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Original Article

SOFTWARE FOR MONITORING HAM PRODUCTION

Saša Sudar
Visoka škola strukovnih studija za vaspitače i poslovne informatičare - Sirmium, Sremska Mitrovica, Srbija
sasa.sudar@gmail.com
ORCID: 0009-0002-2601-2993

Zdravko Ivanković
Visoka škola strukovnih studija za vaspitače i poslovne informatičare - Sirmium, Sremska Mitrovica, Srbija
ivankovic.zdravko@gmail.com
ORCID: 0009-0003-4044-6445

Srđan Damjanović
Fakultet poslovne ekonomije Bijeljina, Bosna i Hercegovina
srdjan.damjanovic@fpe.ues.rs.ba
ORCID: 0000-0003-4807-5311

***Abstract**: Technological progress brings revolutionary changes to people's everyday lives. Already today, the worldwide issue of food scarcity and the challenge of monitoring the quality of consumed food are present. New technologies provide traceability management for food from primary production to the finished product.*

Through this paper, we aim to showcase that we also have experts successfully addressing this issue. The paper describes a practical solution for tracking the entire production chain of ham, developed by our specialists for the needs of an Italian company. This company produces indigenous products with geographical indication protection. This solution was implemented as part of the Horizon 2020 project, funded by the European Union.

The foundation for our practical ham production tracking solution lies in the development of Industry 4.0, artificial intelligence, Web 3.0, semantic web, robotics, blockchain, IoT, Beacon, RFID, and similar technologies.

First, the traditional method of ham production is described before the use of modern information technologies. Then, the paper outlines the functioning of the program for tracking ham production, starting from pig slaughtering to the distribution of finished products in shops.

The main advantage of the presented system is information tracking. Since the RFID tag preserves product information throughout the supply chain, in case of a food safety incident, faulty products can be immediately located. The causes of errors, locations, and responsible personnel can be detected and proven through a web 3.0 application based on the OriginTrail blockchain protocol. This could significantly reduce business losses. Transparency of product information could significantly increase consumer trust in products and as a result boost their confidence in the food market.

***Key words**: ham, traceability, production, software, food supply chain, OriginTrail, blockchain*

JEL classification: O33

1. INTRODUCTION

In today's world, people enjoy all the conveniences brought about by the progress of science and technology. Technological advancement is ushering in revolutionary changes in people's daily lives. The increasing need for efficient resource management, safety, and comfort has led technologically advanced companies to integrate innovations that facilitate everyday tasks.

Currently, there is a global issue of food scarcity and a challenge in controlling the quality of the food people consume. Therefore, various research efforts are underway to ensure the traceability management of food from primary production to the finished product. The development of information technologies and artificial intelligence has enabled a large number of researchers worldwide to address this issue.

The European Commission has defined this problem as the "ability to trace and track food, feed, food-producing animals, or substances intended to be, or expected to be, incorporated into food or feed, throughout all stages of production, processing, and distribution." The European Union financially supports projects dealing with food production quality control through various funds.

Through this paper, we aim to showcase that we also have experts successfully addressing this issue. The paper describes a practical solution for tracking the entire production chain of ham, developed by our specialists for the needs of an Italian company. This company produces indigenous products with geographical indication protection. This solution was implemented as part of the Horizon 2020 project, funded by the European Union.

The foundation for our practical ham production tracking solution lies in the development of Industry 4.0, artificial intelligence, Web 3.0, semantic web, robotics, blockchain, IoT, Beacon, RFID, and similar technologies.
Through this paper, we seek to confirm the main hypothesis that information technologies can provide automation and optimization of various processes in food production, leading to increased efficiency and reduced production costs.

2. LITERATURE REVIEW

Over the past decade, there has been an increase in the professional and scientific literature addressing technologies that enable tracking all processes from food production and distribution to consumption.

There is a long history of research related to agriculture, food networks, and the entire food supply chain. As early as 1998, Felne investigated the traceability of beef in supply chains in the United Kingdom.
Global supply chain traceability has become an increasingly important issue in recent years, with calls for greater control and transparency, as highlighted by Steven in his work. Ensuring traceability in the food supply chain represents a significant advantage for companies in terms of quality control, product safety, product recall tracking, and optimization of reverse logistics processes.

