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THESE DE DOCTORAT

Présenté par

Mr : BOUGDIRA ABDESSELAM

Discipline : Sciences de l'Ingénieur

Spécialité : Systèmes Intelligents

Sujet de la thèse : A Generic Model for Intelligent Traceability

Formation doctorale : Sciences de l'ingénieur, sciences physiques, Mathématiques et Informatique.

Thèse présentée et soutenue le samedi 10 octobre 2020 à 10h au Centre de conférences devant le jury composé de :

Nom Prénom	Titre	Etablissement	
Abdelouahed ESSAHLAOUI	PES	Faculté Polydisciplinaire-Taza	Président
Mohammed ERRAMDANI	PES	Ecole Supérieure de Technologie- Oujda	Rapporteur
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I am dedicating this thesis to the beloved people who have meant and continue to mean so much to me…

My parents

My little family

My Sisters and Brothers

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Résumé

Ce mémoire de thèse a été consacré au développement d'un modèle générique pour l'implémentation de la traçabilité dans l'industrie moderne dont la tendance actuelle est à l'usine intelligente et à l'échange croissant de données hétérogènes et distribuées. Parallèlement, chaque solution de traçabilité est spécifiquement dédiée à un produit particulier et la plupart des solutions de traçabilité intelligente se différencient au vu des techniques et des technologies d'implémentations déployées. Dans ce contexte, nous avons avancé l'idée d'existence d'un écart entre la conceptualisation et l'implémentation d'une solution de traçabilité.

A cet effet, nous avons proposé un modèle générique qui vise à garantir une traçabilité générale, interopérable et intelligente. Ce modèle implique deux outils ; un Framework conceptuel et une caractérisation de la traçabilité intelligente. Le Framework introduit les bases d'une solution de traçabilité et conduit sa réalisation. La caractérisation de la traçabilité intelligente s'est appuyée sur la modélisation des informations de traçabilité et la mise en place du processus de prise de décision (apprentissage et raisonnement). Sur la base de ce modèle générique, nous avons développé une solution typique de traçabilité intelligente, comprenant des bases, une modélisation contextuelle des informations de traçabilité, une ontologie à usage général et un mécanisme de prise de décision. La faisabilité théorique du modèle a été démontrée par comparaison avec trois systèmes différents (pharmaceutique, céramique et bois), tandis que la faisabilité pratique a été démontrée par implémentation en milieu industriel (trois secteurs différents : industrie alimentaire, agriculture et automobile). À cette fin, trois prototypes de traçabilité intelligentes ont été développés et validés à l'aide de la logique floue, des réseaux de neurones artificiels, et des réseaux bayésiens.

Mots Clés : Intelligence Artificielle, Intelligence Ambiante, Soft Computing, Industrie 4.0, Traçabilité.

Abstract

The purpose of this thesis was providing a formal and structured model of traceability implementation for modern manufacturing. Such environment implies smart factory, continuous technological advances, and an ever-growing volume of heterogeneous and distributed data. On the other side, the most of existing traceability solutions are specific-situation systems and the intelligent ones might create confusion during developing or comparing solutions due to lack of formal description and characteristics. In this context, we advanced the hypothesis about the existing of a gap between standardizing, conceptualizing, and implementing a traceability solution.

Therefore, we proposed a generic model that aims to guarantee a general, interoperable, and intelligent traceability. The proposal involves the usage of a conceptual framework and the characterization of intelligent traceability. The framework lays the basis for a traceability solution and conducts its realization. The characterization of intelligent traceability relied on the modeling of the knowledge representation of traceable information and the setting of the decision-making process (learning and reasoning mechanisms). As a result, we proposed the foundation of a typical intelligent traceability solution, including bases, context-modeling of traceable information, a general-purpose ontology, and a decision-making mechanism. The theoretical feasibility of the generic model has been shown through the comparison with three different systems (pharmaceutical, ceramic, and wood), whereas the practical feasibility has been shown through three different industrial implantations (seafood industry, agricultural, and automotive). To this end, three prototypes of intelligent traceability solutions have been developed and validated, using the Fuzzy set, Artificial Neural Networks, and Bayesian networks.

Keywords: Artificial Intelligence, Ambient Intelligence, Soft Computing, Industry 4.0, Traceability.

List of Abbreviations

6LoWPAN: IPv6 over Low Power Personal Area Network:
AaaS: Anything as a service
AI: Artificial Intelligence
ANN: Artificial Neural Network
BPMN: Business Process Model and Notation
BPO: Business Process Outsourcing
CC: Cognitive Computing
CoAP: Constrained Application Protocol
CPS: Cyber-Physical Systems
DL: Description Logic
EPC: Electronic Product Code
EPC-DS: EPC Discovery Services
EPC-IS: EPC Information Services
EPC-TS: EPC Trust Services
FCM: Fuzzy Cognitive Maps
FOAF: Friend Of A Friend
FOL: First Order Logic
GPS: Global Positioning System
GS1: Global Standards
GTIN: Global Trade Item Number
HACCP: Hazard Analysis Critical Control Point
IaaS: Infrastructure as a Service
ID: Identification
IIoT: Industrial Internet of Things
IoS: Internet of services
IoT: Internet of things
IS: Information Systems
ISO: International Organization for Standardization
ITaaS: Intelligent Traceability as a Service
ITO: Intelligent Traceability Ontology
JSON: JavaScript Object Notation
LLNs: Low Power and Lossy Networks
MES: Manufacturing Execution Systems
NFC: Near Field Communication
NIST: National Institute of Standards and Technology
ONS: Object Naming Service
OWL: Web Ontology Language
PaaS: Platform as a Service
PML: Physical Markup Language
PROV-O : Provenance Ontology
QR : Quick Response Codes
RDF: Resource Description Framework
RDFS: Resource Description Framework Schemas
RFID: Radio Frequency Identification
ROLL: Routing Over Low power and Lossy networks
RTLS: Real Time Locating System
SaaS: Software as a Service
SMEs: Small and medium-sized enterprises
SOA: Service-Oriented Architecture
SOSA: Sensors, Observations, Samples, and Actuators
SPARQL: SPARQL Protocol and RDF Query Language
SSCC: Serial Shipping Container Code
SSN: Semantic Sensor Network
SWRL: Semantic Web Rule Language
TRU: Traceable Resource Unit
WSN: Wireless Sensors Network
XML: Extensible Markup Language

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General Introduction

1.1 *Context*

The need to document product's data is ever-expanding, national and international legislation were introduced to force such documentation (i.e., the Moroccan decree "#2-18-44, published in BO #6684/ 2018", and the European regulation 178/2002). Also, extensive efforts are made to ensure additional knowledge about origin, processes, and other properties concerning the product. This information is essential for both the industry and consumers, and since then the usage of traceability is highly required.

In the food supply chain, the need for traceability is driven by legislation, safety, quality, welfare, certification, and competitive advantages (Karlsen 2011; Bosona et al., 2013; Aung et al., 2014). In the pharmaceutical industry, traceability ensures respect for specific security and safety standards (Barchetti et al., 2011). Generally, traceability is required also for product withdrawal, recall, and safety management (Anal et al., 2018). Also, we assume that traceability would be an efficient tool for enhancing supply chain sustainability (Bougdira et al., 2016c).

Regarding the implementation of traceability, three common features are noticed, (1) variety of data sources in the modern supply chain that generate an increasing and heterogenous traceable information, (2) the particularity scope of each traceability solution, (3) the extensive usage of intelligent traceability systems over the past decade.

In manufacturing, the trend is towards smart factory (Zhong et al., 2017) that involves several technologies (i.e., Artificial Intelligence, Cyber-Physical Systems, Internet of Things (IoT), and Cloud Computing) (Xu et al., 2018). These technologies impact the supply chain and promote the emergence of industry 4.0 (Oztemel and Gursev, 2020) where various sources generate and share heterogeneous, distributed, and ever-growing volume, namely Big data.

Typically, each proposed solution provided a traceability system to a particular product. Mainetti et al. (2014) proposed a traceability system for fresh vegetables. Liang et al. (2015) focused on cattle/beef traceability. Whereas, Barata et al., (2018) proposed a traceability system for ceramic material. Salah et al. (2019) suggested traceability for agricultural products.

During the last ten years, many researchers introduced different forms of intelligent traceability. Wang (2014) meant by intelligent traceability a real-time view into the production processes. Xiao et al. (2016) adopted mixed methods to establish intelligent traceability as a monitoring tool of the cold chain. Wang et al., (2017) considered intelligent traceability as a food quality tool. Besides consideration of quality, Yongjun et al. (2019) classified intelligent traceability as safety tool for transparency during products transportation.

1.2 Research questions

The review of traceability shows that the existing solutions differ broadly from each other regarding purposes, implementations, characteristics, and techniques. Therefore, we can advance the following hypothesis:

H_1: It is hypothesized that a gap still exists between standardizing, conceptualizing, and implementing a traceability solution. To enlighten the essence of this gap, we establish the following research questions:

Q_1: Would the extension of traceability beyond its classical functions (tracing and tracking) be an important asset to enhance traceability efficiency?

From the perspective of the system's capabilities, we wonder whether additional functions would be helpful to enhance the scalability and resilience of a traceability solution, especially to cope with the continuous advances in industrial environment.

Q_2: Does the heterogeneous data have an effect on the way of capturing and using traceable information?

Here, we inquire about how to deal with the ever-growing data volume that generated within the supply chain. This point refers to the interoperability challenge and data-integration issue.

Q_3: Does the establishment of a situation-specific traceability suitable to face internal and external changes in processing?

As mentioned, most traceability systems are expected to satisfy a specific case and provide a solution to a particular product. From this standpoint, if a company had to make an alteration to its scope (i.e. changes in the business processes, targeting new markets, facing new legislation and standards), or produce different and seasonal products, then one wonders whether this business should replace the traceability system, or at least make significant changes in the existing situation-specific system, or it should develop a traceability system for each product. Such a tough decision depends on practices, technical feasibility, implementation complexity and cost-effectiveness.

Q_4: What an intelligent traceability would look like?

Different forms and propositions of intelligent traceability can create confusion during developing or comparing solutions. We question whether a formal description of intelligent traceability would be need. If so, what are their characteristics and properties.

1.3 Thesis statement

We provide answers to the questions research (Q_i), these answers (A_i) help to set the following properties (Pi) that check the veracity of the hypothesis (H1).

A_1 to Q_1: Yes, Then P_1: Manage to expand traceability scope using additional activities.
A_2 to Q_2: Yes, Then P_2: Elaborate interoperable representation of traceable information.
A_3 to Q_3: No, Then P_3: Require to set general-purpose traceability solution.
A_4 to Q_4: No, Then P_4: Require that the traceability process, itself, should be intelligent.

As a result, we propose a generic model that aims to guarantee a general, interoperable, and intelligent traceability. This proposal involves two related tools; a conceptual framework and a characterization of intelligent traceability. Based on both tools, we conduct the different works presented in the current thesis.

The conceptual Framework combines and synchronizes the functioning of Description, Engineering, and Executive aspects. It ensures the inclusions of (P_1, P_2, P_3, and P_4). Hence, it ascertains the following elements:
Lays the basis for a traceability solution before its realization.
Conducts the traceability solution realization.

In the light of the mentioned elements, the characterization of intelligent traceability is based on a set of activities that enhance traceability efficiency. The intelligence aspect relies on the core idea of "Ability to know and think".
Know: Set the modeling of the knowledge representation of traceable information.
Think: Set the decision-making process, including learning and reasoning mechanisms.

1.4 Thesis contributions

Our contributions encompass Theoretical contributions and Empirical contributions. Regarding the theoretical contributions, we developed the basis for a typical intelligent traceability solution using the conceptual Framework. Also, we proposed a general context-modeling of traceability using the First Order Logic and Description Logic. Based on this modeling, we developed a general-purpose ontology, namely Intelligent Traceability Ontology (ITO) using Web Ontology Language (OWL2). Afterward, we developed a generic-prototype application, namely Intelligent Traceability as a Service (ITaaS) using cloud technology and ITO. Finally, we checked the theoretical feasibility of the generic model by comparison with systems from three different industries (pharmaceutical, ceramic, and wood).

Based on the theoretical contributions, we derive and customize three different intelligent traceability solutions for implementation in three different industries (seafood, agricultural, and automotive). In the context of these empirical contributions, we developed and tested a prototype for each single intelligent traceability solution using the Fuzzy set, Artificial Neural Networks, and Bayesian networks. We checked the practical feasibility of the generic model through an evaluation of every single solution.

1.5 Thesis structure

This thesis comprises four chapters that detail the survey of traceability and our theoretical and empirical contributions. Also, it involves four appendixes, including a semantics formalization of the conceptual framework and three certifications of the industrial implementations.

Chapter 1 gives a state-of-the-art of traceability. Thus, it reviews the traceability core concepts, principally those referring to the supply chain field. Afterward, it summarizes technological tools applied in traceability, particularly from the perspective of the modern supply chain. This technological study is done before the study of exiting traceability systems because we assume that the review of these technologies is necessary to describe the industrial environment where systems are implemented. Next, sections examine and detail the existing traceability systems. It is an empirical investigation into traceability implementation, including EPC-based systems, standalone, and intelligent traceability systems.

Chapter 2 is a presentation of the generic model for intelligent traceability. It provides a general overview of the generic model. Next, it details the conceptual framework that comprises three complementary aspects (description, engineering, and executive) that address the issue from an implementation point of view. The framework can lay the bases and describe steps to implement a solution. Afterward, it characterizes the intelligence aspect, including a definition, features, knowledge representation, learning, and deciding mechanisms. Last, an intelligent traceability ontology (ITO) was presented and detailed.

Chapter 3 is a presentation of a typical prototype for intelligent traceability (ITaaS). It illustrates the usage of the conceptual framework through a scenario tailed for canned fish. Hence, it details a "step-by-step" guide of the functioning way of the framework. In addition, it introduces the basis for a typical solution, including aims, functions, data classification, processes, and procedures. Next, sections present the steps of developing different activities (collecting, retrieving, and monitoring). This implementation uses a development-ecosystem that comprises tools like OWL2, Protégé 5.5.0, Jena API, and J2EE. The theoretical feasibility of the typical solution was evaluated and compared with three different traceability.

Chapter 4 is a presentation of three different industrial implementations. All three prototypes use a “knowledge-base” that is customized and derived from ITO. The first intelligent traceability prototype is developed to evaluate the possible degradation of quality during fish processing (seafood industry). This solution uses a fuzzy logic algorithm to support the decision-making process and recommend necessary actions for monitoring quality. The second prototype is developed to assess and predict the overall acceptability of vegetables within the agricultural supply chain. It is based on the sensory parameters (appearance, texture, flavor, and convenience), and it combines Artificial Neural Networks and fuzzy logic to propose recommendations for enhancing the standards and practices of raw product sorting. The third solution is developed to follow and predict the number of parts used in automotive production. This solution uses Bayesian networks to ensure more supply chain visibility and synchronization between information and physical flows.

Chapter 1: Traceability from Theory to Application

1 Introduction

Traceability was first mentioned within automotive manufacturing in the 1970s (Karlsen et al., 2016). Afterwards, traceability was applied in documenting software projects and enterprise modeling. However, the turning point came with the food scandals of the 1990s (e.g., mad cow disease). Since then, traceability was included in food regulations and has become used in many other industries.

During establishing the traceability state of the art, one could note that researchers use the term 'traceability' in different ways. Therefore, several conflicting interpretations prevail among scientific publications. Many traceability systems already exist, although practitioners do not agree on how traceability properties could be properly implemented. On the other hand, no common framework to design or even compare these solutions exists. In addition, the usage of "intelligent traceability system" has increased in the last decade. However, the literature reveals that there is no unanimous version of intelligent traceability.

For the sake of clarity, we approach the survey of traceability from three different angles, as depicted below. Therefore, the theoretical aspect of traceability involves traceability core concepts, principally those referring to the supply chain field, including sector like food where concepts are strictly defined. Next and since traceability systems use different technologies, we urge that before moving to review the existing traceability systems, a description of technological impacts on traceability is necessary.

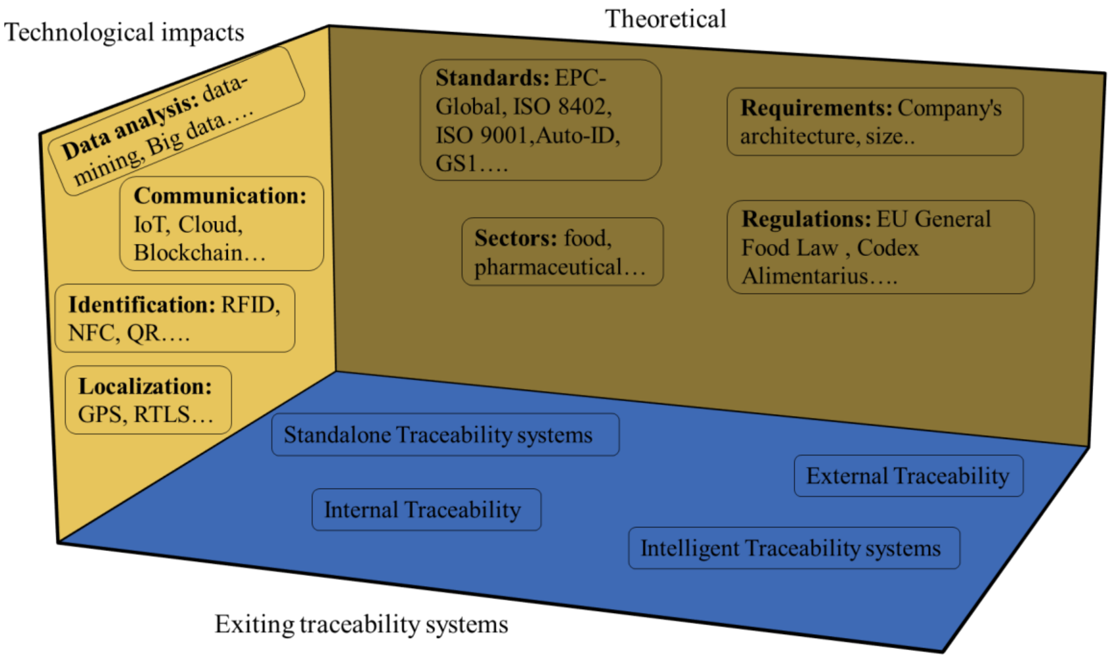

Figure 1. 1:Survey of traceability regarding theory, technologies, and applications.

2 Traceability in Theory

When we started our investigation, we have noticed that traceability is often used in the general sense. For instance, the word tracking and tracing are used interchangeably, which is a source of confusion of the concepts. There is also a lack of consistency in using some other concepts like a batch and unit. Besides that, there is a general consensus on how much traceability is important. However, there are many propositions on what traceability is and what properties could and should have.

2.1 Definitions

Many definitions exist in different industries, which can make the term traceability confusing. For instance, differences exist between traceability as applied in the information technology and food industry. In addition, we found several definitions in frequent use referring to many scopes and sectors.

As we cannot assume that the reader is familiar with all the various definitions of traceability that exist, we begin by listing the most of them. Thus, to increase consistency and readability, this subsection includes only the pre-existing definitions as described in international standard and legislation, in the supply chain, in the product's industry, and also information technology. Table 1.1 summarizes the main elements of this investigation.

Scope	Definitions
Standards and legislations	
Traceability	'The ability to trace the history, application or location of an entity by means of recorded identifications' ISO 8402_1994
Traceability	'The ability to trace the history, application or location of that which is under consideration' ISO 9000_2000 and ISO 22005_2005
Traceability	"The ability to trace and follow a food, feed, food producing animal or substance intended to be, or expected to be incorporated into a food or feed, through all stages of production, processing and distribution" The EU General Food Law (EU, 2002)
Traceability (food)	'The ability to follow the movement of a food through specified stage(s) of production, processing and distribution". The Codex Alimentarius Commission Procedural Manual (FAO/WHO, 1997)
Supply Chain Stages	
External Traceability	'…All traceable items must be uniquely identified, and the information be shared… from some or all stages of transformation to some or all parties in the value chain'. (Zhang and Bhatt, 2014).
Internal Traceability	'...refers to the processes that individual firms use which link the identities of the products that enter the firm's operations and the products that leave its operations.' (Bhatt et al., 2016)

Chain Traceability	'...ability to track a product batch and its history through the whole, or part, of a production chain from harvest through transport, storage, processing, distribution and sales' (Moe, 1998)
Product's Industry	
Tracing (upstream)	'...the ability, in every point of the supply chain, to find origin and characteristics of a product from one or several given criteria' (Dupuy et al. 2005)
Tracking (downstream)	'...the ability, in every point of the supply chain, to find the localization of products from one or several given criteria' (Dupuy et al. 2005)
Traceability	The ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, by means of recorded identifications (Olsen and Borit, 2013).
Information Technology	
Traceability (Software Engineering)	'…to trace all the elements that can be considered relevant enough for the organization within a particular project or software product' (García et al. 2008).
Requirement Traceability	'…the ability to follow the life of software artifact… has been used as a quality attribute for software' (Winkler and Pilgrim et al., 2010).
Vertical, Horizontal Traceability	'…to trace dependent items within a model', '…to trace correspondent items between different models' (Lindvall and Sandahl, 1996).

Table 1. 1: Definitions of Traceability.

The most practical definition was found in the International Standardization Organization (ISO). For 8402 (1994), traceability is "the ability to trace the history, application or location of an entity by means of recorded identifications".

This definition clearly highlights elements that should be traced (history, application, and location). Further, it outlines the manner used to trace (by means of recorded identifications). However, a definition that uses "trace" to define "traceability" seems to be confusing and incomplete. The other definitions (ISO_9000 and ISO_22005) have a slightly less specific definition. ISO_9000 is a standard for quality management systems. Whereas, ISO 22005 is a specific standard for traceability in the food and feed chain.

Definitions in Codex Alimentarius and EU's legislation are concerned with food safety and quality. Both are recognized by the World Trade Organization as an international reference to resolve food disputes. These definitions emphasize the importance of following the food path through supply chain stages. In this context, Ringsberg (2011) studied the traceability from a supply chain perspective where various stages could be identified according to each sector. Typically, there are always six main elements: supplier, manufacturer, distributor, retailer, logistics, and customer.

These components describe the process from the supplier to the end user. For the rest of this thesis, the supply chain is considered as depicted in figure 1.2 Note that logistics describes the flow of things between origin and final destination and can mean materials handling, production, transportation, and warehousing.

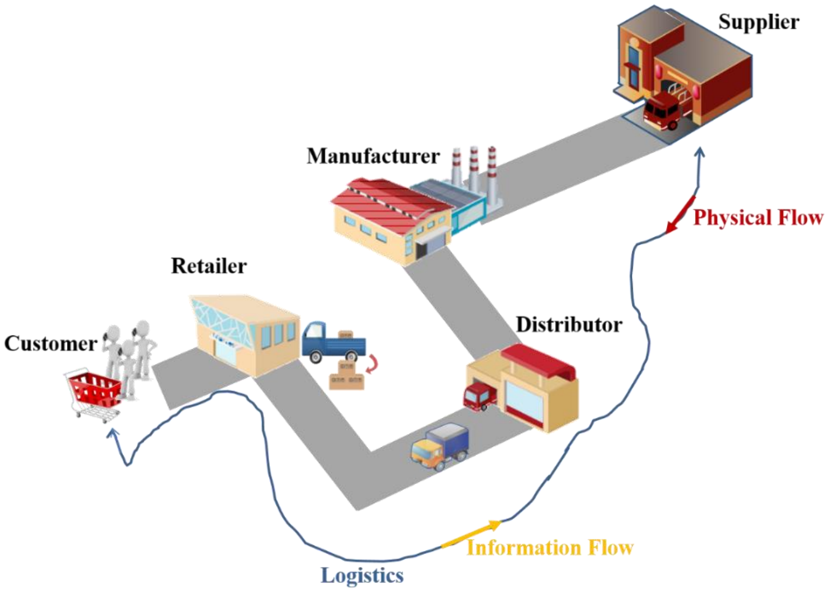

Figure 1. 2: General description of supply chain.

In this case, traceability is internal or external, it aims to track and trace information flow linked to a physical item. Information could refer to a product or its physical movement within a company or between other companies. If these are combined, that could enable fast and precise tracing.

An efficient system should address both internal and external traceability with clear connections between them. This combination might ensure total chain traceability, where information and details about an item are available through the whole supply chain.

When relating to the product's industry, traceability specifically entails materials and parts origin, the processing history, and the product location. Here, we remark that the terms tracing and tracking are essential for product traceability. These terms stress the need for monitoring supply chain activities whether those belong to the upstream or downstream of the chain.

In addition, these definitions underline the importance of recording information, assigning identifiers, and accessing these records. This requires complete knowledge of the chain and a well-designed mechanism.

Traceability in information technology refers to the history of artifact, project, or software product. It helps to follow items within a single model or between different ones. Since this study does not try to detail the term “traceability” in domains other than the ones just mentioned, the discussion of traceability from this point of view is beyond the scope of our thesis.

Note that, still several of these definitions have something in common such as ‘the ability’ ‘tracing’, ‘tracking’, and ‘information’. The current thesis has a special interest for products manufacturing and supply chain in a general way. Therefore, for the rest of this thesis, “traceability” should be understood to have reference to these two contexts.

2.2 Drivers and requirements

Generally, drivers attempt to answer the questions who, what, when, where and why. Global Standards 1 (GS1) stresses the importance of this information as fundamental principles of good traceability. These questions are also in line with social concerns and some business needs.

For the pharmaceutical industry, traceability could be a tool to show respect for specific security and safety standards. Economic challenges might be a powerful factor that induces stakeholders to establish traceability. Thus, traceability helps managers reduce logistics costs and manage resources more efficiently.

