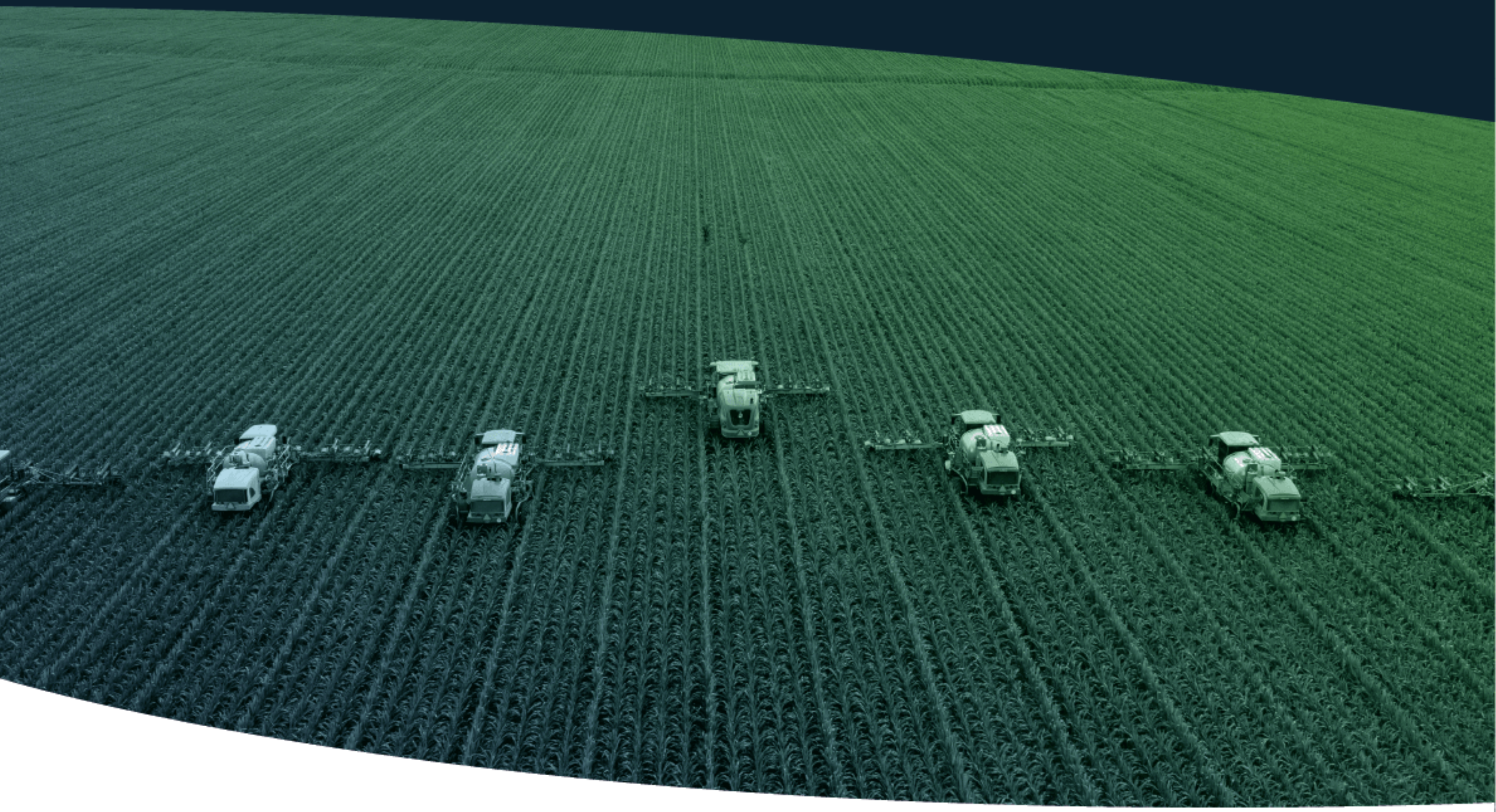
ALLIANCE

A hoListic framework in the quality Labelled food supply chain systems' management towards enhanced data Integrity and verAcity, interoperability, traNsparenCy, and tracEability



DELIVERABLE 2.3 – INTERIM AI-ENABLED TOOLS FOR VULNERABILITY RISK ASSESSMENT, EARLY WARNING INDICATION AND DECISION SUPPORT PREVENTIVE ACTIONS

GRANT AGREEMENT NUMBER: 101084188

This project has received funding from the European Union's HE research and innovation programme under grant agreement No 101084188

Lead Beneficiary: University of Thessaly

Type of Deliverable: Report

Dissemination Level: Public/Confidential

Submission Date: 30.04.2024

Version: 1.0

Versioning and contribution history

Version	Description	Contributions
0.1	Table of Contents	
0.2	First round of UTH contributions	Description of architecture layers and blockchain database.
0.3	Second round of UTH contributions	Figures of blockchain channels.
0.4	Third round of UTH contributions & INTRASOFT contribution	Description of information flows & T2.4 results.
0.5	Final round of UTH contributions before internal review	Final corrections and missing parts.
0.6	Integration of internal reviews	Integration of internal reviews

Authors

Author	Partner
Apostolis Apostolaras	UTH
Kostas Choumas	UTH
Dimitris Kanavaris	UTH
Marialena Lefkopoulou	UTH
Amalia Ntemou	INTRA
Pantelis Lappas	INTRA

Reviewers

Name	Organisation
Alessandra Castellini	UNIBO
Francesca Gori	UNIBO
Tamara Zivadinovic	MENA

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List of Abbreviations

Abbreviation	Description
AI	Artificial Intelligence
CBV	Core Business Vocabulary
DoA	Description of Action
EPCIS	Electronic Product Code Information Services
EWDSS	Early Warning Decision Support System
FSC	Food Supply Chain
HSI	Hyperspectral Imaging
IoT	Internet of Things
NIR	Near-Infrared
PDO	Protected Designation of Origin
PGI	Protected Geographical Indication
VRAMF	Vulnerability Risk Assessment Management Framework

Executive Summary

This deliverable signifies the initial phase of developing software components within the framework of ALLIANCE WP2, dedicated to Food Traceability. The document details the progress achieved across the four of the five tasks (T2.2-T2.5) within the work package, emphasizing the implementation aspects, and elucidates the primary components and features that have been successfully implemented to date.

The document initiates by introducing a comprehensive overview of the primary vision behind the work package, describing the document's purpose and scope, the relation to project work, and providing the document structure. A key point of this deliverable is the ALLIANCE Architecture. The emphasis is on delivering the initial consolidated version of the ALLIANCE Reference Architecture, designed to facilitate the understanding of the various technical solutions.

Secondly, the document offers a detailed breakdown for each task and technology component, encompassing the description of the deployed technologies, features implemented to date and the expected support for pilots. This comprehensive information is presented for all tools developed within WP2, including blockchain-based resilient value chains, vulnerability risk assessment for critical control points, AI enabled Early Warning and Decision Support System and Interoperability Mechanisms.

Finally, the document concludes with a summary of the work done so far and the work to be done for the integration of the tools and the remaining aspects to be covered in following releases.

1 Introduction

1.1. Document purpose & scope

WP2 belongs to the core technical work packages of ALLIANCE. It provides key technical components and solutions for the implementation of the ALLIANCE platform. This deliverable D2.3 *Interim AI-enabled tools for Vulnerability Risk Assessment, Early Warning Indication and Decision Support Preventive Actions,* describes the results of WP2 achieved within the period of M5-M18 of the project with an aim to attain the following objectives (according to the Description of Action (DoA)):

- **WP2.Obj.1:** To create the Blockchain framework for providing increased traceability in organic, PDO, PGI and GI food products.
- **WP2.Obj.2:** To provide food actors with increased visibility and situational awareness about the performance of the quality labelled Food Supply Chain (FSC) against the strict organic, PDO, PGI and GI standards.
- **WP2.Obj.3:** To design and implement an interoperability framework for consolidating different data sources and incorporating IoT devices and rapid authenticity testing devices.
- **WP2.Obj.4:** To design and implement a Vulnerability Risk Assessment Framework to assess Critical Point within the FSC.
- **WP2.Obj.5:** To design and implement an Early Warning & Decision Support System based on AI and predictive analytics for supporting proactively interventions against food fraud.

Attaining the aforementioned objectives has been accomplished so far by the progress made within the activities carried out within the following Tasks:

- **Task 2.2** - Resilient Food Supply Chain Systems using Blockchain
- **Task 2.3** - Vulnerability Risk Assessment for Critical Control Points Identification in quality-labelled FSCs
- **Task 2.4** – AI-enabled Early Warning and Decision Support System
- **Task 2.5** – Interoperability Mechanisms in Complex Food Systems

The following Table summarizes how each Task has contributed to the WP2 objectives.

Tasks	*Contribution to attain to the WP2 Objectives*
T2.2	**WP2.Obj.1:** Apart from the digital transformation of the current FSCs, the use of the Blockchain Technology in the ALLIANCE platform offers also increased traceability allowing stakeholders to trace back the origin of the food products, verify and justify the data accompany the food products, confirm food sources and ensure quality standards for PDO, PGI, and GI food products. **WP2.Obj.2:** Utilizing Blockchain technology provides transparent and immutable data records, allowing food actors (and according to their roles) access to authenticated and trustworthy information considering the journey of the food products in real-time. Data integrity is ensured through cryptography,

	which allows information related to production dates, packaging numbers etc. to be accessed only by the authorised users in a secure way.
T2.3	**WP2.Obj.4:** Strengthening the quality labelled food supply chains against adulteration and fraud requires continuous and systematic assessment of the related vulnerabilities, the identification of the threats in every step across the entire food chain and the linkage with the associated vulnerabilities, as well as fraud risk assessment. Task 2.4 provides the framework that utilizes the Blockchain technology and the AI with an aim to identify the key point within the FSCs that are prone to vulnerabilities.
T2.4	**WP2.Obj.5:** Leveraging AI technology for analysing the data stemming from the various steps of the food supply chains allows for the detection and the identification of behaviours or performance that may indicate a deviation or an anomaly comparing to the normal operation of the FSC, and might be categorized after assessment as a risk or threat which in sequence allows the FSCs operators to take immediate actions to investigate further the incidence and make informed decisions to address it. The ALLIANE AI Early Warning system is fed with real-time data and along with the historic records of the data already being in stored in the Blockchain it is trained to identify unusual patterns or unexpected changes from outliers.
T2.5	**WP2.Obj.3:** As the digital transformation of the food systems and the utilization of different types of Blockchain technology lead to the creation of data ecosystems, which are described by heterogeneity in data management and formats, the challenge of data sharing and exchange can lead to fragmented digital chains. By aligning with the GS1 EPCIS standard and adopting a common vocabulary, ALLLIANCE aims to support interoperability among different food systems and facilitate data discovery, sharing and exchange among different food supply chains

1.2. Relation to project work

This deliverable describes the outcomes achieved so far, not only to attain the aforementioned objectives listed in Section 1.1, but also to describe the advancements achieved so far with an aim to attaining the overall objectives of the project and contributing to the related KPIs. It provides the first description of results so far concerning all the Tasks of WP2 (except T2.1).

Obj.1 To provide food producers and retailers with a holistic framework consisting of innovative methods, state-of-the-art technologies, reliable processes, and interoperable systems that ensure data veracity and accelerate transparency and trust throughout the EU quality-labelled food chains.	
Measurable Outcomes and Success Indicators	
Target Measurable KPIs	**Progress so far within WP2 to attain the KPIs**
Increased prevention of fraudulent activities in the quality-labelled FSC	The AI-enabled Early Warning and Decision Support System developed in T2.4, aims to combat food fraud within quality-labelled FSCs. The offered early warning system serves as an

>**60%**	essential safeguard ensuring the integrity and reliability of the FSCs offering enhanced capabilities for the detection and mitigation of food fraud incidences through the utilization of advanced AI algorithms and decision analysis tools. The specific KPIs mentioned will be assessed during the pilot demonstration phase by utilizing the AI Early Warning and Decision Support System along with Blockchain Technology offered through the ALLIANCE platform.
Improved quality-labelled food products' traceability >**90%**	The digital transformation of the food supply chains (which will be the pilot demonstrators of the ALLIANCE) and the utilization of Blockchain technology as this is achieved through the activities conducted in T2.2 enable the increased transparency and the traceability of all the steps of those chains. The specific KPI will be assessed during the pilot demonstration phase by utilizing the Blockchain Technology offered through the ALLIANCE platform
Number of interoperable food data systems connected >= **5**	Considering the Interoperability of the Food Supply Chains, we plan to interconnect the Food Supply chains of the two retailers (namely, Masoutis-GR and Migros-TR) with the 5 of the existing PUC-demonstrators as this described in D2.1. The specific KPI will be realized during the pilot demonstration phase.

Obj.2 To investigate the Food Fraud Landscape and propose systemic solutions that move beyond current practices with an aim to enhance traceability, ensure authenticity, preserve quality and eliminate the fraud in food products through novel cost-effective methods and tools that can detect adulteration on the spot and provide trusted interoperable quality-labelled FSCs.	
Measurable Outcomes and Success Indicators	
Target Measurable KPIs	**Progress so far within WP2 to attain the KPIs**
Increase in Supply Chain Velocity for Food Fraud Mitigation > 40%	The work conducted within T2.2 provides the Blockchain system that will allow the trusted accessing of food data records in every step of the supply chains. The utilization of Blockchain allows for streamlining the processes by automating tasks related to inventory management, handling of the procurement and supplies, tracking and tracing quantities and the packages of the food products in the entire value chain and enabling efficient inventory management. Along with the T2.3 and T2.4 the identification of the critical control points of the food chains and the proactive early warning and decision support system allows for immediate reaction assisting the responsible food actors with informed decision making to apply efficient quality assurance and control. This KPI will be assessed during the Pilot demonstration phase.

Auditing and Certification Expenses <=10%	Specific capabilities, enabled through T2.2-T2.5, such as the increased transparency and improved traceability, the data integrity and tamper-proofed records, the critical control point identification and the vulnerability risk assessment, the proactive mitigation of potential risks (that are assessed with the use of AI to facilitate the monitoring of the food supply chains) contribute to improved efficiency, accuracy and cost-effective management in auditing and certification processes for quality labelled foods, which require strict conformance to European legislation. This KPI will be assessed in the Pilot Demonstration Phase.

Obj.4 Increase transparency in quality labeled supply chains, of organic, PDO, PGI and GI food, through innovative and improved track-and-trace mechanisms containing accurate, time-relevant, and untampered information for the food product throughout its whole journey from farm to fork.	
Measurable Outcomes and Success Indicators	
Target Measurable KPIs	**Progress so far within WP2 to attain the KPIs**
Real-Time Visibility of All Data Exchanges and Operations>90%	ALLIANCE leverages the Blockchain technology and the Hyperledger Fabric for implementing real-time food product tracking and monitoring of the food supply chains. Real-time tracking of products provides valuable information about the location, quantities, the quality control parameters, and other factors that can affect the quality and safety of food products. The capability for continuous monitoring of this information is used to streamline the operational processes that occur within the FSC offering advanced mechanisms for performance analysis and detect unusual behavior or patterns that might indicate a risk for food fraud incident. The specific KPI will be assessed during the pilot demonstration phase.
Seamless End-to-End Processes for Data Transformation, Orchestration >90%	ALLIANCE utilizes Blockchain technology for keeping tamper-proofed and immutable records of transactions. Through the mechanisms implemented in T2.2, ALLIANCE provides reliable and verified evidence of food certifications, the identity of the producers and the involved intermediates, the authenticity and the provenance of the food products, and the compliance in accordance with stringent quality standards for the quality labelled food products. Through T2.2 and based on Hyperledger Fabric, ALLIANCE provides a transparent, secure, and immutable ledger for recording and sharing data across the entire food supply chains, which in turn enables continuous visibility of the operational processes. The specific KPI will be assessed during the pilot demonstration phase.
Automate Core Integration	Through T2.5 ALLIANCE Blockchain facilitates interoperability

Processes to Reduce Manual Errors and increase Interoperability > 80%	by aligning with standardized data formats and protocols EPCIS and GS1 across the food supply chains. By using interoperable database schemas for the data records of the food products, ALLIANCE enables the seamless exchange of data between different supply chains systems thus eventually reducing the risk of errors caused by incompatibilities and human interventions. The specific KPI will be assessed during the pilot demonstration phase

Obj.5 Equip food actors, farmers, public authorities, and policy makers with meaningful insights to have the complete situational awareness of the food supply chain (in particular organic, PDO, PGI and GI) while at the same time monitoring the financial, nutritional, environmental, social performance of different parts and processes of the food system.	
Measurable Outcomes and Success Indicators	
Target Measurable KPIs	**Progress so far within WP2 to attain the KPIs**
Increased Agility, Flexibility and Redundancy > 60 %	Through the AI Early Warning and Decision Support System implemented in T2.4, analysis is conducted in the historical data of the food value chain with an aim to forecast future performance values. Therefore, any potential deviation, unusual pattern or operation anomaly can be proactively identified, thus allowing for timely intervention and immediate response of involved actors. This increases the agility offered to responsible actors to apply quality control and compliance assurance and make informed decisions for developing contingency plans and food fraud risk mitigation strategies. Moreover, the decentralized architecture of the Blockchain network allows for continuity of operation considering the tracking of data if for example one (or more than one node) fails. The specific KPI will be assessed during the pilot demonstration phase.
Improved Risk Management >80 %	By leveraging the ALLIANCE Blockchain platform and the AI enabled early warning system, the quality labelled food value chains improve their risk management capabilities by allowing for informed decision making and timely actions for fighting and restricting food fraud. With increased transparency and traceability, the compliance with quality standards and regulatory requirements is strengthened. The specific KPI will be assessed during the pilot demonstration phase.
Improved Information Sharing >90 %	Transparent and immutable data records are handled by the Blockchain network to offer to each participant (according to their authorised role) access on the data records as well as contribution to the validation of the information recorded on the Blockchain. Authorized participants who are responsible for a specific action/operation in the supply chain can share the data they handle through the Blockchain network. A significant

	feature enabled through Blockchain is non-repudiation which is achieved through the immutable and tamper-proof nature of the blockchain technology. When a transaction occurs, it becomes a permanent part of the ledger as a part of the Blockchain. Therefore, users can be sure about the veracity of the information that they want to access, since transactions are verified by the rest of the participants in the network and in case of intentional or accidental misinformation the transaction is fully tractable and identifiable. The specific KPI will be assessed during the pilot demonstration phase.
Increased Visibility > 90 %	ALLIANCE solution will facilitate the visualization of conditions of inventories, demand and supply from upstream to downstream of the quality labelled food supply chain and it will provide valuable situational awareness tools for food actors to align their capabilities to mitigate disruptive impacts. The specific KPI will be assessed during the pilot demonstration phase.

1.3. Document Structure

The document is structured in 7 major Sections. Executive summary provides a summary of the whole document. Section 1 introduces the main purpose and scope, the relation to project work and the structure of this deliverable. Section 2 provides an overview of the ALLIANCE concept and introduces the ALLIANCE Reference Architecture that provides a comprehensive overview, transitioning from the Logical Architecture (described in the DoA) to the Reference Architecture encompassing all the different technology solutions of WP2 and WP3. The digital transformation of the food value chains utilizing the Blockchain technologies is given in Section 3, while Intelligent Food Supply Chain Systems are described in Section 4 to elucidate the mechanisms how AI can be utilized to provide early warnings and decision support against food fraud. Section 5 describes the Vulnerability Risk Assessment for the identification of the critical control points of the food value chains, while Section 6 describes the overview to enable interoperability between food supply chains. Lastly, Section 7 concludes the document and provides an overview of the next steps.

2 System Architecture

2.1 Overview

The ALLIANCE architecture consolidates key technologies and data processing layers, such as the **Data Acquisition**, **Data Management** and **Application** layers, as depicted in Figure 1. It is actually a wholistic approach for FSCs that encompasses the entire process of gathering and utilizing data related to them, from data harvesting to data consumption.