In 2019, Pal et al. stated that combining blockchain technology with automated IoT sensors, artificial intelligence, and industrial robotics would make the system more robust and reliable.
Several companies have started using IoT sensors to ensure food traceability. For instance, Shanghai ZhongAn places sensors on chickens to record their location and daily movements.

The use of blockchain to enhance the safety and quality of agricultural and food products was considered by Xu and colleagues in their work, focusing on four aspects: improving data transparency, achieving data traceability, enhancing food safety and quality tracking, and reducing financial transaction costs. The study includes a case study on Walmart, demonstrating how blockchain can be used to improve food traceability and quality.
Unfortunately, today there are food products on the market for which it is not possible to ascertain health safety, geographical origin, or even the production date with certainty. Food producers and distributors worldwide are under pressure from governments, consumers, non-governmental organizations, and other stakeholders to disclose sufficient information to citizens about the origin of their products, composition, and production conditions. Traceability of food using modern information technologies, including temperature regulation during transport and storage, and more precise tracking, better quality control, safety, and supply chain process optimization, significantly lead to cost reduction, especially in the case of product recalls. In recent times, internet scams targeting users of e-commerce platforms have intensified. This type of fraud is directed at individuals looking to sell their products online. Katanic and colleagues in 2022 emphasized the need to educate people selling products online about the significant risks they may face if they are not cautious and readily provide their personal information to unverified individuals.

Yadava and colleagues in 2022 presented a systematic literature review on Industry 4.0 specifically in the agri-food supply chain. In their work, they noted that the need for Industry 4.0 is felt throughout the entire agriculture food supply chain to address global demand for food products and concerns about food safety. They highlighted that this industry transformation is made possible by recent technological advancements, including the Internet of Things, Blockchain, Big Data, Information and Communication Technology, Cloud Computing, and Cyber-Physical System. Each of these technologies can make the system smart enough to meet today's global challenges. The paper provides a detailed overview of the main technologies, aiming to understand their applications and emerging trends.

In study 2024 Wang and and colleagues presented how the digital transformation of food supply chains can be achieved by adopting key technologies such as the Internet of Things, cloud computing, and Big Data Analytics. Basic goals and principles for digitally transforming food supply chains are identified for the initial stage of development in this economic branch. A four-layer technology implementation structure is developed for the implementation phase, development software for food supply chains digital transformation. This paper contributes to the development of theory on digital transformation in food supply chains and offers more instructions for accelerating the growth of the food industry using key Industry 4.0 emerging technologies. The study highlights the need for a balanced integration of Internet of Things, cloud computing, and Big Data Analytics as key Industry 4.0 technologies to achieve digital transformation successfully.

3. DEVELOPMENT OF A PROGRAM FOR TRACKING HAM PRODUCTION

The process of ham production in an Italian company traditionally unfolds as follows before the implementation of our software solution for achieving complete traceability in the food supply chain:

1) Receipt of fresh ham thighs, processing, and salting. Salted hams are placed in Chamber 1 for aging (7 days, 0 ^{o}C to 4 ^{o}C, on a plastic platform shelf).
2) Second additional salting of the ham. Salted hams go then to Chamber 2 for aging (15 days, 0 ^{o}C to 4 ^{o}C, on a plastic platform shelf).
3) Removal of salt, tying a string around the ham, removal from the plastic shelf, and placement on a metal shelf. Hams go to Chamber 3 for aging (15 days, 0 ^{o}C to 4 ^{o}C, metal shelf).
4) Cleaning mold around the ham bone. Hams go to Chamber 4 for additional aging (80 days, 1 ^{o}C to 6 ^{o}C metal shelf).
5) Machine washing of the entire ham and drying. Hams go to Chamber 5 for aging (7 days 16 ^{o}C to 18 ^{o}C, metal shelf).
6) Pre-curing stage of ham. Hams go to Chamber 6 for aging (90 days, 16 ^{o}C to 19 ^{o}C, metal shelf).
7) Greasing the ham with lard. Hams are divided by size and placed on another metal shelf.
8) Proces final curing of the ham. Hams go to Chamber 7 for aging (until the ham is ready for sale, 16 ^{o}C to 19 ^{o}C, metal shelf).