On the other hand, traceability has to fulfill some requirements. The data integrity is one among others. This means the assurance of the accuracy and consistency of traceable information overall supply chain stages. Also, transparency is essential to preserve consumers’ and authorities’ confidence in the product. Thus, collecting and recording information should be clearly defined and under strict control to avoid fraud.

Moreover, data completeness should be observed in line with legislation and logistics constraints. In diseases or counterfeiting cases, traceability has to provide a quick response to isolate the issue source and reduce the impact. During recall activities, traceability requires the availability of adequate information to ensure appropriate decisions and reduce costs. Also, traceability should be seen as a complementary tool for quality and safety activities.

One can notice that if there is an agreement on a traceability’s aspect, its importance is the most one that fulfills this unanimity. Most stakeholders state the need for traceability and praise its importance for achieving multiple benefits. This consensus is rapidly lost while addressing traceability properties.

2.3 Properties

While trying to point out the traceability basics and properties, one can notice that there are several points of view, and there is no unanimous agreement on a unique description. However, there are some common points that are shared by different propositions.

According to Golan et al., (2004), traceability can have breadth, depth, and precision. Breadth represents the traceable information amount. Depth specifies how far a system has information about the downstream and upstream chain. Precision stands for assurance that one can pinpoint the exact location of an object.

Furthermore, traceability needs the connection between physical and information flow (Bosona and Gebresenbet, 2013). Stakeholders should provide details about design parameters to decide what products and levels to be included in traceability. Also, a well-designed traceability requires knowledge of supply chain structure, relationships, and capacity.

As previously mentioned, most definitions attempt to explain how traceability can follow the product and/or information. Another important question is what information is essential. According to Regattieri et al. (2007) four traceability pillars exist product, identification, data to trace, product routing, and traceability tools.

Each entity must have a unique identifier. Entity refers to the "Traceable Resource Unit" (TRU). Several authors discussed and detailed this concept aspects (Moe, 1998; Aung and Cheng, 2014; Pizzuti and Mirabelli, 2014; Olsen et al., 2018).

Next, actors should choose adequate and useful traceable information. This factor depends on the actors' capabilities and technological means. For example, data could be a product ID, product description, lot number, quantity, or supplier ID.

Product routing dictates that stakeholders should ensure to cover the entire supply chain. The last pillar underscores the technical solutions that are used for traceability. These tools should help with capturing data and identifying products.

Moe (1998) identifies two traceability core entities; product and activity. These entities are subdivided into other elements. The product includes type and amount, and activity includes type and time. In this setting, three categories of TRU exist; batch, trade unit, and logistics unit. A batch is a unit quantity that moves in the same process. Whereas, a trade unit is a unit that moves from one stakeholder to the next one in a supply chain. The logistics unit refers to a trade unit before transportation or storage.

2.4 Interpretations from theoretical aspect

The described situation above can lead to some confusion. Accordingly, traceability is confused with tracing, tracking, identification, product recall, and product withdrawal. In addition, traceability is usually associated with other concepts, such as standards, legislation, regulations, safety, and quality.

Moreover, there is a difference between traceability as an activity and the techniques and technologies applied to perform this task. Sometimes, traceability becomes equivalent or competitor to notions like traceability system, quality tool, autonomous tracking, intelligent tracing, and RFID based-identification. We should also indicate that all the mentioned basics and properties are mandatory for effective traceability.

In practice, other ones must be strictly observed. Thus, a traceability mechanism should provide ways to record and retrieve information. Raw materials details must somehow be gathered into units with similar properties. Furthermore, identifiers must be assigned to these units. Ideally, keys must be globally unique and never re-utilized. In addition, information must be reported and either directly or indirectly associated with identifiers.

The next subsection addresses the description of technological impacts on traceability. In other words, we try to summarizes the most noticeable technological tools applied in traceability with respect to modern manufacturing and supply chain.

3 Technological Impacts on Traceability

In manufacturing, the trend is towards more automation and interoperability (i.e., Industry 4.0) (Zhong et al., 2017; Bortoliniet et al., 2017). Such industrial environment implies several technologies like Cyber-Physical Systems, Internet of Things, Cloud Computing, and blockchain (Xu et al., 2018). These technologies impact the traceability in different ways including communication, identification, localization, data analysis, and intelligent applications. In a previous study, we have summarized these impacts from a supply chain perspective (Bougdira et al. 2015; 2016a).

3.1 Cyber-Physical Systems

Cyber-Physical Systems (CPS) promote the integration of computation with physical processes. These systems use the potentials and resources of man-machine interaction to enhance process monitoring in cases like processing, transportation, and supply chain management.

The CPS operations are coordinated and monitored by computing and communication systems. This controlling is ensured by feedback loops where physical processes affect computations and vice versa (Ragunathan et al., 2010). The implementation of CPS combines real-world objects with networked computers (i.e., Distributed Control System, Networked Control System, and Supervisory Control and Data Acquisition) (Shi et al., 2011).

CPS merge Cyber (i.e., network components and commodity servers) and physical (i.e., sensors and actuators), hence CPS are heterogeneous, large-scale, federated, and geographically dispersed. Consequently, CPS could face some common issues like availability, distributed management, re-configurability, real-time operation (timeliness), fault-tolerance, scalability, autonomy, reliability, and security.

3.2 Internet of Things

The Internet of Things (IoT), also known as the Industrial Internet of Things (IIoT) (Boyes et al., 2018) is an initiator of Industry 4.0. From the angle of infrastructure, services, and applications, the Internet of Things is a global network infrastructure intended to link objects from the physical and virtual world through data collection and communication capability (Atzori et al., 2010).

IoT can enable object identification, autonomous data capture, and connection within social, environmental, and user contexts (Xu et al., 2014). This technology has several blocks (Boyes et al., 2018). First, devices collect, process, send, and exchange data with other connected devices and applications. Second, the communication block helps with integration between devices and remote servers. Third, the services block ensures functions like device modeling, device control, data publishing, and device discovery.

Fourth, the management and security blocks help to govern and secure an IoT system. Finally, the application block provides users with interfaces to monitor IoT status. These blocks can work in a three-layer scheme that comprises a perception layer, a network layer, and a service layer.

In the industrial context (Trappey et al., 2017), connected products can offer expanding opportunities for new traceability functionality. For example, a product that communicates its status and its environment parameters will help to assess the product monitoring.

3.3 Cloud Computing

According to the National Institute of Standards and Technology (NIST), "cloud computing is a model for enabling ubiquitous, convenient, and on-demand access" (Zissis and Lekkas, 2012). Manageability, scalability, and availability are its main characteristics.

Cloud has other properties such as ubiquitous, multi-tenant, elasticity, and stability. Cloud computing offers three models: Infrastructure as a Service (IaaS); Platform as a Service (PaaS); and Software as a Service (SaaS) (Hashizume et al., 2013). According to (Singh et al., 2016) Anything as a service (AaaS) can be a cloud model.

Cloud computing comprises several servers in data centers. This architecture is a large-scale, distributed, and networked system that can be changed according to different contexts. Data centers enable users with the hardware facility and infrastructure for clouds. In this setting, customers can access high-speed networks.

On top of this layer, IaaS provides means such as storage capacity, hardware, servers, and networking components. Next, PaaS furnishes an integrated environment for building, trial, and implementing custom applications. Finally, SaaS allows the distribution of software under specific requirements. Thus, users can access an application and information remotely via the Internet and pay only for that they use.

3.4 Blockchain technology

Blockchain has capacities to help with supply chain visibility and traceability by tracking the product's provenance. It is a peer-to-peer network technology that uses a distributed ledger which refers to synchronized digital data. This information is replicated, shared, and spread across multiple sites (Wang et al., 2019). Thus, the storage of data is not centralized nor managed by an administrator.

In the blockchain, data are structured as an ordered and back-linked list of blocks (Nofer et al., 2017). A block is unique and contains an encapsulating hash of the previous block. Blocks are time-stamped transactions that are propagated and broadcasted to all nodes (i.e., miners). Mainly, three mechanisms are used cryptography, consensus, and smart contract.

within the blockchain, security and integrity are ensured thanks to cryptography techniques (e.g., hash function and elliptic curve public-key). Furthermore, the consensus mechanism guarantees to authenticate and validate transactions without a central power. Consequently, the distributed ledger should be kept synchronized (Zheng et al., 2018). Smart contracts, digital form, specify clauses and protocols to mediate and perform transactions promises. If contracts are initiated and conditions are met, the transaction becomes an automatic and irrevocable process.

Blockchain comprises three categories public, private, and permission blockchain. This technology can allow some visibility into the product's life cycle. It can show where things are and have been. It allows users to record every event, attribute, and data. These functions ease the traceability of goods.

However, we presume that blockchain does not provide clear means to ensure permanent monitoring of product quality and safety along the entire supply chain. Blockchain should permit to include in ledgers other information such as actor's identity involved in different physical operations.

Another issue is related to the track function in a traceability system. Blockchain provides the product location as 'a product came from a place and went to another', however traceability should also allow tracking in real-time.

Also, if one registers a piece of information in the blockchain, it can never be deleted or changed. However, tasks are physical, and operators involved in these activities can still lie when recording properties. This fraud cannot be corrected even if it was detected.

3.5 Communication within industrial environment

Due to some constraints like reduced capacity and low autonomy, physical objects (e.g., smart products and sensors) can only communicate in Low Power and Lossy Networks (LLNs).

To succeed in this communication, objects use a specific protocol stack, an encapsulation mechanism for compressing headers (IPv6 over Low Power Personal Area Network: 6LoWPAN), a suitable routing mechanism (Routing Over Low power and Lossy networks: ROLL), an adequate transport protocol like the Constrained Application Protocol (CoAP).

Several wireless networks are used such as Zigbee, Thread, Z-Wave, and EnOcean. These technologies enable objects to communicate with each other and to be tied to another broad network. For instance, at the retail level, connected products also help to disseminate the user's need, which lowers costs and saves perishable goods quality.

When integrated, Cloud computing, IoT, and smarts objects provide Internet of services (IoS). In industries, these services use tools such as service-oriented architecture (SOA), software as a service (SaaS), or business process outsourcing (BPO). Such advancements aim to enhance the efficiency of industrial practices.

Consequently, Manufacturing Execution Systems (MES) seek to realize production flexibility and resource decentralization. The modern cloud-based version of MES handles industry operations, process supervision, and status control. This information system coordinates factory workflows. MES integrates different information from suppliers, real-time data, and product information. As a result, it can deal with product traceability in distributed manufacturing.

3.6 Identification and localization

In manufacturing, network agents involve sensors and actuators such as Sensor Actuator Network and Wireless Industrial Sensor Network. These agents allow data-acquisition and adjustments-making. In terms of tracking and tracing, such functions enable essential information for accurate traceability (i.e., identification and localization).

For example, Radio Frequency Identification (RFID) enables products and pallets to be automatically identified using a system of reader/tags. Another technology that uses the same principle is Near Field Communication (NFC). It is based on an initiator controls communication with tags.

Further, there are techniques for labeling like Quick Response Codes (QR), Data-Matrix, and Barcode. Other technologies exist for identifying objects such as the integration of chips in the design of non-consumable products, use of DNA markers for liquid and gaseous products, and use of Nano-tracers (emitting tracers and nanoparticles) for textile products.

While the position of objects (i.e., products, pallets, and containers) changes throughout the supply chain stages, their localization, in an open space (e.g., transportation), require an outdoor technique like GPS. If the objects are in an enclosed environment (i.e., the storage), the localization depends on indoor methods such as the angle of arrival and return time of flight. Generally, a real-time monitoring requires to combine the two techniques (i.e., Real Time Locating System RTLS).

Four both identification and localization, objects need a standardized identifier. This mechanism depends on the identifier type and structure. Keys can be either numeric or alphanumeric. Several structures exist like those of Global Standards (GS1) and Auto-Id Labs.

GS1 defines numbers such as Electronic Product Code (EPC), Global Trade Item Number (GTIN) for products and services, Serial Shipping Container Code (SSCC) for logistics units.

Auto-ID Labs lead efforts in the area of Automated Identification of objects in the supply chain and the Internet of Things. Both the mentioned organizations work closely to develop a global framework for Event-Based Traceability.

3.7 Data analysis

Machines and sensors generate a large volume of data that is collected not only at the level Information Systems (IS) but also at level of the physical thing. Therefore, users can identify products, track their location, and share other properties.

This ever-growing amount of data is often referred to as Big data that has several characteristics like the high volume, the high variety, and the high velocity (Chen et al., 2014). The volume of data involves the large volume of data. The variety refers to multiple data sources, and the velocity describes the movement and flow of data.

Big Data is also characterized by Veracity, Value, and Variability (Chen et al., 2014). In general, data is structured, unstructured, or semi-structured, and implies the timeliness constraints, particularly during data collection and analysis.

In Industry 4.0, data analysis is a cornerstone of an efficient decision-making process. However, it is difficult to manage and analyze this data with conventional tools of database management. This requires novel techniques and architectures that are designed to obtain valuable information from raw data (i.e., data mining, cognitive agents, and automation of knowledge).

For instance, an intelligent algorithm can match supply and demand to facilitate the collaboration between the responsible for the process-planning and the production unit. Such decision-process would rely on traceable information, in a previous study we detailed this aspect (Bougdira et al., 2016b).

3.8 Intelligence within industrial environment

In manufacturing, the intelligent solutions have been widely used (Li et al., 2017). Applications include the usage of robotics, intelligence processes, decentralized production, connection between machines and human beings (Hofmann and Rüsch, 2017). This combination of intelligent products and industrial processes refers to industry 4.0 (Zheng et al., 2018), which also pushes towards logistics 4.0 and supply chain 4.0 (Oleśków-Szłapka and Stachowiak 2019).

Such utilization requires tools and techniques, including context-awareness, denotational mathematics, ambient intelligence, cognitive computing, and artificial intelligence. In industry, these concepts are often interchangeable and generally a combination of two or more of them is needed to empower systems to know and think. The mentioned techniques imply that computers, systems, machines and agent could perform tasks autonomously to achieve a desired goal **(**Bekey, 1998**).**

From the context-awareness stand point, an intelligent entity can sense or detect the situation at hand, perceive the conditions, analyze and make decisions for actions, and execute an action or response (Rodis, 2018). Such model requires the usage of a common knowledge representation (Lemaignan et al., 2017). Herein lies the importance of using denotational mathematics that help to formalize conceptual abstractions and build chains of inference processes (Wang, 2009). For example, concept algebra and system algebra provide basics for treating concepts and their relations trough first-order logic and description logic (Wang, 2009; Pinter, 1973).

If the context is identical to the surroundings, ambient-aware systems (ambient intelligence) and context-aware are considered the same (Tao Xu, 2013). An ambient environment can be diverse, such as manufacturing plants and homes, whereas context includes, among others, location and time awareness. Typically, both comprise data acquisition, context-modeling, reasoning, and distribution steps (Aguilar et al., 2018). The modeling involves means like ontologies, Web Ontology Language (OWL), and Resource Description Framework (RDF).

While ambient and context-awareness pinpoint what and where are data generated and consumed, cognitive computing (CC) focuses on mimicking the human brain functions by understanding and simulating human behavior and reasoning upon data (Raghavan et al., 2016). In this context, CC supplements information and plays the role of decision-support systems for humans (Chen et al., 2016). In contrast, Artificial Intelligence (AI) techniques are able to minimize the role of humans and make decisions on their own, which requires machine learning techniques (i.e., supervised/ unsupervised algorithms, deep, and reinforcement learning) (Shivi et al., 2019). Besides learning how to act, AI help the decision-making mechanism using methods like Artificial Neural Network, Fuzzy Logic set, and Bayesian nets (Pezeshki and Mazinani, 2019).

4 Traceability in Application

Many approaches can be used to examine and study existing traceability systems. For example, grouping solutions that refer to the same application domain (i.e., food industry, pharmaceutical chain, and agricultural sector). In this case, such categories might involve many subgroups (e.g., for the food sector, there are seafood traceability and cold chain traceability). Also, one would group solutions according to their design, implementations, and technologies (i.e., identification and localization techniques). One can also categorize traceability systems in line with respect to regulations, requirements and legislation.

Based on these mentioned options and due to the absence of a common and shared categorization, we propose to examine traceability systems following three main groups (1) EPC-based systems; (2) standalone systems; and (3) intelligent ones.

4.1 EPC-based traceability systems

The EPC-global Network aims to provide solutions for a global supply chain across different industries. The following figure describe the functioning aspects of EPC. Note that the figure is inspired by (Sanjay et al., 2000; Brock, 2001; Thiesse and Michahelles 2006).

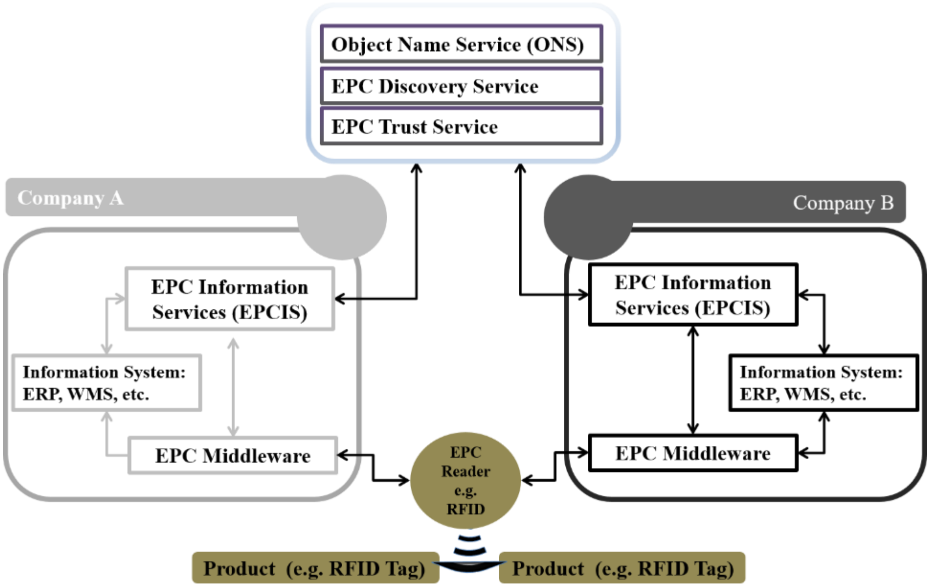

Figure 1. 3: Overview of EPC-global Network.

Companies assign to products a code such as GLN: Global Location Number, GTIN: Global Trade Item Number, and SSCC: Serial Shipping Container Code. To successfully integrate physical products in the cloud.

EPC adds a unique serial number and a URI prefix to the product code (URN: EPC: ID: SSCC). This binary code can be stored in the RFID memory, and it refers to an Internet resource. In this network, RFID readers identify the EPC code that is stored in the tag. This code is processed by a middleware that provides real-time authentication.

A middleware gathers the product data from company's Information Systems and EPC Information Services (EPC-IS). Data is stored in PML formats (Physical Markup Language). When an operator who has an authorization from the EPC Trust Services (EPC-TS), wants to access the data through the cloud, he uses the EPC Discovery Services (EPC DS) which ask the ONS (Object Naming Service) to seek the corresponding host (a PML page) to the product code and display product information.

The literature reveals that the traceability systems based on the above-described model are from various industrial sectors such as pharmaceutical, agricultural, and food.

Barchetti et al. (2011) addressed the problems related to pharmaceutical product traceability and identification. The proposed solution relies on the use of passive UHF-RFID and the architecture of EPC global. The second pillar of the proposed solution is e-business XML standard for exchanging information.

In the same context, Solanki et al., (2014) suggested to implement a product tracing and tracking through the automated generation of linked pedigrees. To that end, the mentioned work has combined EPC-IS events with OWL/RDF to generate linked pedigrees. This combination has proved efficiency, particularly in counterfeit detection.

In agricultural industry, several traceability systems can be found. Liang et al., (2015) dealt with traceability in the cattle/beef chain. The cited authors stressed the usage of internal and external traceability. The proposed solution used animal ear-tag and EPC-IS framework. This solution was implemented based on Fosstrak and FreePastry.

Mainetti et al., (2013) addressed the issue of fresh ready-to-eat (RTE) vegetables. This traceability system links plants and traceability information using an "Android mobile App" and Near Field Communication (NFC) using the EPC global standard.

On the other hand, Hwang et al., (2015) dealt with the Korean ginseng industry (a plant). The suggested system collects environment-related information of ginseng planting using sensors nodes. Next, the sync-node, RFID, and middleware upload automatically all collected information to the Enterprise Resource Planning (ERP) and EPC-IS that exchange information.

In the food sector, Zhang et al., (2019) attempted to follow the whole life cycle of the Old Godmother Flavor Food. The system gathers data using a design similar to the Internet of

Things model. Moreover, the suggested solution is based on RFID technology and EPC standard.

In contrast to this solution, Lin et al., (2019) combined the blockchain technology with EPC-IS to develop a prototype system. This solution was implemented using the Ethereum. Hence, blockchain was used to store the proof information and some key traceability information. Similarly, Salah et al., (2019) used the Blockchain principles to enable the soybean traceability.

We remark that the most traceability systems based on EPC depend on RFID technology, although there is no EPC specification for that. We assume that this dependence would be a potential weakness that restricts the range of EPC usage, especially for companies that rely on other tagging techniques. Also, the implementation cost of EPC could be a nightmare for companies, particularly for small and medium businesses.

Additionally, the above-overview shows that EPC could pose real security risks. Since EPC intends to be open and global, authentication and privacy breach will permanently arise. Due to its event-oriented approach, it is hard for stakeholders to protect sensitive information at each object level. This issue and a proposed solution to achieve efficient and privacy has been detailed in (Byun et al., 2017).

Further, we notice that, in EPC global, users should repeatedly invoke the core services to acquires products information. In (Kang and Lee, 2013) authors have proposed a set of traceability services that aim to enhance this tedious and redundant inquiry way.

4.2 Standalone traceability systems

We select this category of solutions according to two criteria. First, these systems use a specific technique or technology. Second, the application domain of traceability is specific, such as ceramic, construction material, and wood products.

Mao et al., (2015) proposed a food traceability based on video surveillance. This suggested traceability uses cameras to register all actions and subjects such as vehicles and people, and it generates image-based traceability information.

The cited authors claim that such solution enhances the creditability of traceability systems by avoiding fraud caused by producers. With all due respect, we argue with the cited authors, we think it is still possible for producers to deceive cameras and introduce false data.

Another solution that has gained our attention is suggested by Borja et al., (2015). In contrast to traditional tag-based traceability, this solution proposed Cyber-Physical System traceability using cybernetic glove and cybernetic table. This suggestion was designed for small and medium enterprises and allowed managers to monitor both workers' and products.

However, we urge that this real-time traceability does not fulfill all traceability requirements, particularly with respect to backward analysis. When a product crisis happens, authorities need to retrieve recorded data. This information helps to lead investigation and control the possible impact. Therefore, real-time traceability is efficient for manufacturing visibility, but it is insufficient for all supply chain visibility (i.e., transportation).

Dai et al., (2015) proposed an improved traceability for addressing product recall using several layers between suppliers and manufacturers. Mathematical expressions represent ID technology, coding level, manufacturer order, and the supply periods. This decentralized system enabled the detection of defective components from suppliers and then eased its recall even after the manufacturing process.

We can see that this system is specifically designed for recall cases. However, a traceability system should also answer other cases, such as product withdrawal and real-time tracking. We advocate that a traceability system should not only be a passive system, that helps to find failures, but also a proactive tool, that helps to anticipate failures.

Wang and Yang (2019) applied game theory to analyze the traceability system in the herbal product industry. Their solution attempted to evaluate product problems and traceability impacts on different stakeholders.

Semantics technologies can play a key role in developing effective traceability (Salampasis et al., 2012; Alonso-Rorís et al., 2016). Both publications proposed traceability systems using semantic web technology. The first solution (TraceALL) provides formal support to represent knowledge and model information. The second work used a holistic and reusable platform for tracing products and controlling processes.

We urge that semantic technology can be relevant for modeling efficient traceability. Such an approach allows to model information according to different scenarios. Moreover, it enables the software agents to exchange information with each other.

Traceability for ceramic, material construction and wood products are a category that is slightly unusual in the traceability research field. Barata et al., (2018) proposed an integration of traceability functions with the cloud-based Manufacturing Execution Systems (MES). The cited authors used mobile devices, QR codes, barcodes, and RFID to design the system. In the same way, Hoo et al., (2016) used the cloud-based model to design a traceability system for materials management in construction. This tracking solution is based on cloud-computing service integrated with RFID and bar-coding system. However, we think that effective traceability requires also other functionality like tracing which provides material history and paths.

Appelhanz et al., (2016) studied consumers trust in the wood furniture supply chain. The proposed system is based on an application layer, network, integration, and infrastructure one. This design is similar to the IoT architecture.

Practically, we assume that the cloud-based architecture proves effectiveness and efficiency in traceability design because it is cost-effective, especially for small and medium businesses. Moreover, it enables users with information access anywhere and anytime. Also, we presuppose that the IoT model fits perfectly with traceability requirements regarding capturing, processing, and exchanging information.

The above-detailed category specifies distinct and particular traceability solutions regarding the field of application or the used techniques. Note that this type is less frequent compared to other categories. Moreover, works in such research axis are neither yet mature nor deeply studied and propagated.

4.3 Intelligent traceability systems

While conducting a holistic survey of traceability, one can see that the trend in the last decade is to develop intelligent traceability systems. However, the literature reveals that there is no unanimous version of intelligent traceability. To best of our knowledge, there is no explicit explanation or characterization of what is intelligent traceability.