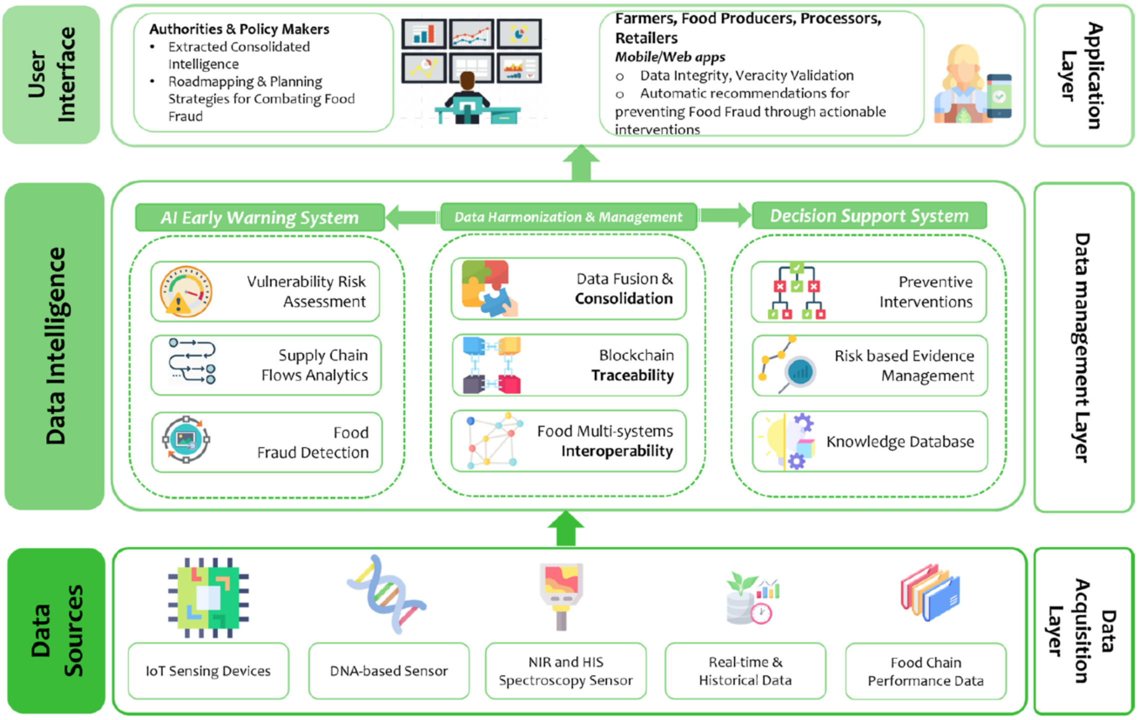


Figure 1: The ALLIANCE Logical Architecture from DoA.

Below, we present more precisely the components existing at the three layers of the ALLIANCE architecture, as well as their interactions. Almost all components are half-mature, since the project is currently in M18, which is in the midst of almost all tasks (T2.2-T2.5 & T3.2-T3.4) producing these components (started in M5 and scheduled to conclude in M30), apart from the less mature result of T5.4 that recently started in M15 and will go until M36. The final D2.4 in M30 will present a more refined architecture that will include the final versions of these components and their interactions. Below we present the current status of the ALLIANCE architecture, following a bottom-up approach, according to which:

1. The first layer is the **Data Acquisition** layer. It includes the data sources, which currently are of three types. It is modular and allows for dynamic extension with additional data sources during the project lifetime or even after its expiration. The two types of data sources are the **DNA-based** and the **NIR & HSI** (Near-Infrared & Hyperspectral Imaging) **Spectroscopy sensors** (results of T3.2 & T3.3, presented in D3.2), and the third type is the **Historical data** that is retrieved from the local databases of the actors involved in the FSCs (result of T2.2).

2. The second layer is the **Data Management** layer, which is responsible for the data processing and consists of three systems: **Data Harmonization, AI Early Warning** and **Decision Support** systems. In turn,
    2.1. The **Data Harmonization** system consists of the **Data Interoperability** process (result of T2.5) that harmonizes the data, which are stored right after in the **Blockchain** and **Off-chain** databases (results of T2.2).
    2.2. The **AI Early Warning** system consists of **VRAMF** (Vulnerability Risk Assessment Management Framework, result of T2.3) and a process of the same name, which is the first half of **EWDSS** (Early Warning Decision Support System, result of T2.4). The AI Early Warning process uses the stored data in the Blockchain and Off-chain databases to detect potential food frauds and interacts with **VRAMF**, which continuously exploits the produced warnings to identify the critical control points in the FSCs.
    2.3. The **Decision Support** system (result of T2.4) consists of a process of the same name that is the other half of **EWDSS**, which is fed by the AI Early Warning system and suggests actions to the administrator to mitigate the possibilities of food frauds. This system also includes the **Knowledge Database** (result of T3.4, presented in D3.2), which uses data retrieved by the Blockchain and Off-chain databases and the Internet open datastores to create a broader collection of information that is related to food fraud.
3. Finally, the third layer is the **Application** Layer that includes Mobile/Web Applications, which enable end users to interact with the FSCs. These applications include the **Blockchain App** (result of T2.2), the **Decision Support App** (result of T2.4), the **Knowledge Database App** (result of T3.4), the **Food Fraud Prevention system** (result of T3.5) and the **Marketplace** (result of T5.4). The Blockchain App is used for interacting with the databases, the Decision Support App exports the results of the data analysis, the Knowledge Database App interacts with external sources from the Internet and the Marketplace handles the industrial data. Figure 2 illustrates all these interactions between the aforementioned components, presenting the aforementioned layers in a left-to-right manner rather than a bottom-up one.

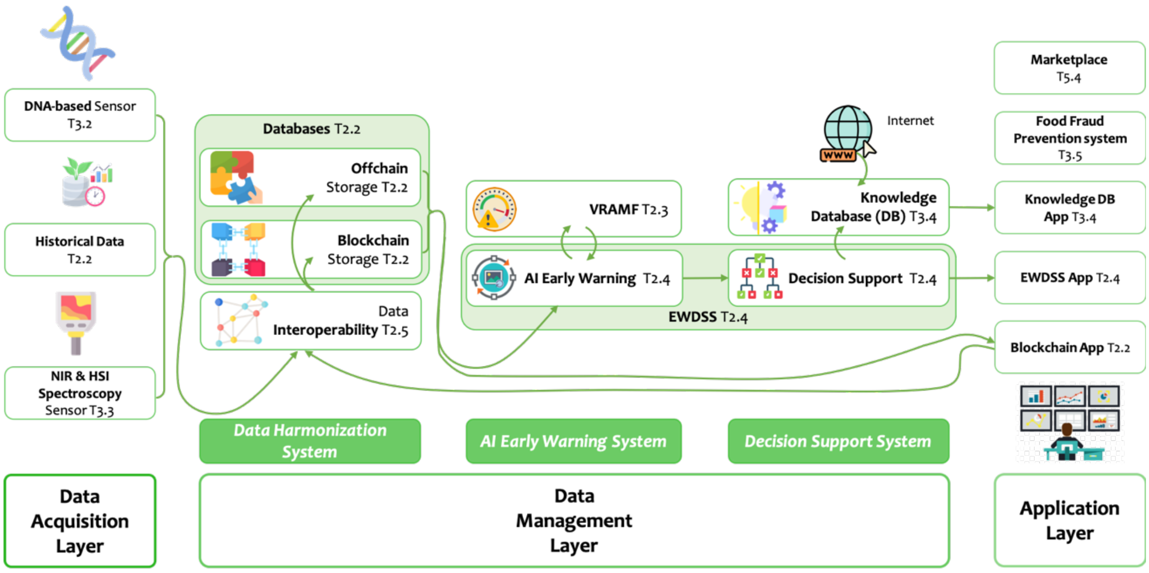


Figure 2: The ALLIANCE Reference Architecture.

2.2 Information Flow

Prior to delving into a more intricate explanation of the components of ALLIANCE situated at the three layers, we will provide the **information flow for the 7 FSCs** that have been created in this project, **focusing on the data stored in the two databases, Blockchain and Off-chain**. These FSCs correspond to the following products:

- *PDO/PGI Extra Virgin Olive Oil* (referred from now on as ***Olive Oil*** for simplicity reasons)
- *PDO Feta Cheese* (referred from now on as ***Feta Cheese*** for simplicity reasons)
- ***Organic Honey***
- *PGI Asturian Faba Beans* (referred from now on as ***Faba Beans*** for simplicity reasons)
- *PGI Lika Potatoes* (referred from now on as ***Lika Potatoes*** for simplicity reasons)
- ***Organic Pasta***
- *PDO Arilje Raspberries* (referred from now on as ***Arilje Raspberries*** for simplicity reasons)

In the following subsections, we describe in detail the information flow of each FSC.

2.2.1 Information Flow in the Olive Oil FSC

The main stakeholder in the Olive Oil FSC is CIAUM, which participates with workers of 7 different roles, namely the i) *Producer*, ii) *Reception Manager*, iii) *Milling Manager*, iv) *Packaging Manager*, v) *Storage Manager*, vi) *Distribution Manager* and vii) *Quality Control Manager*, which are presented in Figure 3 and their detailed description is given below.

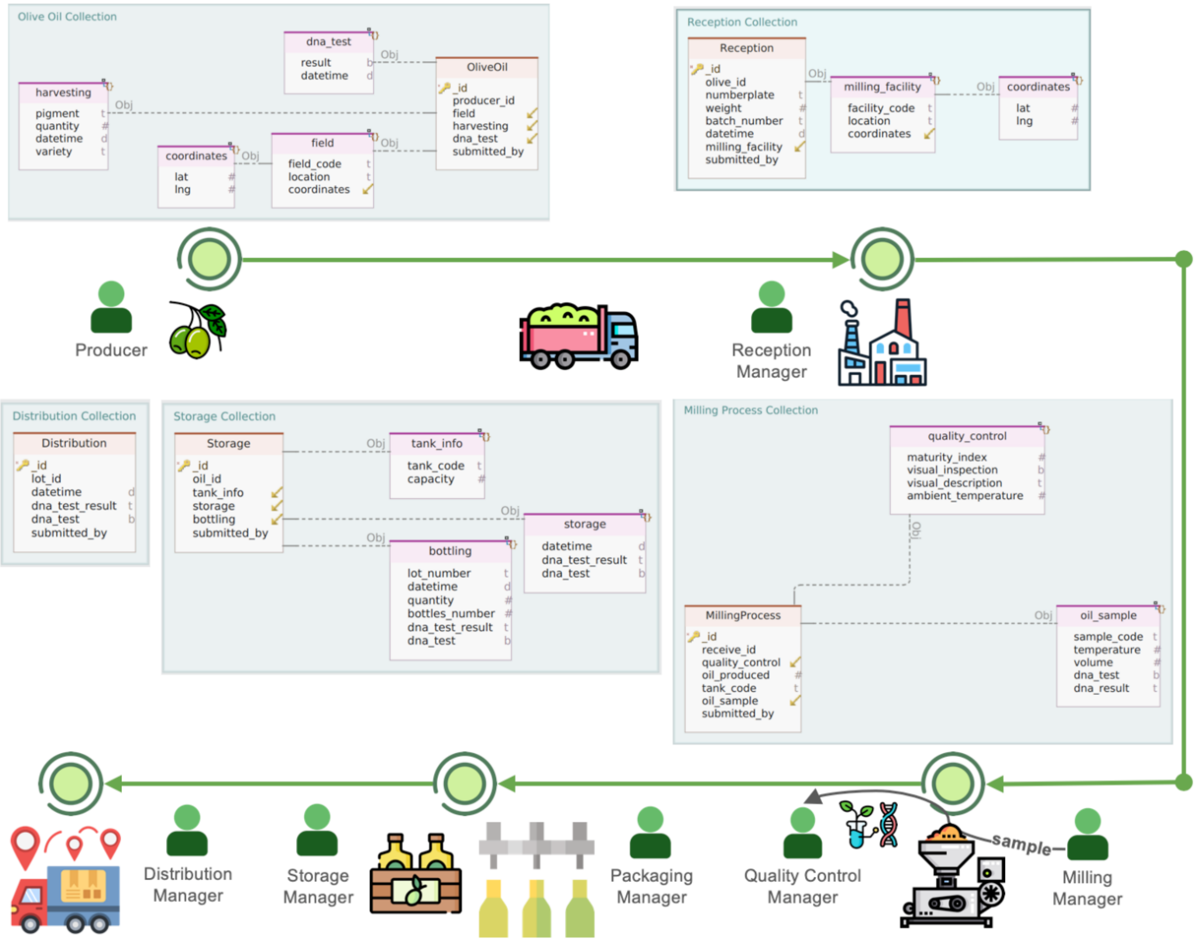


Figure 3: Information Flow of the Olive Oil FSC.

The Olive Oil FSC commences with the harvesting of olives from *Producers*. The *Producer*, deeply knowledgeable about the intricate connection between the quality of olive oil and the nuances of the harvest, conducts thorough inspections of the olive fruit. This critical evaluation allows the *Producer* to determine the optimal harvest date, a decision influenced by a variety of factors including the fruit's pigmentation index. The chosen date reflects the producer's expertise in balancing the desired olive oil quality attributes, which are significantly influenced by the timing of the harvest. Following the harvest, the *Producer* then undertakes the task of transporting the freshly collected olives to the milling company. This step is pivotal in the olive oil production process, as timely and careful transportation of the olives is crucial to preserving their quality and ensuring that the resulting olive oil meets the high standards expected of olive oil. This seamless transition from harvest to milling is essential for capturing the olives' optimal flavours and health benefits, underlying the importance of the grower's decisions and actions in producing premium olive oil. The recorded data during this stage includes:

Olive Oil		
Producer id	used to identify the producer who cultivated the olives	
Field	information containing details such as:	
	Field code	unique id used to identify the field
	Location	of the field
	Coordinates	of the field

Harvesting	Information regarding the harvesting process, such as:	
	Pigment	of the harvest
	Quantity	of the harvest
	Date&time	of the harvest
	Variety	of the harvest
DNA test	**Result**	of the DNA test, pass of fail
	Date&time	of when the test was conducted

The *Producer*, upon harvesting the ripe olives, transports the collected fruit to the milling company. This crucial step is meticulously planned by the *Reception Manager* to ensure the olives are milled as soon as possible after harvesting to preserve their quality and to maximize the oil's aroma and nutritional properties. The transportation of the olives is a delicate process, as the fruit must be handled carefully to prevent bruising and damage that could affect the quality of the oil. The swift and careful transport of olives from the grove to the mill is essential for producing high-quality olive oil. The data recorded during this transportation stage includes:

Reception		
Olive id	used to identify the origin of the olives, connected to the previous step	
Number plate	of the truck used for the transportation	
Weight	of the olives	
Batch number	of the harvested olives	
Date&time	of the reception	
Milling facility	information, including:	
	Facility code	unique id used to identify the facility
	Location	of the facility
	Coordinates	the geolocation of the facility

The *Milling Manager* is responsible for the olive milling, which is a crucial step in the production of olive oil, where the harvested olives are transformed into oil. This process requires precise control and documentation to ensure the quality and characteristics of the final product, especially for PDO olive oil. The *Quality Control Manager* conducts a visual assessment of the fruit, evaluating its condition, level of ripeness, and any signs of damage or disease that could affect the quality of the oil. Moreover, leveraging BIOCOS technology, the *Quality Control Manager* conducts DNA tests on the olive, a sophisticated step in the quality assurance process. This cutting-edge technology enables the precise verification of the olive's origin, confirming its geographical production region, and assessing its quality. This assessment is pivotal in ensuring that only the best quality olives proceed to the next stage. With the initial evaluations complete, the *Quality Control Manager*, who may also be an agronomist with specialized knowledge in olive cultivation and oil production, oversees the commencement of the milling process. This process involves crushing the olives and extracting the oil, a critical phase where the quality and characteristics of the olive oil are significantly influenced by the handling and treatment of the fruit. Throughout this journey from tree to mill, the emphasis on quality and meticulous handling underscores the commitment to producing superior olive oil. The data recorded during the milling stage includes:

Milling Process		
Receive id	used to connect this stage to the reception stage	
Quality control	includes the following parameters:	
	Maturity index	of the olives

	Visual inspection	of the olives
	Visual description	of the olives
	Ambient temperature	of the olives
Oil produced	quantity of Olive Oil	
Tank code	where the produced Olive Oil will be stored	
Oil sample	used to ensure the desired characteristics, including the following information:	
	Sample code	used to identify the sample
	Temperature	of the sample
	Volume	of the sample
	DNA test	pass or fail
	DNA results	text informing of the DNA test

After milling, the *Storage Manager* registers the information regarding the storage of the newly extracted olive oil in tanks within the facility's storage area, awaiting the bottling phase. When the time for bottling arrives, the *Packaging manager* submits a form informing the system about the bottling of the olive oil. Each tank of olive oil is assigned a unique LOT number, ensuring traceability and quality control. This meticulous process ensures that each bottle of olive oil maintains the highest standards of purity and taste. The data recorded during the packaging stage includes:

Storage		
Oil id	to determine the oil that will be stored	
Tank information	including tank code and maximum capacity	
Storage	information such as:	
	Date&time	of storage
	DNA test	flag indicating if a DNA test was carried out during the storage phase
	DNA test result	the results of the respective DNA test if it was carried out
Bottling	information such as:	
	LOT number	used to identify the sample
	Date&time	of the sample
	Quantity	of the sample
	Bottles number	how many bottles have been produced
	DNA test	flag indicating if a DNA test was carried out during the bottling phase
	DNA test result	the results of the respective DNA test if it was carried out

The final stage of the supply chain is marked by the distribution of the end products to retailers, with MASOUTIS being the designated retailer in this instance. This distribution is carried out by the *Distribution Manager*, through a dedicated fleet of trucks, which ensure the efficient delivery of products to MASOUTIS distribution centers. To maintain rigorous quality control and traceability, the LOT number corresponding to the distributed olive oil is meticulously recorded in a database. This systematic tracking enables MASOUTIS to verify the lineage and quality of the products at any point in time. Furthermore, MASOUTIS has the capability to conduct DNA testing on a selection of the received bottles. This advanced testing method is employed to verify the authenticity and quality of the olive oil, ensuring that the products adhere to the high standards expected by both the retailer and its customers. The collected data in this stage is:

Distribution	
LOT id	the LOT number of the previous step
Date&time	when the distribution started
DNA test	flag indicating if a DNA test was carried out during the distribution phase
DNA test result	the results of the respective DNA test, if it was carried out

2.2.2 Information Flow in the Feta Cheese FSC

The main stakeholder in the Feta Cheese FSC is OLYMPOS, which participates with workers of 7 different roles, namely the i) *Truck Driver*, ii) *Reception Manager*, iii) *Pasteurization Manager*, iv) *Production Manager*, v) *Storage Manager*, vi) *Distribution Manager* and vii) *Quality Control Manager*, which are presented in Figure 4 and their detailed description is given below.