Each pig, intended for ham production, is tattooed on the thighs at the farm. This identification number remains visible throughout the entire drying and curing process. The initial traceability level occurs at the slaughterhouse, where all fresh thighs for ham production originate. During the slaughtering process, the slaughterhouse tattoos its slaughter LOT number, which remains visible throughout the drying and curing process.
When the meat is received at the ham factory, a metal ring with the date of receipt (beginning of processing) is placed on each leg. Additionally, a paper containing information about the LOT and the date of the first salting is placed on each platform. This paper accompanies the platform throughout the "PigLard" process, where pork fat is applied to the ham during ham production. After this process, the hams are removed, redistributed on racks based on size, and the final curing process begins.
Throughout the curing process (after one year), representatives of the consortium, if the ham meets quality requirements, tattoo the crown and the hamery code. This designates the product as of authentic origin and of specific quality.

In the described process, there was no digitalization. Traceability is lost during ham production in the "Pig Lard" process because the papers with information about the receipt of fresh meat (thighs) and the salting date are removed from the platforms at that stage.

To achieve complete and automated traceability in ham production, the following levels of digitalization need to be implemented:

1) Software for receipt input-output
2) RFID tags on hams (fresh thighs from the slaughterhouse)
3) RFID for platform racks (pre-curing process)
4) Software for ham greasing (pig lard – greasing process) with IoT scales for reading RFID tags on hams
5) Beacons and RFID in the curing process
6) Photo module
7) Beacon/Agv for automatic inventory of ham status
8) Data logger (information on destination and transport conditions)
9) Blockchain/ OriginTrail.

These processes involve the implementation of digitalization within the real production process through the development of an ERP production system architecture and its integration with IoT sensors such as RFID, NFC, Beacon tags, and Data Loggers, along with the use of robotics such as AGV vehicles and robotic arms. This is done to achieve automatic and timely reading and collection of traceability information, which the ERP system should automatically send to a WEB3.0 developed application based on the OriginTrail (blockchain) protocol.

3.1. DATA ENTRY SOFTWARE

The software for entering the reception of fresh thighs represents the first step towards digitalization in achieving complete traceability within the production process. Introducing an ERP system enables the linking of the ham reception LOT number at the factory with previous traceability data for each ham, as well as the later creation of work orders in the process of dispatching finished products. Each line within the reception document represents one LOT number from that slaughterhouse. In ham production from the slaughterhouse, reception notes arrive with multiple slaughter LOT numbers for the delivered hams, containing data about their breeder, tattoo numbers, slaughterhouse, transporter, and similar information. In the first stage of digitalization, the data from the reception document is entered into the ERP software by office employees.

The output of finished products into the supply chain also occurs through ERP software in the following steps:

1) Office employees create a work order for production, specifying how many hams to pack for exit from the factory.
2) Employees in the ham dispatch department receive the work order, where they can see the required hams according to aging and customer.
3) Employees in the dispatch process pack the hams and record how many hams with the LOT number they have packed.
4) Finally, dispatch employees enter this data into the ERP software.

In the first step of digitalization when only an information system was introduced (without RFID technology), the primary drawback was that after a production process lasting 2 years, the worker in the dispatch department often could not clearly see the tattoo numbers on the hams, nor could they see the breeder (farm) numbers. What was visible was the LOT reception number. As a result, when traceability was displayed, the LOT reception number of the ham being sold was linked to the dispatch. Consequently, it was sometimes impossible to accurately identify the slaughterhouse from which the ham originated, as well as the farm from which the ham further entered the supply chain.

3.2. PLACEMENT OF RFID TAGS ON FRESH MEAT FROM SLAUGHTERHOUSE

The placement of RFID tags on fresh meat - thighs that arrive for ham production from the slaughterhouse is carried out as follows:

1) Office employees, based on the reception document from the consortium website, know the number of thighs arriving from the slaughterhouse on that day.
2) Office employees take the necessary number of RFID tags from the warehouse.
3) Office employees take an RFID terminal reader, scan the required number of RFID tags, and link them to the current LOT reception number - all this data is automatically entered into the ERP software.
4) Office employees send the previously read and linked tags to employees in production.
5) Production employees place RFID tags on the incoming fresh thighs. The production worker has nothing to do with the software. They only physically place the tags on the hams.

Reading of hams at the dispatch, the outgoing process of finished products from the ham factory, based on the described process, would proceed as follows:

1) Office employees create a production work order - indicating how many hams need to be packed for dispatch.
2) Employees in the dispatch process retrieve the work order, which specifies the required hams according to their aging and the customer.
3) Employees in the dispatch process read the RFID tags on the hams by passing them near an RFID antenna reader, which automatically communicates with the ERP software. They then pack the hams into plastic boxes for dispatch. The software automatically knows the quantity of hams and from which LOT reception number they were packed by the worker.