Wang (2014) considered intelligent traceability as a real-time view into the production processes. This instant traceability is based on the intensive usage of RFID. It used six levels that combine data acquisition and EPC-IS with decision-making process. However, we wonder if one has instant traceability, does one then have intelligent traceability?

We conclude that this functionality is important for intelligent traceability, but it is not enough for characterizing an effective one. Such one might require a whole supply chain visibility.
On the contrary, Xiao et al., (2015; 2016) proposed two intelligent traceability systems for aquatic product using applied statistical process control, fault-tree analysis, and wireless sensors

network. This combination intended to promote a proactive model for enhancing process management and food safety.

Very few would argue that this characteristic could not be very significant to reach intelligent traceability. However, such a system should also consider other aspects of aquatic product traceability like instantaneously following the product's movements.

In contrast to these solutions, Parreño-Marchante et al., (2014) suggested advanced aquaculture traceability that is suitable for SMEs. The suggested system combined data captured through RFID with data gathered from WSN. This integration is based on web services architecture. Therefore, product information is available along the entire chain, and product tracking is ensured from the farm to the consumer.

The presented results show efficiency during the collection of traceability information, nevertheless it did not provide details about the intelligence aspect of the proposed traceability. We suppose the authors emphasized the system benefits and how business processes can be improved rather than how many functions the proposed traceability has.

Other intelligent traceability systems based on IoT technologies and fuzzy rules could be found in the literature (Chen, 2015; 2017). The cited author proposed autonomous traceability inspired by system automation. This solution is a tracing agent-based on IoT architecture. The backward design dealt with product life cycle issues, particularly safety and quality.

The first solutions applied Fuzzy Cognitive Maps (FCM) to implement an algorithm for building an object-oriented relational database. This data management system is important for efficient traceability because it permits recording information, link tracing information between different parties, simplify the record-keeping, and ease information exchange.

The second solution proposed a value stream-based food traceability. Besides the fuzzy approach, this one used a cyber-physical system, EPCglobal, and value stream mapping combined with a fog computing network. In other words, the proposed design allows the assessment of the most critical traceable events for tracking and tracing processes.

Luo et al., (2016) tackled the issue of goods transported in a cold chain. Therefore, they proposed an intelligent tracking system based on IoT, sensors, and tracking technologies. This integration used a Zigbee network. Typically, monitoring the real-time temperature, humidity, and physical products is essential for sensitive products. Ideally, this aspect would be one of the pillars of intelligent traceability.

Wang et al., (2017) designed a traceability system using fuzzy classification and neural network. Besides tracking and tracing products, the suggested solution is intended to help to evaluate product quality in pork industrial chains. Therefore, devices collect product information, fuzzy rules classify the food quality stages, and the artificial neural network determines the final quality grade.

Since intelligence should include means to support decisions, we notice that this typical decision-making process could be a core part of intelligent traceability.

Yongjun et al., (2019) addressed the seafood traceability. This system combined the Hazard Analysis and Critical Control Points (HACCP) method with wireless monitoring (QR, EPC-IS, and sensors). This solution used a survival prediction model (fuzzy and neural network) by controlling oxygen change and quality.

We note that most of these intelligent solutions are intended to ensure product quality management. It is worth noting that if we accept this claim, intelligent traceability would be just another tool of quality control. Basically, at least, an intelligent traceability should supervise the product quality throughout its life cycle. However, we advocate that intelligent traceability would have a much broader picture.

Earlier, we have tried to provide a first description of an intelligent traceability (Bougdira et.al, 2016a). Thus, it is important to retain that an intelligent solution shouldn't be limited to "tracing'' and "tracking" a product, it should, also, provide a tool to control and make decisions. Therefore, it should have the means to strengthen the safety, security, and quality of products throughout the entire supply chain.

5 Conclusion

The presented state of the art summarizes different traceability aspects, including properties, technological tools, and various implementations. Primarily, it supports our hypothesis about the exiting gap between standardizing, conceptualizing, and implementing a traceability solution. On the other hand, it shows the opportunities and challenges brought by technological advances in industries. Due to these technologies it is possible to set efficient solutions, but the development task could be arduous and more complex. Moreover, the literature proved the necessity for a general-purpose framework that helps and conducts the development and deployment of a traceability solution. It emphasized also the importance of defining and describing intelligent traceability.

Chapter 2: Overview of the Generic Model

1 Introduction

The proposed generic model involves the combination between a conceptual framework (Bougdira et al., 2019c), a set of activities, and a characterization of intelligent traceability (Bougdira et al., 2019d).

The framework lays the solution bases for a general traceability and provides the means and steps of implementation. The characterization describes the interoperable vacuum for traceable information and the intelligent aspect. Activities are the conjunction between practices described in the solution bases and the functionalities included in intelligent traceability application. These three elements are required to implement a general, interoperable and intelligent traceability.

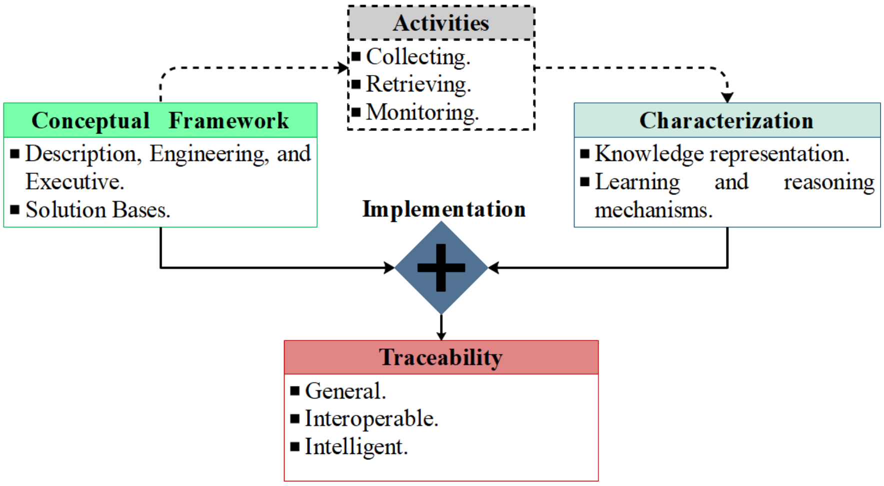

Figure 2. 1: Overview of the generic model.

2 Conceptual Framework

The conceptual framework comprises three complementary aspects (description, engineering and executive) that address the traceability issue from an implementation point of view. These aspects involve three components that contain different elements. Thus, the framework lays the solution bases and describes the steps to implement a system. These bases are aims, functions, specifications, data classification, processes and procedures.

2.1 Framework components

The framework is expected to provide the bases for general traceability solution. It addresses the traceability implementation focusing on three aspects. The description aspect provides the basis for a solution. The engineering aspect describes technologies, techniques and tools to design a system. The executive one enables a developer to direct the steps of implementation.

The description aspect enables the modeling of a traceability case. It describes how to approach a problem and how to establish a traceability system. This aspect comprises modeling, operating modes and approach. During the modeling step, a user examines axes from a practical point of view. Note that the requirements (axes) depend on the case constraints. The operating modes help developers with traceability implementation.

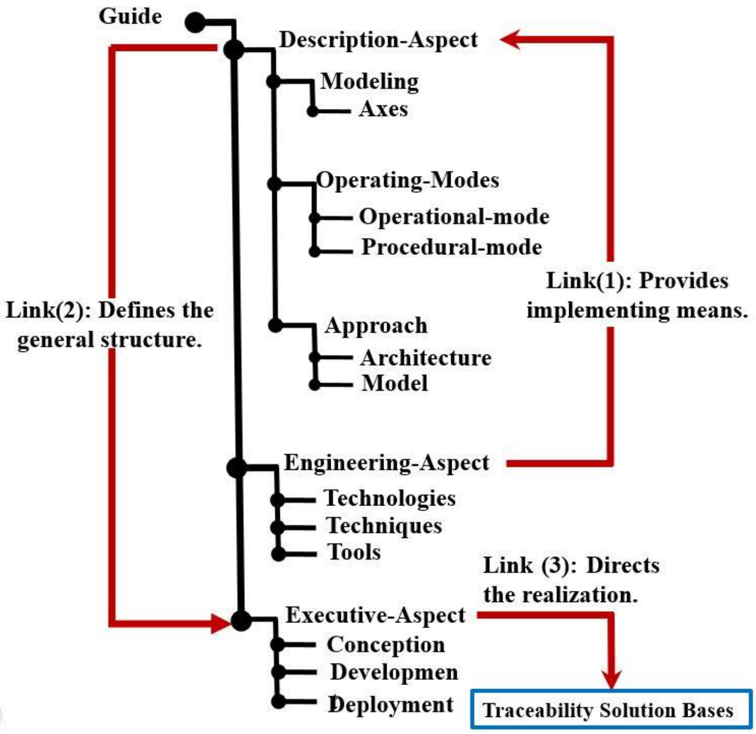

Figure 2. 2: Overview of the framework.

From the perspective of the system functionalities, these components specify details about the system design (operational mode) and implementation (procedural mode). The approach describes how to deal with a system configuration and how to develop and deploy a solution. Therefore, the architecture lists the system parts, and the model delineates the system design.

The engineering aspect provides means that satisfy the requirements for system development. It includes technologies, techniques and tools that depend on the defined operating modes and the selected approach (architecture and model). The executive aspect highlights steps in planning the implementation of the traceability system. These components interact with each other to generate traceability bases. As of right now, Figure 2.2 provides a general description of the links between aspects.

A first link (1) connects the engineering aspect with the description one. It refers to the use of an engineering element to process a description one. For instance, if the proposed solution adopts a cloud model, the engineering aspect defines the required cloud technologies.

A second link (2) connects the description aspect to the executive one. This relationship draws a general description of the system. The executive aspect underlines the necessary steps in design that result in the traceability solution bases (link 3).

In a logical way, the links can be interpreted as a set of axioms using for example first-order logic. Consequently, one can infer statements from axioms according to a set of rules. For example, using quantifier logic, we can say for each description element D_e, there exists some engineering element E_e that ensures the processing of D_e :

$$\forall D_e \in DescriptionAspect.\ \exists E_e \in EngineeringAspect.\ E_e\ process\ D_e$$

Note that a logical formalization of the framework is provided in Appendix 1.

2.2 Framework functioning

Practically, the framework should be viewed as a three-part system that comprises inputs, core-part and outputs. The modeling axes (description) and the modeling principles (conception) are the inputs. The aspects are the system core-part that processes the inputs to generate the outputs (traceability solution bases) (figure 2.3).

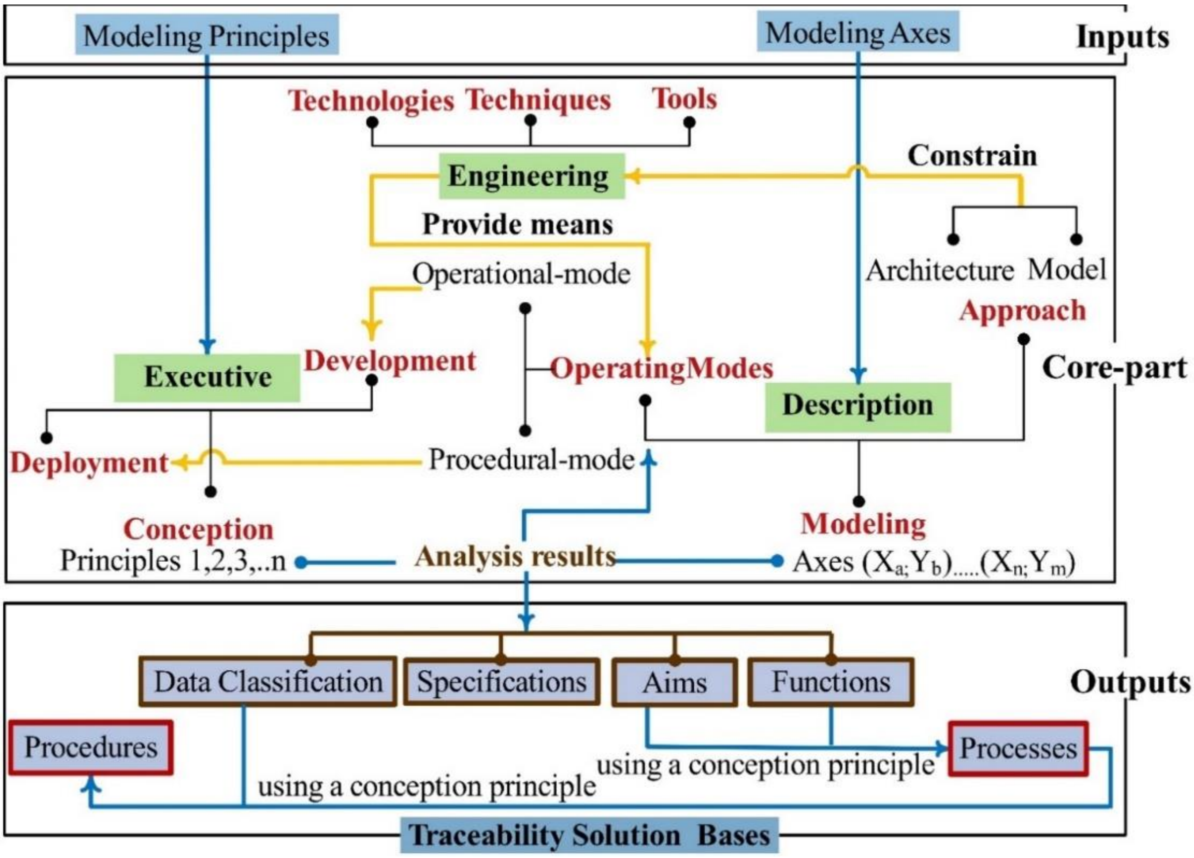

Figure 2. 3: Overview of the framework functioning.

During a real case scenario, the selection of the modeling axes (i.e., X_a and Y_b) is conditioned by the studied case. Moreover, one should select the modeling principles (i.e., principle1) that enable axes' analysis. This analysis is the first stage of conception resulting in the definition of six elements: operational mode, procedural mode, data classification, specifications, aims, and functions. The second stage of conception comprises two consecutive operations.

The first operation uses a conception principle, aims, and function to generate processes. The second operation uses another conception principle, processes, and data classification to generate procedures. Therefore, the traceability solution bases are data classification, specifications, aims, functions, processes, and procedures.

So far, the conception stages are complete. Next, one could move towards system development and deployment. Operational mode and procedural mode describe the solution functionalities that will consecutively serve as a basis for system development as well as system deployment (orange arrows). In the same context, the processes provide a basis for the development of the operational mode, and the procedures form the basis of the procedural deployment.

At this stage, one should define the approach to use for the solution (architecture and model). Hence, the choice of technologies and techniques (engineering aspect) is conditioned by the selected architecture and model (orange arrows in figure 2.3).

The engineering aspect defines the means that ease the development and deployment of operational and procedural modes (orange arrows in figure 2.3). Once one has defined processes and operational mode, procedures and procedural mode, architecture and model, technologies and techniques, one could proceed with the practical implementation of the traceability system.

2.3 Practical implementation

Determining processes and procedures help to set the different tasks for doing traceability. These units of work can be grouped into a set of activities that achieve the objectives of processes and follow the instructions of procedures. These activities are the central-part of intelligent traceability. For practitioners, these activities are the tasks that should be done. For engineers, these activities are the functionalities that should be developed.

Basically, traceability systems ensure at least two main functions (Trace and Track). Trace's function indeed enables to record and retrieve product properties or information that comes from using an analytical method or instrument. Track's function should give access to product location at a given time.

As we already mentioned, these functions could represent only one traceability aspect, while in modern supply chain, that is characterized as being a pervasive environment (i.e., industry 4.0, logistics 4.0, and smart products), additional functions, like supervising product's environment, might be essential. Jansen-Vullers et al., (2003) discussed a part of this claim as "active traceability". Therefore, we urge that intelligent traceability should not only ensure products tracing and tracking but also monitoring and assist with the decision-making process.

3 Activities

We define three main activities that are essential for a traceability solution, including collecting, retrieving, and monitoring.

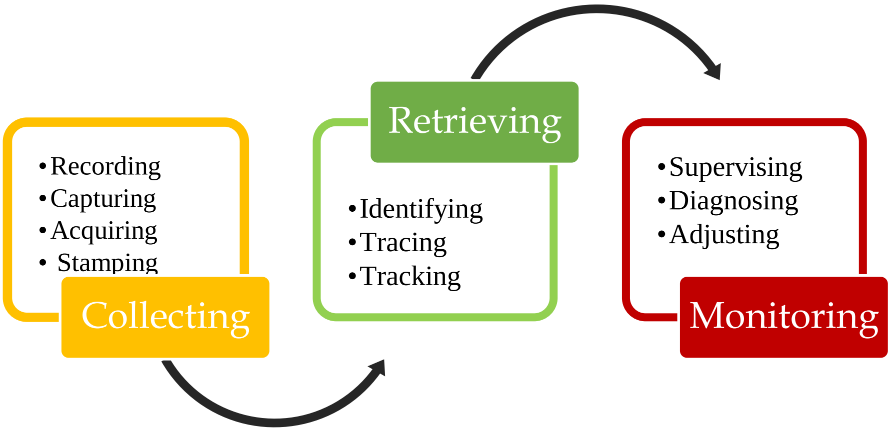

Figure 2. 4: Intelligent Traceability activities.

3.1 Collecting activities

Collecting includes Recording, Capturing, Acquiring, and Stamping. These activities should gather not only immediate product properties but also information about the origin, processing, and history. Information can include the owner's identity, processing conditions, and task's description at various stages in the chain. Other data are relevant even it did not directly influence the product properties. For example, information from entities that exist in the product's surroundings.

Recording activity ensures that all data element is properly stored and arranged. It guarantees to link all properties with an object identifier (i.e., ID). Whereas the capturing activity enables the data capture. This data could refer to the process's execution, operations step, and an event's history through which an object has been passed. Since an efficient traceability solution should keep tracking all data, both activities intend to ensure data recording and keep-recording information.

Acquiring activity is the whole data-acquisition tasks that enable to integrate information from the surroundings (i.e., sensors' observation). 'Time-stamped' and 'location-stamped' are essential for the accuracy of traceable information. Hence, the last activity aims to identify where and when an object exists or an event occurs.

3.2 Retrieving activities

Retrieving involves Identifying, Tracing, and Tracking. These activities describe the sequence of information retrieval. This organization attempts to provide more meaning traceable information. For instance, a user who needs only to locate a product, can use directly the tracking activity without retrieving all the other information. These activities guarantee that a product is properly identified, traced, and located.

The identification information should be accessible, every time and everywhere, to the user. This information involves, for example, the product ID, name, origin, and the contact information of its owner. Note that in the food industry case this type of information cannot be analytically verified. Therefore, introducing an identification activity is helpful and useful. The tracing information include ingredients or parts, or its properties. The tracking activity enables users to follow the product geographically, one could see exactly where a product and all its ingredients came from and went.

3.3 Monitoring activities

Monitoring comprises Supervising, Diagnosing, and Adjusting. With the help of recorded data and the sensors ones, a user can supervise the product environment, makes the proper diagnosis, and take the right decisions. These activities follow indeed a sequence to assist users in the decision-making process.

For example, if a system user supervises an object's environment, based on the acquired information and the retrieved one, one could make an instant diagnosis of the status of the situation. If the situation needs adjustments, one takes the appropriate decisions. In the case of processing, these cooperative actions permit to pro-actively adjust production processes and optimize production characteristics and results.

To sum up, we urge that a typical intelligent traceability should at least include these activities. Such as, this arrangement of activities operates as a reasoning stream to perform a detailed analysis using traceability.

4 Intelligent traceability

We tried to provide some properties of a typical intelligent traceability. Such an effort aims to characterize explicitly what is intelligent traceability.

4.1 Proposed definition

The following suggested definition helps to understand intelligent traceability (this definition paraphrases some aspects mentioned by Olsen et al., (2013), ISO 8402, and ISO 9000).

> a set of activities that is endowed with the ability to record identifications, collect, from heterogeneous sources, and retrieve any or all object's information that is processed not only to trace and track but also to ensure object monitoring by implementing decisions that achieve specific objectives even variability and uncertainty.

Herein, a set of activities refers to the whole necessary tasks for traceability. Operations are expected to report information about entities involved in the product lifecycle (i.e., operators, raw material, and processing steps). These could be done manually or automatically using a paper-based technique or information and communications technology (ICT). Thereby, the ability refers to the available means of interfacing "the doing of a traceability activity" with "the entity who does this activity".

Moreover, this definition takes into consideration the importance of recording information. Furthermore, it stresses the need for keep-recording all events information. This property is needed each time a product is transformed from input to output. In addition, the definition considers also the data captured in product surroundings. Additionally, it underlines the importance of linking this information to the product through identifiers. Our proposal emphasizes also the importance of the management of traceable information, both raw data and processed information. In this case, intelligent traceability should be endowed with a decision-making process to better exploit this information.

4.2 Decision-making process

An intelligent traceability should involve powerful tools of conducting a decision-making process. Therefore, this process has to identify relevant information, tangible evidence, and available alternatives. In addition, it should specify adequate means to implement decisions and perform actions. For intelligent traceability, the decision-making process should be continuous as well as proactive and responsive.

Typically, collecting activities ensure that all product information is correctly captured and arranged. Hence, if collecting activities had appropriately done, the obtained information through retrieving activities would be reliable and fruitful. This traceable information is processed and analyzed for eliciting partial or complete knowledge that specify the entities, variables, facts, and details of the context where intelligent traceability is implemented.

Taking advantage of this knowledge can be performed according to monitoring activities, and by using appropriate means. These ones involve the definition of mechanisms such as predictive models and diagnosis structures, also the determination of methods and techniques such as fuzzy sets, Artificial Neural Network (ANN), Support Vector Machine (SVM), Genetic Algorithm, and Bayesian Network.

4.3 Knowledge representation

Since a powerful decision-making process requires reliable information, the establishment of an adequate knowledge representation is essential. Accordingly, our representation depends utterly on the context-modeling of intelligent traceability.

4.3.1 Implementation context

In this thesis, the context of implementation refers to different supply chain stages, especially the industrial ones. Accordingly, the following figure provides an overview of this context.

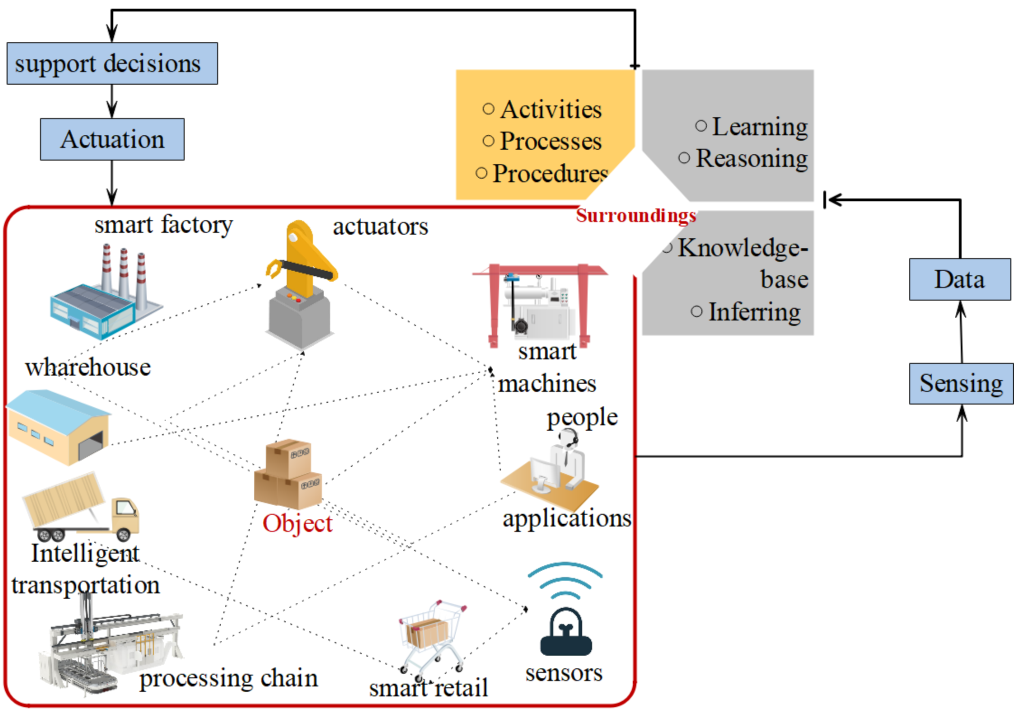

Figure 2. 5: Overview of the traceability context.

Here, elements that surround an object (i.e., a product) are various and interact with each other using different modalities (i.e., information and status). Note that the object's surroundings are identical to the context of intelligent traceability.

Moreover, different types of information are captured whereas its manipulation implies a knowledge-base and inference or derivation from known context information to deduce new piece of information. Learning and reasoning reinforce the knowledge used by intelligent traceability to support decisions.

4.3.2 Context formalization

At a high-level of abstraction, the representation of knowledge focuses on identifying and modeling the concepts that represents real-world and perceived facts. Accordingly, using denotational notions (Yingxu, 2009 and 2012), we give some examples to provide insights into the formalization of the studied context. Let consider the following notation:

φ_c : The Studied context.

Λ: A finite nonempty set of attributes.

Θ: A finite nonempty set of objects where Θ_t refers to items under traceability and Θ_ε refers to the surroundings elements.

Ɍ: A finite nonempty set of relationships.

