is to analyze the collected data for future endeavors, such as constructing an advanced recommendation system that can further enhance internal processes and subsequently enhance the overall final results.

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Institutional Review Board Statement: Ethical review and approval were waived for this study due to fact that we used only secondary data provided by the corresponding companies (Temeteron S.A. and Mpisiritsas brothers S.A.) and this study has not any direct involvement with animal data.

Data Availability Statement: Data is private and belong to the corresponding companies who provided to us.

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