By tagging hams with RFID tags, we can track each ham by its LOT reception number. In terms of traceability, we can confidently determine that the hams come from a specific pig breeder, slaughterhouse, identify the meat carrier, and obtain a range of other data related to the production process.

3.3. PLACING HAMS ON SHELVES FOR CURING

The process of placing hams on curing shelves is carried out automatically using a robotic arm and RFID reader. Hams already have RFID tags on them, which uniquely identify them. The goal is to track hams even on the platform racks. Each platform rack has its own RFID tag attached to it. When the platform rack approaches the robotic arm, the RFID tag on the platform rack is scanned, and the information is recorded in the database.

Hams with RFID tags from previous production processes pass through the salting machine. At the end of the salting line, there is a robotic arm. The robotic arm picks up 3 hams at a time and transfers them to the appropriate shelving rack. To associate the hams with the shelving rack, we can place an RFID tag on the top of each platform rack, which is pulled through the factory by the conveyor system. Additionally, an antenna is installed on the conveyor system for the racks and another antenna is placed above the salting line to read the hams.

In the continuation of the production process, the next platform rack, which will be filled with hams, approaches the robotic arm. When the platform rack approaches the robotic arm, the RFID antenna will read the RFID tag of this rack, and the information about which platform rack is currently being used for placing hams by the robotic arm will be automatically sent to the ERP software.

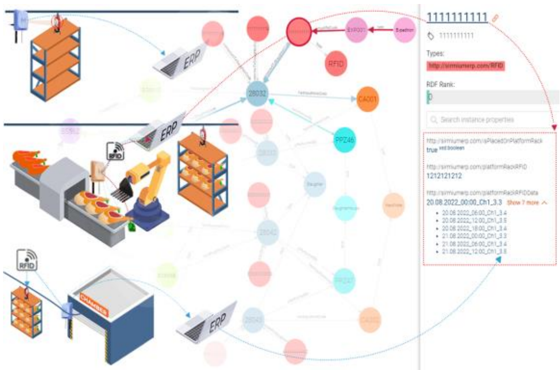

Figure 1. The robotic arm moves the hams
Source: Authors

After this, the robotic arm moves the hams from the salting line to the platform rack, which is then carried by the transport system, as in Figure 1. This figure also depicts a part of the knowledge graph with nodes and connections between the data. The graph knowledge graph allows for easy tracking of the data origin, connections between the data, and their storage in the database. In front of each chamber for fresh meat (hams), an RFID antenna can be placed next to the transport system, where the platform racks pass. This way, it is known when a platform rack (with all connected hams) enters or exits a chamber. This enables us to automatically know within the ERP system where each ham is located.

3.4. SOFTWARE FOR PIG LARD

The next step in ham production involves applying pig lard to the hams and separating them into large and small ones. To perform this task, an IoT scale is required, which automatically for each ham:

- Read (RFID)
- Measures the weight
- Inputs size division (large, small)
- Automatically records the date, measurement.

All this data is sent to the ERP software by the IoT scale. Employees in the process of greasing the hams with lard remove the ham from the pre-curing shelf and place it in front of the antenna - RFID reader. The RFID reader reads the RFID from the ham and automatically sends information to the ERP software that the ham has entered the gresasing process with lard. Employees in the process of greasing the hams with lard place the ham on the IoT scale. The scale automatically sends the measured weight of the ham to the ERP software, which is then linked to the last read RFID of the ham. Also, based on the weight received from the scale, the ERP software labels the hams as LARGE – SMALL, as illustrated in Figure 2. Employees apply lard to the ham and place them on the shelf. Large hams will be placed on one shelf, and small hams on another, as they have different curing times. In this way, a person is prevented from making a mistake when sorting the hams, because this later directly affects the uneven ripening time of the hams.