Then a context corresponds to: $\varphi_c \triangleq (\Theta, \Lambda, Ɍ)= Ɍ : \ \Theta \to \Theta \mid \Theta \to \Lambda \ \mid \ \Lambda \to \Theta \ \mid \Lambda \to \Lambda$

Let consider C a concept that identify or model a perceived fact. This abstract structure carries certain meaning that is used for cognitive process (i.e. thinking, learning, and reasoning):

$$C \triangleq (\Theta, \Lambda, Ɍ^i, Ɍ^e, Ɍ^o)$$

$Ɍ^i$ is a set of internal relationships, where $Ɍ^i = \Theta \times \Lambda$

$Ɍ^e$ is a set of external relationships, where $Ɍ^e = C' \times C$

C' is a set of external concepts, where $C' \sqsubseteq \varphi_c$

$Ɍ^o$ is a set of outputs relations, where $Ɍ^o = C \times C'$

Assuming two objects (Θ_ε) (i.e., a technician and an assemblingMachine1), if one wants to describe the context (φ_c), one can use questions such as: Who are the objects? How are they come here? Where are they going? When does an object need to leave? What are these objects doing?

Each answer to these questions is essential for building a piece of knowledge that describes the context (φ_c). Attributes (Λ) and relationships ($Ɍ^i$ and $Ɍ^e$) are also needed in this case.

These following statements formalize some answers to the mentioned questions using First Order Logic (Diekert et al., 2008).

- ∀x technician(x) → operates (x, assemblingMachine1): There are all x where x is a technician who operates the assemblingMachine1.
- ¬∀ (x) [technician(x) → existWith (x, manager1) ∧ existIn (x, plant1)]: There is some x where x are technicians that exist with the manager1 and exist in the plant1.
- ∃(x) [technician(x) → operates (x, assemblingMachine1) ∧∀ (y) [¬(x==y) ∧ technician(y) → ¬operates (x, assemblingMachine1)]: There is only one technician that operates the assemblingMachine1.

4.3.3 Rules of context-modeling

Essentially, the context-modeling aims to build an ontology that is able to manage, integrate and share necessary traceable data. To that end, the following table sums up the main rules used to govern the modeling.

(1) Distinction between two major categories; the industrial environment components and intelligent traceability activities.	▪ Determination of main components that form the industrial environment and the intelligent traceability activities. ▪ Bring together all components in the same model. ▪ Definition of four major components of industrial environment, Object, Surroundings, Physical Context, and Data Element.
(2) All industry components should be under the traceability process.	▪ Any noticeable information about industrial environment should be collected and processed to ensure efficient traceability. ▪ Every element within industry that generates data should be involved in the traceable data life cycle.
(3) The modeling takes an activity-centric perspective.	▪ Focus on the context that surrounds "the performance of an activity by an agent" (Prekop and Burnett, 2003). ▪ Merge intelligent traceability activities with the processing flow of supply chain steps.
(4) The modeling of industrial environment revolves around relationships between components	▪ Highlight the relationships between each industry components.

Table 2. 1: Rules of context-modeling.

5 Intelligent Traceability Ontology (ITO)

Based on the context-modeling, we introduce the basics of an original ontology that is the core-part of the knowledge-base. ITO is based on a set of primitives' models (modelling of activities and industrial environment) that form the basis for extended cases and situations (Bougdira et al., 2019b).

5.1 Basic structure

According to the rule (1) the studied domain involves two categories: Industrial Environment and intelligent traceability activities (figure 2.6). Industrial Environment (i.e., industry 4.0) comprise four main components, object (i.e., products), physical context (e.g., location and time of an event), data element (e.g., traceable information), and surroundings (i.e., an operator).

So far, activities and industrial components are the pillars and the starting point category of the ontology-based modeling. These comprise a small set of classes and properties that can promote simple and initial descriptions. The suggested design-approach (rule 2) urges that all the mentioned components are under traceability. Hence, the object property "isUnder" denotes the relation between industrial environment and traceability. Activities cooperate between each them (reflexive property "cooperatesWith"). At the same time, each element could be "composedOf" another one.

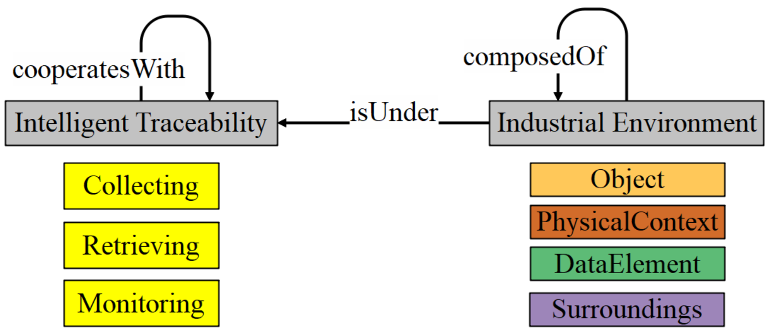

Figure 2. 6: The modeling of primitives.

At this level of modeling, we use Description Logics (Baader and Nutt, 2007; Hotz et al (2014)) to express traceable information and knowledge about the context. The following expressions provide some examples:

- dataElement ≡ IndusrtialEnvironment⊓ ∃isUnder.Collecting⊓∃isUnder.Retrieving : Data elements are exactly those of industry environment that are under collecting activities and are under retrieving activities. This statement can be seen as a definition of data element.
- Collecting ⊑ (= 2 cooperatesWith. Activities): Collecting activities cooperates with exactly two other type of intelligent traceability activities.

5.2 Modeling of activities

Since the proposed traceability bases involves a number of processes and procedures, the underlying structure of activities modeling is based around a process-flow model, as the prov-ontology does (Timothy et al., 2013).

5.2.1 Activity-centric perspective

The key purpose of activities modeling is to facilitate their integration into different industrial and logistics processes. This aspect is essential to capture the different information. According to the rule (3) intelligent traceability activities should be merged with various processing operations and tasks throughout the supply chain. Therefore, information about an object is mapped and combined with information about every supply chain operation and tasks. In addition, the contents and the sources of this information are also mapped.

Combining traceability activities with supply chain ones allows implementing a continuous traceability process. Such modeling provides a permanent recording of useful traceable information, an object would be traceable every time at every step. For example, if one conducts a process (e.g., manufacturing process and logistics process), one can report it using the corresponding activity (e.g., capturing and recording activities). Therefore, A user can collect, correlate, and retrieve data as an object moves throughout the entire supply chain.

5.2.2 Formalization of activities

The proposed representation conceives intelligent traceability as a set of activities that result in information being generated or a change in the surrounding environment (adjusting parameters). Therefore, the formalization includes activities, a number of entities, agents, and time (figure 2.7).

The alignment of activities modeling with PROV-Ontology is an obvious choice (Timothy et al., 2013). Therefore, the proposed activities are modeled using the PROV-O scheme, since it is already mainly and widely used for describing existing entities, activities, and agents (i.e., analysis data, processing step, and operator). Thus, the insertion of traceability activities into existing industrial and logistics models would be smooth and easy, which improve the interoperability and rapidity.

This modeling formalizes the main relationships between traceability activities and the entities involved in these activities. Activities use a specified procedure. For instance, sensor's observations are conducted according to their procedure, the acquiring activity uses this one.

Also, the property "pertainedTo" expresses the relationship between each activity and an entity from industrial environment. For instance, an entity could be a report of a task's execution. Also, an activity manipulates information from the data element "manipulatesData" and uses a procedure for executing this task "usedProcedure".

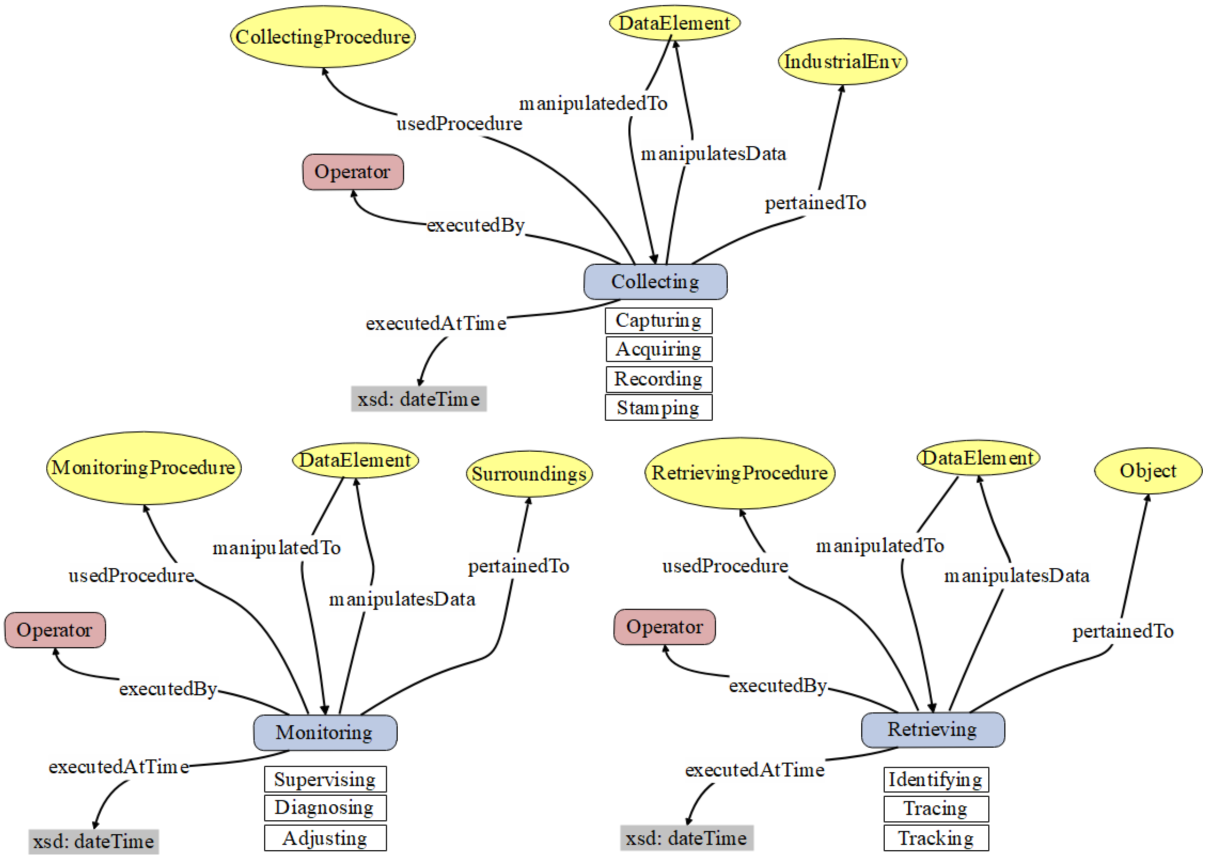

Figure 2. 7: General Model of activities.

Activities are performed by a user who could be an operator, a manager, or whoever is responsible for the activities. These activities are executed within a period "executedAtTime". Note that these relationships are the fundamental ones to model and represent a traceability activity, one can derive other new relationships or sub-properties of defined ones.

Assuming an entity that belongs to industry 4.0 environment, namely "transformation1report". In prov-o, this entity shows information about an activity, namely "transformation1" (i.e., a transformation of raw material to a semi-finished product by adding some ingredients). If capturing pertainedTo transformation1report, this means the aggregation (data capture) of all information about this processing operation (transformation1). Also, capturing maniplutesData OccurenceInforamtion, occurrence information belongs to the data element and refers to the useful information used for traceability. Also, the statement capturing usedProcedure procedure1 refers to a document that instructs users on executing the mentioned activity (capturing). The following table describes the resources involved when creating this capturing sequence for traceability.

The "capturing sequence"

```
@prefix xsd:  <http://www.w3.org/2001/XMLSchema#>.
@prefix foaf: <http://xmlns.com/foaf/0.1/>.
@prefix prov: <http://www.w3.org/ns/prov#>.
@prefix trac-o: <http://www.w3.org/ns/traco#>.

:transformation1
   a prov:Activity;
   prov:used              :transformation1report;
   prov:wasAssociatedWith :operator1;
.
: transformation1report
   a prov:Entity;
   prov:wasGeneratedBy  :transformation1;
   prov:wasAttributedTo :operator1;
.
: operator1
   a foaf:Person, trac-o:operator;
   foaf:givenName       "mohamed";
   foaf:mbox            <mailto:mohamed@example.org>;
.
: capturing
   a trac-o:CollectingActivity;
   trac-o:pertainedTo      :transformation1report;
   trac-o:manipulatesData  :occurenceinformation;
   trac-o:usedProcedure    :capturingprocedure;
   trac-o:executedBy       :operator1;
   trac-o:executedAtTime    "2019-07-26T01:01:01Z"^^xsd:dateTime;
.
```

Table 2. 2: Modeling of capturing activity.

5.3 Modeling of industrial environment

The modeling of industry requires the determination of its main components and relationships between them.

5.3.1 Description of components

5.3.1.1 Object

This thesis considers an object as a Traceable Unit Resource (TRU). This concept has been detailed in several studies (Moe 1998; Pizzuti et al., 2014; Olsen and Borit 2018). TRU can be a batch, a trade unit, or a variation of these two main types.

Therefore, an object could also be a product, pallet, container, or ingredient. These items may be priced, ordered or invoiced at any point in a supply chain. Hence, these objects refer to a pre-defined piece of information that could be retrieved.

5.3.1.2 Physical context

The physical context denotes the time and location (Bettini et al., 2010; Topcu 2011). This aspect provides a spatiotemporal meaning to the logical statements. Hence, while modeling a context, it is primordial to include the location and the time of each entity.

Therefore, the proposed modeling of industrial environment allows a timestamp of context information that may change over time. In addition, the model requires the integration of spatial information that organizes context information by physical location (Topcu, 2011). Spatial information is divided into symbolic and geometric coordinates (Lieberman et al., 2007).

5.3.1.3 Data element

The data element involves all useful information that helps with traceability. Data element involves recorded and retrieved information that would describe the object from the source through to its final destination. Therefore, modeling traceability data facilitates interoperability and improves information transparency throughout the supply chain.

Data is established internally for each enterprise (e.g., information about incoming materials and processes). Hence, data is stored locally, and only the product identification is shared with value chain partners. Thanks to identifiers, one is able to follow the product all the way through the entire supply chain, and map this data with existing tools.

5.3.1.4 Surroundings

Surroundings refer to entities that surround, affect, and interact with an object. This would include persons, sensors, plants, machines, processes, and operations. In this setting, these elements are not only interrelated but also centered upon the surrounding elements.

The whole modeling of industrial environment is centered on this important element. For instance, what is the importance of information about a product if this object is not referred to its surroundings. Also, what a physical context (time and location) would provide, in terms of traceable information, if it does not refer to a sensor measure time or a plant location.

5.3.2 Relationships between components

At this level, the presented context involves generic entities that are described primarily (abstract level). According to rule (4), the modeling objective involves relationships and roles of industrial components. The following figure summarizes the core classes and properties of the industrial environment modeling.

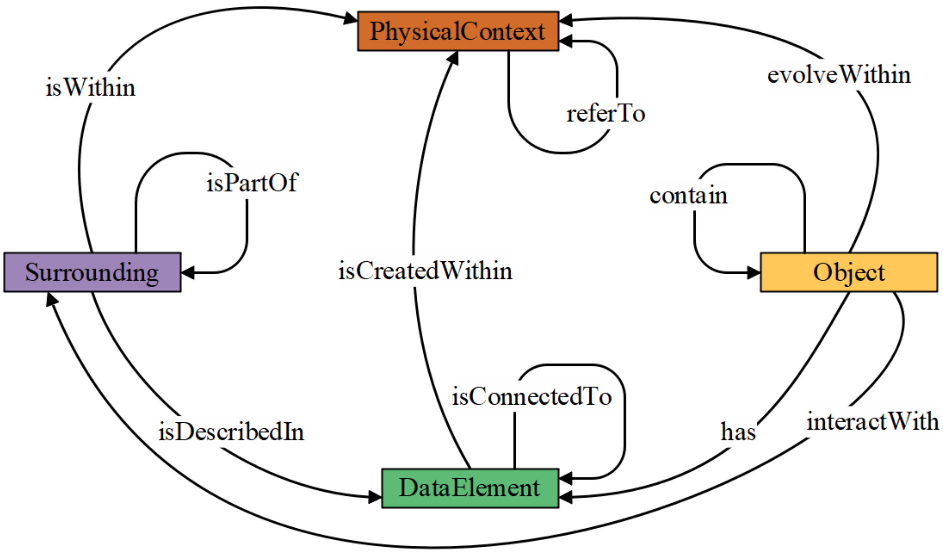

Figure 2. 8: Relationships between industrial components.

- Each described class indeed has reflexive and other object properties. Thus, an object could contain another one. For instance, a container contains products, and a product contains some ingredients.
- Each data element isConnectedTo another one. In traceability case, information about the product's owner and its ingredients are directly bound and combined to provide accurate information. For example:

- OwnerInfromation⊑ DataElement, Object ⊓ ∃has.ID⊑DataElement ⊓∃ isConnectedTo. OwnerInfromation

Note that Owner Information is a data element, which an object that has an ID is connected to this piece of information that provides details about the object's owner.

- A surroundings element can constitute another one (isPartOf). Similarly, Machine isPartOf WorkStation, WorkStation isPartOf Line, and Line isPartOf ManufacturingPlant. Using description logic, this natural language can be expressed as follow:

- Machine⊑ Surroundings, Machine ⊓ ∃isPartOf.Workstation⊑Line ⊓∃ isPartOf. ManufacturingPlant

- Time and Location, each one referTo the other. A location is determined in a specific time, and vice versa.
- "interactWith" designates the relation between an object and its Surroundings. Hence, each object has a kind of interaction with, at least, one element of industrial environment. This property could encompass several relationships and have sub-properties. Thus, an Operator handles Object at the same time a Process transforms Object from input to new output.

- Here, the usage of an inverse functional relationship expresses this statement (transformedBy inverse of transform).

- Operator⊑ Surroundings, Operator ⊓ ∃handles product1⊑Object⊓∃ transformedBy. Process

- The relation “has” links Object and DataElement. Thus, an object possesses data useful for traceability. “isDescribedIn” is a connection between Surroundings and DataElement. Each surroundings element assigns or provides data necessary for traceability.

- Object evolveWithin PhysicalContext: such a relation aims to follow object’s transformations in terms of time and location. This link can include subproperties and generates other statements, like Object isInLocation Location and Object isAtTime Time.

- Simultaneously, surroundings elements need a context description. “isWithin” property and its sub-properties fulfill this role. For example: Process occurIn Location and Process occurAt Time.

- Data element relates to the time and location thanks to “isCreatedWithin” property. It helps to know the source of each data piece in terms of time and location.

These main relationships help to write several assertions that are of crucial importance in inferring and reasoning. For instance, table 2.3 shows the modeling of a product (object).

The instance “cannedFish”


```
{
  "@id": "http://www.semanticweb.org/abdslam/ontologies/2019/9/untitled-ontology-18#cannedFish",
  "@type":["http://www.w3.org/2002/07/owl#NamedIndividual",
"http://www.semanticweb.org/abdslam/ontologies/2019/9/untitled-ontology-18#Object" ],
  "http://www.semanticweb.org/abdslam/ontologies/2019/9/untitled-ontology-18#contain": [ {
    "@id": "http://www.semanticweb.org/abdslam/ontologies/2019/9/untitled-ontology-18#cumin"
  }, {
    "@id" : "http://www.semanticweb.org/abdslam/ontologies/2019/9/untitled-ontology-18#salt"
  }, {
    "@id" : "http://www.semanticweb.org/abdslam/ontologies/2019/9/untitled-ontology-18#sauce"
  }, {
    "@id" : "http://www.semanticweb.org/abdslam/ontologies/2019/9/untitled-ontology-18#tuna"
  } ]
}, {
  "@id" : "http://www.semanticweb.org/abdslam/ontologies/2019/9/untitled-ontology-18#contain",
  "@type":["http://www.w3.org/2002/07/owl#ObjectProperty",
"http://www.w3.org/2002/07/owl#ReflexiveProperty" ],
  "http://www.w3.org/2000/01/rdf-schema#domain" : [ {
    "@id" : "http://www.semanticweb.org/abdslam/ontologies/2019/9/untitled-ontology-18#Object"
  } ],
  "http://www.w3.org/2000/01/rdf-schema#range" : [ {
    "@id" : "http://www.semanticweb.org/abdslam/ontologies/2019/9/untitled-ontology-18#Object"
  } ],
```


Table 2. 3: Sample of the modeling as described in JSON format.

At this level of detail, an entity can exchange and reuse this information. This description uses a JavaScript Object Notation (JSON) format, which is a minimal and readable format for structuring and sharing data between intelligent agents.

5.4 Main modules of ITO

The established modeling of activities and industrial environment form the basis for constructing different modules of ITO, including the core-part, internal and external relationships, and the traceable information.

5.4.1 Core-part of ITO

To extend these initial representations, the core-part of the modeling is centered upon the object and its interaction with the context, precisely the surroundings. Hence, by reducing the modeling level of abstraction, the focus becomes on the object and its surroundings. At this low level, the preliminary categories of modeling are merged into one representation that highlights different elements of supply chain and their internal and external relationships (figure 2.9).

Therefore, we detail the main elements of surroundings. Also, we describe the internal relationships between an object and its surroundings, and the external relationships between the modeling and existing ontologies. These ones will describe also the structure of traceable information and operations that can be performed in a traceability context.

Thus, the surroundings are represented as three major elements: Operator, Resource, and Occurrence (O, R, Oc). In a general sense, an **O**perator is an agent (i.e., software, manager, or technician). It operates a facility, a platform, a manufacturing plant, or another **R**esource. A Resource generates occurrence. An **Oc**currence could be a production process, a human's operation, or an assessment situation.

From this representation of the knowledge about the supply chain, one can detail other aspects (i.e., focusing only on the representation of processing context) and provide additional semantics (i.e., adding mores sub-classes and sub-properties).

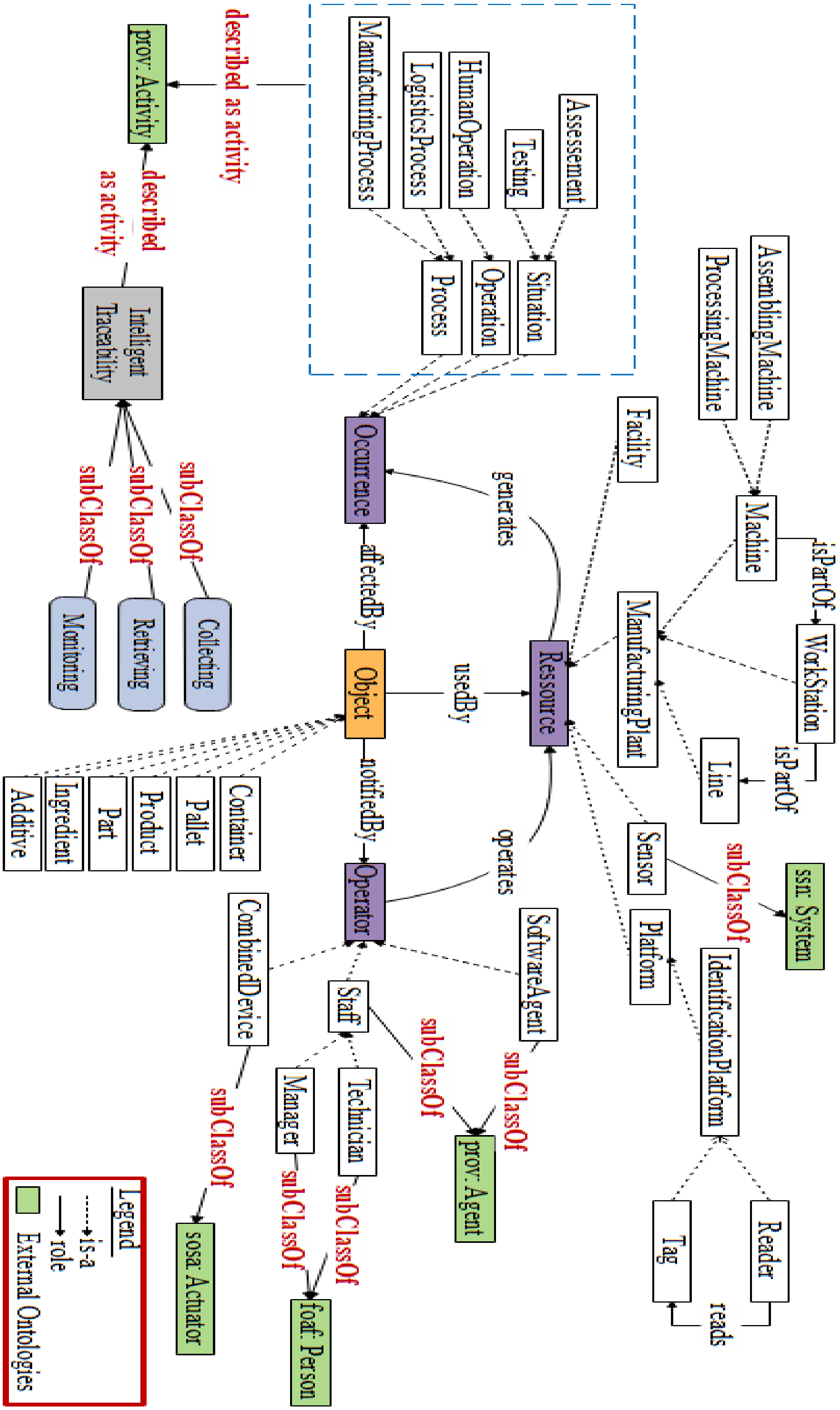

Figure 2. 9: Detailed concepts of the knowledge representation.