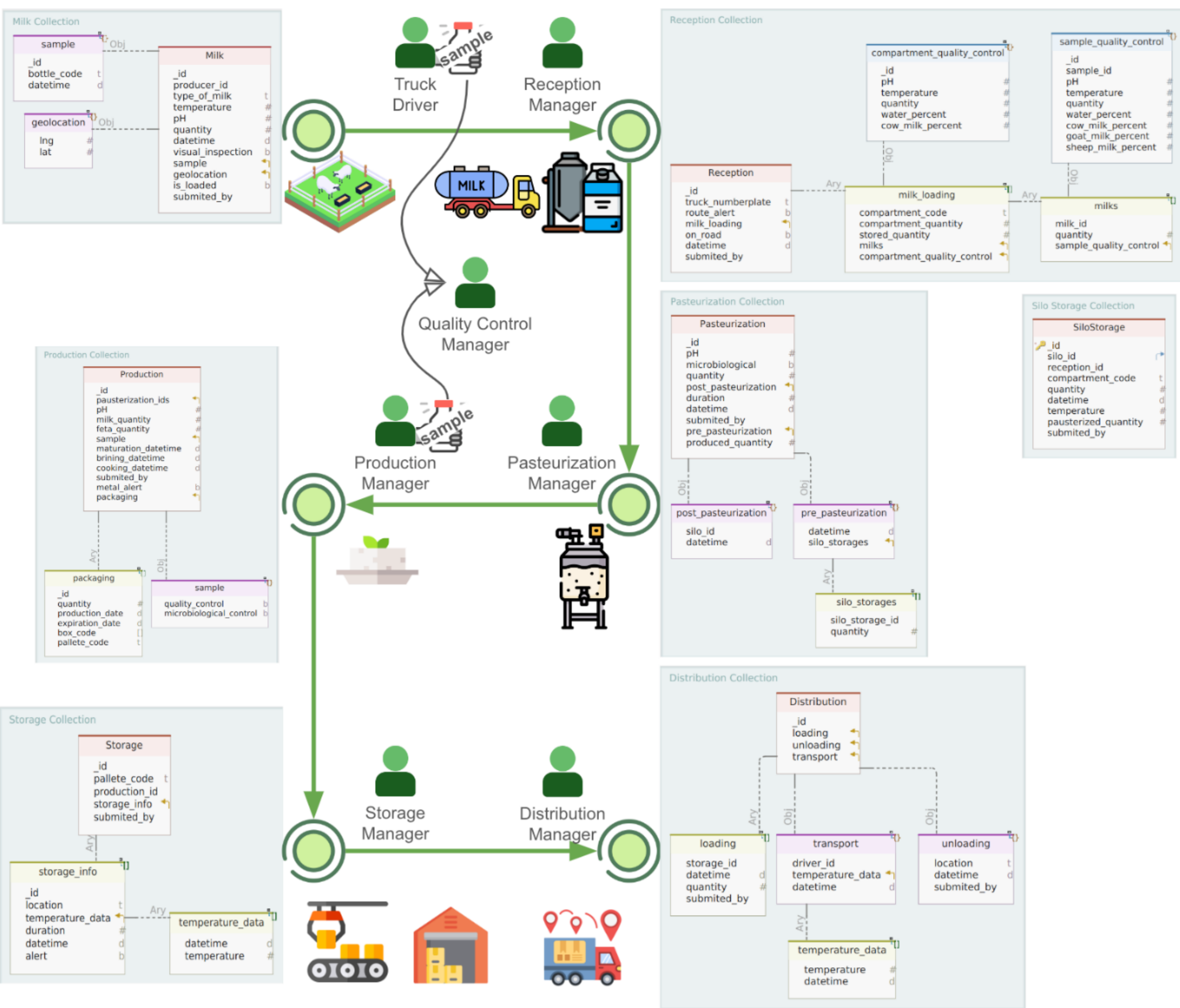


Figure 4: Information Flow of the Feta Cheese FSC.

The Feta Cheese FSC commences with the collection of milk from producers. The *Truck Drivers*, following predetermined routes, gather milk from various sources, ensuring its freshness by storing it in icebox-equipped compartments within the truck. Additionally, for the purpose of later conducting quality control tests, *Truck Drivers* take samples of the collected milk, storing these in specifically designated bottles. Throughout this process, *Truck Drivers* meticulously record various parameters related to the milk collection. This critical data is then systematically submitted to the Alliance platform via detailed forms, encapsulating essential information for quality assurance and traceability. This methodical approach not only ensures the integrity and quality of the milk from the outset but also lays the groundwork for a transparent and efficient FSC operation. The collected data in this stage is:

Milk		
Producer id	specifying the producer from who the milk was produced	
Type of milk	either Goat or Sheep milk	
Temperature	of the milk at the time of the collection	
pH	of the milk	
Quantity	of the milk collected	
Date&time	of the milk collection	
Visual inspection	conducted from the truck driver to identify any potential issues	
Sample	of the collected milk taken from the truck driver and stored in a small bottle separately to be given for quality control. This data includes:	
	Bottle code	of the sample
	Date&time	of when the sample was taken
Geolocation	of the collected milk	
Is loaded	indicates if the milk is loaded to the truck	

Once the milk has been collected, the next step is to transport it to the facilities of OLYMPOS. The *Truck Driver* is once again responsible for loading the milk into the truck and transporting it to OLYMPOS. The milk is loaded into the compartments of the truck and transported to the factory where it will be received by the *Reception Manager*. The collected data is:

Reception		
Truck numberplate	of the truck	
Route alert	used to indicate if an alert was issued during the transportation of the milk	
Milk loading	the compartment of the truck that milk is loaded. This data includes:	
	Compartment code	where the milk is loaded
	Compartment quantity	
	Stored quantity	of milk to silos after reception
	Milks	array of identified milk quantities
	Compartment quality control	sample results
Date&time	of the reception	
On road	flag to indicate if the truck has arrived at the factory	

Upon the truck's arrival at the factory, the *Reception Manager*, responsible for overseeing the milk's intake, meticulously records the date and time of reception. Following this initial step, the manager then proceeds to facilitate the transfer of milk into designated storage silos.

Throughout this stage, a series of critical data points are collected to ensure thorough documentation and traceability of the milk. The collected data is:

Silo Storage	
Silo id	Which silo is used for the milk storage
Reception id	that identifies a milk reception of the previous step
Compartment code	in which compartment the milk was stored in during transportation
Quantity	the quantity of the stored milk
Pasteurized quantity	the quantity of the pasteurized milk
Temperature	of the milk
Date&time	of the storage of the milk

The *Pasteurization Manager* tasked with pasteurizing the raw milk begins the critical process of eliminating harmful bacteria and pathogens. This process involves heating the milk to a precisely controlled temperature for a specified duration, effectively neutralizing potential disease-causing microorganisms. Following the pasteurization, the same manager oversees the careful storage of the now-pasteurized milk, ensuring it is kept under optimal conditions to maintain its quality and safety.

In tandem, the *Quality Control Manager* conducts thorough quality and microbiological assessments. These controls are designed to verify that the pasteurization process has successfully achieved its goal of sterilizing the milk, ensuring it meets stringent health standards and is safe for consumption. This meticulous approach to monitoring ensures the highest quality of dairy products, safeguarding public health and upholding the integrity of the production process. The collected data in this stage is:

<table>
<tr><th colspan="3">Pasteurization</th></tr>
<tr><td>pH</td><td colspan="2">of the milk</td></tr>
<tr><td>Microbiological</td><td colspan="2">control used to ensure that no pathogens or microbes are present after the pasteurization process</td></tr>
<tr><td>Quantity</td><td colspan="2">of the pasteurized milk</td></tr>
<tr><td>Produced quantity</td><td colspan="2">how much milk has been removed for production</td></tr>
<tr><td>Duration</td><td colspan="2">of the pasteurized process</td></tr>
<tr><td>Date&time</td><td colspan="2">of when the process began</td></tr>
<tr><td rowspan="3">Pre-pasteurization</td><td colspan="2">Information related to the silo used for the milk storage. This data includes:</td></tr>
<tr><td>Silo id</td><td>The id of the used silo</td></tr>
<tr><td>Date&time</td><td>when the milk was stored</td></tr>
<tr><td rowspan="3">Post-pasteurization</td><td colspan="2">Information related to the silo used for the storage of the pasteurized milk. This data includes:</td></tr>
<tr><td>Silo storages</td><td>Array of the ids of the used silos</td></tr>
<tr><td>Date&time</td><td>when the milk was stored</td></tr>
</table>

Before the commencement of feta cheese production, the *Quality Control Manager* rigorously verifies the milk's quality through various checks. This critical step ensures the milk's suitability for transforming into high-quality feta cheese, meeting all required standards. Subsequently, the *Production Manager* begins the intricate cheese-making process. This involves several key steps, such as Coagulation (the milk is coagulated using rennet or acidic substances, causing it to solidify), Curd Cutting (the solidified milk, now curd, is carefully cut into smaller pieces to facilitate whey separation), Stirring (the cut curd is gently stirred, further encouraging the separation of curds and whey), Cooking (the curds are cooked at a controlled temperature, enhancing their texture and flavour), Draining (excess whey is drained from the curds, concentrating the cheese), Salting (salt is added for flavour and as a preservative) and Pressing (the curds are pressed into molds, shaping the cheese and removing any remaining whey).

After these steps, the *Quality Control Manager* conducts samples for quality and microbiological analysis to ensure the cheese meets all safety and quality criteria. Following the initial processing, the *Production Manager* initiates the maturation and brining phase, where the cheese is aged in a brine solution to develop its characteristic flavor and texture. Before packaging, the cheese undergoes a final safety check for metal particles using a metal detector, ensuring the product is safe for consumption and free from any contaminants. This thorough process from milk quality verification to final product checks ensures that the feta cheese produced is of the highest standard, ready for packaging and distribution. The collected data in this stage is:

Production		
Pasteurization ids	indicating the pasteurized milk used for the production of feta cheese	
pH	of the pasteurized milk	
Milk quantity	used for the produced cheese	
Feta quantity	produced	
Matur/ion date&time	of when the cheese is maturated	
Brining date&time	of when the cheese is brined	
Cooking date&time	of when the cheese is cooked	
Metal alert	used to ensure that cheese is free from metal contaminants	
Sample	used for quality control. This data includes:	
	Quality control	flag indicating if the sample passed all checks
	Microbiological control	ensures the absence of pathogens
Packaging	identifies individual packages of feta cheese.	
	Quantity	of the package
	Production date	the date that package was produced
	Expiration date	the date that package is expired
	Box code	identifies the box that this package is in
	Pallete code	identifies the pallete that this package is in

Upon reaching the final stage of production, the feta cheese undergoes packaging through automated machines, precisely portioning it into 200g packages. Each package is meticulously labelled to include a PDO quality certification, which attests to its authenticity and adherence to traditional production methods specific to its geographical origin. Additionally, a coded label is affixed to provide essential product information such as quantity, lot number, production date, and expiration date, ensuring traceability and consumer safety. Multiple packages are grouped in a box, and multiple boxes are grouped again to form a pallet. Following packaging, the pallets of feta cheese are then transferred to the OLYMPOS refrigerating warehouse, where it is stored by the *Storage Manager* under optimal conditions to maintain its quality until distribution. The warehouse's storage temperature is rigorously monitored around the clock. A sophisticated alert system is in place to notify management if the temperature rises above a predetermined threshold, signalling potential risk to the product's integrity. If the temperature issue persists, proactive measures are taken to relocate the products to another compartment within the warehouse, safeguarding them against spoilage. This meticulous approach to packaging, labelling, and storage ensures that the feta cheese retains its high quality, safety, and freshness from production to delivery at retailing or wholesale outlets.

Storage		
Production id	indicating the production from which the Feta came from	
Pallet code	indicating the pallet of the cheese packages	
Storage info	regarding the storage warehouse conditions such as:	
	Location	The location of the storage warehouse
	Temperature data	array of multiple temperatures at different times
	Duration	of the storage
	Date&time	that storage occurred
	Alert	triggered when the storage conditions drop below a pre-designated standard

The *Distribution Manager* tasked with managing feta cheese orders takes a proactive role in fulfilling wholesale customer requests. Upon receiving an order, he/she meticulously compile it in accordance with the specific needs and preferences of the wholesale customer. This process involves not only the selection of the appropriate quantities and types of feta cheese but also a careful consideration of the logistics involved in delivering these orders efficiently and safely. To ensure the seamless transportation of feta cheese products to the retailers' facilities, which are the MASOUTIS distribution centers, the *Distribution Manager* develops a detailed routing and scheduling table. These centers act as crucial hubs, distributing the products to various MASOUTIS markets to meet consumer demand. This thoughtful and organized approach to order fulfilment and logistics underscores the commitment to customer satisfaction and operational efficiency, ensuring that the delivery of feta cheese to retail and wholesale outlets is managed smoothly and effectively.

Distribution		
Loading	information regarding the loading process, such as:	
	Storage id	from where the packaged feta cheese came from
	Date&time	of the loading process
	Quantity	of the total loaded quantity
Transport	information of the transportation process, such as:	
	Driver id	the driver that is responsible for this transportation
	Temperature data	array of temperatures at various moments
	Date&time	of the transportation process
Unloading	information regarding the unloading process, once the truck has reached the destination, such as:	
	Location	of the unloading process
	Date&time	of the unloading process

2.2.3 Information Flow in the Organic Honey FSC

The main stakeholder in the Organic Honey FSC is HONEY ASSOC, which participates with workers of 5 different roles, namely the i) *Beekeeper*, ii) *Association Manager*, iii) *Packaging*

Manager, iv) *Storage Manager*, and v) *Quality Control Manager*, which are presented in Figure 5 and their detailed description is given below.

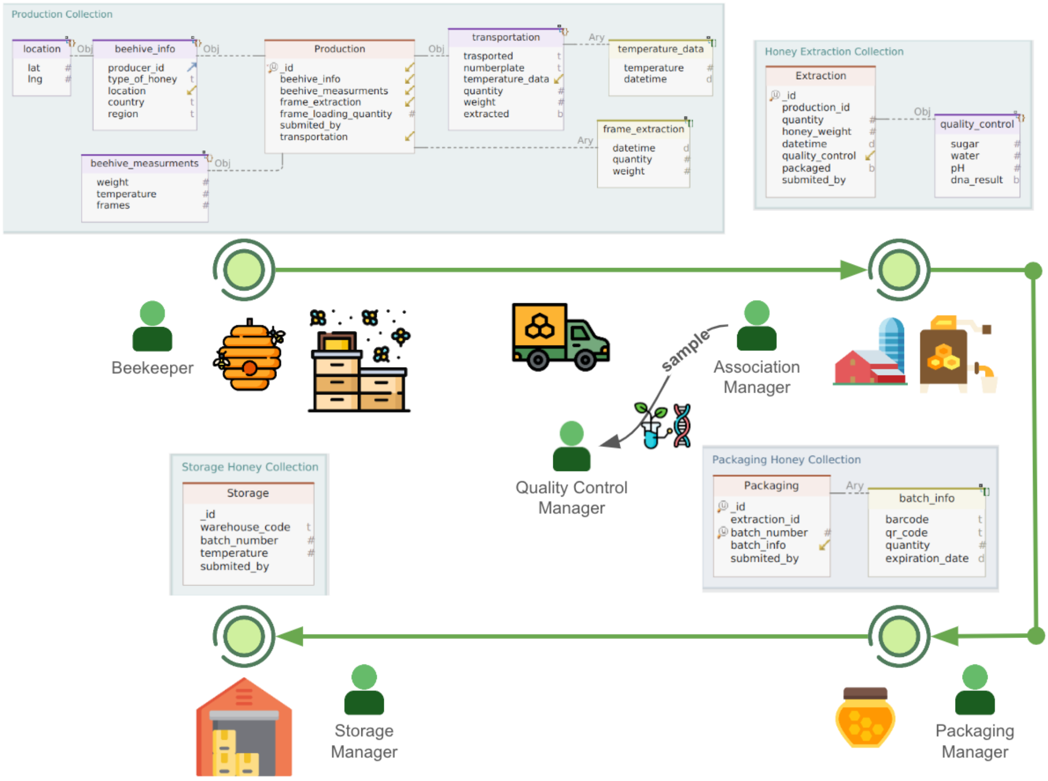


Figure 5: Information Flow of the Organic Honey FSC.

The Organic Honey FSC commences with the collection of honey from *Beekeepers*. The *Beekeeper* plays a crucial role in initiating the process. The first step involves strategically placing the hive in a specific location, selected for its abundance of flora that bees can forage, thus kick-starting the honey production cycle. Within each hive, numerous frames are installed, serving as spaces where bees can build their wax combs and store honey. Harvesting the honey is a careful, phased process, dictated by the readiness of each individual frame. Not all frames become ready for harvesting simultaneously; their readiness depends on the bees' efficiency in filling them with honey and the availability of nectar sources. The beekeeper meticulously monitors the progress within each frame, deciding on the perfect timing for harvest to ensure the highest quality honey. Crucially, the beekeeper maintains detailed records of the harvesting process. This includes the specific dates when honey is extracted and the identification of the frames removed from the hive. Such documentation is essential for tracking the production process, understanding the yield patterns, and ensuring the traceability of the honey. This thorough approach underlines the beekeeper's commitment to quality and the sustainable management of the hives, contributing to the overall integrity and value of the honey produced.

Once all the frames within a hive are ready for harvest, the Beekeeper carefully transports them from the production site to the extraction facility. This transportation is meticulously planned to ensure that the frames, filled with mature honey, are moved only when they have been completely utilized by the bees, optimizing the yield and quality of the honey. The process of transporting these frames is critical; it requires careful handling to preserve the integrity of the honeycomb and prevent any loss or contamination of the honey. This step marks a significant phase in the journey from hive to consumer, transitioning from the natural process of honey collection by the bees to the human-led process of honey extraction and preparation for consumption. More specifically the production details include:

Production		
Beehive info	describes the beehive, including information such as:	
	Producer id	Identifies the honey producer
	Type of honey	if it is blossom, forest, etc. honey
	Location	of honey using coordinates
	Country	of honey
	Region	of honey
Beehive measurements	including measurements related to the beehive:	
	Weight	of beehive
	Temperature	of beehive
	Frames	the number of frames included in the beehive
Frame extraction	array with data for each extracted frame:	
	Quantity	of extracted frames
	Weight	of extracted frames
	Date&time	of extraction
Frame loading quantity	the number of frames that are still loading	
Transportation	Information related to the transportation of the beehives:	
	Transported	flag indicating if the frames of hive are transported
	Numberplate	of track that does the transportation
	Quantity	of the received frames
	Weight	of the received frames
	Extracted	flag indicating if the extraction happened
	Temperature data	Array with temperatures of different moments

Upon arrival at the extraction facility, the *Association Manager* takes charge of the honey frames. This worker is responsible for carefully recording essential details about the incoming frames, including the quantity of frames received and the specific id or location of the facility where the extraction will take place. This documentation is crucial for maintaining an organized workflow and ensuring traceability of the honey from hive to bottle. Following the recording process, the *Association Manager* then proceeds to extract the honey from the frames using a honey extractor. This machine centrifugally forces the honey out of the comb without damaging the wax, allowing the frames to be reused by the bees. The extraction process is carefully managed to preserve the honey's natural flavors and properties, ensuring that the final product retains all the beneficial qualities of raw honey. Through these steps, the *Association Manager* plays a key role in transforming the raw honey collected from the frames into a form that is ready for further processing and eventually, consumption.

Then, leveraging BIOCOS technology, the *Quality Control Manager* conducts DNA tests on the extracted honey, a sophisticated step in the quality assurance process. This cutting-edge technology enables the precise verification of the honey's origin, confirming its geographical production region, and assessing its quality. DNA testing is particularly crucial for distinguishing the honey's floral sources, ensuring its purity, and validating claims regarding its organic or specific varietal status. This advanced method of quality control plays a vital role in maintaining the integrity of the honey, offering consumers assurance about the authenticity and safety of the product. By analyzing the DNA present in the honey, the cooperative can detect potential adulteration, mislabeling, or contamination, thereby upholding high standards of quality and transparency in the honey production process. This technology empowers the cooperative to guarantee that the honey not only meets the expected quality parameters but also faithfully represents its stated origin and production practices. The data collected is:

Honey Extraction		
Production id	referring to the previous production stage	
Quantity	of the frames	
Honey weight	specifying the quantity of the extracted honey	
Date&time	of the extraction	
Packaged	flag indicating if the extracted honey is packaged	
Quality control	the results of the quality control, including:	
	Sugar	percentage of sugar in the honey
	Water	percentage of water in the honey
	pH	of the honey
	DNA result	the results of the BIOCOS DNA test on honey

After the extraction process, under the view of the *Packaging Manager*, the honey is carefully poured into containers, available in various sizes such as 250g, 500g, and 1000g, made of either glass or plastic. These containers are chosen to preserve the honey's quality and ensure its longevity, allowing consumers to enjoy the product at its best. In a move towards transparency and traceability, the *Association Manager* then utilizes blockchain technology to access vital information about each batch of honey. This innovative approach ensures that all data related to the honey's origin, production region, and quality checks is securely stored and easily verifiable. Leveraging this information, labels are printed that contain a wealth of details about the honey, possibly including its floral source, harvest date, and any certifications it may hold. These labels are then meticulously affixed to the jars, providing consumers with a direct link to the honey's journey from hive to jar. This process not only enhances consumer trust in the product's authenticity and quality but also represents a significant step forward in the integration of modern technology with traditional honey production practices, setting a new standard for transparency in the food industry. The data collected is the following:

Packaging Honey		
Extraction id	referring to the honey extraction from the previous stage	
Batch number	of the packaging process	
Batch info	array containing the following information:	
	Barcode	of the jar
	QR code	of the jar
	Quantity	of the jar
	Expiration Date	of the jar

Finally, the Storage Manager is responsible for the safe storage of the packaged organic honey into warehouses. The respective data are the following:

Storage Honey	
Warehouse code	where the jars are stored

Batch number	to be stored
Temperature	of the warehouse

2.2.4 Information Flow in the Faba Beans FSC

The main stakeholder in the Fava Beans FSC is IGPFA, which participates with workers of 3 different roles, namely the i) *Producer*, ii) *Packaging Manager* and iii) *Certification Body Manager*, which are presented in Figure 6 and their detailed description is given below.