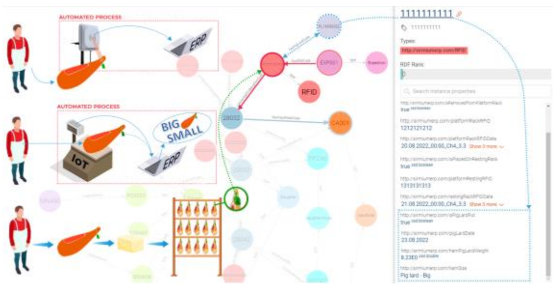

Figure 2. Weighing and Sorting of Hams
Source: Authors

3.5. BEACONS AND RFID IN CURING PROCESS AND INVENTORY PROCESS

The ham curing process occurs after the previous pig lard process, where sorted hams are placed on wooden racks, initiating a new curing process that lasts for one year. The digitalization of this process aims to achieve traceability of each ham.

An RFID tag is placed on each curing rack. When an employee fills a rack with hams during the greasing process, they can use an RFID reader to scan the RFID tag on the rack and then scan all RFID tags on each ham on the rack. The ERP software will automatically link the RFID tag to all the information for each ham. After this step, based on the entered data, we can determine when the ham entered the curing process, on which rack it is located precisely, and from which rack it entered this process.

The employee responsible for quality control and photographing the products will take a phone with a developed mobile application. First, they will scan the RFID on the rack and then take a picture of the hams. This way, the picture is linked to specific hams. A report can be generated with all the photos of the racks containing hams in all stages of production. These images can be uploaded to the blockchain. This enhances the digital identity of the ham and provides evidence of its quality and that the hams of that LOT number have undergone key production processes.

Inventory of hams could be conducted in two ways. The first method involves beacon antennas placed around the curing chamber. This way, we can have the position of each rack and each ham in real-time within the ERP software. The second method involves AGV vehicles (Automated Guided Vehicles), which would have an integrated RFID reader, as shown in Figure 3. Passing through the warehouse, next to the racks with hams, the AGV could automatically read the RFID tag of the rack and the RFID tags of the hams. This confirms that the ham is in stock in the warehouse. This ensures traceability, and we can have information about where the ham was located and when it was moved exactly on a daily basis if the inventory is conducted at the end of each workday.

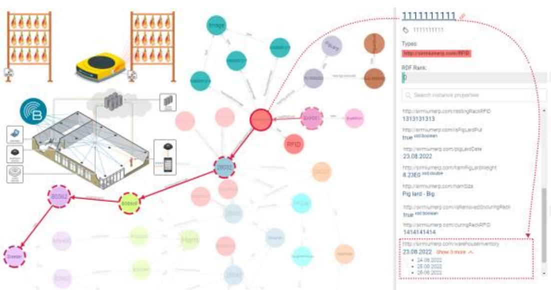

Figure 3. Inventory of Hams with AGV Vehicle
Source: Authors

The primary advantages of this automatic ham tracking system are:

- Real-time location tracking of hams during curing.
- Real-time location tracking of reserved hams.
- Real-time location tracking of hams ready for shipment.

3.6. TRANSPORT TRACKING WITH DATA LOGGER

After the ham dispatch process from the factory, we can track the products during their transportation using a data logger. The data logger collects information about transportation conditions such as GPS coordinates, destinations, truck routes, humidity, and temperature of the cargo area, and automatically sends this data to the ERP software where it can be further monitored in real-time. The digitization of this process unfolds as follows: Employees involved in the ham dispatch process connect the data logger to the shipment's LOT number via a mobile application. Then, the data logger is placed inside the shipping box along with the hams for transport. During dispatch, employees scan the hams by passing them near an RFID antenna reader while placing them into the box. The ERP software automatically associates the hams with the data logger. The data logger sends transportation data, destination (GPS coordinates), temperature, humidity, and other information to the ERP software. This way, data about the hams is tracked by the data logger after the dispatch process as they leave the factory and during their distribution in the supply chain. This ensures complete product tracking from the factory to the point of sale.

The main operational advantage of this digitization process is obtaining information about the final products when they leave the factory.

The main business-to-business (B2B) advantage of this digitization process is tracking products from the factory to their destination.

The main business-to-customer (B2C) advantage of this digitization process is tracking items from the factory to the store.

3.7. BLOCKCHAIN ORIGIN TRAIL APPLICATION

The Origin Trail blockchain technology doesn't enable us to detect errors starting from the production process all the way to the ham selling process. We use it only to decentralize and irrevocably store all relevant data that we previously collected during the production process via IoT technology, with complete certainty in the immutability of these stored data. It allows us to know with certainty that no one can alter or influence the stored data or recorded transactions found in the blockchain. Figure 4 depicts a scheme describing the connection between the technologies used in the process of tracking ham from production to sale.