5.4.2 Internal relationships

From figure 2.9, we can extract several relationships and infer several statements, the following examples concern statements and inference in the context of internal relationships:

- If the property "operates" relates an operator (o) to a manufacturing plant (mp) and this one generates an occurrence (oc), one can deduce that o involvedIn oc.
- If a product (p) interacts with its surroundings, i.e., p interactsWith oc, a user can draw an inference from this evidence. Consequently, one can know; the manufacturing (mp) that has transformed the product (p); the operator (o) that has been involved in this transformation; and the identity of this transformation (oc). Information about o, oc, mp isDescribedIn DataElement. This includes subclasses such as OwnerInformation, OccurenceInforamtion, and OperatorInfromation.
- Hence, p has OwnerInformation(mp), p has OccurenceInfromation(oc), and p has OperatorInfromation(o).
- Typically, each data element possesses data properties, which refer to a piece of information (i.e., OwnerInfroamtion(mp) hasName, hasAdress, hasOrigin), (i.e., OccurenceInfromation(oc) hasDetails, hasStepDescription, hasProcessingHistory) and (i.e., OperatorInfromation hasFirstName, hasLastName, hasRole).

These Statements provide inferential evidence about the product (p). Further, we ca also provide other evidence using the Semantic Web Rule Language (SWRL) (Horrocks et al., 2004), for example:

Container(?c)∧Product(?p)∧contains(?c,?p)∧Tag(?t)∧carries(?c,?t)∧Reader(?r))∧reads(?r ,?t)
∧Platform(?pt)∧isPartOf (?r,?pt)∧Operator(?o) ∧operates(?o,?pt)∧Identification(?id)
∧generates(?pt,?id)∧ IdentityInfromation(?i)∧isDescribedIn(?id,?i)

This expression stands for a Container ?c that contains some Products ?p. The interaction between the container and its surroundings is interpreted as; Container carries Tag ?t ; and Reader ?r reads Tag. The tag is part of a Platform ?pt and Operator ?o operates platform. This manipulation generates an Identification?id (occurrence). The container's identification is described in data element (IdentityInformation).

5.4.3 External relationships

The proposed ontology (ITO) is capable to align externally with other ontologies such as SSN, SOSA, FOAF, and prov-o.

Accordingly, sensors and actuations generate a stream of time-stamped data. This stream is an important asset to traceability since it enriches the knowledge about an object and enhances the monitoring of its environment.

For example, ITO can use the measurements that are related to sensing and observations from the Semantic Sensor Network ontology (SSN) (Compton et al., 2012). SSN introduces two kinds of results; hasResult; and hasSimpleResult. In our ontology, "Data Element" describes this information using sub-classes and their data properties. Therefore, MeasurementsInformation represents the observation and their values (figure 2.10).

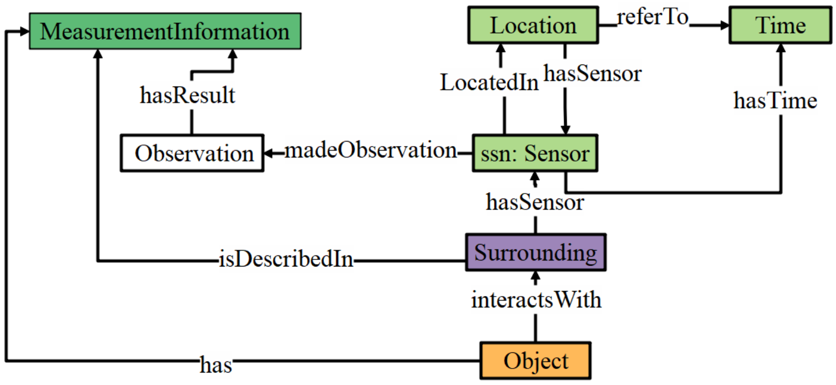

Figure 2. 10: Relationships with SSN ontology.

Supposing a product that exists in a storage facility, the surroundings information (storage facility) isDescribedIn MeasurementsInformation. Product interactsWith Surroundings and Product has DataElement. Inferring from these statements, one can know the storage conditions (e.g., temperature and humidity). The following statement stands for a surroundings element?s that possesses a sensor ?se which makes an Observation?ob.

Surrounding(?s)∧Sensor(?se)∧hasSensor(?s,?se)∧snn:Observation(?ob)∧madeObservation(?se,?ob)∧MeasurementsInformation(?m)∧hasResult(?ob,?m)

In case of actuation, assuming the following adjusting activity: Due to a problem of humidity, it is required to move (actuation) raw material from store1 to store2 using cartA (actuator)). ITO can get all information about this actuation (i.e., who is responsible for this activity and how long this activity last) by using the information provided by SOSA (Krzysztof et al., 2019) (figure2.11).

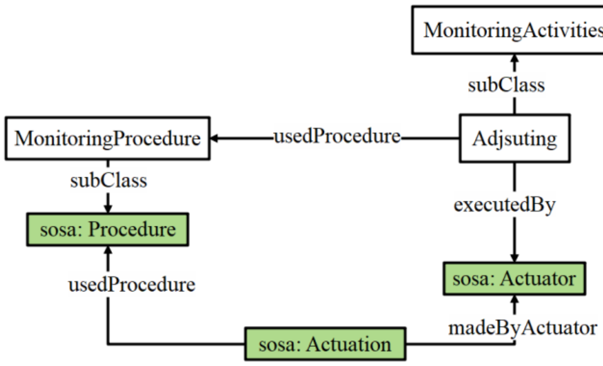

Figure 2. 11: Relationships with SOSA ontology.

In case of Friend Of A Friend ontology (Brickley and Libby, 2014), ITO can get information from this ontology (i.e., first/ last name and role of an operator that operates a machine) (figure 2.12).

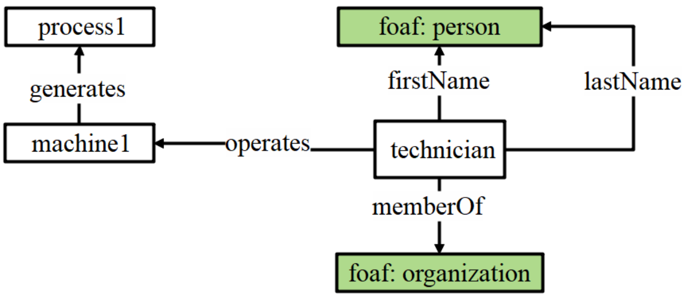

Figure 2. 12: Relationships with FOAF ontology.

Regarding provenance ontology (prov-o) (Timothy et al., 2013), most of instances that belongs to Occurrence in ITO are subclasses of activity in prov-o, this equivalence allows to map information from prov-o to ITO (figure 2.13).

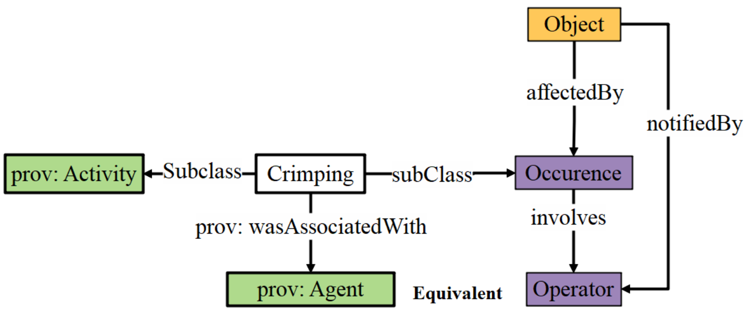

Figure 2. 13: Relationships with prov-o ontology.

5.4.4 Traceable data

Figure 2.14 represents the most noticeable information needed for efficient traceability without pretending that the ontology includes all possible information. Hence, Data element involves several sub-information such as OperatorInformation, OccurrenceInformation, OwnerInformation and IdentifityInformation.

In addition, time and location are presented in the ontology. For example, the following expression stands for a Specialist ?s operates a ProcessingMachine ?pm in order to cut raw meat into pieces. This process occurs in a location ?l and at a time ?t.

ProcessingMachine(?pm)∧Specialist(?s)∧operates(?s,?pm)Cutting(?c)∧generates(?pm,?c)∧Location(?l)∧occursIn(?c,?l)∧Time(?t)∧occursAt(?c,?t)

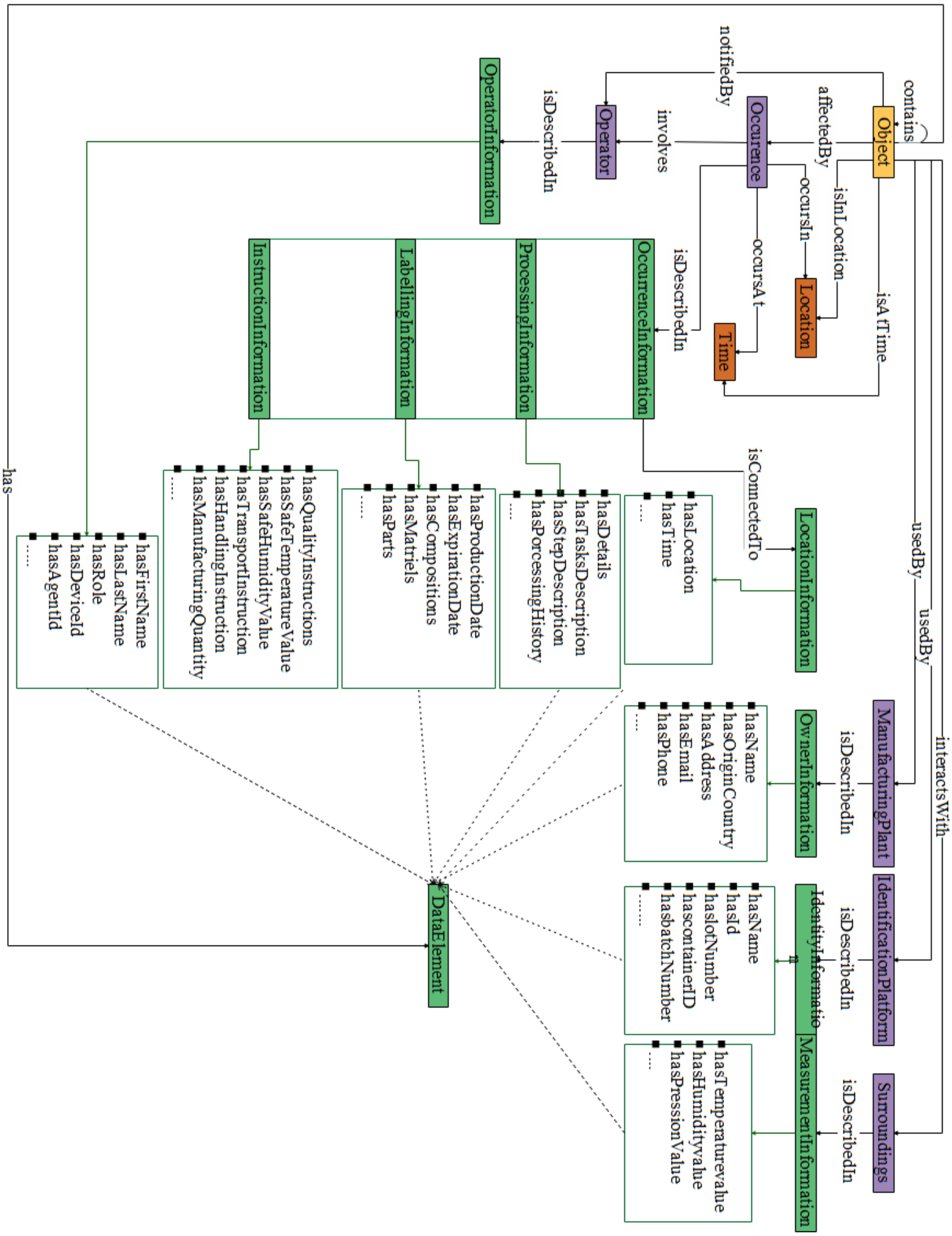

Figure 2. 14: Main information represented in ITO.

6 Conclusion

To sum up, the development of a general, interoperable and intelligent traceability requires properties that involve general bases, interoperable representation of traceable information, intelligence functionalities that have abilities to proactively provide adaptive behavior to changes in industrial environment.

The establishment of these properties is possible thanks to the proposed framework, which synchronize the description, engineering and executive component to reach bases that are likely to be relevant and applicable to several traceability cases. Also, the ontology-based approach for context modeling has been proven able to provide interoperable platform for managing and sharing traceability data. Moreover, it is essential for making the traceability process, itself, intelligent to develop a knowledge representation and define the decision-making process. Thus, the traceability process would be sensitive and responsive to the object and its surroundings.

Chapter 3: Intelligent Traceability as a Service (ITaaS)

1 Introduction

In the following subsections, a simulation scenario is conducted to address explicitly the functioning way of the conceptual framework. Such initial analysis aims primarily to feature the framework functioning way and the possible outcomes of the framework application.

Based on the solution bases, this scenario results in defining the possible shape of a typical intelligent traceability solution, namely Intelligent Traceability as a Service (ITaaS). This solution might be considered as general, interoperable, and intelligent. Thus, we illustrate the development of ITaaS through several examples.

2 Case Scenario

In Morocco the sea fishing is important to the industrial sector. According to Naji et al. (2015), this activity revolves around the fish canning, where canneries are still its most important sub-sector. Thus, using an effective traceability system is an absolute necessity for enhancing the canneries chain efficiency. Regarding this canning case, we opted for a mixed data-gathering process, including field investigations and literature (Bratt, 2010; Featherstone, 2016).

The gathered data provided details about the canning industry in a general way, and the Moroccan one specifically. Such information gives details about three main aspects, including the main stakeholders involved in the canneries chain, an overview of the canned fish process, and the main products and commodities used in the canned fish. Also, it helps us to determine the main requirements with respect to traceability.

3 Implementation steps

As a first testing step, the framework will define and determine the necessary traceability bases for general traceability. Normally, in any case, the framework application should provide the basis for a solution to meet the supply chain challenges. Furthermore, the bases will support the development and deployment of the system. The system is expected to ensure traceability data management and would include the functionality for continuous monitoring of the product. The next subsections are a step-by-step guide, which describes how the framework is applied in real case.

3.1 Modeling: axes and principles

First, we chose the inputs of the framework. Therefore, we defined the modeling axes and the modeling principles to start our analysis. This phase involves the description aspect (modeling) and the executive aspect (conception). The collected data shows four groups of requirements (modeling axes) (figure 3.1).

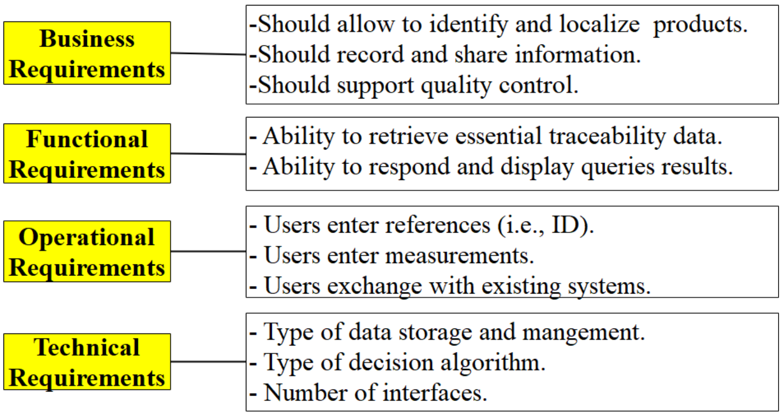

Figure 3. 1: Modeling axes

Business Requirements (BR) define the objectives assigned to the intelligent traceability solution and Functional Requirements (FR) analyze the solution user's expectation from the system functionalities perspective. Operational Requirements (OR) describe the relationships between different actors in terms of the execution of different operations. It supposes that users, devices, sensors, and tags interact with each another during a traceability process. Technical Requirements (TR) outline means and forms to realize a solution. These requirements handle traceability process from the practical and the application perspective.

For this case, we propose three modeling principles: grouping method, matrix principle and black box principle. In the first stage of conception, we will analyze the axes (a set of requirements) using a conception principal (grouping method). We form and analyze six groups by analogy with discriminant function analysis: (FR, TR), (FR, BR), (FR, OR), (BR, TR), (BR, OR) and (OR, TR). Note that (FR, BR) is similar to (BR, FR). The analysis classifies results in aims, functions, specifications, data classification, operational mode and procedural mode.

The set (BR, OR) helps to define three major aims, including information tracing, product tracking and conditions controlling. These aims are essential to direct the development of a solution in terms of what is exactly expected from this solution. The analysis of (OR, FR) results in five traceability functions: memorizing, processing, communicating information, informing users and acting on a product's environment. These functions show to a developer what is essential for a solution in terms of functionalities.

The set (BR, TR) defines the technical specifications that include autonomy, response time, heterogeneity integration, ubiquity and security. The specifications stress the importance of what is needed to technically achieve a solution implementation.

The set (TR, FR) subdivides product data into time (timing) such as instantaneous or prerecorded (i.e., linking and positioning), users, and sources. The analysis of (BR, FR) describes the operational mode that enables users to record data and events.

The group (OR, TR) details the procedural mode that allows information retrieval and product monitoring. Figure 3.2 shows the analysis results. Note that the second stage of conception is subdivided into two operations. The first operation is detailed in (subsection 3.2) and the second one is detailed in (subsection 3.3).

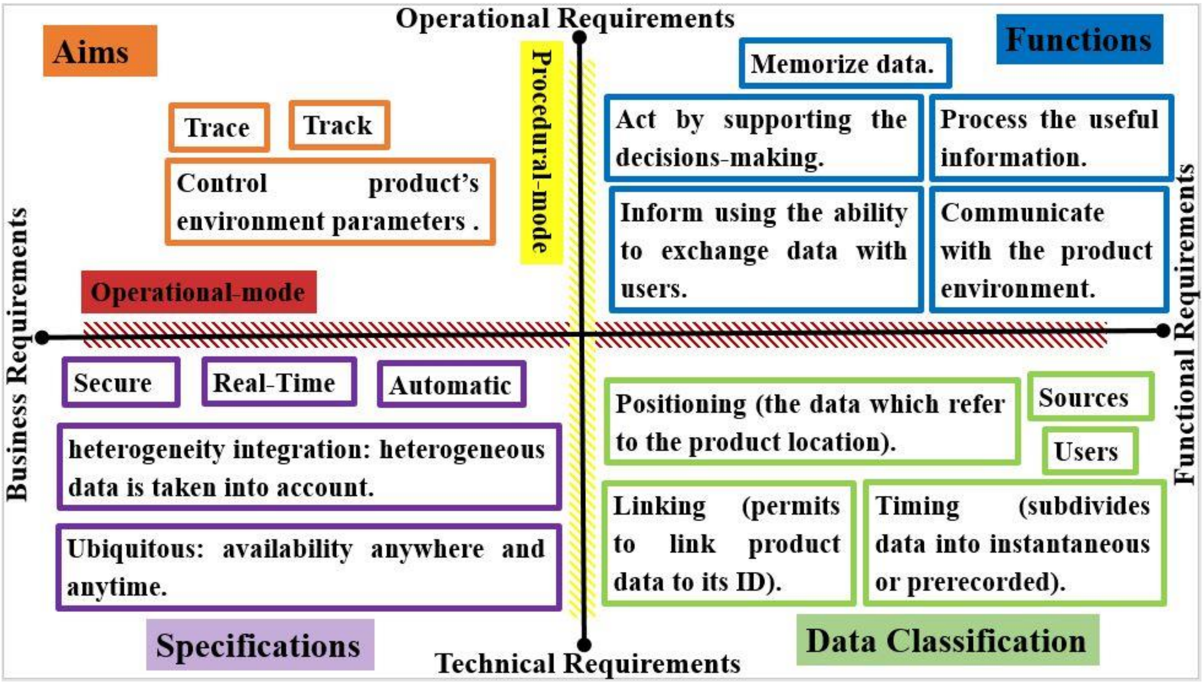

Figure 3. 2: The results of the modeling analysis.

3.2 Processes and operational mode

The first operation aims to define the solution processes, which describe a series of tasks to carry out a part of the traceability functionalities. The processes enable product identification and localization. Moreover, these activities include data-processing (capturing, accessing, linking, and structuring), and the system should ensure security and support supply chain monitoring. Herein, we used the conception principle, namely, the matrix principle. Hence, we used a table of two dimensions that seek to define the traceability processes.

Typically, the matrix describes how to express the links between traceability functions and aims. Rows represent the aims whereas columns represent the functions. The table cells express answers to the questions: What traceability requires? What is achieved by traceability? The principle permits getting ten processes, and the value “0” means there is no link.

What is required from intelligent traceability ?

	Memorize	Communicate	Inform	Process	Act
Trace	**Data Storing**	**Identification**	**Data Capture**	**Data Associating**	0
Track	0	**Transferring**	**Localization**	0	0
Control	**Data Access**	**Security**	0	**Data structuring**	**Decision-making**

What is achived by intelligent traceability ?

Figure 3. 3: The matrix of the proposed processes.

These processes depend on the current studied case. For instance, if one tries to pinpoint what is expected from the function (Act) to achieve the aim (Track), one could claim that the result should be the localization process; however, this process already exists in the cell (Inform, Track). Therefore, the proposed method manages to avoid the recursion that could be present in some similar cases. Note that, in other cases, the cell (Act, Track) might yield a novel link (process). Hence, we urge that these ten presented processes, while being fairly generic, can achieve a satisfactory outcome for promoting traceability efficiency.

The identification process permits coordinating and appointing a unique product ID. Also, the localization defines means to get the product location along the entire supply chain. The data-processing encompasses data capture, data storing, data associating, data structuring and data access. These activities seek to implement systematic recording and record-keeping along the entire supply chain. Hence, an efficient system permits collecting data from heterogeneous sources, it designates means to store data, and it relates data to the product identifier (ID).

Moreover, this system has to filter and organize data depending on time, type and user. The data access and transfer processes manage to share the product information among stakeholders. The decision-making process defines rules to make adjustments to a product’s environment. In this context, some publications have proposed several monitoring scenarios (Matkovic et al., 2014; Bougdira et al., 2016b).

Finally, the security process ensures the reliability and confidentiality of the solution. The detailed processes form the basis of operational mode development. Therefore, system operational mode enables a user to assign an ID to each product. It handles the product position, along with other product information and events (i.e. country of origin, owner, ingredients, expiration date and processing history). The operational mode also allows users to customize security, access options and data integrity. Furthermore, it helps in supporting the decision-making task and monitoring activities.

3.3 Procedures and procedural mode

The second operation in the second stage aims to specify the procedures, which complete the other functional part of traceability. Thus, the activities should comprise separate and precise functions that ensure adequate product traceability. The processes and the data classification are the core parts of procedures.

We use black-box behavior as a conception principle to define five procedures. The processes represent the black box. The data classification is the input, and the procedures are the outputs. The procedures encompass accessing, identifying, tracing, tracking, and monitoring.

In this work, the procedures rely on the accurate determination of needs and requirements for doing correctly and smoothly the traceability activities (collecting, retrieving, and monitoring). In this setting, the procedures are used to direct those activities in which several operations are linked and different contributors are involved. For example, monitoring activities involves supervising, diagnosing, and adjusting, hence the controlling procedure ensure success in synchronizing activities with each other.

The accessing procedure allows a user to have access to the system user-interface. The data access and the security processes handle the data user (e.g. username, login and password). The identifying procedure verifies information such as product identity and owner. Note that in the food industry, this information cannot be analytically verified.

The identification and data associating processes relate each product ID to its proper data. The tracing procedure enables users to retrieve the captured and recorded data. These data come from different sources (i.e. sensors, tags and information systems). Therefore, a system uses the data-associating process to relate these data to the product ID. The tracking procedure seeks to provide a permanent recording of the position data (real-time localization). This procedure uses the localization process and transferring process.

The controlling procedure enables users to adjust the product environment parameters, e.g. the data structuring process classifies product data into instantaneous and prerecorded ones. Thus, the system could help a user to compare the quality values (i.e. preservation conditions, temperature, and humidity) with those measured in the store. In case of any unconformity, the decision-making process proposes a change.

Combining processes with procedures is an asset to a solution efficiency. This idea is originated from the background of Information systems and Business Process. In this context, a process should comprise a clear series of related tasks that interact to generate outputs from inputs. In our case, each process is a step-by-step protocol to achieve specific traceability task or objective. Moreover, a procedure should outline the way of undertaking a process in terms of who is responsible for and when should the process occur. Figure 3.4 shows the interaction between the processes and procedures.

Therefore, Procedures are crucial to set effective traceability and help the developers to establish the system procedural mode, which achieves the other part of the traceability functionalities. This mode permits the user’s authentication and secures access. Afterward, a user can proceed with identifying a product by entering the ID. Users can also check the product origin and the owner contact information. The tracing activities help to retrieve information such as product ingredients and processing history. The coordination between localization devices and the product ID ensures continuous tracking.

A user, because of the monitoring functionalities, could assess the product conditions, take the correct decision and appoint the adequate executors (person or actuators) to undertake the adjustment task. The decision-making process is an important feature of an intelligent traceability system. This mechanism might help stakeholders to enhance supply chain visibility, provide supply chain sustainability benchmarks and test supply chain indicators (Carter and Easton, 2011; Bougdira et al., 2016c).