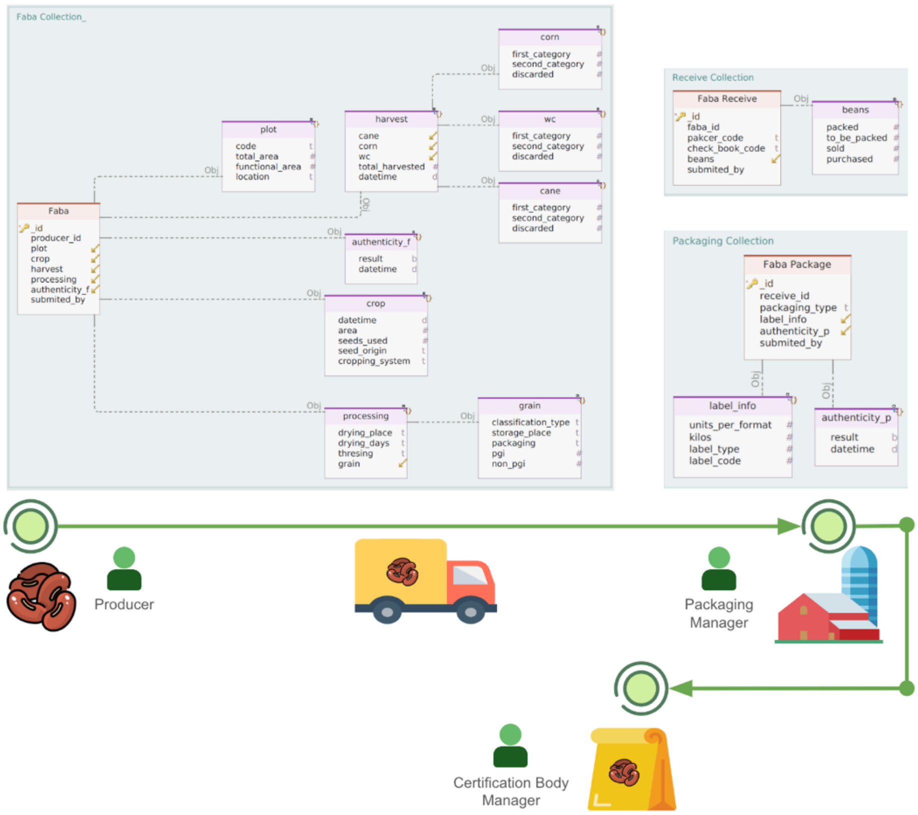


Figure 6: Information Flow of the Faba Beans FSC.

The Faba Beans FSC commences with the collection of faba beans from *Producers*. Asturian faba beans are large, ivory-white beans that are produced in Asturias (Spain). The *Producers* are responsible for cultivating and harvesting the Asturian faba beans. To ensure traceability and quality control, the *Producer* is required to complete specific forms providing essential information about the cultivation process. After harvesting, the faba beans undergo processing, which involves cleaning and sorting. The *Producer* is required to provide details of the processing activities in a comprehensive form. This form captures critical aspects of the processing phase, ensuring consistency and quality standards are met. Following processing, the faba undergoes authenticity control utilizing the innovative ALLIANCE tool. Specifically, portable NIR and HSI techniques are employed to identify food fraud in Faba beans. Faba beans failing to meet the required standards are discarded. The overall information collected includes:

Faba	
Producer id	identifies the *Producer*
Plot	details such as

	Code	identifies the plot	
	Total area	of the plot	
	Functional area	of the plot	
	Location	coordinates	
Crop	details such as		
	Date&time	the cropping date	
	Area	the cropped area	
	Seeds used	number of seeds used	
	Seed origin	the variety and origin of the seed	
	Cropping system	the cultivation system employed	
Harvest	details such as		
	Date&time	of harvesting	
	Total harvested	total amount in kilograms	
	Cane	amounts of cane classified as either first category or second category or they have been discarded	
	Corn	amounts of cane classified as either first category or second category or they have been discarded	
	WC	amounts of WC classified as either first category or second category or they have been discarded	
Processing	details such as		
	Drying place	drying location	
	Drying days	drying duration	
	Threshing	method employed	
	Grain	details such as	
		Classific. type	of the grain
		Storage place	of the grain
		Packaging type	how many kilos supports the package
		PGI	kilos not registered under PGI
		Non PGI	kilos not registered under PGI
Authenticity	details such as		
	Result	yes or no of the NIR & HSI test	
	Date&time	of the test	

Subsequent to authenticity control, the receipt stage commences. The *Packaging Manager* is responsible to procure faba from producers or other packers and can also distribute faba to other companies. Then, following reception, the packaging process begins. Each package may feature a specific packaging type and a label containing relevant information. Subsequent to packaging, the process concludes with final authenticity control by the *Certificate Body Manager*. Information pertaining to the receipt, packaging and certification includes:

Receive		
Faba id	Indicating the source production	
Packer code	unique identifier for each packaging company	
Check book code	identifies the check book	
Beans	information:	
	Packed	packed beans in kilograms

	To be packed	beans in kilograms to be packed
	Sold	beans in kilograms sold to another packing company
	Purchased	purchased beans in kilograms

Packaging		
Receive id	denoting the source of the faba for packaging	
Packaging type	number of kilos can be included in the package	
Label info	information:	
	Units per format	number of units per each category (first, second, etc.)
	Kilos	the quantity in kilograms
	Label type	(PE, 2, 3, 4, H5, H10, H25)
	Label code	identifies the package
Authenticity	data:	
	Result	outcome of the authenticity control test
	Date and time	of the test

2.2.5 Information Flow in the Lika Potatoes FSC

The main stakeholder in the Lika Potatoes FSC is AGROVELEBIT, which participates with workers of 8 different roles, namely the i) *Producer*, ii) *Certification Body Manager*, iii) *Association Manager*, iv) *Reception Manager*, v) *Storage Manager*, vi) *Packaging Manager*, vii) *Distribution Manager* and viii) *Quality Control Manager*, which are presented in Figure 7 and their detailed description is given below.

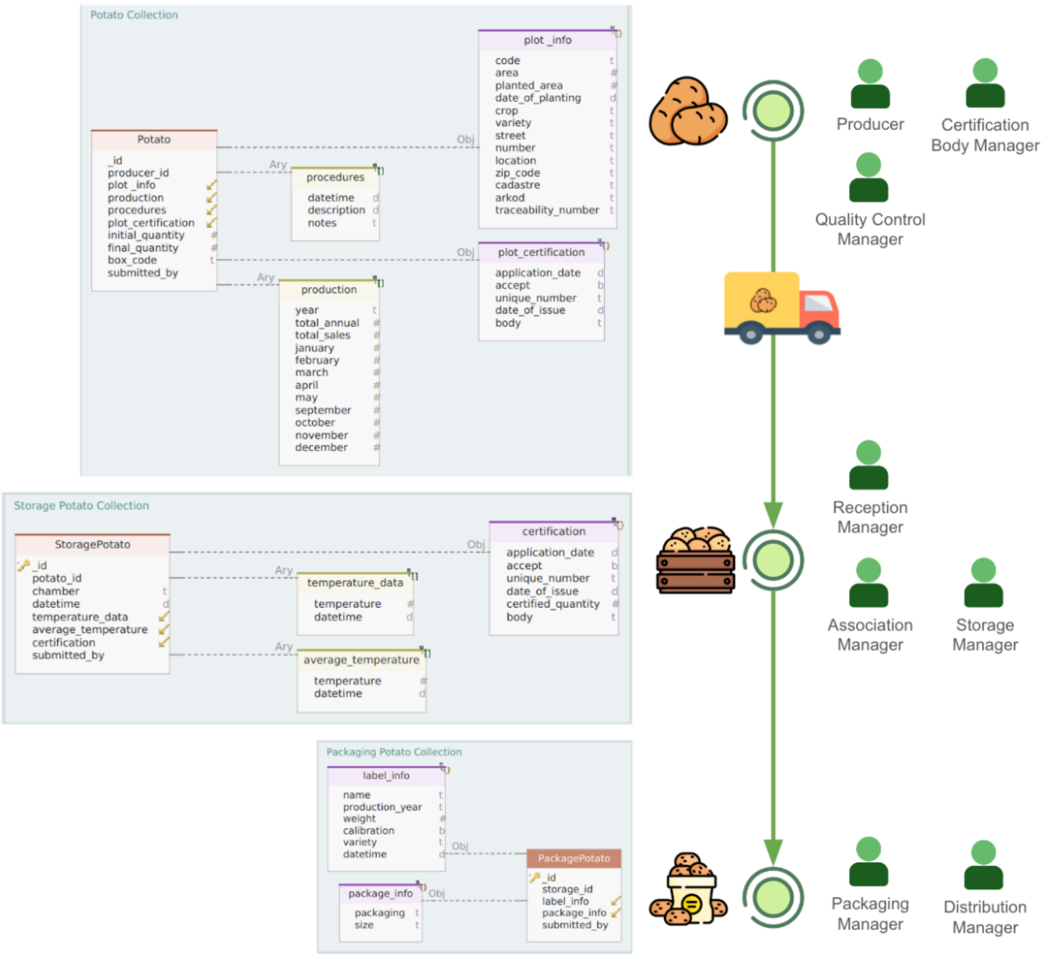


Figure 7: Information Flow of the Lika Potatoes FSC.

The Lika Potatoes FSC commences with the collection of Lika potatoes that are produced in Croatia. The *Producer*s cultivate potatoes in fields, meticulously recording origin field data. Then they apply for certification from the *Certification Body Manager*, which evaluates plot and planting records. The certification body provides acceptance or rejection responses, ensuring adherence to standards. Upon certification, during harvesting, *Producers* document details including procedures and monthly production quantities. Potatoes are transported in trailers from specific fields to the processing facility. At the processing facility, potatoes undergo thorough inspection under the supervision of the *Quality Control Manager*. Potatoes failing to meet requirements are discarded. Following inspection, potatoes pass through the production line and are packed into boxes labelled with QR codes for traceability. More specifically into database we keep:

Potato		
Producer id	Identifies the *Producer*	
Plot info	details such as:	
	Code	identifies the plot
	Area	totally area of the plot
	Planted area	totally area of the planted plot
	Date of planting	when the plot has been planted
	Crop	the crop that was planted there

	Variety	the variety of the crop
	Street	identifies the location of the plot
	Number	identifies the location of the plot
	Location	identifies the location of the plot
	ZIP code	identifies the location of the plot
	Cadastre	a comprehensive recording of the real estate or real property's metes-and-bounds of a country. Often it is represented graphically in a cadastral map.
	Arkod	number that has been collating and mapping information about agricultural land.
	Traceability number	A combination of producer's ID and Annual production plot number.
Production	harvesting and sales information:	
	Year	of production
	Total annual	production
	Total sales	of production in kilograms
	Each month	the production in kilograms per month
Procedures	details such as:	
	Date&time	that procedure happened
	Description	of the procedure
	Notes	about the procedure
Plot certification	details such as:	
	Application date	when the application has been done
	Accept	boolean variable for the acceptance result
	Unique number	of the application
	Date of issue	when the certification has been issued
	Body	about the details of application
Initial quantity	the quantity of potatoes initially in the box	
Final quantity	the quantity of potatoes in the box after the sorting	
Box code	identifies the box of potatoes	

Following the completion of filling a box pallet, the *Reception Manager* scans its QR code for identification. Subsequently, the pallet is carefully positioned by the *Storage Manager* within a dedicated storage chamber where it is maintained under controlled temperature conditions. Daily temperature checks are conducted to ensure optimal storage conditions. The potatoes remain within the chamber until an order is received. Post-storage, an application is sent by the *Producers* to a certification body, providing detailed information regarding the quantity and quality of the potatoes stored, through a traceability number that is provided by the *Association Manager*. The data maintained for storage includes:

Storage Potato	
Potato id	connects the storage with the potato production
Chamber	that is used for the storage
Date&time	of storage
Temperature data	array with multiple temperatures of various moments
Avg. temperature	array with the average temperature of various days
Certification	data such as:

	Application date	when the application has been done
	Accept	boolean variable keeping the acceptance result
	Unique number	of the certification application
	Date of issue	when the certification has been issued
	Certified quantity	how many potatoes have been certified
	Body	for more information of the application

In this final step of the process, when the forklift retrieves the box pallet from the storage chamber, it scans the QR code to identify the type of potato contained within. The pallet is then transported to the packaging room, where a thorough inspection is conducted by the *Packaging Manager*. The potatoes are meticulously cleaned using brushes to remove any dirt or debris. Subsequently, a label is generated and affixed to the packaging, and the potatoes are sorted and packed according to their size. The database retains the following information pertaining to the packaging process:

Packaging Potato		
Storage id	shows from which storage chamber was used for this package	
Label info	details such as:	
	Name	of the label
	Production year	of the potatoes
	Weight	of the package
	Calibration	boolean indicating if calibration has been done
	Variety	of the potatoes
	Date&time	of the packaging
Package info	details such as:	
	Packaging	type
	Size	of packaging

2.2.6 Information Flow in the Organic Pasta FSC

The main stakeholder in the Organic Pasta FSC is ALCENERO, which participates with workers of 9 different roles, namely the i) *Producer*, ii) *Wheat Reception Manager*, iii) *Wheat Storage Manager*, iv) *Wheat Quality Control Manager*, v) *Semolina Production Manager*, vi) *Semolina Reception Manager*, vii) *Pasta Production Manager*, viii) *Pasta Storage Manager* and ix) *Pasta Distribution Manager*, which are presented in Figure 8 and their detailed description is given below.

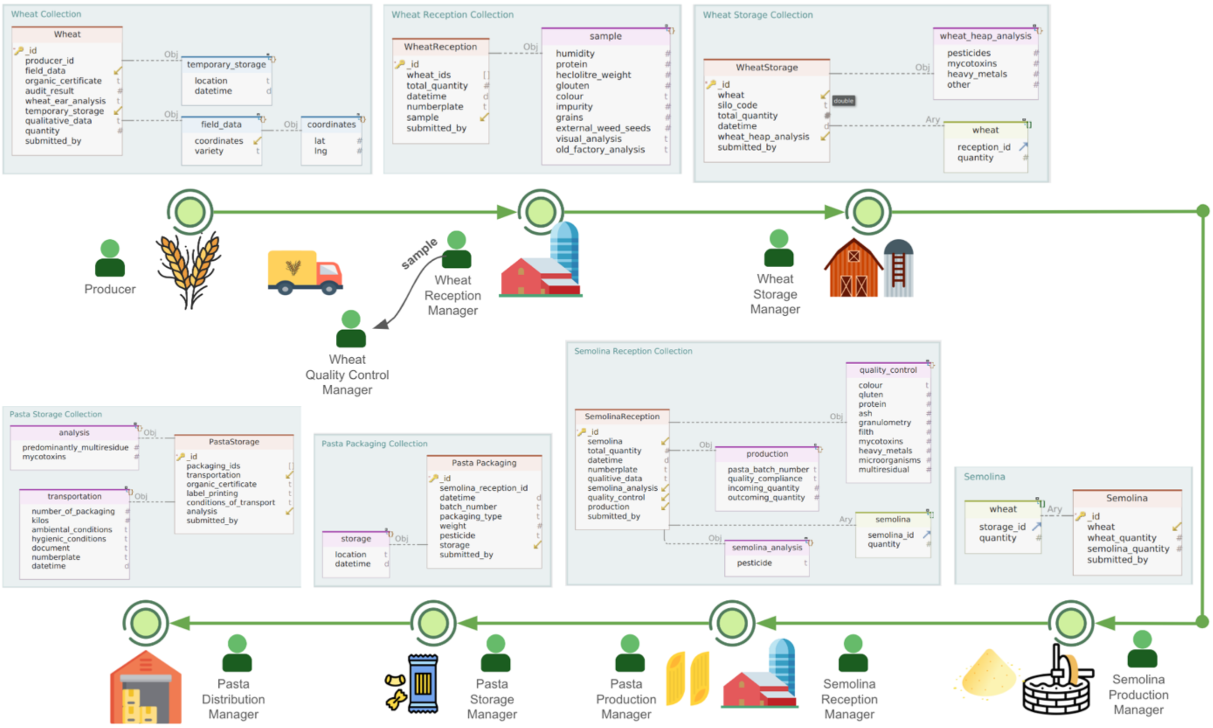


Figure 8: Information Flow of the Organic Pasta FSC.

The Organic Pasta FSC commences with the wheat cultivation from *Producers*. ALCENERO forecasts the quantity of durum wheat required for the upcoming year's pasta production and communicates this to the agronomic technical studio. This studio then allocates the needed quantities among agricultural cooperatives and individual farmers. Throughout the crop year, the studio provides ALCENERO with a list of participating *Producers* and essential documentation, such as organic certificates and the Production Annual Programme (PAP), with field books required in certain cases. Before the harvest, wheat samples may be collected from fields for pesticide residue analysis, with farm selection based on audit scores and other risk factors. The field book records the history of agricultural practices, and farmers annually complete the PAP document, detailing each crop's location and expected yield. To sell their wheat, farmers must have passed an audit confirming their compliance with organic standards. Organic certification integrity is vital, as fraud can originate from unauthorized product use or contamination from adjacent areas. Human errors, especially in farms practicing both conventional and organic farming, pose additional risks to organic integrity. To safeguard organic standards, the agronomic technical studio, in collaboration with ALCENERO's agronomist, conducts multiple field audits to ensure practices meet organic criteria.

During this stage, the collected data encompasses a comprehensive set of details aimed at ensuring quality, traceability, and sustainability, including:

Wheat		
Producer id	identifies the producer of the wheat	
Field data	where we store the following data	
	Coordinates	of the field
	Variety	Cultivated
Organic certificate	of the field	

Audit result	used to issue the certificate	
Wheat ear analysis	results of this analysis	
Temporary storage	wheat before it is transported to the processing facility it occasionally needs to be temporarily stored until a sufficient amount is reached. The data recorded is the following:	
	Location	of the storage
	Date&time	of the storage
Qualitative data	information related to wheat	
Quantity	of transferred wheat	

Once the wheat is harvested, it is transported to the wheat processing facility, where it is received by the *Wheat Reception Manager*. A sample is also collected on which a quality control is conducted by the *Wheat Quality Control Manager* to determine the quality of the received wheats. At this reception stage, the following data is meticulously collected to ensure quality, traceability, and efficiency:

Wheat Reception		
Wheat ids	array of the wheats received from the previous stage	
Total quantity	received	
Date&time	of the reception	
Numberplate	of the truck that transported the wheat	
Sample	collected to conduct quality control of the wheat. The related data is:	
	Humidity	of the sample
	Protein	of the sample
	Hectoliter weight	of the sample
	Gluten	of the sample
	Colour	of the sample
	Impurity	of the sample
	Grains	of the sample
	External weed seeds	of the sample
	Visual analysis	of the sample
	Old factory analysis	of the sample

After the wheat is received at the processing facility, it is moved to storage, under the view of *Wheat Storage Manager*, as a preparatory step before processing. During this storage stage, data collection is focused on ensuring the optimal preservation of the wheat's quality and facilitating efficient management of the stock, including:

Wheat Storage		
Wheat	that is stored after the reception	
Silo code	where the wheat is going to be stored	
Total quantity	stored	
Date&time	of the storage	
Wheat heap analysis	where the following parameters are recorded:	
	Pesticides	result of the analysis
	Mycotoxins	result of the analysis
	Heavy metals	result of the analysis
	Other	parameters

After the wheat has been stored appropriately, the next step in the production process is the transformation of wheat into semolina by the *Semolina Production Manager*. During this crucial stage, precise data collection is imperative to ensure the quality of the semolina and efficiency of the process. The processing of durum wheat into semolina begins when ALCENERO places a pasta order with the pasta factory, which in turn requests semolina from the mill. This demand-driven approach ensures the mill grinds wheat into semolina only upon receiving an order, optimizing freshness and efficiency. Key to this process are the multi-residual analyses conducted on the semolina, focusing on ensuring the quality and safety of the product for pasta production. This meticulous attention to detail reflects ALCENERO's commitment to providing high-quality, organic pasta by closely monitoring and controlling each step of the supply chain, from field to fork. The collected data at the semolina production stage includes:

Semolina		
Wheat	array of the storages that the wheat was taken	
	Storage id	identifies the storage
	Quantity	the quantity of the wheat that has been taken
Wheat quantity	the total wheat quantity	
Semolina quantity	the total quantity of the produced semolina	

Once the semolina is produced, it is transported to the pasta production facility, where it will undergo transformation into the final product: organic pasta. The reception of semolina at this facility is under the view of the *Semolina Reception Manager*, necessitating the careful recording of specific data to ensure quality, traceability, and efficiency. Prior to dispatching the semolina, the mill conducts a comprehensive multimethod analysis to verify the absence of substances not permitted under organic standards. This crucial step ensures that the semolina meets the stringent requirements necessary for organic certification. Upon completion of the analysis, the results are compiled into a PDF document and sent to ALCENERO. This process underscores the commitment to transparency and adherence to organic integrity, enabling ALCENERO to maintain the highest standards of quality and safety for their products.