The operational OriginTrail blockchain application is developed with the aim of inputting production data necessary for traceability into the blockchain. In the background of this web application, data for signing is received by ERP software. After the operational application signs these data, it sends them to the blockchain/Origin Trail. In response, the OriginTrail network returns recorded transactions to the operational web application. This application is designed as a middleware independent service to which the ERP distributed information system sends data for signing so that it can record them in the blockchain. This service utilizes an authorized worker to verify (record in the blockchain) the data of the described key processes in ham production, which are created by the ERP software. When the authorized user signs or records the data with this application, the data remain permanently recorded in the blockchain. Within the application, alongside the main menu for recording incoming data, a history of recorded transactions is implemented, enabling searching for each transaction recorded in the blockchain. By using this method to communicate with the blockchain, there is no need to change the existing ERP software and its logic in production. Additionally, through this application, the manufacturer can verify or recall products by searching for each specific ham that is permanently recorded in the blockchain.

The second application retrieves production traceability data from the blockchain/OriginTrail knowledge graph. This is a business-to-business (B2B) application. It contains detailed information related to the ham production process so that the business partner can ensure the quality of the product and the production process, confirming that it is indeed what they are purchasing. This mobile application is developed for complete product traceability. It is used by business partners and is designed to provide full control over the production process to ensure the quality of purchased products. In this mobile application, all data from the blockchain about specific hams can be seen in detail. The data that can be viewed include whether the product is authentic, which farm it comes from, the tattoo number of the animal, which slaughterhouse processed it, in which LOT it belongs, the processes the ham went through, the duration of aging, the temperatures in which it was stored in warehouses, the conditions of transportation including GPS coordinates of its movement during transportation, and temperatures, along with photographs of the hams at each stage of the process.

The third application, business-to-customer (B2C), is developed for end customers. Compared to the previous B2B application, this application contains much less traceability information and does not include individual photographs of each production process. Not all processes and other unnecessary information for the end-user are displayed. The data presented in this application include the breeder, slaughterhouse, receipt, aging, and dispatch. For example, a customer in a shop scans the QR code on the ham and receives key traceability information about the scanned product on their phone using augmented reality. The QR code contains the ham code from the blockchain, through which data on key processes are pulled from the knowledge graph on the OriginTrail network. These data are then displayed to the user in the mobile application on their phone.

In this way, the customer can get a lot of new information about the product he is buying. Today's customers have become increasingly demanding, and those producers who in the future will provide customers with additional data on the process of producing food products will be much more recognizable on the market. This kind of news and data spreads quickly and easily on social networks, and it also becomes a new channel for advertising products.