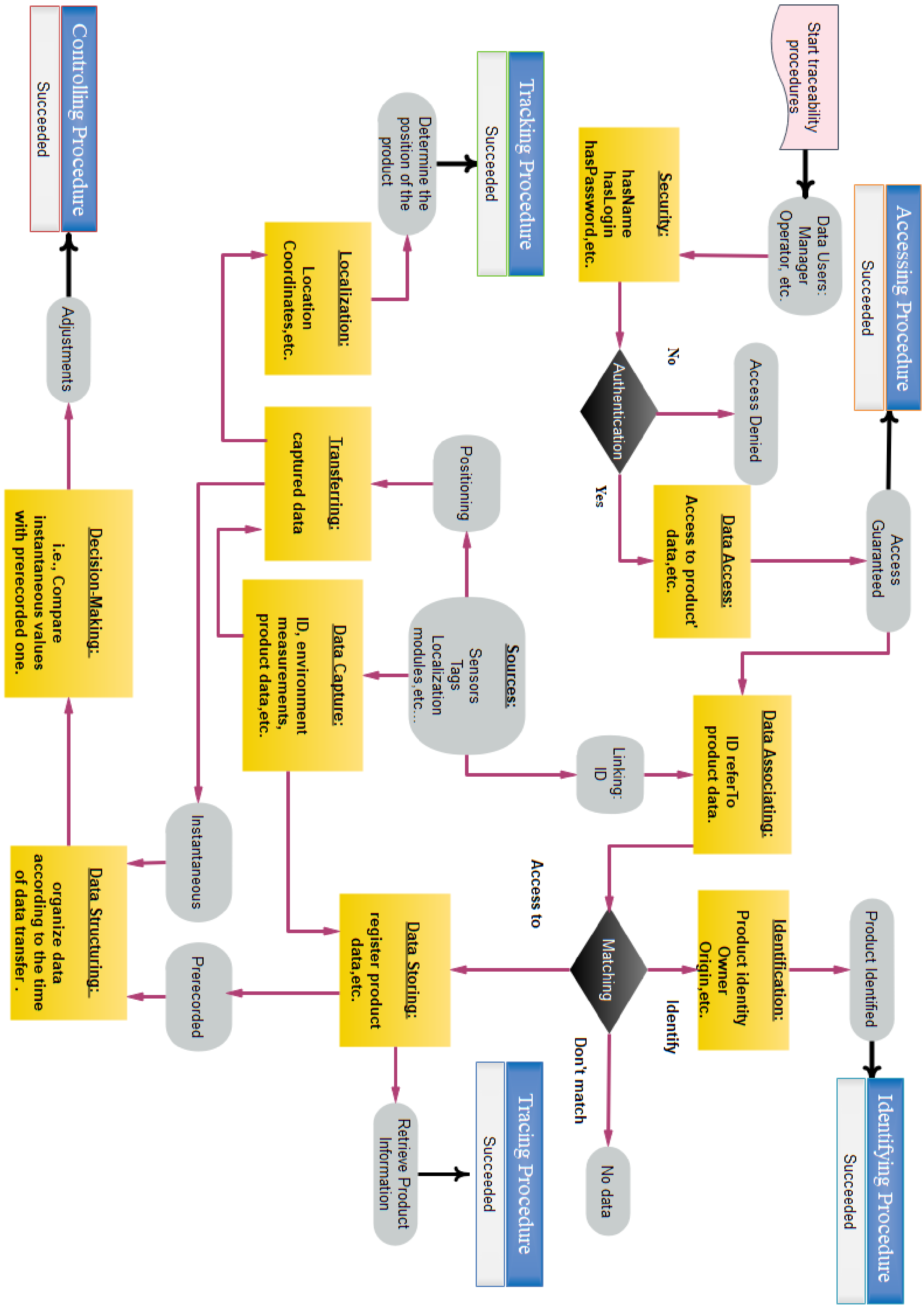

Figure 3. 4: The interactions between processes and procedures.

3.4 Approach: architecture and model

As of right now, the stages of conception are complete. One can move forward to define the approach. This approach facilitates the architecture definition and model description. Thus, we propose a functional oriented-approach to address the examined case issue. It relies on breaking down the system components into a set of interacting functions, and it underlines the importance of what the traceability system does.

However, a functional approach has certain limitations. First, when producing a specific outcome, the functions should operate as a whole organization. Also, these different functions have to effectively communicate and cooperate. Second, these functions need a centralized core element to coordinate the operations. Therefore, we propose a mixed design method to overcome the approach drawbacks. Thus, we use service-oriented for the architecture and the cloud-based for the model. A service-oriented architecture (SOA) helps to divide each function into several services. Next, these services become available to users through a cloud-based model. In this setting, each service represents a traceability task (Erl 2005).

In this context, we have co-supervised a Master thesis (Maroi et al. 2017) in which we have studied the benefits and the possibilities of SOA, especially for real-time, embedded, and distributed systems. As a result, the importance and the usefulness of this architecture has been shown, and a prototype application has been developed. These finds support the choice of SOA in the current work. Therefore, the core idea of our proposal is representing intelligent traceability as a set of activities. In order words, when one would implement a traceability solution, one could allocate a set of services for each traceability activity.

In this setting, users can separate traceability services physically. Afterward, one can executes and reuses these services for other purposes. Thanks to SOA, a designer could easily reconfigure a service into a new one. If a business process evolves or changes, the designer has not to remake the design.

Also, this system design helps to distribute solution services across the supply chain applications. Hence, collaborators can access these services remotely via the cloud infrastructure. Figure 3.5 shows a sketch of the suggested approach, including architecture and model. The user can invoke the services through an operational mode or procedural one. The system designer uses processes for operational mode development and the procedures for procedural mode deployment. The activities are split into interacting services. Each service provides access to a well-defined functionality (figure 3.5).

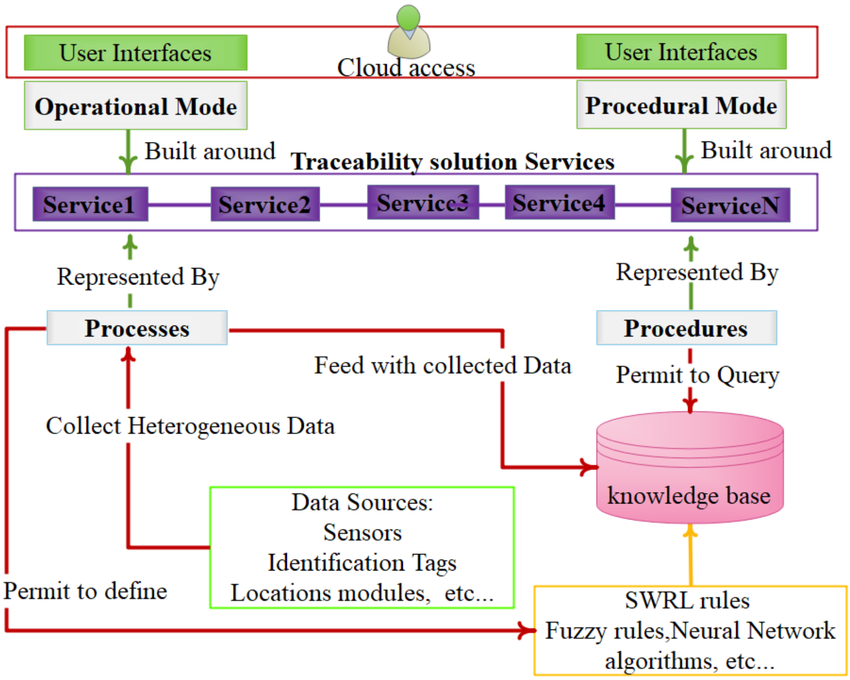

Figure 3. 5: Overview of the proposed approach.

A service provides users with an interface that manipulates the value object. A user can invoke services via cloud infrastructure. Figure 3.6 describes an example at a design level. It implements functionalities for capturing traceable information during product transformation.

This figure shows two interfaces published by the proposed component. A user can create tasks and detail information about them. These interfaces manipulate some value objects like the step duration and number. Moreover, one can assign operation and describe the operator's role.

Hence, the user can capture data about the role's name and description. "ProcessingCapturing" service permits recording and collecting information about production steps and entities involved in each step. These data are integrated into the ontology-based model. This integration enriches the knowledge base and reinforces retrieving and monitoring efficiency. The mentioned example is useful to give a brief overview of the expected design manner.

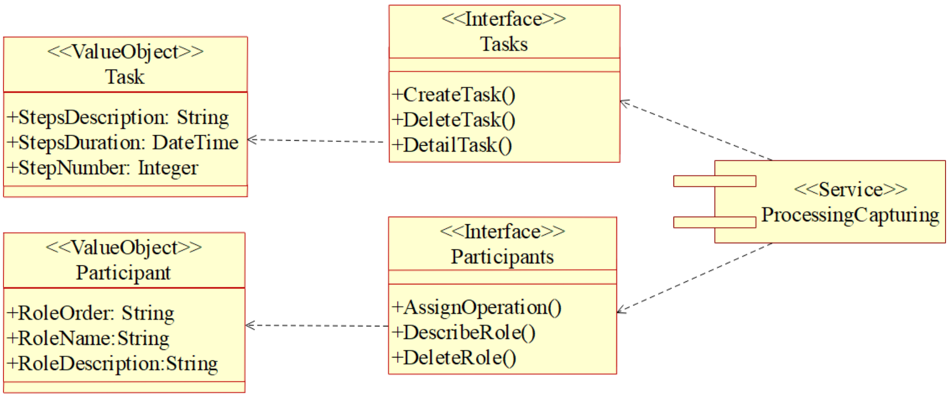

Figure 3. 6: A service-oriented design example.

3.5 Engineering aspect, development, and deployment

Now, the conception phase is over (executive aspect) and yields two outcomes. First, the traceability solution bases are defined (aims, functions, data classification, specifications, processes and procedures). Second, the description aspect is complete (modeling, operational mode, procedural mode, architecture and model). These results are an important asset to implementing a solution. Thus, one can proceed with the setting of the traceability system (development and deployment). Both steps use the engineering aspect and are constrained to comply with the specifications (bases) and the defined approach. In the following paragraphs, we give examples of using certain technologies and techniques.

Example 1: Our studied case adopts a cloud-based model; hence, one should use cloud technologies for solution development and deployment (i.e. Internets of Things technologies). In this case, we use technologies like use J2EE and Java Server Page (JSP) to develop and to interact with the application. Figure (3.7) shows a user interface of the developed application.

Figure 3. 7: Prototype application interface (ITaaS).

Example 2: one can implement the acquisition of sensors data as a kind of web service. Accordingly, the broker ‘mosquitto’ is used to publish the acquired temperature and humidity. Here, we have used the MCU node (a) and the DHT11 sensor (b). The developed web service (c) allowed users to check the temperature and humidity of the environment, follow the changing curve in real-time, and share this contextual information between entities as XML data (figure 3.8).

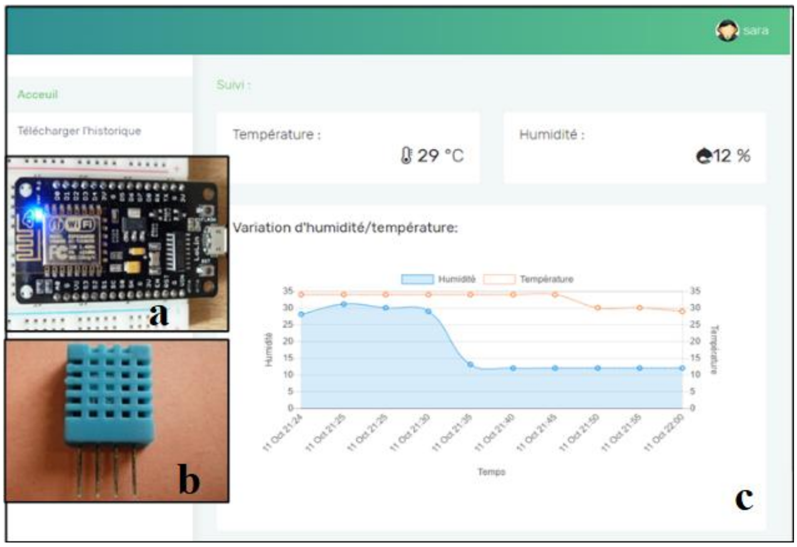

Figure 3. 8: Context-acquisition with respect to Humidity/Temperature sensor.

Example 3: In case of identification, the specification (automatic) underlines the need for an automatic technique (e.g. RFID, Near Field Communication (NFC) and Quick Response (QR)-code). Accordingly, the figure below shows the RFID reader RC522, tags, and Arduino UNO module (a). In (b), the assembly of these elements is depicted. In (c), the code and reading results are shown. Here, each tag allocates an ID for a product (e.g., 0E BA 38 D5). This contextual information is transferred to the system every time a product is detected by a reader.

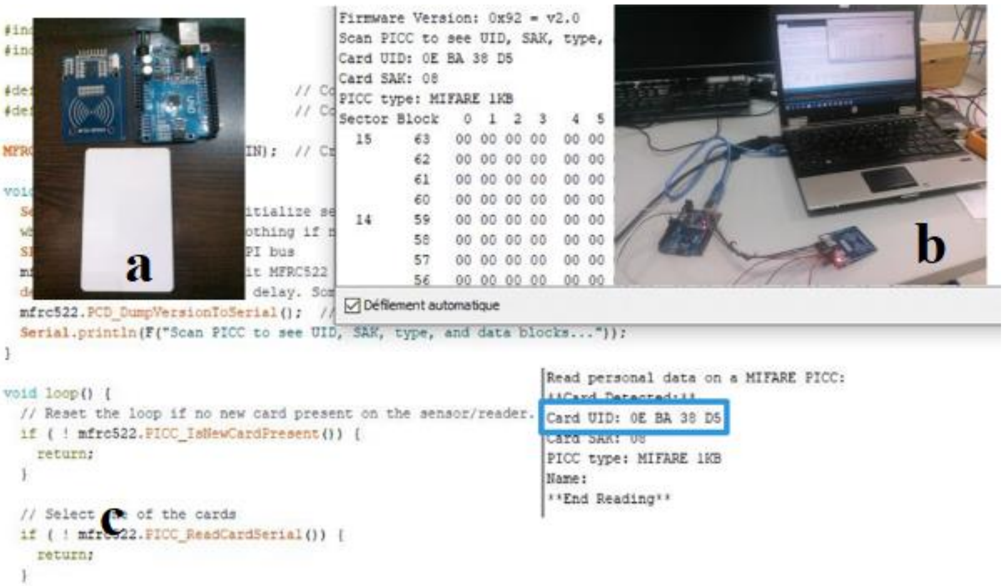

Figure 3. 9: Context-acquisition with respect to RFID tag and reader.

Example 4: In the case of localization, the specification (real-time) requires that the system should combine indoors with outdoor positioning techniques (i.e. Real-Time Locating Systems: RTLS). Also, the specification (ubiquitous) points the way to ensure availability of traceable information anywhere and anytime.

Note that for context acquisition (examples 2,3, and 4) the canning supply chain can involve various sensing, recording, and positioning data (i.e., RFID, Sensor Networks, and GPS). Providing insights into all possible traceable information sources is beyond the scope of this thesis. However, we have examined the mentioned three illustrative examples.

Example 5: In the case of knowledge-base, we use the developed ontology ITO, and we integrate the Jena API with J2EE. This combination allows us to interrogate the knowledge-base and obtain results.

Assuming a scenario when a food crisis occurs due to several fish cans. A medical unit reports that several intoxicated persons have eaten a canned fish. Authorized person elaborates data querying via ITaaS. Hence, the first reasoning operation performed is oriented to the identification of owners (figure 3.10).

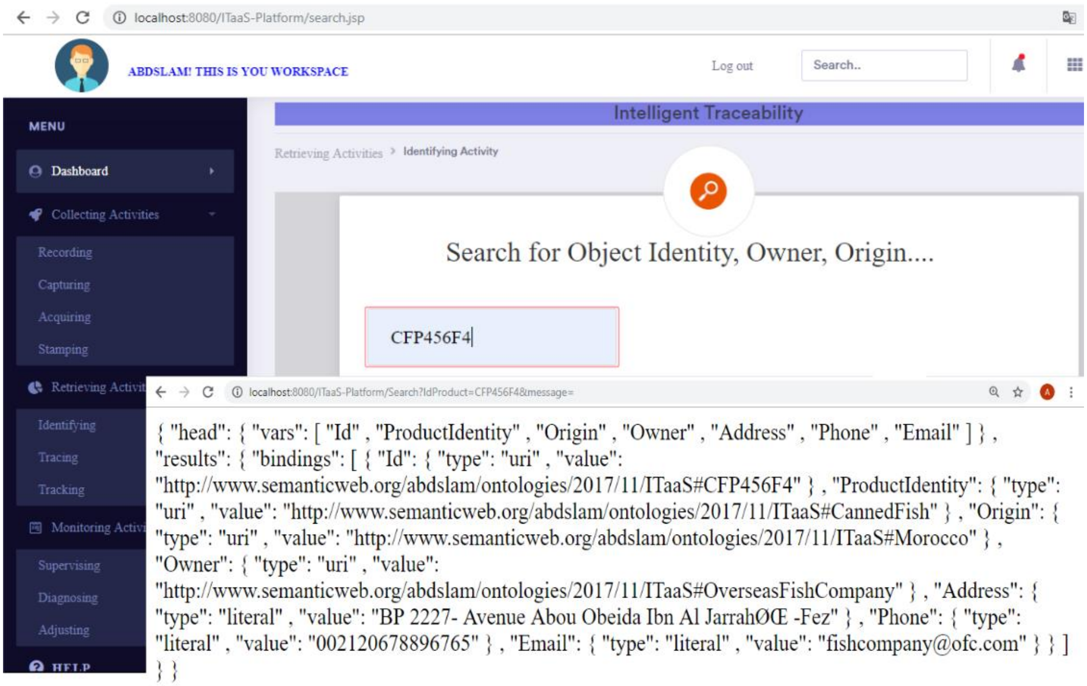

Figure 3. 10: Identifying query results.

Accordingly, the data includes the identity of owners, addresses, and contact information. Supplier information is essential for recognizing the steps followed by the contaminated products and for product recall.

During the investigation, some cans are not produced by the same company. Moreover, those produced by the same company do not belong to the same lots. As a consequence, authorities use the tracing activity. They try to know ingredients, quality conditions, and production dates. Figure 3.11 depicts the obtained data, which reveals the presence of a common ingredient (tomato sauce) that could be responsible for this contamination.

{ "head": { "vars": ["ProductionDate" , "ExpirationDate" , "IngredientsNumber" , "QualityPreservationConditions" , "value" , "Ingredients"] } , "results": { "bindings": [{ "Ingredients": { "type": "uri" , "value": "http://www.semanticweb.org/abdslam/ontologies/2017/11/ITaaS#salt" } } , { "Ingredients": { "type": "uri" , "value": "http://www.semanticweb.org/abdslam/ontologies/2017/11/ITaaS#cumin" } } , { "Ingredients": { "type": "uri" , "value": "http://www.semanticweb.org/abdslam/ontologies/2017/11/ITaaS#sauce" } } , { "Ingredients": { "type": "uri" , "value": "http://www.semanticweb.org/abdslam/ontologies/2017/11/ITaaS#oil" } } , { "Ingredients": { "type": "uri" , "value": "http://www.semanticweb.org/abdslam/ontologies/2017/11/ITaaS#tuna" } } , { "ProductionDate": { "type": "literal" , "datatype": "http://www.w3.org/2001/XMLSchema#dateTime" , "value": "2018-10-26T21:32:52" } , "ExpirationDate": { "type": "literal" , "datatype": "http://www.w3.org/2001/XMLSchema#dateTime" , "value": "2019-10-26T21:32:52" } , "IngredientsNumber": { "type": "literal" , "value": "1" } } , { "ProductionDate": { "type": "literal" , "datatype": "http://www.w3.org/2001/XMLSchema#dateTime" , "value": "2017-10-26T21:32:52" } , "ExpirationDate": { "type": "literal" , "datatype": "http://www.w3.org/2001/XMLSchema#dateTime" , "value": "2022-10-26T21:32:52" } , "IngredientsNumber": { "type": "literal" , "datatype": "http://www.w3.org/2001/XMLSchema#integer" , "value": "5" } } , { "QualityPreservationConditions": { "type": "uri" , "value": "http://www.semanticweb.org/abdslam/ontologies/2017/11/ITaaS#qualityTemperature01CF" } , "value": { "type": "literal" , "datatype": "http://www.w3.org/2001/XMLSchema#float" , "value": "15.0" } } , { "QualityPreservationConditions": { "type": "uri" , "value": "http://www.semanticweb.org/abdslam/ontologies/2017/11/ITaaS#qualityHumidity01CF" } , "value": { "type": "literal" , "datatype": "http://www.w3.org/2001/XMLSchema#float" , "value": "60.0" } }] } }

Figure 3. 11: Tracing query results.

Example 6: For the decision-making process, we propose to use the fuzzy logic sets to monitor the quality within canning supply chain. In a previous work (Bougdira et al., 2019a), we have detailed such a fuzzy model that allows us to evaluate the quality during processing. This evaluation helps managing the quality and intervening pro-actively to adjust any unconformity.

The proposed tool used two major factors that could affect the product quality during processing (inputs: Contingency and Sensitivity) to predict the possible quality degradation (output: Loss) (figure 3.12). Here, we can see that the model predicts that the possible loss during the cutting operation is in the range of important (11,7) as Sensitivity=6 and Contingency=5.5.

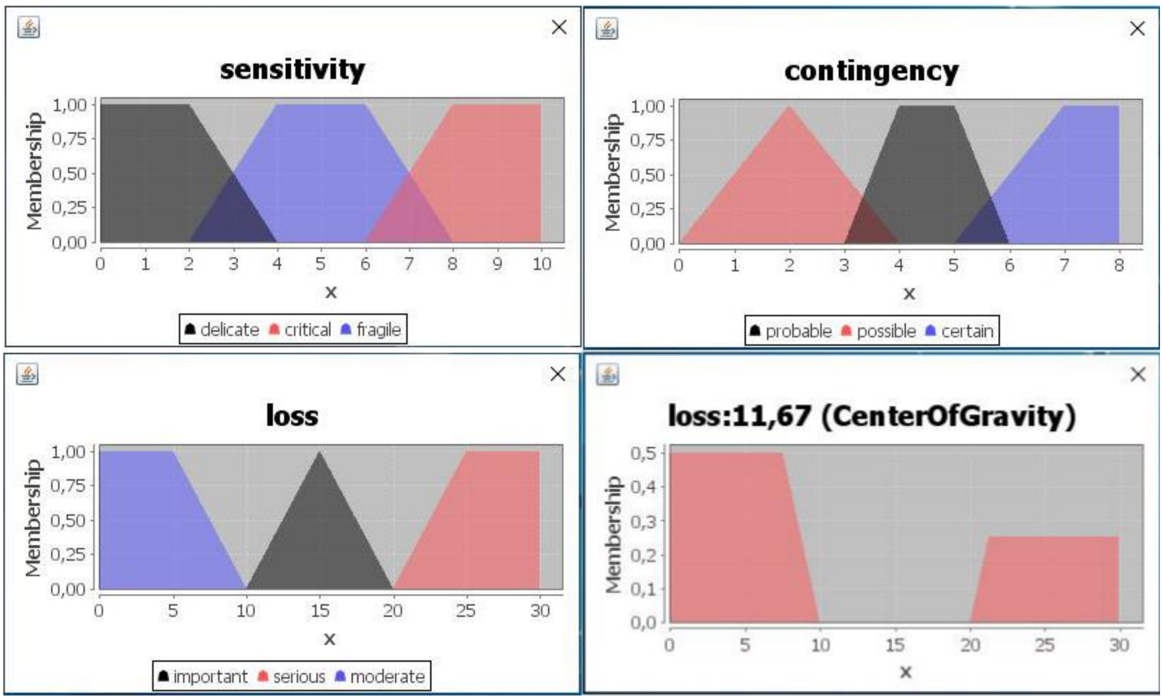

Figure 3. 12: Membership functions of inputs and outputs.

In a general way, a designer could use other technologies, apart from the proposed ones (examples). The studied cases and the implementation circumstances dictate which ones could be used. Alos, one can learn from experiments and studies to succeed in finding the adequate technologies. In this context, some studies provide an overview of the technologies that impact supply chain functioning and support traceability implementation (Badia and Ruiz-Garcia, 2016; Bougdira et al., 2016b).

4 Overall evaluation of the generic model

The assessment of the suggested generic model is centered around two axes. The first one underlines the accuracy and effectiveness of ITaaS, which is the direct result of the application of the generic model (conceptual framework and intelligent characterization). The second one evaluates the conceptual framework.

4.1 Evaluation of ITaaS

We assess the model effectiveness in terms of performance and benefits. Thus, this evaluation focuses on the system functioning, and it depends on two factors: the accuracy of the system and its benefits.

In terms of efficiency, ITaaS helps to conduct a backward analysis. It results in identifying a product, its owner, and food commodities in a finished product. Activities arrangement (i.e., identifying and tracing) is helpful, especially with a disease outbreak. This arrangement operates as a reasoning stream to perform a detailed analysis. It starts with identifying an object and supplier identities. Next, it permits exploring components, elements, instructions, and information about each entity. The tracking activity determines entities' position and can support product recalls. This activity completes and improves crisis analysis accuracy. Hence, the users could see exactly where a product and all its ingredients came from and went.

Therefore, this system might help to combat counterfeiting, ease products recall, supervise product life cycle, and assist in product withdrawal. The flow of activities is a rapid instrument for accurate analysis. ITaaS could conduct the main analysis steps even if a non-specialist third-party leads the investigation since the main activities are pre-programmed (i.e., identifying, tracing, and tracking).

Our suggested typical solution uses an ontology-based approach (ITO) to integrate different data types and using valuable information to ensure traceability efficiency. Also, our modeling uses a unique concept (occurrence) to represent the process and situation in an industrial environment. This utilization facilitates the context-modeling, increases the modeling consistency, and decreases the ontology weight (complexity). Moreover, the current prototype has a traceability-centric vision. Thus, our context-modeling separately represents the resource, the operator, and the object. This separation between these elements helps to enable an accurate description of manufacturing knowledge in a machine-interpretable way. Also, our modeling seeks to enable better integration of traceable data from different sources, an easy transformation from a context-modeling to a context-aware, and better reasoning on context-related semantics and information.