With the reception of semolina at the pasta production facility, the stage is set for the commencement of pasta manufacturing, under the view of *Pasta Production Manager*. This step transforms the semolina into organic pasta, and it's critical to document a variety of data points to ensure product quality, operational efficiency, and traceability throughout this process. The data recorded during the pasta production stage includes:

Semolina Reception		
Semolina	list of multiple semolina received	
Total quantity	total semolina quantity received	
Date&time	of the reception	
Numberplate	of the truck that was used for the transportation	
Qualitive data	of the received semolina	
Semolina analysis	table with pesticide values	
Quality control	containing multiple quality control parameters:	
	Colour	of the sample
	Gluten	of the sample
	Protein	of the sample
	Ash	of the sample
	Granulometry	of the sample

	Filth	of the sample
	Mycotoxins	of the sample
	Heavy metals	of the sample
	Microorganisms	of the sample
	Multiresidual	of the sample
Production	Data recorded during the pasta production stage:	
	Pasta batch number	identifies the batch of the produced pasta
	Quality compliance	describes if the produced pasta is compliant
	Incoming quantity	of the semolina
	Outgoing quantity	of the produced pasta

Once the organic pasta has been produced, the *Pasta Storage Manager* takes the responsibility for the packaging, which is pivotal for protecting the product, ensuring its quality, and preparing it for distribution to consumers. The pasta produced for ALCENERO is packaged in either paper or plastic materials, each bearing the ALCENERO brand. This branding approach eliminates the need for any additional labelling in subsequent steps of the supply chain, ensuring that the products are readily identifiable as ALCENERO's at every stage, from packaging to final retail display. This strategy not only streamlines the process but also reinforces brand recognition and trust among consumers, as the consistent branding clearly communicates the product's quality and origin directly on its packaging. During the packaging stage, the following data is meticulously recorded to ensure traceability, quality control, and compliance with packaging standards:

Pasta Packaging		
Semolina reception id	the id of the reception in order to identify the raw material from which the pasta was produced	
Date&time	of the packaging	
Batch number	of the produced pasta	
Packaging type	the type of the package	
Weight	of each package	
Pesticide	control of the pasta	
Storage	information containing:	
	Location	of the storage
	Date&time	of the storage

The final step in the journey of the organic, packaged pasta involves its transportation and storage at the ALCENERO's facility, under the view of the *Pasta Distribution Manager*, a crucial phase for ensuring the product reaches the consumer in optimal condition. During this stage, comprehensive data collection is essential for maintaining the integrity of the product, managing inventory, and ensuring logistical efficiency. The data recorded at this transportation and storage stage includes:

Pasta Storage		
Packaging ids	List of packages that were transported and stored	
Transportation	details such as:	
	Number of packaging	
	Kilos	quantity in kilograms

	Ambiental conditions	of the truck used for the transportation
	Hygienic conditions	of the truck
	Document	transportation document
	Numberplate	of the truck
	Date&time	of the transportation
Organic certificate	of the pasta	
Label printing	of the packages	
Conditions of transport		
Analysis	at the time of the reception, containing:	
	Predominantly Multiresidue	results of the analysis
	Mycotoxins	results of the analysis

The culmination of the supply chain involves the distribution of the final products to retailers, specifically MASOUTIS in this scenario. Utilizing a fleet of trucks, these products are efficiently transported to MASOUTIS Distribution Centers, serving as the pivotal points from which individual markets are replenished. This strategic distribution ensures that the final products are readily.

2.2.7 Information Flow in the Arijle Raspberries FSC

The main stakeholder in the Arijle Raspberries FSC is ARIJLE ASSOC, which participates with workers of 5 different roles, namely the i) *Producer*, ii) *Reception Manager*, iii) *Production Manager*, iv) *Packaging Manager* and v) *Storage Manager*, which are presented in Figure 9 and their detailed description is given below.

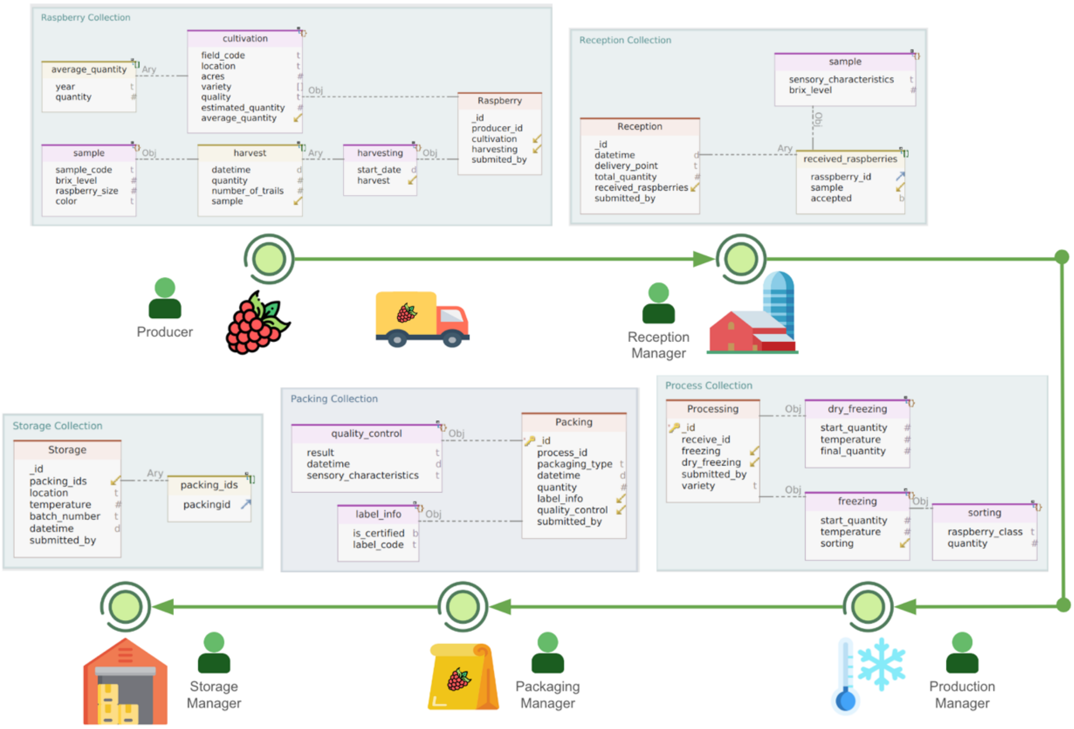


Figure 9: Information Flow of the Arijle Raspberries FSC.

Raspberries are mainly grown on small family-business farms, where the farm owners and their families themselves carry out all necessary activities, hiring seasonal labor during harvesting time (labor intensive due to the hand picking). The marketing chain of primary producers is short and ends at the nearest cooling storage/chamber. A very small portion is sold as fresh, while as frozen raspberries are mainly sold and are further processed into jams, juices and/or as dried. Foreign buyers have recognized the specific quality of Arilje raspberry, while the domestic market is still not fully aware of its extraordinary quality.

The Arijle Raspberries FSC commences with the cultivation and harvesting from *Producers*. To ensure traceability, it is mandatory for the producer to complete forms that provide the platform with detailed information about the cultivation and harvesting process. The information that will be recorded includes:

Raspberry		
Producer id	identifies the producer	
Cultivation	details such as	
	Field code	of the producer
	Location	of the field
	Acres	field acres
	Variety	cultivated
	Quality	of the cultivated variety
	Estimated quantity	that is expected to be produced
	Average quantity	array of collected quantities per year
Harvesting	details such as:	

	Start date	day the harvesting started		
	Harvest	array of harvest data		
		Date&time	of harvest	
		Quantity	harvested	
		Number of trails		
		Sample	of each harvest	
			Sample code	identifies the sample
			Brix level	of the sample
			Raspberry size	of the sample
			Color	of the sample

After completing the cultivation process, the *Producer* transports the raspberries to the processing cooling chamber, under the view of the *Reception Manager*. During the transportation to the cooling chambers, tractors are used. Upon arrival, designated workers are responsible for filling out a form to document the reception details. The collected data includes:

Reception			
Date&time	of the reception		
Delivery point	of the reception		
Total quantity	received		
Received raspberries	array containing the following information:		
	Accepted	whether the raspberries are accepted or not	
	Sample	contains the following data:	
		Sensory characteristics	of the sample
		Brix level	of the sample

During the post-harvest process, freshly picked raspberries initially undergo a sorting phase, where they are meticulously selected based on quality and size. Subsequently, these berries are transformed into their final product form by the *Production Manager* through one of two methods: freezing or freeze-drying. The data collected at this stage encompasses:

Process		
Variety	to be processed	
Freezing	data regarding the freezing process	
	Start quantity	before freezing
	Temperature	at which the freezing occurs
	Sorting	where the raspberries are assigned a class and the quantity is recorded
Dry freezing	data regarding the dry freezing process	
	Start quantity	before the dry freezing
	Temperature	during the dry freezing
	Final quantity	after the dry freezing

Following the processing stage, the final product is meticulously packaged by the *Package Manager* for sale to the end consumer. The information gathered at this packaging stage is detailed and comprehensive, aimed at ensuring quality and traceability. This data includes:

Packaging		
Process id	refers to the previous step	
Packaging type	the type of the package	
Date&time	of the packaging process	
Quantity	total quantity packaged	
Label info	a flag indicating if the product is certified and the label code	
Quality control	of the packet product	
	Results	of the quality control
	Date&time	of the quality control
	Sensory characteristics	of the quality control

The final packaged product is securely stored by the *Storage Manager* in preparation for distribution and sale to end consumers. At this storage stage, the recorded data meticulously tracks and ensures product integrity and logistical efficiency, including:

Storage	
Location	where the packaged products are stored
Temperature	of the storage location
Batch number	of the packaged products
Date&time	of the storage
Packing ids	array indicating the stored packaged products

The culmination of the supply chain involves the distribution of the final products to MIGROS, under the view of the Distribution Manager. Utilizing a fleet of trucks, these products are efficiently transported to MIGROS Distribution Centers, serving as the pivotal points from which individual markets are replenished. This strategic distribution ensures that the final products are readily available for purchase by consumers, seamlessly connecting the end of the supply chain with the beginning of consumer satisfaction.

2.3 Architecture Layers and Components

This section provides a more comprehensive explanation of the three levels of the ALLIANCE architecture and their components. Following Section 2.1, which begins with a brief outline of the ALLIANCE architecture (Figure 2), Section **Error! Reference source not found.** proceeds with a description of the information flows in all FSCs, and now this section continues with a more detailed presentation of the ALLIANCE components, providing also references to the following sections for further more specific information. Whenever it is necessary, the FSC of Feta Cheese is used as an illustrative example to demonstrate the role of each component.

2.3.1 Data Acquisition Layer

In the Data Acquisition Layer, data is primarily generated and collected automatically through the utilization of distributed IoT sensing devices, rather than being manually injected by users. The generated data either refers to performance metrics from the FCS operations or testing scores of the authenticity and the origin of the food products. Apart from these data collected currently by **DNA-based** and **NIR & HSI Spectroscopy sensors**, there are also **Historical data**, which are actually datasets of historic metrics from the FSC operations, which are necessary for the data analytics. The Historical data will be updated during the project's lifetime with the information produced by the developed FSCs. The architecture is designed to be flexible and modular, allowing it to easily adapt to any type of IoT device. D3.2 presents in detail the two types of IoT devices that currently are integrated in our architecture.

2.3.2 Data Management Layer

The Data Management Layer is tasked with the storage and processing of data received from the lower layer. It composes of a centralized service that has the data storage capabilities to store the entire dataset. Additionally, it utilizes a blockchain distributed ledger for the most critical data. The data are firstly harmonized and then stored in a standardized manner, mitigating their variability and heterogeneity. Simultaneously, there exists a procedure at the same level for utilizing this data to uncover, via AI, methods to improve the performance of the FSCs. The Data Management layer comprises three distinct systems:

a) The **Data Harmonization System**

This system is responsible to harmonize the heterogeneous data coming from different FSCs, allowing their common processing to simplify and enrich their analysis. The data are stored and shared according to the **EPCIS** (Electronic Product Code Information Services) [1]standard of GS1, which is a flagship data sharing standard for enabling visibility within the stakeholders even of different FSCs. EPCIS helps provide the "what, when, where, why and how" of food products, enabling the capture and sharing of interoperable information about their status, location, movement and chain of custody. Together with the **CBV** (Core Business Vocabulary) [2] that is a companion standard to EPCIS, both standards provide definitions of data values that can be used within the data structures used in the data storage.

Part of the data is stored in parallel in the **Blockchain** [3]distributed ledger by leveraging a private permissioned Blockchain network that supports multiple channels, one for each FSC, which can be bridged through cross-chain and data sharing to support interoperability between different FSCs. More details for the utilization of the Blockchain technology are presented later in Section 3. At this point, we would like to highlight that the storage of the whole dataset on Blockchain would be inefficient, since there are big data that could introduce high delays for their Blockchain storage without being critical to be misused or intentionally manipulated. Thus, Blockchain is exclusively used for the storage of the data that needs to be secured, and the centralized storage, called **Off-chain** [4] (as the opposite of Blockchain that is the On-chain database), is used in parallel for the storage of the whole dataset. The schemas of Figure 3 - Figure 9 represent the tables of the Off-chain databases of all FSCs.

b) The **AI Early Warning System**

The main component of this system is the **AI Early Warning** process, which is one of the two components of **EWDSS**, the product of T2.4. This process uses AI and the harmonized data to predict and determine with increased probability possible food fraud incidences within the FSCs. It reactively monitors the FSC operational performance to assess the fraud risk factors and the actual fraud vulnerability of the food products. By harnessing the capabilities of AI [5], it proactively recommends interventions, enabling faster and adaptable decision-making processes crucial for mitigating food fraud. As part of the proposed solution, employing a Mamdani Fuzzy Inference System (more details in Section 4) for early warning demonstrates the effectiveness of AI technologies in detecting anomalies within the complex food supply chain. Crucially, this process will be demonstrated in real-life case studies through rigorous testing, with a focus on a practical use case centered around the FSC of Feta Cheese.

VRAMF is a concurrent parallel component that functions as a supplement to the previous process. The result of T3.1, which ended in M6, was the basis for identifying a first set of critical control points [6] in each FSC for mitigating the food fraud incidences. Specifically, each FSC's stakeholders responded to questionnaires, refined through the Delphi technique [7], [8], [9] as it was presented in D2.1, to identify the initial set of critical control points. These control points are mainly the points in each FSC that samples are generated and used for the quality control. During the lifetime of ALLIANCE, the effectiveness of the results of the AI process, which relies on the samples and the data produced by the current control points, will be improved by redefining this set of control points. In turn, the change in the control points will affect the AI process, thus, an interacting relationship exists between these two processes. More details on this tool are given in Section 5.

c) The **Decision Support System**

This system includes the **Decision Support** process, the other half of the **EWDSS** component, which exploits the analytics produced by the AI Early Warning System to provide risk management and decision making for preventing interventions against the food fraud incidences. The integration of a Multi-criteria Decision Analysis [10], [11] process for the Decision Support tool further enhances the system's ability to provide informed and strategic recommendations based on real-time data insights. Furthermore, the application of a multi-criteria decision analysis framework facilitates expert decision-making by allowing preferences among predefined actions, ranking available alternatives, ensuring consistency, and refining decisions under risk and uncertainty [12]. This comprehensive approach empowers experts to navigate complex scenarios, enhancing the efficacy and resilience of food fraud detection and mitigation strategies.

The development of a human-in-the-loop hybrid-augmented AI model has been proposed, seamlessly integrating human expertise into computational intelligence algorithms [13]. This innovative approach harnesses the cognitive capabilities of experts, synergizing them with computational power to ensure the delivery of highly accurate and reliable solutions. Particularly noteworthy is the proposal for a solution that merges fuzzy logic and multi-criteria decision analysis principles [14]. This innovative hybridization enables the quantification of food fraud risk based on specific variables of interest. Fuzzy logic theory forms the basis of a rule-based system, wherein fuzzified variable inputs converge to establish rule strength, graded on a low/medium/high scale, in relation to food fraud risk.

The **Knowledge Database** is conceptualized as an all-inclusive repository, well-designed with the assimilation of processed data, insights, and inferences derived from the analysis of food products along with their supply chains in an immaculate manner. The integration of external data (standards, certificates, PDO/PGI CoPs, scientific articles, links to related websites, etc.) with the data originating from the project makes it easy to take a thorough examination and extraction of valuable insights and reports by each product. The Knowledge Database is bound together with EWDSS that systematically captures the relevant information for potential fraud or adulteration cases across the FSCs. More details are given D3.2.

2.3.3 Application Layer

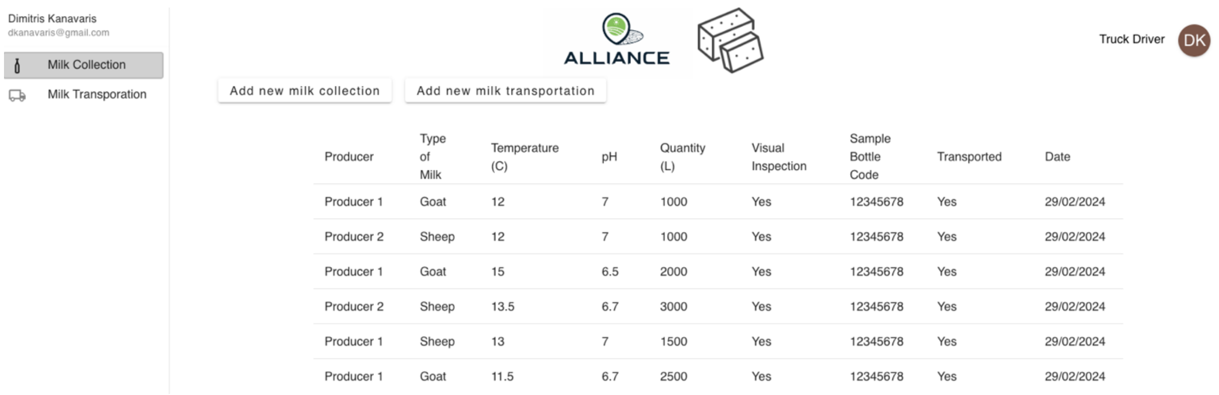
The Application Layer provides interactive **Mobile/Web applications** for comparing and filtering the data analytics and the suggested decisions of the Data Management layer. These user-friendly applications can support multiple roles of end users, such as farmers, producers, processors and retailers, who are informed about the analytics or the decisions of their interest. Moreover, the policy makers and authorities can access this information to design countermeasures for food fraud mitigation.

There are 4 Apps to be developed in ALLIANCE, including:

1. the **Blockchain App**,
2. the **Decision Support App**,
3. the **Knowledge Database App**
4. **the Food Fraud Prevention system** and
5. the **Marketplace**.