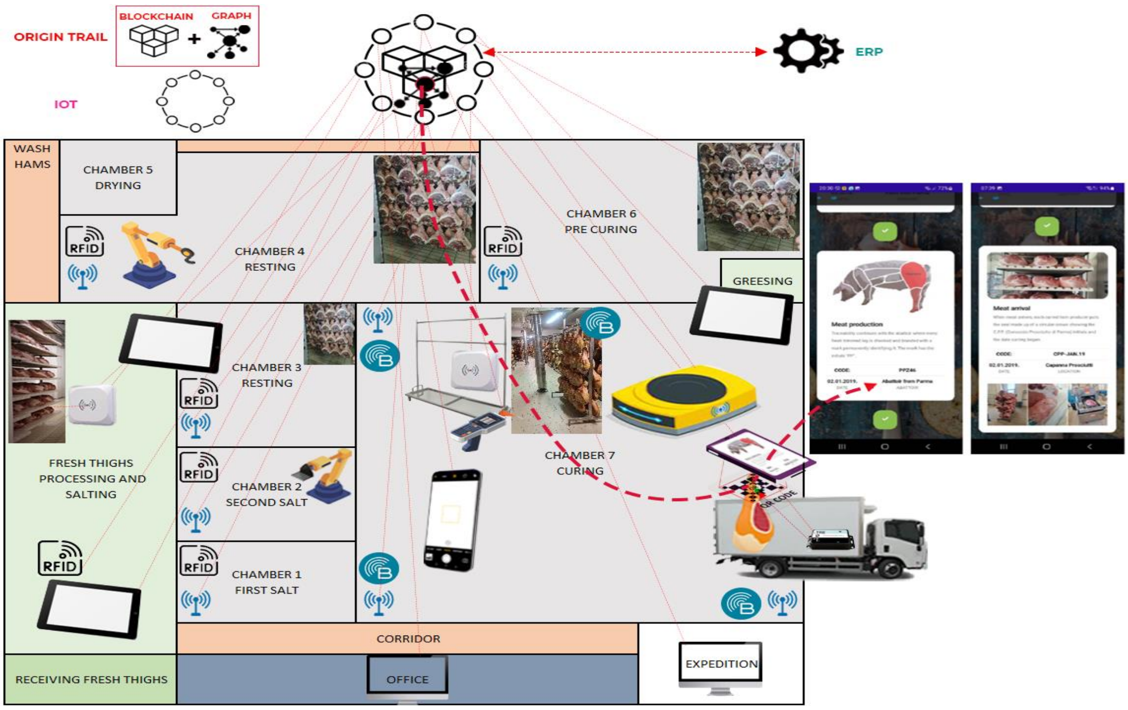

Figure 4. Schema of technologies used in tracking the production and sale of hams
Source: Authors

CONCLUSION

The transparency deficiency in meat supply chains is a significant problem, as evidenced by crises and scandals related to meat products. Implementing a system that ensures meat traceability is challenging due to complex dynamic factors and intricate production processes inherent in today's global business environment.
The primary problem addressed by blockchain technology is how we can establish a consensus foundation for secure transactions without worrying about unauthorized data access. Blockchain can guarantee the security of the entire network using a mathematical algorithm mechanism. Thanks to blockchain, all elements in the system can autonomously and securely exchange their data.
We have implemented a ERP system in an Italian company that is one of the leading producers of ham, as part of the Horizon 2020 project, funded by the European Union. This softwe for complete digital traceability in real food production. This software provides tracking and display of a large amount of data in a real food production environment with regards to the presentation of modern and necessary technologies.
The developed transparency system enables all stakeholders throughout the food chain to manage data within their facilities and share information with external operators and interested parties. Achieving true traceability of meat products critically depends on a transparency system that involves data sharing among key actors in the supply chain, thus achieving external transparency. Without appropriate external and internal transparency systems, the desired transparency of meat products cannot be achieved. By utilizing IoT, RFID, and Beacon technologies, minimal human intervention in gathering information for the demonstrated real production system has been achieved. The implemented system relies on the OriginTrail blockchain and has enabled all product information in the supply chain to be transparent and open. Real-time product tracking has been made possible. Regulatory authorities could manage traceability and conduct accountability investigations for faulty products. Consumers can obtain information about products throughout the supply chain. Wholesale buyers can have more information about the quality of products and the production process of all lots within production. This enables a useful system for establishing a healthier and more business-correct environment.
The benefits of a digitized traceability system are manifold. One of the main advantages is protecting the product from counterfeiting, which is particularly important for expensive and original products to protect their geographical origin. In terms of data tracking, the system requires minimal manual operations, greatly reducing errors caused by human factors. Furthermore, by utilizing blockchain technology, all members of this system are unable to

manipulate information, further increasing product security and quality. The system can be applied to track product expiration dates. Therefore, a seller could replace these food products if they have expired or reduce the price before the product's expiration date. We believe that artificial intelligence will increasingly take over a large amount of data from such or similar systems in the future. Artificial intelligence will be increasingly used by both food producers and consumers to quickly find answers to their questions daily.

Finally, the RFID and Beacon system can also be beneficial for verifying storage temperature information, including tracking temperature and humidity. This could be helpful in avoiding food safety issues.

The greatest advantage of the demonstrated system is precisely the tracking of information. Since the RFID tag preserves product information throughout the supply chain, when a food safety incident occurs, faulty products can be immediately located. The reasons for errors, their location, and responsible personnel can be identified and proven using the OriginTrail blockchain system. This could significantly reduce business losses. Transparency of product information could greatly increase consumer trust in products and obviously enhance their trust in food markets.

With minor adjustments, the demonstrated system could also be applied in the production of wine, cheese, and other food products for which ensuring traceability from production to the end consumer is essential. This software can be used to monitor the food production process in all cases where we wants to protect production from illegal copying of products, that is, one wants to ensure the protection of the geographical origin of food.

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