We recognize the potential of the cloud to facilitate traceability. Therefore, the cloud is a main part of the proposed typical solution. Hence, ITaaS is expected to provide not only internal traceability but also to share the traceable information among all the supply chain stakeholders (external traceability). Thus, the proposal is expected to enable users with interfaces to manage and retrieve traceability information. Accordingly, cloud computing has the potential and flexibility to provide such services. These specifications depend on shared resources by local servers or individual devices. Note that in modern industry (i.e., industry 4.0) applications, entities, and machines evolve into distributive environments. These resources should communicate and share information to achieve consistency. Further, the suggested platform ensures the main traceability functions (i.e., identifying, tracing, and tracking) and can be also extended to other functions like supervising and diagnosing product status (fuzzy predictive model).

Thus, ITaaS is generic enough and can extend to other attributes, including different traceability cases and customizable requirements. Consequently, although different technologies and devices are used in industrial environment and traceability, one can see that the proposed model would promote the development of an effective traceability system that properly collects and use these heterogeneous data. Accordingly, our modeling tried to underline and overcome this issue. Hence, one can benefit from all the collected information using the proposed ontology modeling, which allows users to collect the most noticeable product data and provides added-value information to improve the monitoring of operations and their performance.

4.2 Evaluation of the conceptual framework

The evaluation of the conceptual framework concerns its theorical and technical feasibility in terms of scope, challenges, and features.

The suggested framework is expected to support general traceability solutions. The proposed guide enables users to define the main components of traceability and outlines the roadmap to design and implement a system. The fact that the framework achieves satisfactory outcomes, although we provide only the necessary information about a case without reviewing the details of this study industry, might indicate that the framework can operate independently of the product or industry specificity. Moreover, although the majority of examples and references are from the food industry, the framework is likely to be useful for other sectors. Therefore, the framework is compared with three different traceability systems from three different industries (pharmaceutical, ceramic, and wood products). As a basis for our discussion, we evaluate the difference between the framework and these solutions using two questions: Does the framework ensure the same functions? Can the framework help in traceability efficiency?

Solanki and Brewster (2014) proposed a traceability system in the pharmaceutical supply chain. The solution allowed product tracing, tracking and information retrieval. Comparing these properties to our framework, it seems that our solution might carry out these functions (i.e. Tracing and Tracking are outlined in aims and implemented in procedures). Also, information retrieval is ensured using the procedural mode, and the linkage between the identifier and the data is handled by the identification process. According to the authors, counterfeiting is a key issue in the pharmaceutical supply chain. Regarding this problem, one can see that our model emphasizes the importance of security within traceability (i.e. security process and accessing procedure). For example, one can follow the product movement through the supply chain and avoid fraudulent activity (i.e. establishing the authenticity of all user involved in the supply chain when an item moves or is transformed from input to output).

Barata et al. (2018) introduced a traceability system in the ceramic industry 4.0. This traceability was integrated with a cloud-based manufacturing execution systems (MES). Our framework recognizes the potential of the cloud to facilitate traceability. Therefore, this feature is present as the main specification of a traceability solution (Ubiquitous). Also, one could choose the cloud as his traceability model (Approach: Model). Moreover, our method might help to save time and effort during the design of the ceramic traceability. In this context, the authors used mobile devices, QR codes, barcodes and RFID to implement the system. First, one can see that these technologies might generate heterogeneous data, which is underlined and handled by our proposed solution (i.e. heterogeneity integration and data structuring). Second, because of some processing specifications (i.e. the ink of the codes cannot resist high temperature), their system used three identification technologies (QR, barcodes and RFID).

Here, our design facilitates the implementation of the identification process. Hence, the framework highlights the importance of the separation between the three parts: the solution requirements (description aspect: i.e. high temperature during processing as a requirement), the solution means (engineering aspect: i.e. for identification, one should choose technologies that resist high temperature) and the solution implementation (executive aspect: i.e. implementing the identification process).

Appelhanz et al. (2016) dealt with traceability in wood products. The authors were concerned with consumers' trust in the wood furniture supply chain. The proposed system attempted to capture and deliver all information valued by consumers. Note that our framework underscores the need for these functions to ensure effective traceability (i.e. data capture and transferring processes). Furthermore, the system used an architecture similar to the IoT layers (application, network, integration and infrastructure). In our method, one can select an architecture according to the case specifications (Approach: Architecture). Moreover, the authors presented a cost-benefit model to analyze the benefits and corresponding costs. Based on this analysis, our proposed framework might help to improve the performance of the traceability system regarding the transformation coefficients cited by the authors (i.e. transportation). Hence, one can collect information about the product's transportation path using the real-time localization outlined in our solution (i.e. Real-Time and Localization). In case of an inconvenience, one can use the controlling procedure to change the transportation parameters. For instance, to save time, a manger would immediately ask a truck driver to change the transportation path because there is an accident ahead, which would cause a delay. Moreover, for cost-effectiveness, a manager would ask the driver to change the path to satisfy an urgent client's request.

Elaborating on all possible industrial cases is quite difficult, and by far, is impossible. However, looking at these systems, it seems that the proposed framework can be extended to contexts other than the one just specified. Thus, using the framework in other sectors is technically feasible, although a deeper feasibility study could be required.

However, this framework might face some challenges because it covers the implementation phase and emphasizes the importance of technological concerns. Some studied cases might require further study angles (e.g. safety and quality concern). In this case, the framework should include more other features. Reinforcing the description aspect, especially the modeling axes, might help to overcome this problem. The problem of standards integration is certain to occur, particularly in exchanging product information. Storøy et al. (2013) introduced a TraceFood Framework that contains recommendations for Good Traceability Practice. According to the authors, a general framework should be able to specify how to construct, send and receive traceability messages. Also, efficient traceability should be able to identify, measure and interpret data items in a message. In our case, the solution bases can handle a considerable part of this cited challenge. For instance, the data classification, determined in bases, tries to ensure standardization of messages. Integrating more functionalities into the operational and procedural mode can handle the remaining part of this issue.

The traceability requirements and rules might be another challenge. The standards can vary from a country to another one or from a sector to another one. Charlebois et al. (2014) noticed and detailed this issue. The framework should use such a study to enhance the properties of the description aspect. Therefore, the modeling could add a theoretical element along with the modeling axes. These improvements complete and strengthen the framework. The framework should also face different types of products challenge. A convenient approach is to enlarge the framework range and to integrate other system bases. Accordingly, the framework would try to learn from other systems implementations. In this context, Olsen and Borit (2018) considered generic traceability that includes principles, practices and standards regardless of the implementing way. Their study subdivided a traceability system into three components: the identification of the units, the recording of the joining and splitting of these units and the recording of the unit attributes with different functionalities. The observed results would be a powerful asset to future enhancements.

An important feature of the framework is the ability to lay the basis of a traceability solution and support its development. Therefore, one can start with the modeling of a problem and later establish a basis for the system implementation. In practice, these basics are also relevant when analyzing and comparing traceability systems and when suggesting enhancements to a given solution. The framework, in a way, strives to implement a systematic recording and record keeping of the required traceable data. Such a system can record and share the collected information along the entire supply chain. The framework components do not depend on a specific situation and can provide flexibility to model cases and to select the implementation means. In contrast to a specific-situation solution, the framework allows a developer to extend a solution to other functions and to adapt to changes in the conditions of a situation.

Furthermore, a system developer can use all the framework components because he/she might need only some modules. For instance, internal traceability does not need a cloud-based model. The designer can maintain the solution bases and change only the basics of implementation. Hence, this application would yield another new result. This reusability of components is relevant to improve the efficiency of traceability solutions. Moreover, the framework is expected to participate in promoting the development of scalable solutions. Herein, a solution is expected to be fully or at least partially functional, although the means and data volume are in continuous evolution. In practice, when characteristics of the execution environment (i.e. identification technologies) vary over time, a developer would still be able to substitute a used technique for a recent one without affecting the other functionalities.

Regarding these mentioned features, changing some framework parameters is likely to be possible, especially to adapt the framework to some use case. However, we advocate that the eventual alteration would still be minor compared to setting a new solution. Hence, one can replace a module without being forced to set the whole solution bases. Such an alteration might require less effort and time than remake the whole solution. Also, we urge that the framework design is generic enough and can adapt and extend to other attributes, including novel technologies, common practices and customizable requirements. Therefore, the framework might be adaptable to a wide range of case conditions and challenges. Establishing effective traceability also relies on the ability to exchange product information among different partners. In this context, sharing information in an interoperable manner plays a crucial role.

Our conceptual framework helps to provide interoperability between various stakeholders regarding the gathering and sharing of key data elements. If other traceability systems use different data and functions, the ontology-based system enables the collection of various data and exchange of product information among different stakeholders. Note that this modeling is a part of the broad research field of data integration (Ziegler and Dittrich, 2007). In our studied example, data integration is handled by data classification (sources), heterogeneity integration and data structure. At the internal level, the ontology represents several internal sources (e.g. information systems, sensors and identification tags). Hence, the system can collect and share different data types. At the external level, the solution represents the other supply chain stakeholders as external sources. Thus, the solution can share the data with these systems using, for example, mappings method that describes the link between relational database and ontologies.

5 Conclusion

The proposed generic model shows potential as a tool that provides a general, interoperable, and intelligent traceability solution. This performance can be achieved independently of the type of product or industry. In this context, the conducted scenario results in defining the solution bases that help to develop and deploy ITaaS. Practically, the presented case is a simple step to test and validate the generic model. In this context, we are aware that one can objectively assess the model performance only when it applies to several issues and is tested through different cases and rigorous procedures. Consequently, these results are validated by developing three prototypes for different industrial implementations (seafood, agriculture, and automotive).

Chapter 4: Industrial Implementations

1 Introduction

The practical implementation of the proposed generic model was realized in three different types of industry, the seafood industry, agricultural, and automotive ones. This diversity of industry fields helps us to test and validate the proposed intelligent traceability with large range of conditions and circumstances. To conduct these study cases, we proceeded according to the following steps:

Step1: We have contacted several Moroccan companies (i.e., professional meetings, personal contact, email exchange, and phone contact). The exchange of information and field observations were the main objectives of such communications. The following table shows these companies by sector, those in bold letters are the ones where we have tested the proposed solutions and got a certification (Appendixes 2,3, and 4).

Company	Sector	Sites Web
CUMAREX	Seafood	https://www.cumarex.net/copie-de-accueil
MIDAV	Seafood	https://www.midav.ma
FRIGO BOUCHTA	**Seafood**	https://www.FrigoBouchta.com
NEW PEPPERS	**Agricultural**	https://newpeppers.net
SICOPA	Agricultural	https://www.sicopa.ma
YAZAKI (Meknes)	**Automotive**	http://www.yazaki-na.com/company
HIRSCHMANN	Automotive	https://www.hirschmannautomotive.com

Table 4. 1: List of the contacted companies.

Step 2: For each selected company, we held meetings and brainstorming sessions with managers, domain experts, engineers, technicians, and workers. Such meetings help us to understand each sector challenges, issues, and needs. Hence, we provide an overview of the industry, and we state the issue and challenges.

Step3: After assessing the situation, we introduce, for each brand, our vision and proposal for the enhancements and benefits that our modest contribution would bring.

Step 4: For each case, we conduct the implementation using the proposed conceptual framework (description, engineering, and executive aspects).

Step 5: For each intelligent traceability solution, a prototype has been developed and tested.

In the next sections, each case will be presented in details. The whole methods, technologies, techniques, and software used in these industrial implementations are listed in the following table.

Fuzzy Logic	Java Version.8 and Eclipse IDE
Artificial Neural Networks	Jena API
Bayesian Networks	jFuzzyLogic API
First Order Logic	Bayesserver 8.19 API
Description Logic	ARQ API
SWRL	ITO
OWL2	Protégé 5.5.0
SPARQL	MATLAB R2018a
Object-Oriented Programming	Bizager Modeler 3.4.0.062
BPMN 2.0	Netica 6.07

Table 4. 2: Methods and technologies used in the industrial implementations.

2 Intelligent Traceability in Seafood Industry

According to Hamri et al. (2018), fish canning is the most important seafood activity in Morocco. From our field observations, this local sector tries to follow recent developments in terms of technologies and good practices. Thus, canning units endeavor to comply with international standards regarding product safety and quality.

2.1 Overview of the fish canning industry

The following figure (4.1) shows the main tasks commonly used in different fish canned products (i.e., Sardines and Tuna). Note that almost the same steps and phases are used in the processing of other types of fish canning (i.e., Mackerel, Anchovy, and Salmon).

The fish cannery chain comprises four principal stakeholders, fishing units, intermediaries, canning facilities, and distributors. In general, the fish aimed for canning could be fresh or frozen. The preparation sub-process includes several activities according to fish type. Whatever the type of the raw material, it should be washed or thawed. Next, a sequence of activities starts. For instance, sardines are subject to descaling, grading according to size, and nobbing (i.e., de-heading and removing entrails and gills).

Next, sardines could be subject to a brining process before being pre-cooked. In the case of tuna, the fish are cut and cleaned before steaming. Next, operators should remove bones and dark meat, the tuna should also be minced and sized to fit each product type. For both cases, after this pretreatment, the cans are filled with pre-cooked and pre-sorted fish. After packing, the juicing step allows adding oil, sauce, or order ingredients. Next, the seaming of cans and the weighing checks are executed before proceeding with sterilization and cooling. Typically, the cans are usually stored for short periods before marketing.

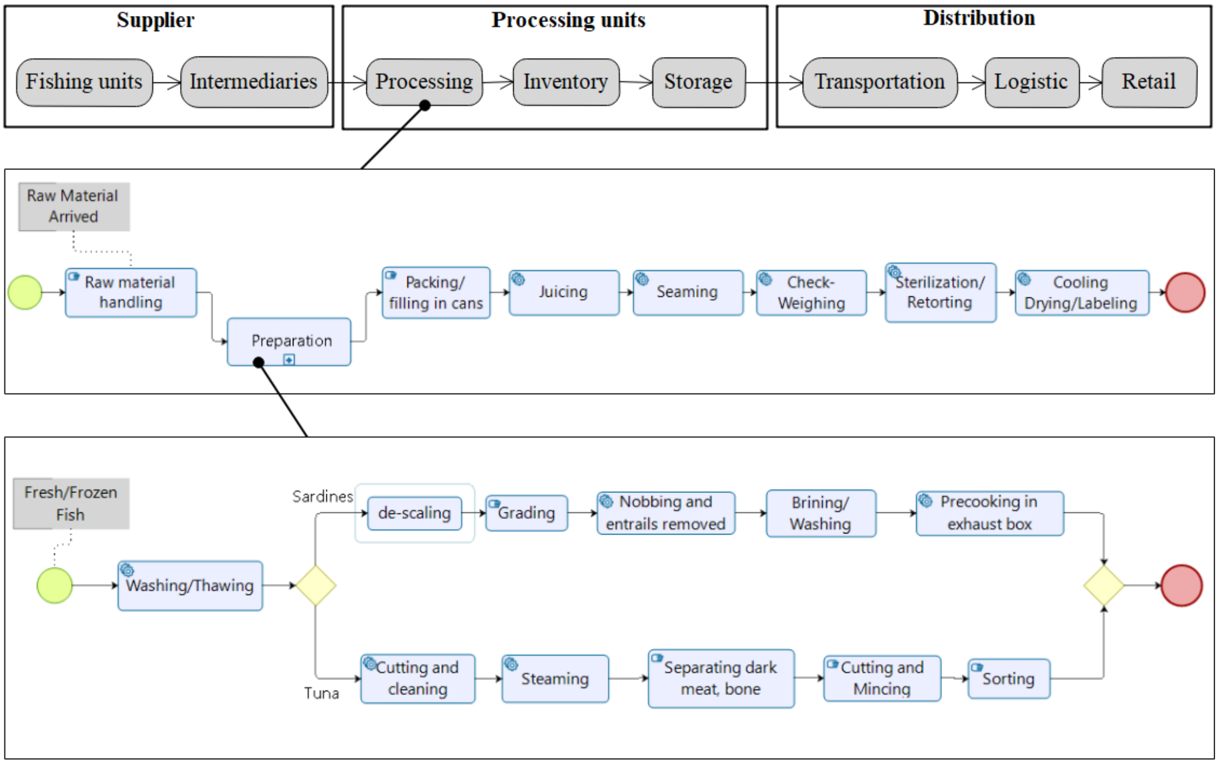

Figure 4. 1: Typical canning process for fish.

2.2 Issue statement

While observing the canning line, we have noticed that some activities are carried out under strict control (i.e., using sensors and rigorous procedures (HACCP)). However, other operations (e.g., raw material handling and pre-treatment tasks) are susceptible to several external influences committing human factors. Thus, we had a special interest in the processing phase, specifically the raw material handling, preparation steps, and filling because these activities involve a lot of manual handling (e.g., cutting). Thus, even though the hygiene practices and safety standards could be efficient, the quality degradation remains possible due to these slight gaps.

We referred to these gaps as an issue of "shadow zone" that combines two factors: An activity sensitive to external influences and an actor that is involved in this activity. In a such case, it could be difficult to detect and evaluate the possible degradation of quality, although it could be serious or even worst.

Another challenge we have faced consists of the heterogeneous data exchanged before, during, and after the processing. This data can come from sensor measurements or information system.

This disparate data poses some problems regarding the sharing and usage of the information. Therefore, we urge that our proposed intelligent traceability might help to resolve these issues by allowing continuous monitoring of quality and integrating different traceable information.

2.3 *System design*

The suggested design comprises five layers (Figure 4.2). The first layer ensures the linkage between different supply chain actors and the system using a querying distribution method either by local or cloud techniques. The second one allows actors to retrieve traceable information and monitor product quality. The third layer involves intelligent traceability functionalities, including identifying, tracing, tracking, and monitoring. The fourth layer contain a knowledge representation. The last one represents the sources that feed the knowledge base with data and rules.

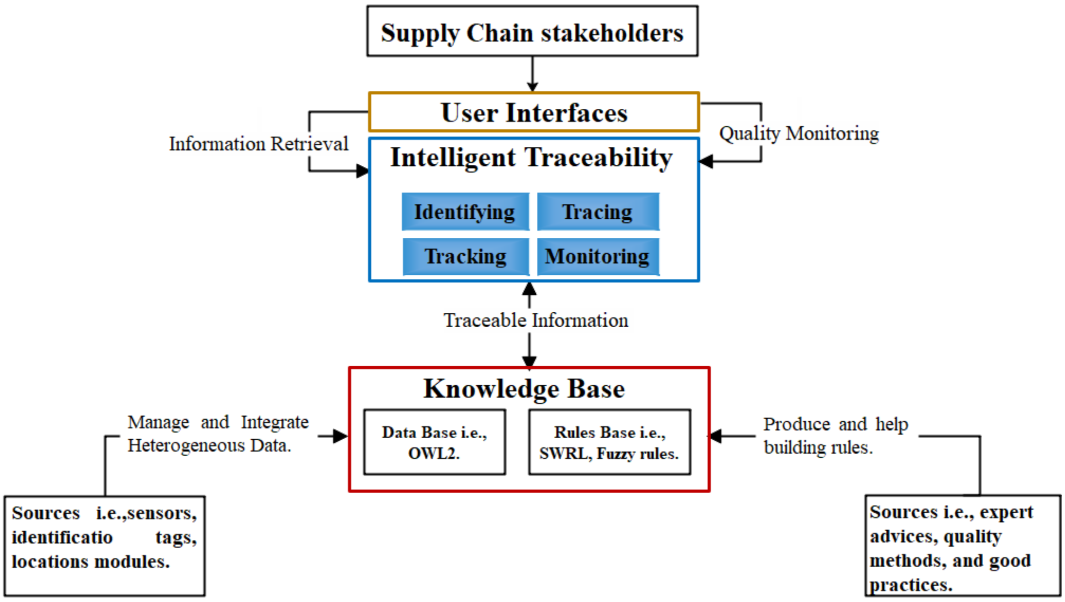

Figure 4. 2: Overview of the proposed design.

2.3.1 Representation of knowledge

To overcome the issue of integrating heterogeneous data regarding different sources of information, the knowledge base is an ontology-centered representation that results in a triple store database file. Hence, it allows representing the product context and data. Moreover, it helps to structure and share product's information; it also includes rules that assist the users in the decision-making process (i.e., Fuzzy rules and SWRL) using the basics of Intelligent Traceability Ontology (ITO). To that end, we derive a customized representation from ITO, which involves five main concepts, including Product, Resource, Device, ID, and Element. The figure 4.3 depicts these elements and the main relationships between each other.

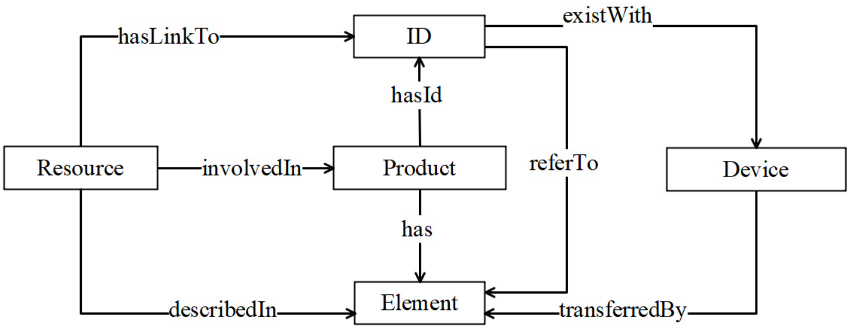

Figure 4. 3: Main concepts of the knowledge representation.

Each product has a unique ID that helps its identification. This ID could refer to an element, which signifies a piece of information. By using a sub-property chain, one can infer that this product has this same element referred by the ID (i.e., the name of the product's owner or properties of a product). A resource is an entity (i.e., an operator or task) that is involved in the production of a product and has a relationship with an ID.

2.3.2 Functionalities

The identifying function enables a user to identify a product where tracing function allows him to retrieve the product properties like ingredients, quality conditions, and processing activities. On the other side, tracking function ensures information about the product location. These three functionalities guarantee backward and forward traceability using a query approach based on SPARQL and SWRL.

The monitoring function allows users to supervise product quality and support a proactive action expected to support the decision-making process. Therefore, the decision to consider can be as follows:
Given a set of data, at what point does this data indicates the probability that a loss of quality could occur during an activity? Based on this evaluation's result, a responsible can support a recommendation on the intervention to do.

This evaluation (output) is determined by mathematically combining variables (inputs) from three fuzzy sets (Zadeh, 1965), including the assessment of **the operation**, **the risk**, and **the action**. To face the complication of the issue, this overall evaluation uses a modular approach that subdivides these main factors into a small set of variables.

2.3.3 Variables determination

Each factor depends on three variables. In total, the loss assessment is related to nine variables (figure 4.4). The company responsible, experts, and workers opined these nine factors. The output of the fuzzy inference system (probability of loss) is expressed as a percentage. It is described using five levels, level 1(L1: 0% -5%) Level 2 (L2: 5% -15%), level 3 (L3: ≥15%-50%), level 4 (L4: ≥50% -80%), and level 5(L5: ≥80% -100 %).

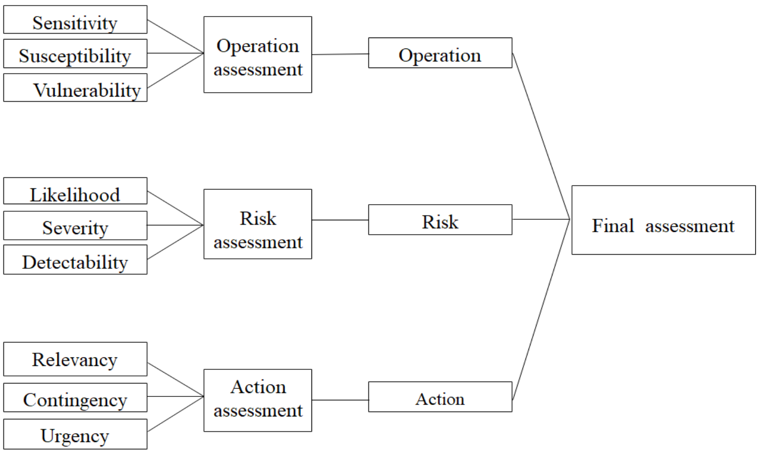

Figure 4. 4: Overview of the proposed fuzzy model.

Operation assessment rates the exposure of a manufacturing operation to external factors, including outside factors that could damage and affect the quality. It is expressed using ***Delicate, Fragile,*** and ***Critical***, and it depends on ***sensitivity, susceptibility***, and ***vulnerability***.

- The ***sensitivity*** evaluates the sensitivity of an operation to risks using ***Moderate, Important,*** and ***Serious.***
- The ***susceptibility*** assesses the eventuality that an actor influences the quality during processing, it is rated as ***Improbable, Probable***, and ***Certain***.
- The ***vulnerability*** means the exposure degree to external circumstances, it is expressed as ***Low, Medium***, and ***High***.

Risk assessment aims to identify and analyze the hazards and risks that have the potential to cause harm to quality. It could be rated using the terms ***Tolerable, Critical***, and ***Unacceptable***. Such assessment takes into consideration the risks assessing, causes, and consequences, and depends on three variables.

- The ***likelihood*** that means the frequency at which a hazard will occur. It is rated: ***Occasional, Probable***, and ***Frequent.***
- The ***severity*** considers how serious risk would cause damage is rated as ***Negligible, Critical,*** and ***Catastrophic.***
- The ***detectability*** evaluates the probability of the risk being detected before it causes harm. This variable is qualified with the terms ***No detection, Late detection,*** and ***Early detection***.