As development of the Food Fraud Prevention system and the Marketplace has only recently commenced, no prototype exists at the moment of writing this deliverable. The Knowledge Database and Decision Support Apps are anticipated to be released at a later date; their status will be detailed in D2.4. Below, an **initial iteration of the Blockchain App** is presented, specifically designed to process the data pertaining to the FSC of Feta Cheese.

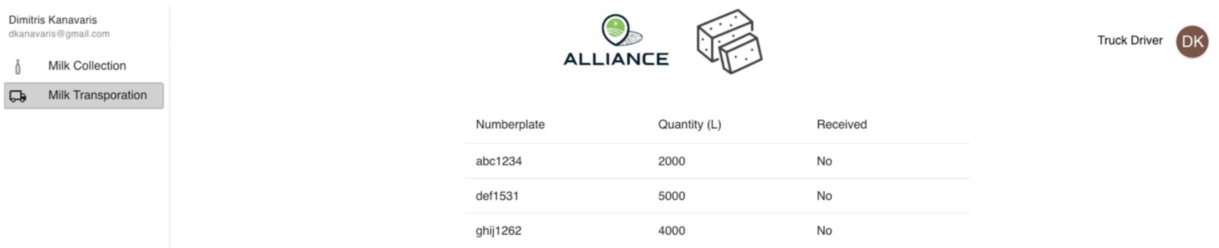
As we have already mentioned, there are 7 roles that are involved in the FSC of the Feta Cheese: i) *Truck Driver*, ii) *Reception Manager*, iii) *Pasteurization Manager*, iv) *Production Manager*, v) *Storage Manager*, vi) *Distribution Manager* and vii) *Quality Control Manager*. Figure 10 shows the actions can be done by the *Truck Driver* through the 'Milk Collection' page of the Blockchain App, who is able to revisit and add information to the platform related to the quantities and the type (goat or sheep) of the collected milk, together with quality features such as temperature, pH and others.



Producer	Type of Milk	Temperature (C)	pH	Quantity (L)	Visual Inspection	Sample Bottle Code	Transported	Date
Producer 1	Goat	12	7	1000	Yes	12345678	Yes	29/02/2024
Producer 2	Sheep	12	7	1000	Yes	12345678	Yes	29/02/2024
Producer 1	Goat	15	6.5	2000	Yes	12345678	Yes	29/02/2024
Producer 2	Sheep	13.5	6.7	3000	Yes	12345678	Yes	29/02/2024
Producer 1	Sheep	13	7	1500	Yes	12345678	Yes	29/02/2024
Producer 1	Goat	11.5	6.7	2500	Yes	12345678	Yes	29/02/2024

Figure 10: The dashboard for the Milk Collection in the Feta Cheese FSC.

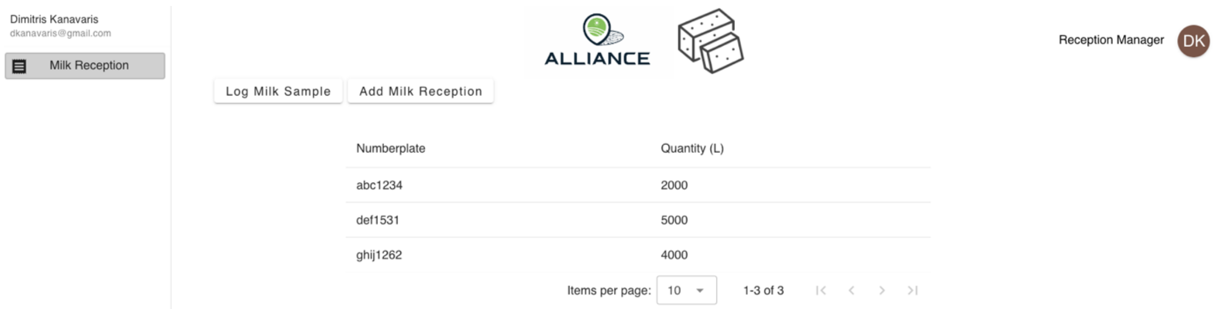
Figure 11 shows how the *Truck Driver* can use the 'Milk Transportation' page to observe the status of the trucks (identified by their number plates) that currently transfer milk, especially if they are in transit or they have reached their destination and the corresponding milk is received.



Numberplate	Quantity (L)	Received
abc1234	2000	No
def1531	5000	No
ghij1262	4000	No

Figure 11: The dashboard for the Milk Transportation in the Feta Cheese FSC.

Figure 12 shows the actions can be done by the *Reception Manager*, who is able to revisit and add newly received milk quantities and identify the silos used for their storage (specified by their codes).



Numberplate	Quantity (L)
abc1234	2000
def1531	5000
ghij1262	4000

Figure 12: The dashboard for the Milk Reception in the Feta Cheese FSC.

Figure 13 shows the capabilities of the *Pasteurization Manager*, who is able to notify which milk quantities have been removed from the silos to be pasteurized and restored to other silos (specified again by their codes).

Silo Code	Quantity (L)	Actions
0	1000	Log Pasteurization
1	4000	Log Pasteurization
4	6000	Log Pasteurization
2	3000	Log Pasteurization

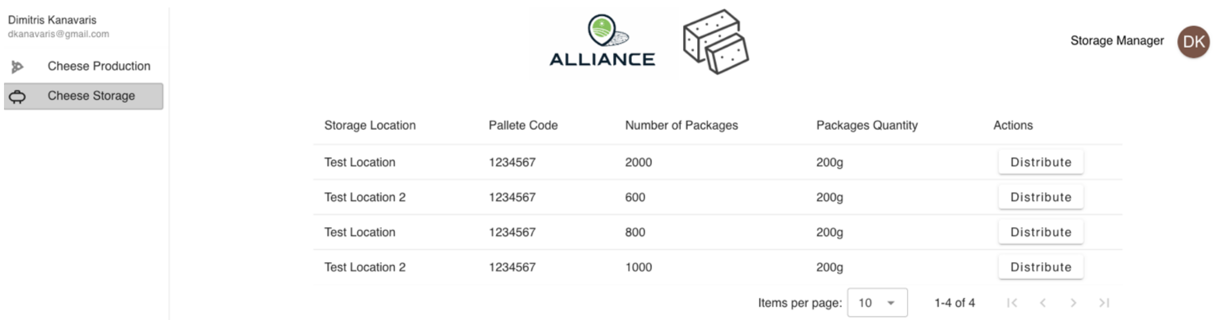
Figure 13: The dashboard of the Milk Pasteurization in the Feta Cheese FSC.

Figure 14 shows the capabilities of the *Production Manager*, who is able to inform the platform that specific pasteurized milk quantities have been removed from the silos to be used for cheese production, using the action 'Add Cheese Production', as well as to monitor the quantities of the produced cheese.

Silo Code	pH	Milk Quantity (L)	Cheese Quantity (Kg)	Metal Alert	Brinning Date	Cooking Date	Maturing Date	Actions
0	7.4	1000	800	No	04/03/2024	04/03/2024	04/03/2024	Package and Store
1	6.2	4000	3600	No	04/03/2024	04/03/2024	04/03/2024	Package and Store
4	6.8	6000	5500	No	04/03/2024	04/03/2024	04/03/2024	Package and Store
2	7.4	3000	2400	No	04/03/2024	04/03/2024	04/03/2024	Package and Store

Figure 14: The dashboard of the Cheese Production in the Feta Cheese FSC.

The *Storage Manager* is able to observe the produced cheese quantities, package them to palletes and store them to specified storage places, using the action 'Package and Store' of the same 'Cheese Production' page. Figure 15 shows how the same role can observe the stored quantities of Feta Cheese using the 'Cheese Storage' page.



Storage Location	Pallete Code	Number of Packages	Packages Quantity	Actions
Test Location	1234567	2000	200g	Distribute
Test Location 2	1234567	600	200g	Distribute
Test Location	1234567	800	200g	Distribute
Test Location 2	1234567	1000	200g	Distribute

Figure 15: The dashboard of the Cheese Storage in the PDO Feta Cheese FSC.

In the same 'Cheese Storage' page, the *Distribution Manager* is able to assign the stored cheese quantities to trucks, in order to transfer them to the retailing points. Figure 16 shows how the same role is able to monitor the trucks that already transfer cheese quantities, using the 'Cheese Distribution' page.

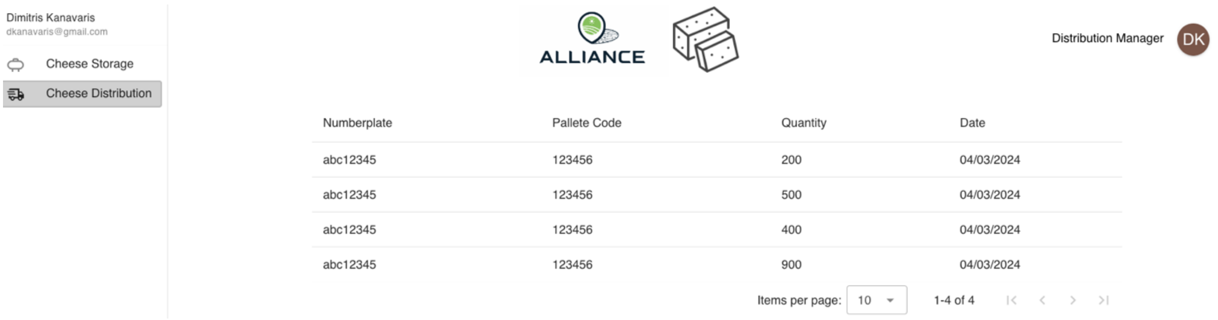


Figure 16: The dashboard of the Cheese Distribution in the Feta Cheese FSC.

Figure 17 shows the capabilities of the *Quality Control Manager*, who is able to observe all aforementioned operations of all roles.

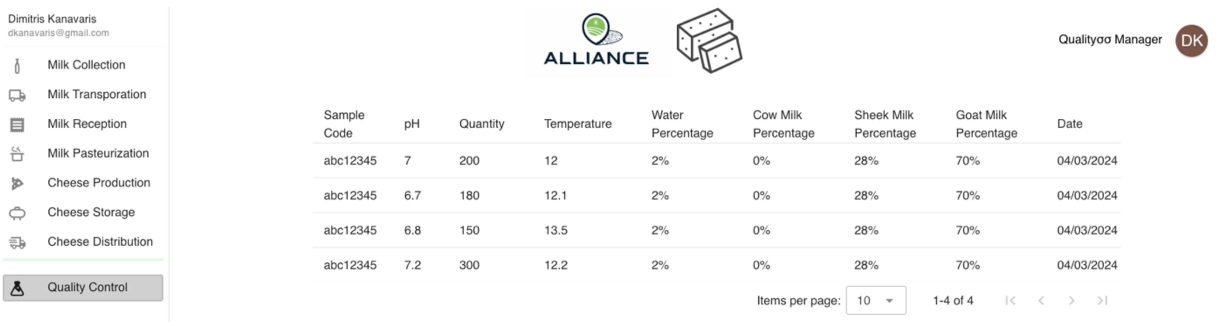


Figure 17: The dashboard of the Quality Control Manager in the Feta Cheese FSC.

3 Resilient Food Supply Chains

3.1 Overview

The resiliency of FSCs against multiple unintentional threats or food frauds is one of the main goals of ALLIANCE. The **Blockchain technology is the main pillar of building resilient FCSs**. Blockchain helps supply chain partners share trusted data through permissioned blockchain solutions. Businesses and consumers want brands to guarantee product authenticity, while supply chain participants demand responsible sourcing and better visibility to minimize disputes. Blockchain for FSCs help supply chain leaders use data to handle the disruptions and build resiliency. Through distributed ledger technology that provides a shared, single version of the truth, blockchain applications give permissioned participants greater visibility across all FSC activities and increase its transparency.

3.2 Blockchain Technology

Blockchain is a technology that enables the record-keeping in a way that transactions, authentications and interactions are recorded across and verified by a network rather than a single central authority. There are two such paradigms that are critical for enterprise decision-making: permissionless vs. permissioned blockchains. In ALLIANCE, permissioned blockchains have been utilized to enable resilient FSCs that run end to end, from farmers to consumers, and in parallel are commercially viable.

In the permissioned blockchains, multiple organizations come together as a consortium to form the network and their permissions are determined by a set of policies that are agreed to by the consortium when the network is originally configured. The network policies can change over time subject to the agreement of the organizations in the consortium. Each organization brings its own clients, peers and/or orderers, with the last ones constituting the ordering service(s). The ordering service is the administration point for the network because it contains the configuration for the channel(s), which are the communication means used to connect the various components of the organizations.

In ALLIANCE, each company is a different organization in the blockchain network, bringing its own peers, two for each department in the company. Each involved member has a specific role in the FSC, depending on his/her company and department, and uses one of the two corresponding peers (there are two peers for resiliency to failures). The list of organizations is the following:

1. Orderers
2. MASOUTIS
3. MIGROS
4. OLYMPOS
5. IGPFA
6. AGROVELEBIT (Founded in Lovinac-Croatia aiming at agricultural production of Lika potatoes.)
7. Honey Assoc. (Association of honey producers in Occitanie-France.)

8. ALCE NERO
9. CIAUM
10. Arilje raspberry Assoc. (Association of Arilje producers in Serbia, member of ORIGINAL.)

The first organization offers the common ordering service for all FSCs, consisting of three orderers: Orderer1, Orderer2 and Orderer3. The ordering service is configured to support seven channels, one channel for each FSC. Each single channel is used by a specific smart contract (distributed app especially designed for blockchain networks), which is tailored to the corresponding use case. In the following sections, we present the organizations and theirs peers for each pilot.

3.2.1 Olive Oil Supply Chain Channel

There are two organizations participating in the channel for Olive Oil: MASOUTIS and CIAUM. MASOUTIS is responsible for the retailing of Olive Oil, while CIAUM organizes the olive reception and milling, as well as the Olive Oil production, packaging, storage and distribution to the retailing points of MASOUTIS. Each of the aforementioned processes is given to a different department, using a separate couple of peers, as it is presented in Figure 18.

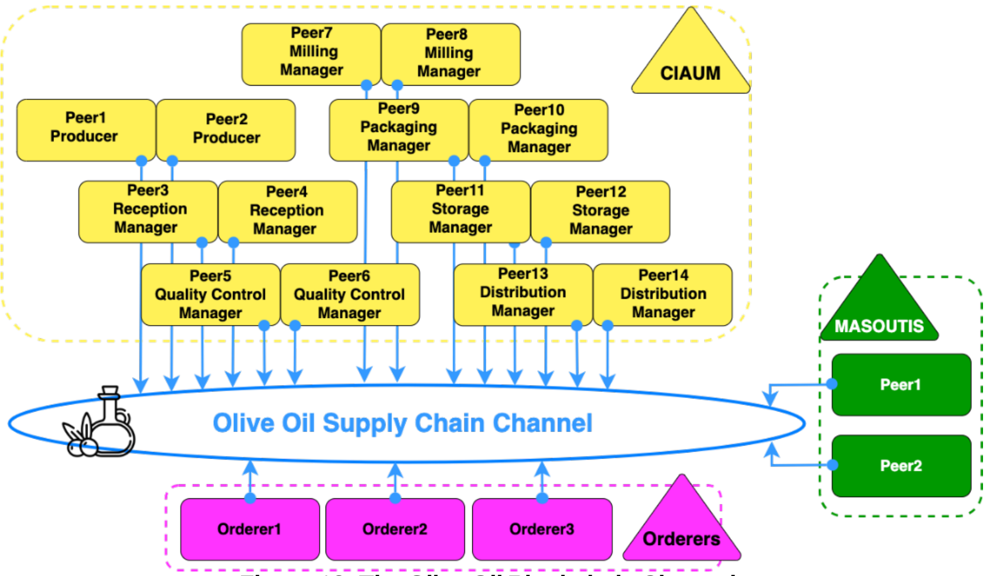


Figure 18: The Olive Oil Blockchain Channel.

3.2.2 Feta Cheese Supply Chain Channel

There are two organizations participating in the channel for Feta Cheese: MASOUTIS and OLYMPOS. MASOUTIS is responsible for the retailing of Feta Cheese, while OLYMPOS organizes the milk transfer and pasteurization, as well as the Feta Cheese production, packaging, internal storage and distribution to the retailing points of MASOUTIS. Each of the aforementioned processes is given to a different department, using a separate couple of peers, as it is presented in Figure 19.

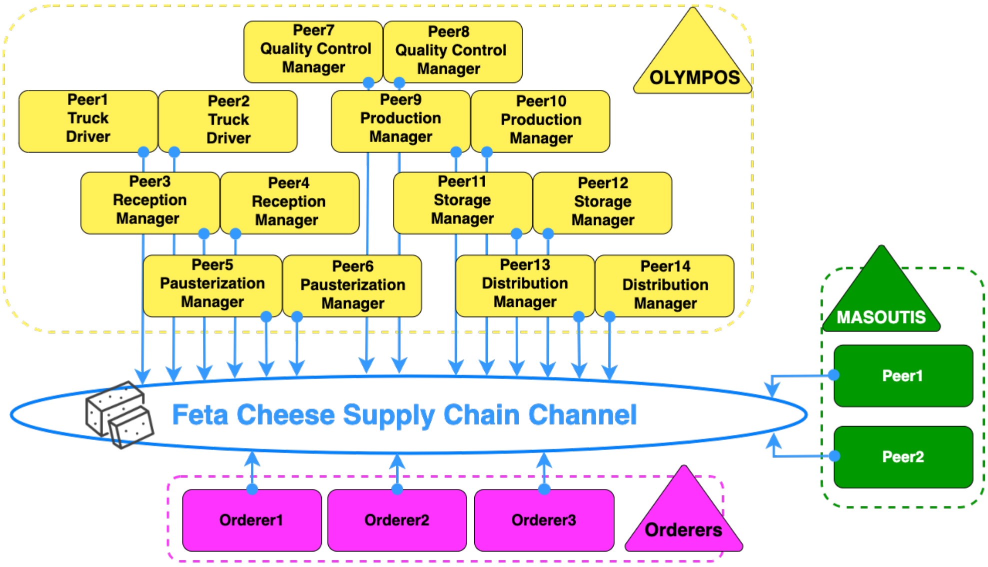


Figure 19: The Feta Cheese Blockchain Channel.

3.2.3 Organic Honey Supply Chain Channel

There is one organization participating in the channel for Organic Honey: Honey Assoc. Honey Assoc organizes the beehive collection, as well as the honey production, packaging and storage. Each of the aforementioned processes is given to a different department, using a separate couple of peers, as it is presented in Figure 20.

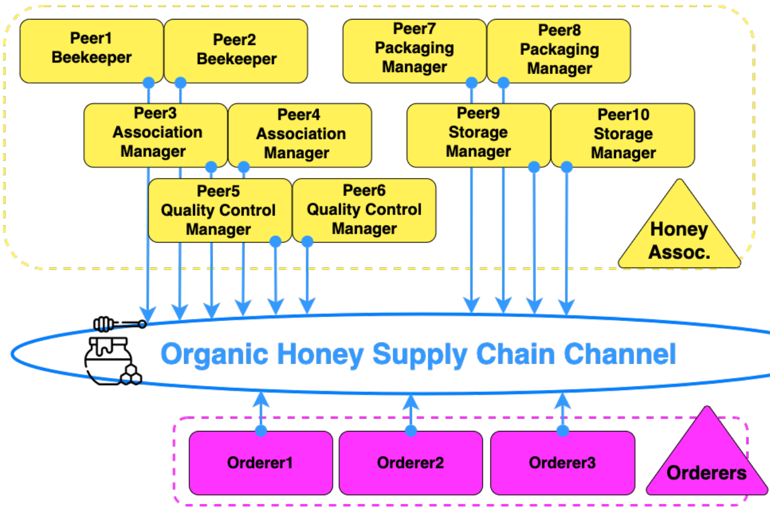


Figure 20: The Organic Honey Blockchain Channel.

3.2.4 Faba Beans Supply Chain Channel

There is one organization participating in the channel for Faba Beans: IGPFA. IGPFA organizes the production and packaging of Faba Beans. Each of the aforementioned processes is given to a different department, using a separate couple of peers, as it is presented in Figure 21.

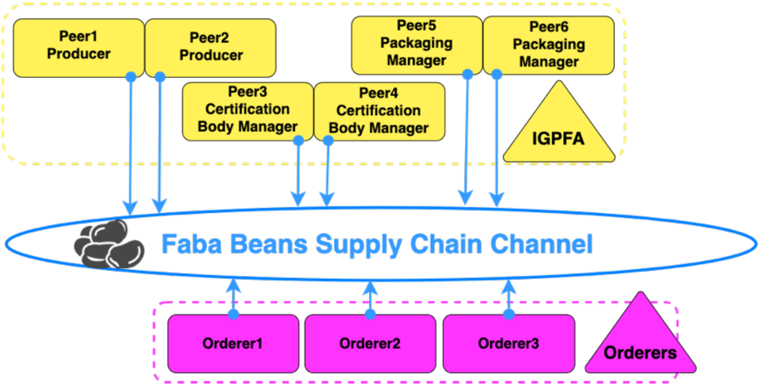


Figure 21: The Faba Beans Blockchain Channel.

3.2.5 Lika Potatoes Supply Chain Channel

There are two organizations participating in the channel for Lika Potatoes: MIGROS and IGPFA. MIGROS is responsible for the retailing of Lika Potatoes, while IGPFA organizes the Lika Potato collection, packaging, internal storage and distribution to the retailing points of MIGROS. Each of the aforementioned processes is given to a different department, using a separate couple of peers, as it is presented in Figure 22.

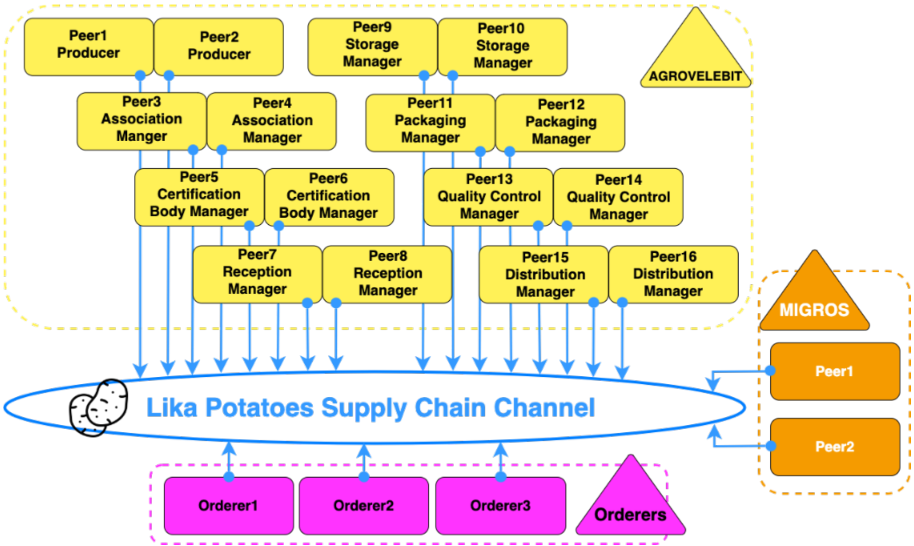


Figure 22: The Lika Potatoes Blockchain Channel.

3.2.6 Organic Pasta Supply Chain Channel

There are two organizations participating in the channel for Organic Pasta: MASOUTIS and ALCE NERO. MASOUTIS is responsible for the retailing of Organic Pasta, while ALCE NERO organizes the durum wheat collection, the semolina production, its processing for the Organic Pasta production, and at the end the its packaging, internal storage and distribution to the retailing points of MASOUTIS. Each of the aforementioned processes is given to a different department, using a separate couple of peers, as it is presented in Figure 23.

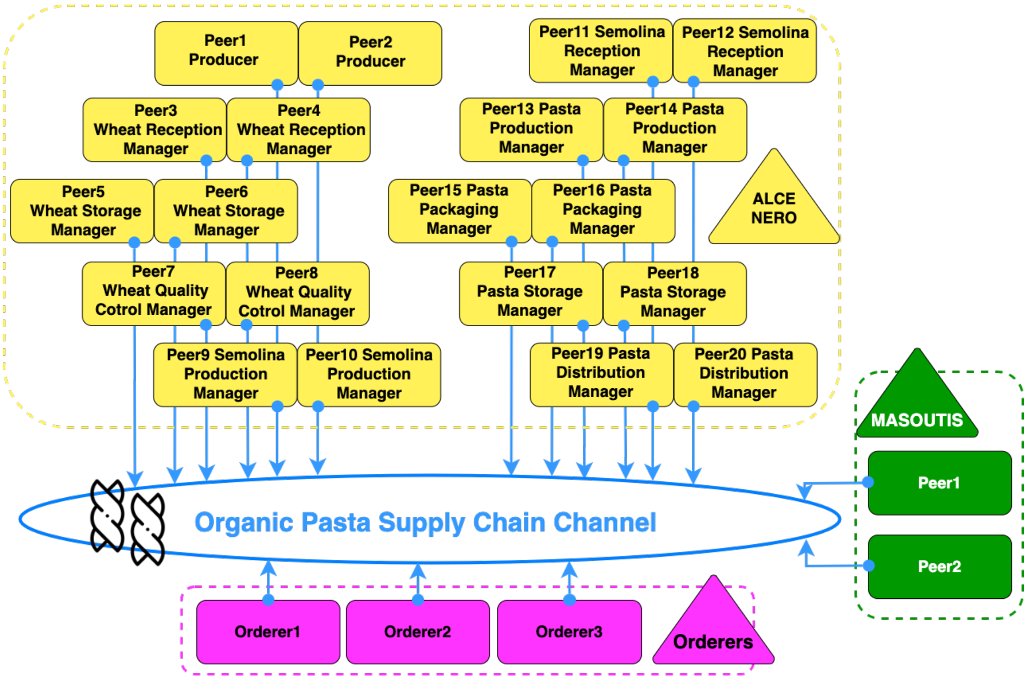


Figure 23: The Organic Pasta Blockchain Channel.

3.2.7 Arilje Raspberries Supply Chain Channel

There are two organizations participating in the channel for Arilje Raspberries: MIGROS and Arijle Assoc. MIGROS is responsible for the retailing of Arijle Raspberries, while Arijle Assoc. organizes the raspberries collection, their processing through freezing, their packaging, storage and distribution to the retailing points of MIGROS. Each of the aforementioned processes is given to a different department, using a separate couple of peers, as it is presented in Figure 24.

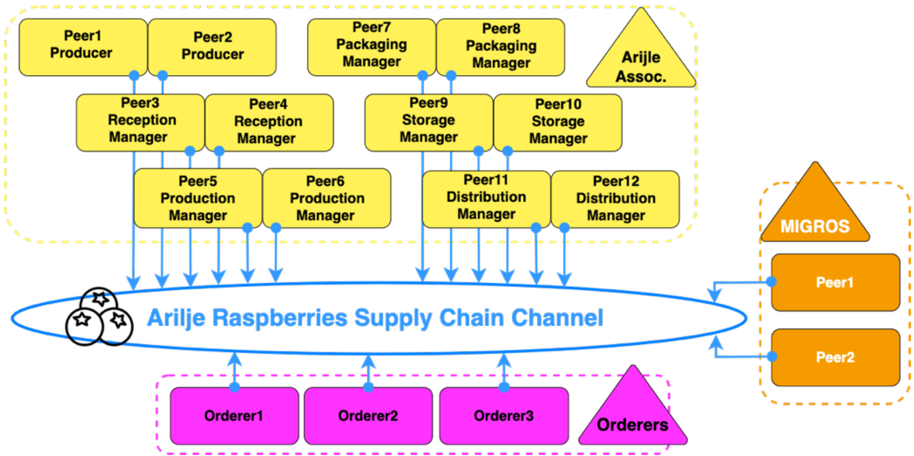


Figure 24: The Arilje Raspberries Blockchain Channel.

4 Intelligent Food Supply Chains

4.1 Overview

The **AI is crucial factor in the success of building intelligent FSCs**. ALLIANCE underscores the critical need for innovative solutions in combating food fraud within quality-labelled FSCs [15]. In today's dynamic industrial landscape, maintaining integrity is paramount. Early warning systems and proactive recommendations serve as essential safeguards, ensuring the integrity and reliability of diverse sectors [16] [17]. Recognizing this challenge, the focus shifts towards the provision of an Early Warning & Decision Support System empowered by AI and Operations Research (OR). This system has the potential to significantly enhance the detection and mitigation of food fraud incidences through the utilization of advanced AI algorithms and decision analysis tools.

4.2 Fuzzy Logic

Mamdani fuzzy inference system has been developed composing of fuzzy rules with linguistic inputs and outputs to obtain rule-based decisions. Inputs reflect main decision variables of interest as defined by experts. Values of these variables are continuously monitored for constructing a decision support pipeline that will facilitate experts to make decisions under uncertainty and risk. When the inputs are given, there are six steps to compute the output of the Mamdani fuzzy inference system [18] (see Figure 25).

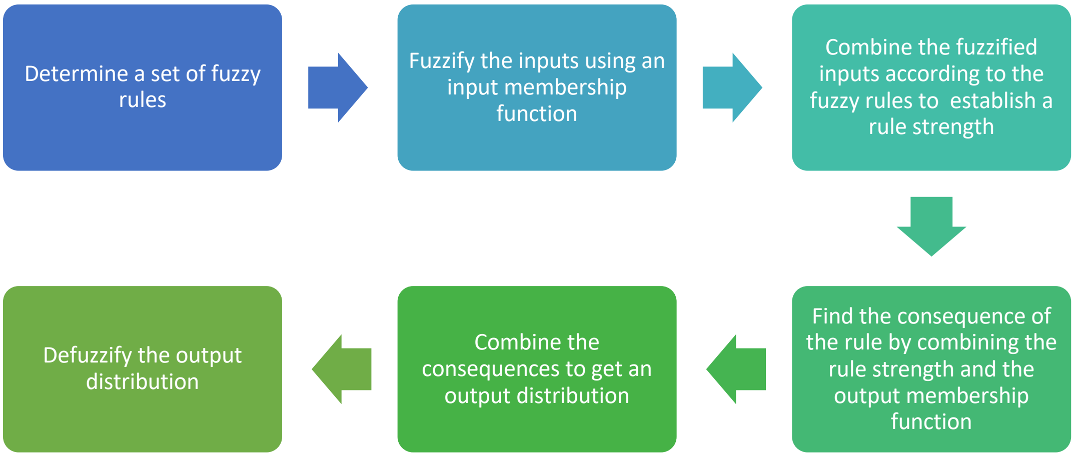


Figure 25: Mamdani Fuzzy Inference Approach.

4.2.1 Inputs and Outputs

As far as the inputs are concerned, variables of interest are initially selected by the expert. In the context of the selected use case, the variables are associated with fat and protein in goat and sheep milk. Through fuzzification, crisp input values related to fat and protein are converted into fuzzy sets using membership functions. These membership functions describe the degree of membership for each input variable in linguistic terms (e.g., low, medium, high). Then, a set of rules that represent expert knowledge are defined. Typically, these rules map combinations of fuzzy input values to fuzzy output values. It is worth noting that the output is associated with a food fraud risk measure. Finally, through defuzzification the fuzzy output set is converted into a crisp output value by selecting a representative value from the aggregated fuzzy output set.

4.2.2 Fuzzy Rules

A fuzzy rule base consists of a set of fuzzy IF-THEN rules depicting the core of the fuzzy inference system in the sense that other components such membership functions are designed to implement these rules in a reasonable, realistic, and efficient manner. These IF-THEN rules are utilized by the fuzzy inference system to determine a mapping from fuzzy sets in the input universe of discourse $U \subset R^n$ to fuzzy sets in the output universe of discourse $V \subset R$, based on fuzzy logic principles. The fuzzy IF-THEN rules are given by the following equation:

$$R^{(\nu)} = IF\ x_1\ is\ F_1^\nu\ and\ \ldots .x_n\ is\ F_n^\nu, THEN\ y\ is\ G^\nu$$

where $F_j^\nu, G^\nu, j = 1, \ldots, n$ are fuzzy sets in $U_j \subset R$, respectively. In addition to this, $x = [x_1, \ldots, x_n]^T \in U$ and $y \in V$ are input and output linguistic variables of the fuzzy inference system which belongs to the input and output universes, respectively. ν represents the number of rules in the fuzzy rule base.

4.2.3 Fuzzy Membership Functions

Furthermore, fuzzy membership function is used to convert the crisp input provided to the fuzzy inference system. Formally, a membership function for a fuzzy set A on the universe of discourse $x \in U$ is defined as $\mu_A: x \to [0, 1]$, where each element of x is mapped to a value between 0 and 1. This value is called membership value or degree of membership, thus quantifying the grade of membership of the variable $x_j \in x, j = 1, \ldots, n$ to the fuzzy set A. Namely, x is the universal set, whereas A is the fuzzy set derived from x.

In the context of the proposed fuzzy-based solution approach, the triangular membership function is used to model input/output variables of interest (i.e., fat, protein, and food fraud risk). The triangular membership function which fuzzifies the input can be defined by three parameters: a, b, and c where a and c define the base, whereas b defines the height of the triangle (see Figure 26).

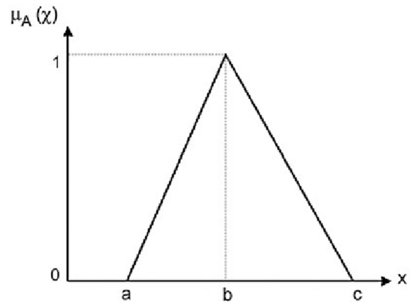


Figure 26: Triangular Membership Function.

X axis represents the input from the process, whereas Y axis represents corresponding fuzzy value. Analytically, if $x_j = b$, then it is having full membership in the given set, that is $\mu(x_j) = 1, if\ x_j = b, j = 1, \ldots, n$. Additionally, if input is less than or greater than c, then it does not belong to fuzzy set at all, and its membership value will be 0, that is $\mu(x_j) = 0, if\ x_j < a\ or\ x_j > c, j =$

$1, \dots, n$. If now $x_j, j = 1, \dots, n$ is between a and b, its membership value varies from 0 to 1. If it is near to a, its membership value is close to 0, and if its membership value is near to b, its membership value gets close to 1: $\mu(x_j) = \frac{x_j - a}{b-a}, a \le x_j \le b$. Finally, if $x_j, j = 1, \dots, n$ is between b and c, its membership value varies from 0 to 1. Specifically, if variable is near to b, its membership value is close to 1, and if it is near to c, its membership value gets close to 0: $\mu(x_j) = \frac{c - x_j}{c-b}, b \le x_j \le c$. Mathematically, the triangular membership function is formulated as:

$$\mu(x_j; a, b, c) = \begin{cases} 0, x_j \le a \\ \dfrac{x_j - a}{b - a}, a \le x_j \le b \\ \dfrac{c - x_j}{c - b}, b \le x_j \le c \\ 0, x_j \ge c \end{cases} = \max\left(min\left(\frac{x_j - a}{b - a}, \frac{c - x_j}{c - b}\right), 0\right)$$

where a, b and c are defined by experts.

4.2.4 Fuzzy Operators

Let μ_A and μ_B be membership functions that define the fuzzy sets A and B, respectively on the universe X. To evaluate the disjunction of the rule inputs, an OR fuzzy operator (representing the union of fuzzy sets) is defined as follows:

$$\mu_{A \cup B}(X) = \max(\mu_A(X), \mu_B(X))$$

Similarly, to evaluate the conjunction of the rule inputs, an AND fuzzy operator (representing the intersection of fuzzy sets) is defined as follows:

$$\mu_{A \cap B}(X) = \min(\mu_A(X), \mu_B(X))$$

Finally, it is worth mentioning that the complement of a fuzzy set A is fuzzy set defined by the membership function:

$$\mu_{A^c}(X) = 1 - \mu_A(X)$$

4.2.5 Fuzzy Logic Illustrative Example

The following Figure 27 depicts an illustrative example of a multi-variable fuzzy rule-based inference approach.

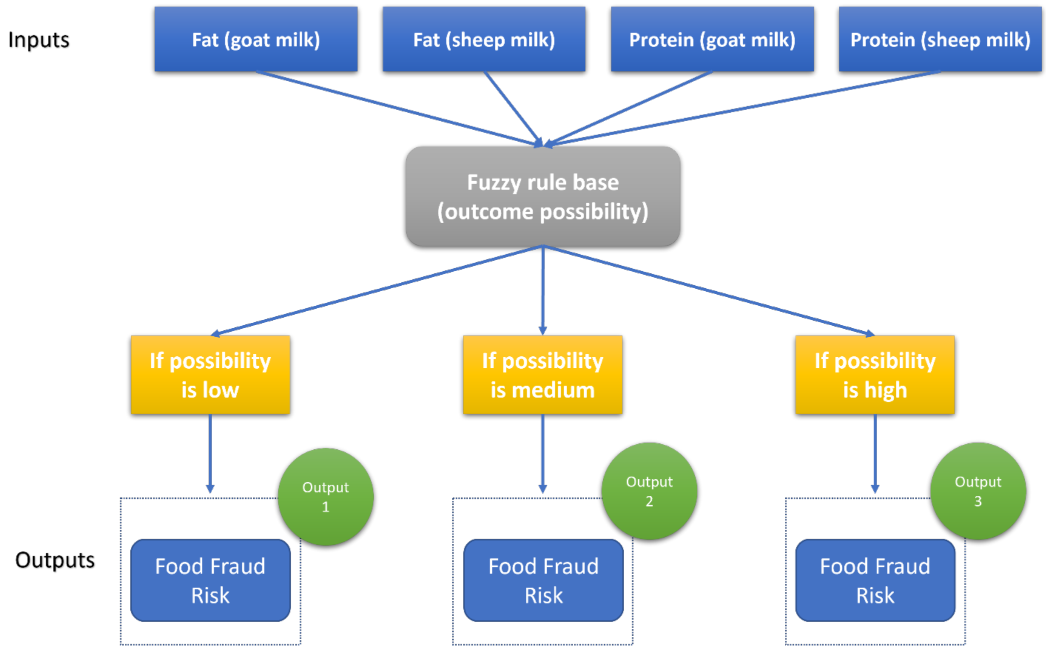


Figure 27: Fuzzy Rule-based Inference Approach.

The inputs of the fuzzy inference approach are four variables associated with fat and protein in goat and sheep milk, respectively. Each input has a membership function that is defined using expert opinions. For instance, if the value of “fat in goat milk” is between x-value and y-value then “fat in goat milk” has a low significance; if the value of “fat in goat milk” is greater than y-value has a high significance, etc. Considering the result obtained from each variable’s membership, an “outcome possibility” can be calculated via the membership function of the output variable (that is based also on expert opinions). The “outcome possibility” depicts a set of possible fuzzy rules that are obtained via the combination of the variables’ significance to recognize the possible outcome when the membership function of the output variable is applied. An example of fuzzy rule is the following: if “fat in goat milk” is low and “fat in sheep milk” is medium and “protein in goat milk” is medium and protein in sheep milk” is low, then the “outcome possibility” is medium. Knowing the “outcome possibility”, the most appropriate output (e.g., Output 1) is recommended. It is worth mentioning that the outputs are related to metric such as the food fraud risk.

Figure 28 illustrates the membership functions for input variables (e.g., fat and protein), as well as output variables (i.e., food fraud risk).

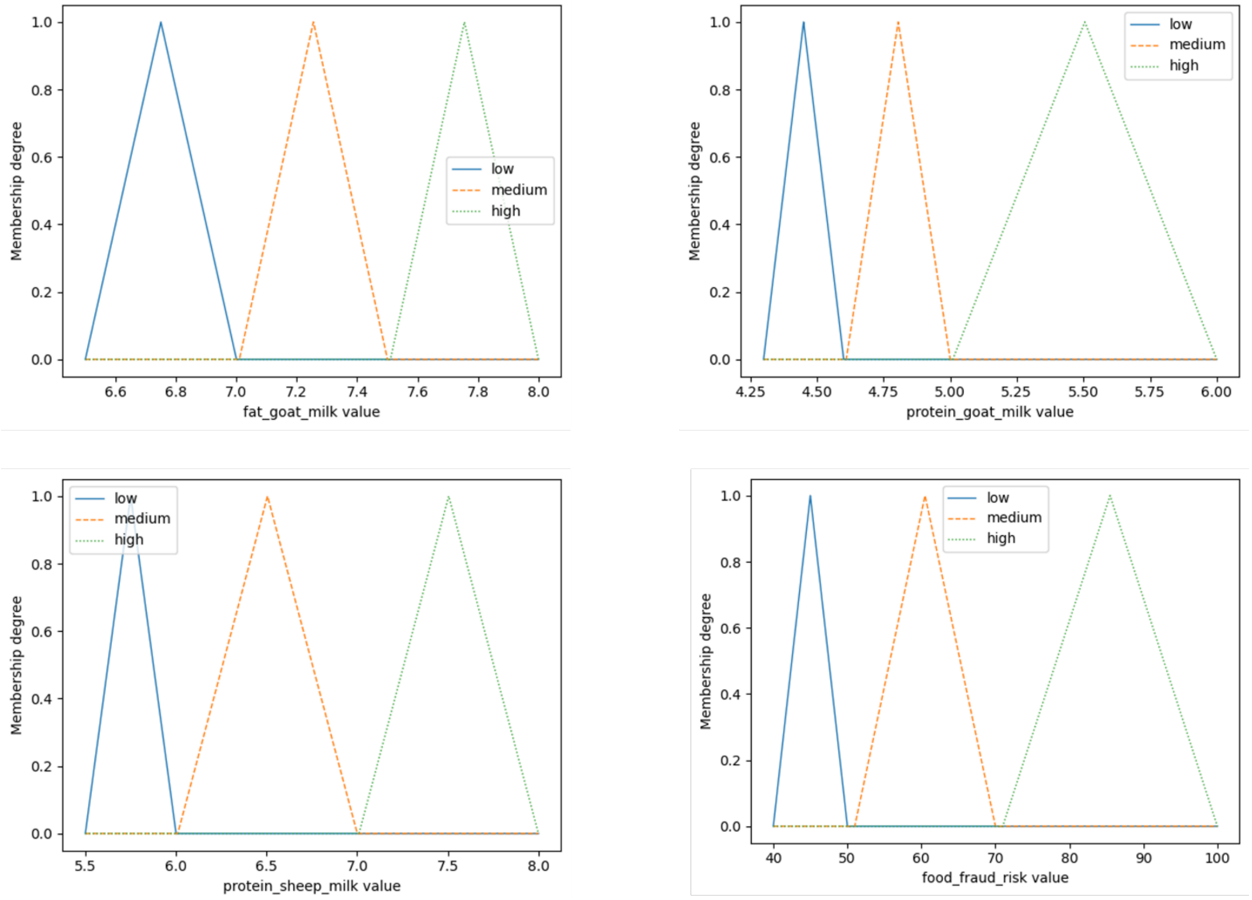


Figure 28: Triangular Membership Functions (fat, protein, and food fraud risk variables).

4.3 Multi-criteria Decision Analysis Approach

Considering the illustrative example of Figure 27, each outcome is associated with a list of pre-defined expert actions (see Figure 29).

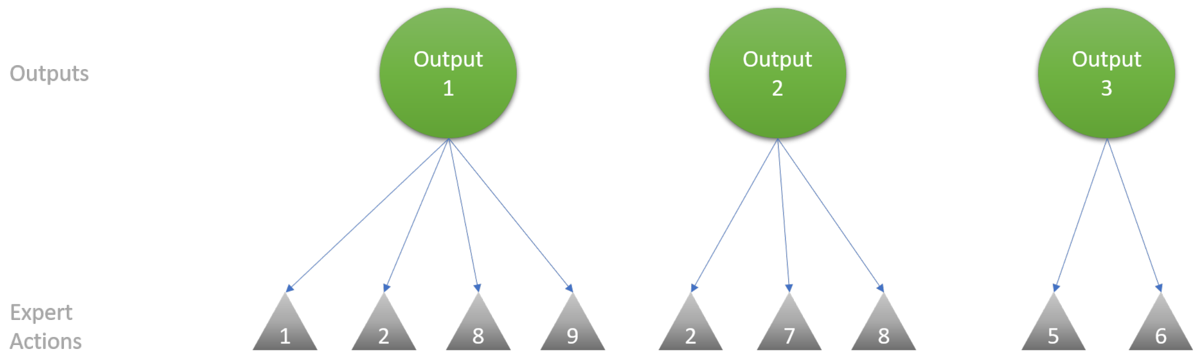


Figure 29: Mapping Fuzzy Rule-based Inference Output with potential Expert Actions.

Focusing on a specific output (e.g., Output 2), a multi-criteria decision analysis approach, where criteria are associated with food fraud risk values, as well as other quantitative and qualitative values of interest, is applied for statistical ranking purposes. In particular, the approach is applied to rank the relative importance of expert actions with respect to the computed values of food fraud risk and other metrics. The main idea is to represent a problem in a hierarchical form as depicted in Figure 30.

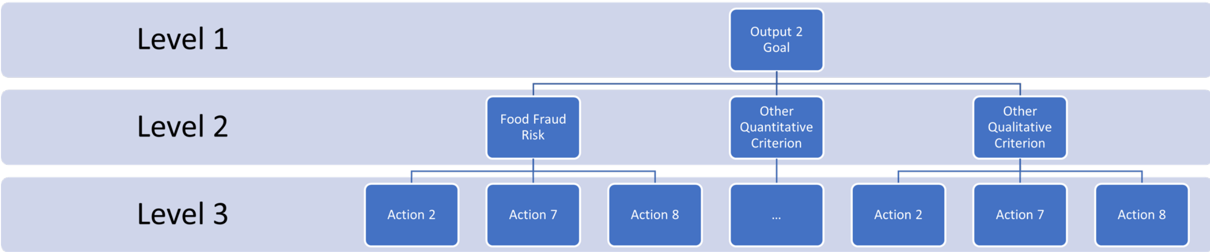


Figure 30: Multi-criteria Decision Analysis Approach.

The above structure consists of three levels. The first level represents the goal of the problem (e.g., rank possible expert actions in terms of their significance in the context of output 2), whereas the second level includes the criteria (i.e., the computed values of food fraud risk and so on) that an expert should consider achieving the goal. As far as the third level is concerned, several alternatives (i.e., expert actions) to be considered are reported. These alternatives should be compared with respect to each criterion of the second level. In addition to this, the criteria should also be compared with respect to the goal.

In particular, the above process answers to the following questions:

(Q1) Regarding the goal, which is the most important criterion?

(Q2) With respect to each criterion which is the most important expert action?

(Q3) With respect to the goal and criteria how expert actions are ranked/ sorted?

The final scores are obtained following statistical methods (e.g., Geometric Mean) with respect to performance measures that guarantee a rational decision-making process. Analytically, the process includes the following steps:

- (step 1) Pair-wise comparisons to rank criteria regarding the problem's goal.
- (step 2) Comparisons to rank expert actions with respect to each criterion.
- (step 3) Synthesize the above comparisons to rank expert actions.

For comparing the importance of criteria/alternatives, the following scale may be used (see Table 1).

Table 1. 1-9 scale for pair-wise comparisons of Variables

Degree	Description
1	Equally importance
3	Moderately importance
5	Strongly importance
7	Very strongly importance
9	Extremely strongly importance

The above scale indicates the level of relative importance from equal, moderate, strong, very strong to extreme level by 1, 3, 5, 7 and 9, respectively (i.e., odd numbers). Figure 31 illustrates an example.

Figure 31: A Pair-wise Comparison.

Suppose two items: “A” and “B”. If “A” and “B” are compared and a user prefers “A” with value 3 this means that “A” is moderately preferred to “B”; if “A” is preferred with value 5, this means that “A” is strongly preferred to “B”. Alternatively, pair-wise comparisons in this form follows the assumption that if “A” is 3 times better than “B”, then it can be deduced that “B” is 1/3 as good as “A”; if “A” is 5 times better than “B”, then “B” is 1/5 as good as “A”.

Furthermore, with respect to each criterion, expert actions are ranked based on expert’s experience. For instance, with respect to food fraud risk, expert action 2 has 20% score, expert action 7 has 70% score and expert action 8 has 10% score (i.e., sum up to 100%). Considering the scores obtained from pair-wise comparisons between criteria and the scores obtained from expert’s preferences regarding the expert actions, the final ranking of the actions obtained applying statistical approaches (e.g., see output 2 in Figure 32).

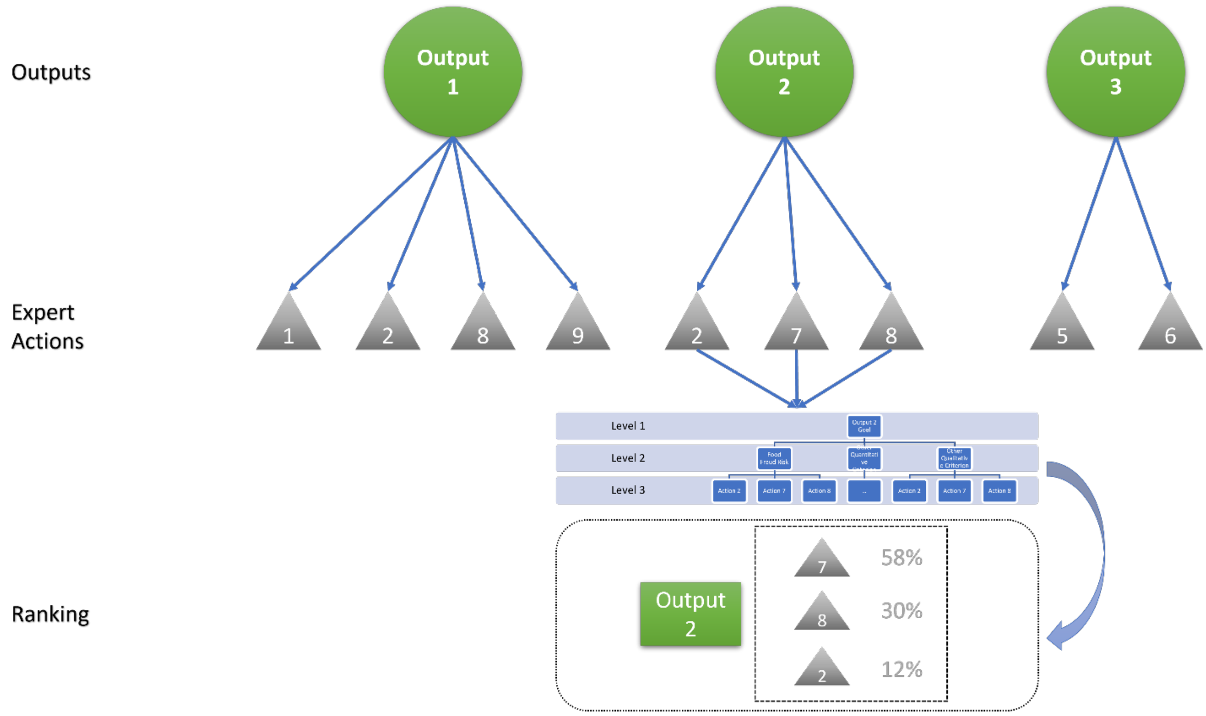


Figure 32: Expert Actions Ranking.

It should be noticed that the scoring of expert actions aims at facilitating the decision-making process under uncertainty or/and risk. The approach is based on the Analytic Hierarchy Process (AHP). The process of scoring actions is fully automated, whereas expert preferences are defined through excel files (see example of Figure 33).

	Message-1	Message-2	Message-3
Message-1	1		
Message-2	-3	1	
Message-3	-2	5	1

Row Scale	Definition	Column Scale
1	Equally important	-1
3	Weakly important	-3
5	Fairly important	-5
7	Strongly important	-7
9	Absolutely important	-9
2	The intermittent values between two adjacent scales	-2
4		-4
6		-6
8		-8

Figure 33: User preferences.

Finally, Figure 34 illustrates the ranking of three actions using the multi-criteria decision analysis approach.

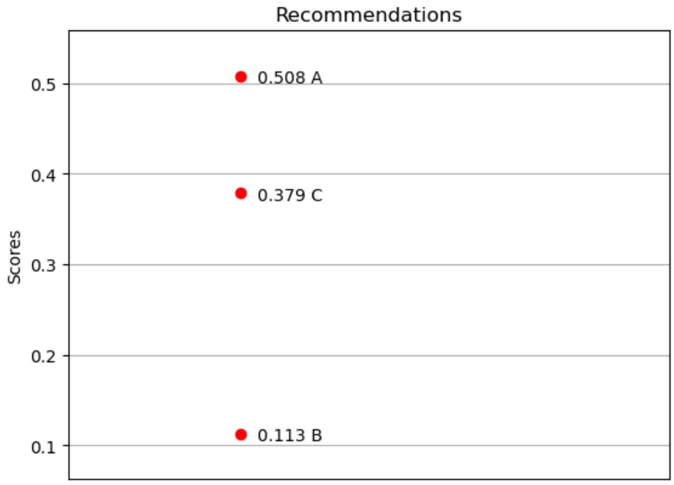


Figure 34: Ranking of Actions.

5 Vulnerability Risk Assessment

The Vulnerability Risk Assessment is actually the combination of two distinct processes that complement each other, the Vulnerability Assessment and the Risk Assessment. The Vulnerability assessment aims to address possible susceptibility in a system, while the main goal of the Risk Assessment is to detect potential threats and create responses to them. In ALLIANCE, we develop a **Vulnerability Risk Assessment Management Framework (VRAMF)**, which is our basis for evaluate the threats and the food fraud possibilities in the developed FSCs. VRAMF is used for the detection of the most critical control points in the FSCs, which are actually the points that extra control is needed for detecting and deteriorating food fraud.

Our initial approach was to introduce **sampling** at the **critical control points** of the FSCs, to detect as earlier as possible if there are strange conditions that could indicate a food fraud. We used the questionnaires based on the Delphi technique to define the first set of sampling points in each FSC. For example, in the FSC of Feta Cheese, we introduced two sampling points, one when the milk is given by the Truck Driver to the Reception Manager and one when the milk is pasteurized and received by the Production Manager to produce the cheese. These two sampling points produce sampling data that are fed to the AI Early Warning system for detecting potential food frauds. VRAMF evaluates the efficiency of the AI Early Warning system and continuously redefines the set of the sampling points in the FSCs in order to increase their efficacy. For example, if one more sampling point is needed after the production of the Feta Cheese, it could be introduced between the Production and the Storage Manager. The continuous interaction between VRAMF and AI Early Warning system is predicated on the fact that VRAMF establishes the sampling points from which the data are produced and fed to the AI Early Warning system, which is then evaluated and the sampling points are redefined if needed. The following Figure 35 illustrates this interaction.

At present, an initial set of sampling points is established for each FSC with the intention of establishing a comprehensive approach that incorporates all components. Simultaneously, VRAMF monitors the developed FSCs and the performance of the AI Early Warning system on an ongoing basis to determine whether a more refined set of sampling points for each FSC should be proposed during the subsequent reporting period.

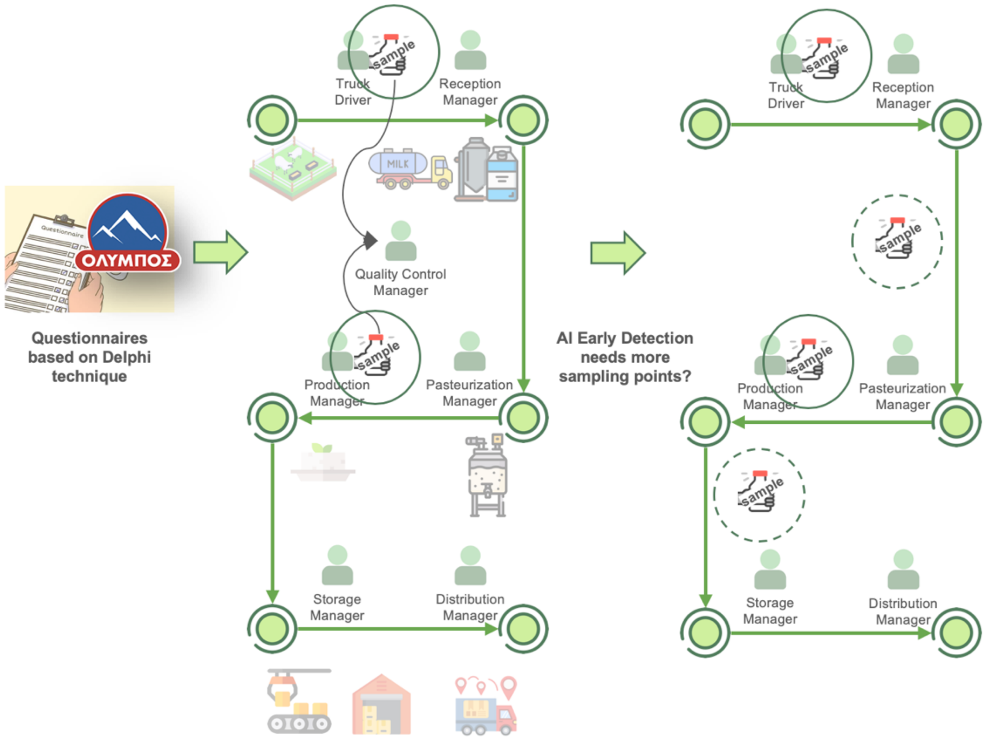


Figure 35: Interaction between VRAMF and AI Early Warning system in Feta Cheese FSC.

6 Interoperability between Food Supply Chains

The interoperability of the data exchanged on the FSCs is a crucial process that focuses on the harmonization of the heterogeneities between these data. The idea is that the datastores (Blockchain and Off-chain) use the **GS1 EPCIS** (Electronic Product Code Information Services) standard and its companion **CBV** (Core Business Vocabulary) to define the fields of the tables in these datastores. The utilization of these standards for the naming of the table fields facilitates easy data sharing within organizations and stakeholders across the entire FSC.

CBV is designed to facilitate interoperability in EPCIS data exchange by providing standard values for vocabulary elements to be included in EPCIS data. The standard recognizes that the greatest interoperability is achieved when all data conforms to the standard, and also recognizes that their users may need to extend the standard in certain situations. To that end, this standard defines two levels of conformance for EPCIS documents:

- CBV-Compliant: An EPCIS document that ONLY uses vocabulary identifiers specified in the CBV standard in the standard fields of EPCIS events.
- CBV-Compatible: An EPCIS document that uses a COMBINATION of vocabulary identifiers specified in the CBV standard and other identifiers that are outside the standard.

Our focus is on facilitating data sharing, when the **products are moved from the producer to the retailer**, using a CBV-Compatible EPCIS document. Currently, we are in the process of using identifiers specified in the CBV standard, especially for the description of the data that are related to packaging. More particularly, until the next reporting period, we will have progress in reshaping the following table collections, in order to be compatible with CBV:

- The Storage and Distribution Collection in the Olive Oil FSC
- The Storage and Distribution Collection in the Feta Cheese FSC
- The Packaging and Storage Honey Collection in the Organic Honey FSC
- The Packaging Collection in the Faba Beans FSC
- The Packaging Potato Collection in the Lika Potatoes FSC
- The Pasta Packaging and Storage Collection in the Organic Pasta FSC
- The Packaging and Storage Collection in the Arilje Rapberries FSC

7 Conclusion and outlook

This deliverable presents an intermediate description of the development of all the technical components realized in work package WP2 within the period of M5-M18. To facilitate the understanding of the ALLIANCE platform, this deliverable presents the design imprints transitioning from the logical architecture given in the DoA to the ALLIANCE Reference Architecture, encompassing all the technical components that are developed and implemented in WP2 and WP3. Then, for each technical component of WP2, an analytical description is presented along with the results achieved during the reporting period. The technical components referring to the Blockchain and the Early Warning and Decision Support System are available in the form of first implementations showing respective key functionalities and providing first concrete insights also to the end users into such modules. On the other hand, the implementations referring to the Vulnerability Risk Assessment and the Interoperability Framework also reveal potential dependencies with the aforementioned components and the feedback received from pilot demonstrators, thus directing future work.

The work on all WP2 components will continue according to the DoA also after submission of this deliverable up to the end of WP2 at month M30. The focus of work in this period M19-M30 is set on continuous improvements and developments of all the technical components, the integration into the ALLIANCE platform and the validation in the context of demonstration within WP4. The final achievements and results of all WP2 components will be summarized within D2.4 (“Final AI-enabled tools for Vulnerability Risk Assessment, Early Warning Indication and Decision Support Preventive Actions) at M30.

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