Action assessment aims to measure the importance of taking action to regulate unconformity during the loss evaluation. This assessment attempts to prioritize the impact of intervening before one proceeds with this intervention. It is defined as ***Low, Medium, High***, and it depends on ***relevancy, contingency, and urgency***.

- The ***relevancy*** means the importance of an operation in terms of quality and safety compared with other activities. It is referred to as ***Irrelevant, Less relevant,*** and ***Relevant***.
- The ***contingency*** defines the possible outcome of an intervention in terms of impacts. It is described using ***Preventive, Corrective***, and ***Proactive***.
- The ***urgency*** evaluates the degree of emergency of a situation. It is expressed using ***Low, Elevated,*** and ***Severe.***

2.3.4 Inference mechanism

After assessing all elements and based on the loss value, an intervention is proposed. The algorithm supporting this decision-making process is depicted in the following figure.

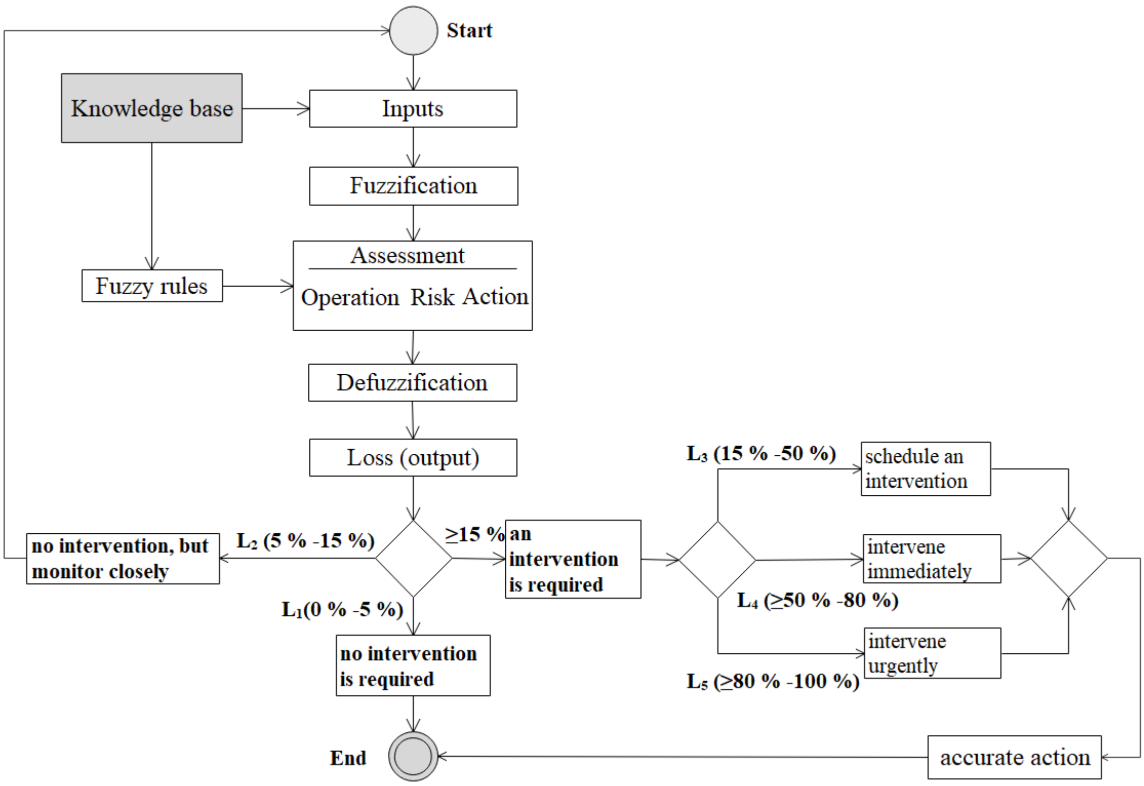

Figure 4. 5: Decision- making algorithm.

Note that most information about inputs comes from the traceability data, which is represented and managed using the knowledge base, which also includes the rules for fuzzy inference. During each operation, the possible degradation is evaluated based on risks, operation, and action assessments. Each time a final assessment is calculated, the system recommends accurate intervention to regulate a situation. Accordingly, the final assessment triggers a recommendation, including three categories: "***no intervention is required***", "***no intervention, but monitor closely***", and "***intervention is required***", which involves "***schedule an intervention***", "***intervene immediately***", "***intervene urgently***". With level 1, one would not intervene, whereas, with level 2, a decision-maker should continue the situation monitoring to avoid any complication. When the estimation is equal or greater than 15%, one has to trigger an action according to the pre-defined levels (3, 4, and 5).

2.4 System deployment

The deployment of the proposed system requires firstly the processing and analysis of the collected data before the final model validation.

2.4.1 Data collection and analysis

Regarding data acquisition, the data collection procedure depends on mixed methods (i.e., qualitative and quantitative). For example, traceable data includes types of canned fish (i.e., the whole sardines in vegetable oil and the boneless sardines in sauce). In addition, a sauce includes a tomato paste (35-36° Brix as 22%), salt as 2%, modified starch as 1%, water as 75%, and spices as required. Besides this information, the details about the person involved in each processing operation are notified (i.e., name and shift number). Moreover, properties of each operation are also reported (e.g., pre-cooking in the exhaust box is done for 12 minutes at 85 °C.).

The setting parameters procedure conducts the gathering of variables data. For example, in some activities, we determine the main variables that influence factors. For instance, regarding the assessment of the operation, we consider the total duration of the operation, the duration of the direct manual contact with a human, and the possibility that an operation could be exposed to external circumstances. For other operations, we rely on experts and workers estimation to rate the importance of factors and activities using a similar point scale of each pre-defined fuzzy input (e.g., Proactive, Predictive, Preventive).

All collected data concern the production during a single eight-hour shift. This sardine cannery has a capacity of 15 tons of raw fish per eight hours. After raw material pre-treatment (i.e., debone, removal of the head, evisceration, and removal of the tail), the overall yields (the rest of sardines) is approximately 50% of the weight of raw fish. In this canning line, one ton of raw sardines could produce approximately 5 200 of "1/4 club rectangle cans with 125g". The studied semi-automated canning line uses approximately 50% of the workers, where the number of employees by a shift is approximately 70 workers.

2.4.2 Testing and validation

The assessing procedure uses a multi-input, single-output fuzzy inference system, which uses the Mamdani approach (Mamdani and Assilian, 1975) and centroid method for defuzzification (Pfluger 1992). Mathematically, we consider three intermediates variables that represent the system inputs as:

$$(1)\quad O = f_1\,(x_1, x_2, x_3\,)\quad R = f_2\,(x_4, x_5, x_6\,)\quad A = f_3\,(x_7, x_8, x_9\,)$$

Where O, R, and A are operation, risk, and action assessment, respectively. Also, $x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, and\ x_9$ are respectively, the main variables that refer to sensitivity, susceptibility, vulnerability, likelihood, severity, detectability, relevancy, contingency, and urgency.

Therefore, the system's final output (L) can be expressed as:

$$(2)\qquad L = g\,(f_1(O), f_2(R), f_3\,(A))$$

Besides the output, for each of these nine variables the universe of discourse and degree of membership function are determined. For the sake of clarity, we use a scale of 100 for the distribution of membership functions within the universe of discourse. Here, we use the Triangular, Trapezoidal, and R/L-Functions membership functions for both inputs and output. Note that we have deployed and validated this fuzzy inference using MATLAB software;

For instance, the sensitivity, namely x_1 has three subsets evaluated as 'moderate', 'important', and 'serious'. Therefore, a triangular function (3) defines the subset 'moderate', a trapezoidal function (4) defines the subset 'important' and L-Function defines the subset 'serious' (5).

$$(3)\qquad f_{1_{moderate}}(x_1) = \begin{cases} \frac{x_1-0}{15-0}, & 0 < x_1 \leq 15 \\ \frac{30-x_1}{30-15}, & 15 < x_1 < 30 \\ 0, & x_1 \geq 30 \end{cases}$$

$$(4)\ f_{1_{important}}(x_1) = \begin{cases} 0, & (x_1 < 30) or (x_1 > 80) \\ \frac{x_1-30}{40-30}, & 30 \leq x_1 \leq 40 \\ 1, & 40 \leq x_1 \leq 70 \\ \frac{80-x_1}{80-70}, & 70 \leq x_1 \leq 80 \end{cases}$$

$$(5)\ f_{1_{serious}}(x_1) = \begin{cases} 0, & x_1 < 70 \\ \frac{x_1-90}{90-70}, & 70 \leq x_1 \leq 90 \\ 1, & x_1 > 90 \end{cases}$$

The following figure shows the membership function of the variable sensitivity within its universe of discourse. Besides the membership functions, the system relies on a set of rules (if-then). Each intermediate variable has three inputs; hence 27 rules are defined, but this initial number is later reduced to solely nine rules.

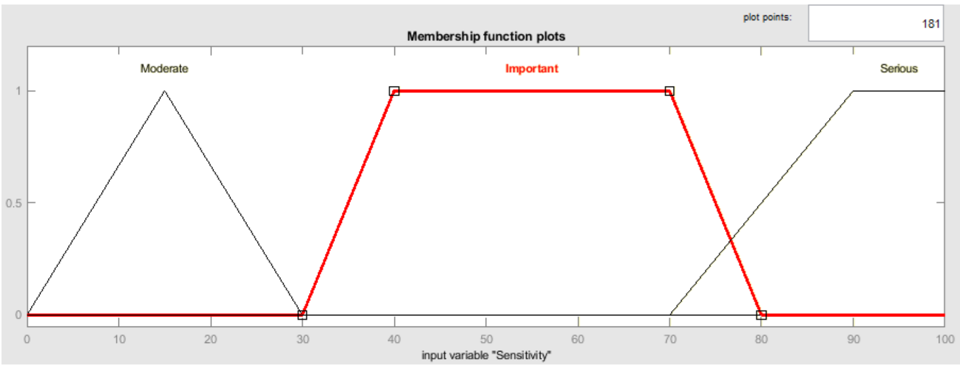

Figure 4. 6: Membership functions of input variable ‘sensitivity’.

The following table shows an example of the rules left for the variable sensitivity. Such reduction aims to eliminate the non-contributing rules using several iterations that point those who do not contribute to the assessment (output). For example, if we add the rule “if sensitivity is moderate and susceptibility is improbable and vulnerability is low”, we notice that this rule has no impact on the result (the output does not change). Consequently, we eliminate this rule.

If x_1 (*sensitivity*)	And x_3(susceptibility)	And x_3 (vulnerability)	Then O (operation)
Moderate	Improbable	High	Safe
Moderate	Probable	Medium	Fragile
Moderate	Certain	Medium	Safe
Important	Improbable	High	Safe
Important	Probable	Low	Fragile
Important	Certain	Medium	Fragile
Serious	Improbable	High	Critical
Serious	Probable	Medium	Fragile
Serious	Certain	Low	Critical

Table 4. 3: Rules for the output ‘Operation’.

Based on this set of rules, the following figure shows the obtained output (assessment is 57.4).

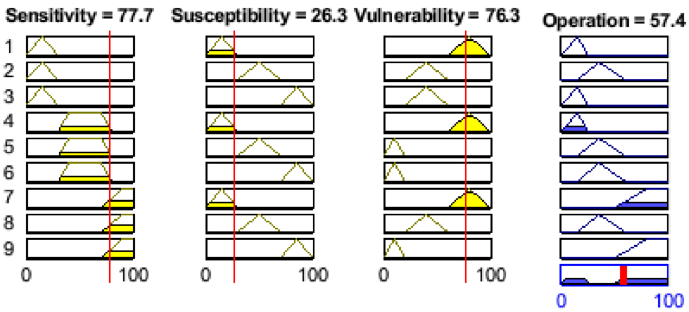

Figure 4. 7: Rule viewers of the output ‘operation’.

Moreover, the following figures depicts the obtained results in case of risk assessment (figure4.8) and action assessment (figure 4.9).

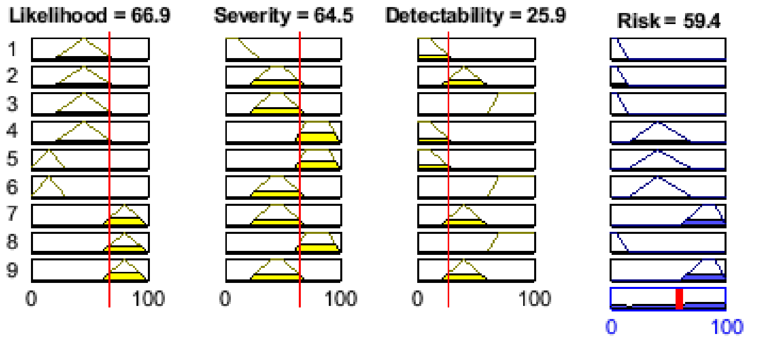

Figure 4. 8: Rule viewers of the output ‘risk’.

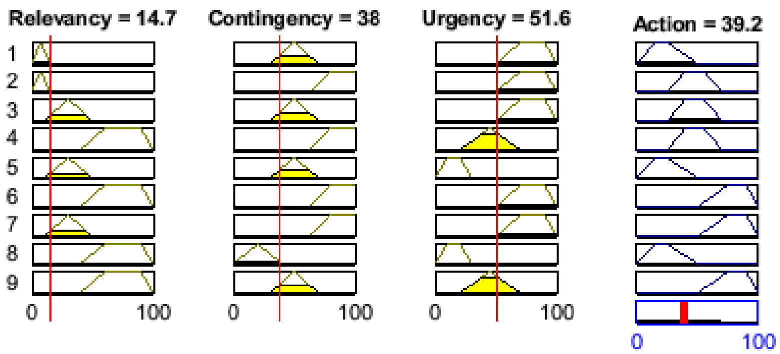

Figure 4. 9: Rule viewers of the output ‘action’.

At last, the final loss based on risk, operation, and action is assessed. Note that this final assessment uses 27 rules with no elimination of a rule (figure 4.10)

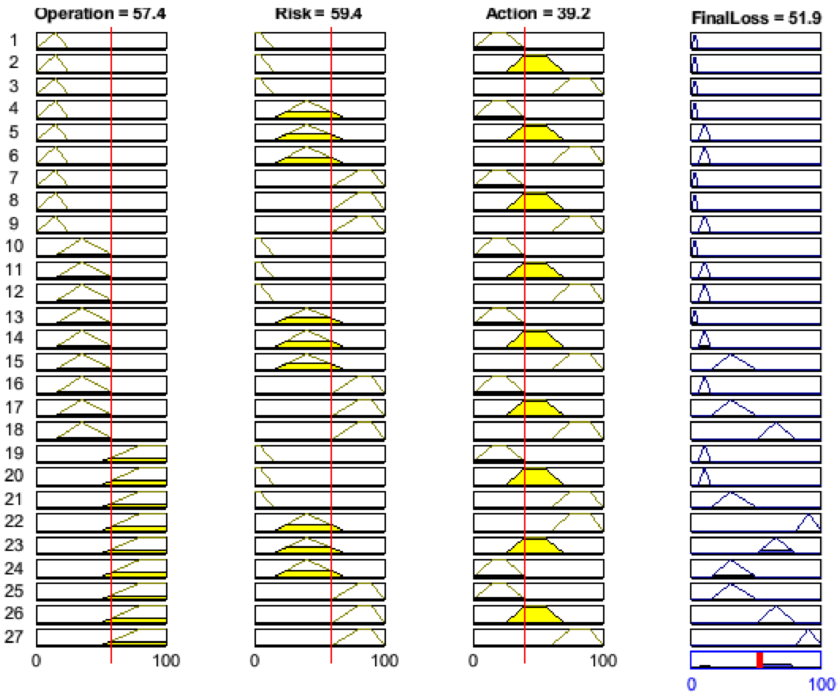

Figure 4. 10: Rule viewers of the output ‘Final Loss’.

2.4.3 Deployment algorithm

Before moving on to the development of the application of intelligent traceability, we established an algorithm that allows the implementation of the decision-making process, the pseudocode of this algorithm is described in the following table.

This algorithm includes 13 steps that define the variables and functions necessary for the price of the decision. Thereafter, the steps of "fuzzification" and of "defuzzification" make it possible to define the different outputs of systems as well those intermediate (o, r and a) as the final output (l). Note that these steps tried a set of rules defined in the “RuleBlock”.

The decision algorithm

1: Start
2: Feed data set;
3: Declare variables;
    inputs $\boldsymbol{x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, and\ x_9}$;
    intermediates variables o, r, and a;
    final loss L;
    level $\boldsymbol{l_1, l_2, l_3, l_4, and\ \ l_5}$;
    recommandation $\boldsymbol{d_1, d_2, d_3, d_4, d_5}$;
4: Define functions;
    $\boldsymbol{f_1}\ (\boldsymbol{x_1, x_2, x_3}\ )$;
    $\boldsymbol{f_2}\ (\boldsymbol{x_4, x_5, x_6}\ )$;
    $\boldsymbol{f_3}\ (\boldsymbol{x_7, x_8, x_9}\ )$;
    $\boldsymbol{g}\ (\boldsymbol{f_1}(\boldsymbol{o}), \boldsymbol{f_2}(\boldsymbol{r}), \boldsymbol{f_3}\ (\boldsymbol{a}))$;
5: load file.fcl;
6: calculate functions $\boldsymbol{f_1}$, $\boldsymbol{f_2}$, $\boldsymbol{f_3}$;
    FUZZIFY $\boldsymbol{x_1, x_2, x_3}$; $\boldsymbol{x_4, x_5, x_6}$; $\boldsymbol{x_7, x_8, x_9}$;
    DEFUZZIFY o, r, and a;
    METHOD: Center of Gravity;
    RULEBLOCK No1, No2, No3;
    AND: MIN; /* De Morgan's Law
    ACTIVATION: MIN;
    ACCUMULATION: MAX;
    END_ DEFUZZIFY;
    $\boldsymbol{o} \leftarrow \boldsymbol{f_1}\ (\boldsymbol{x_1, x_2, x_3}\ )$;
    $\boldsymbol{r} \leftarrow \boldsymbol{f_2}\ (\boldsymbol{x_4, x_5, x_6}\ )$;
    $\boldsymbol{a} \leftarrow \boldsymbol{f_3}\ (\boldsymbol{x_7, x_8, x_9}\ )$;

7: calculate function $\boldsymbol{g}$;
    FUZZIFY o, r, a;
    DEFUZZIFY L;
    METHOD: Center of Gravity;
    RULEBLOCK No4;
    AND: MIN; /* De Morgan's Law
    ACTIVATION: MIN;
    ACCUMULATION: MAX;
    END_ DEFUZZIFY;
    $\boldsymbol{L} \leftarrow \boldsymbol{g}\ (\boldsymbol{f_1}(\boldsymbol{o}), \boldsymbol{f_2}(\boldsymbol{r}), \boldsymbol{f_3}\ (\boldsymbol{a}))$;

8: If 0<L<5
    $\boldsymbol{Level} \leftarrow \boldsymbol{l_1}$
    $\boldsymbol{recom} \leftarrow \boldsymbol{d_1}$
    Display o, r, a, L, and $\boldsymbol{d_1}$.
  End

9: Else If 5≤L<15
    $\boldsymbol{Level} \leftarrow \boldsymbol{l_2}$

$\boldsymbol{recom} \leftarrow \boldsymbol{d_2}$
Display o, r, a, L, and $\boldsymbol{d_2}$.
End

10: Else If 15≤L<50
$\boldsymbol{Level} \leftarrow \boldsymbol{l_3}$
$\boldsymbol{recom} \leftarrow \boldsymbol{d_3}$
Display o, r, a, L, and $\boldsymbol{d_3}$.
End

11: Else If 50≤L<80
$\boldsymbol{Level} \leftarrow \boldsymbol{l_4}$
$\boldsymbol{recom} \leftarrow \boldsymbol{d_4}$
Display o, r, a, L, and $\boldsymbol{d_4}$.
End

12: Else If 80≤L<100
$\boldsymbol{Level} \leftarrow \boldsymbol{l_5}$
$\boldsymbol{recom} \leftarrow \boldsymbol{d_5}$
Display o, r, a, L, and $\boldsymbol{d_5}$.
End

13: Stop

Table 4. 4: Decision algorithm.

2.5 *Implementation*

We used a development-ecosystem that involve Jena API and SPARQL queries to manipulate the ontology in a Java environment. We also used a Java Library ‘jFuzzyLogic’ (Cingolani and Alcala-Fdez, 2013) to implement the fuzzy decision algorithm.

We assume an event based on a scenario during a production shift. The responsible for inventory-checking noticed the existence of some flipper cans within finished products. Such incident pushes responsible for quality to launch an investigation using the proposed tool. This investigation tries to determine the cause of this problem.

Therefore, the investigation team tries firstly to identify the cans. For example, by entering the product ID, a reasoning operation to find out the identity of the canned fish and other relevant information (i.e., the identity of owners and contact information) is performed (figure 4.11).

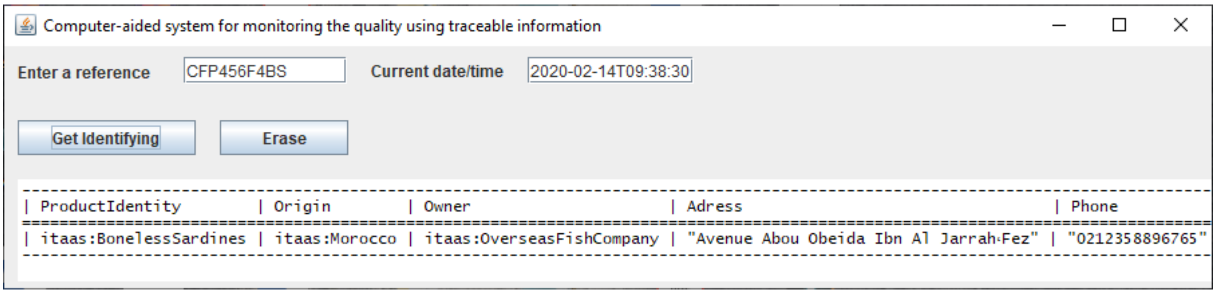

Figure 4. 11: Identification information about the product (ID=CFP456F4BS).

After identifying all flipper cans, authorized person launches a backward-tracing that allows to list details about quality conditions, production activities, production/expiration dates, and essential ingredients of the products (figure 4.12 and figure 4.13).

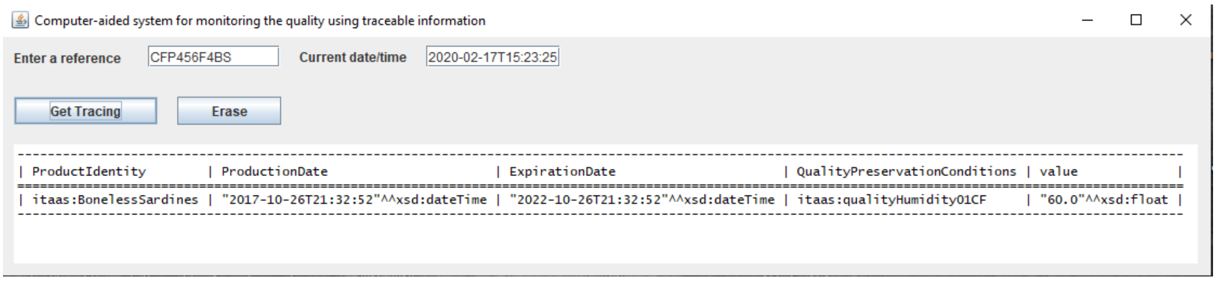

Figure 4. 12: General tracing information about the product (ID=CFP456F4BS).

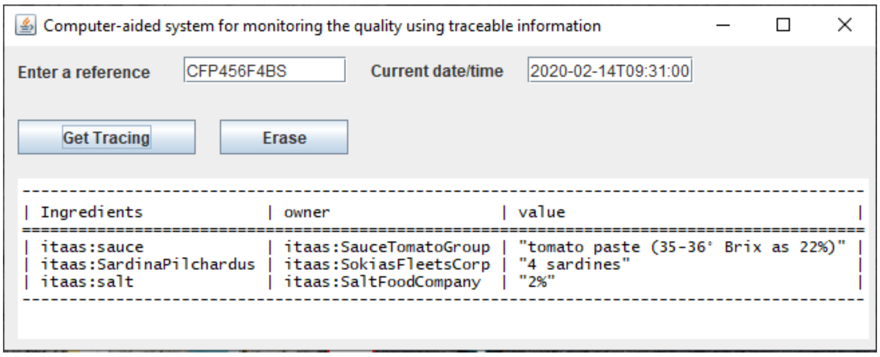

Figure 4. 13: Tracing information about ingredients (ID=CFP456F4BS).

These results allow users to identify the existence of a common ingredient involved in the production of all the investigated cans. In the current case, investigators make two hypotheses. First, they suspect that the sauce, which is the common ingredient, could be responsible for possible spoilage. Hence, they send a sample of sauce for more laboratory analysis. Second, they suspect that an overfilling issue could be the cause of these abnormal cans. Consequently, the team reports these results to the production unit for further and deeper investigation, especially the processing line.

In this context, the production responsible enacts the monitoring function. To that end, the required values to assess the operation, risk, and action are captured two hours from the beginning of the first shift. The following figure shows the results and recommendations suggested by the computer-aided system.

By selecting the targeted operation (filling) and entering different values for assessment, one could evaluate the operation, risk, and action. According to these values, the probability that a loss could occur is a level 4 category (51.9%), which requires immediate intervention. Consequently, the production responsible intervenes to find out the exact problem with the filling activity (i.e., human or an automated filling).

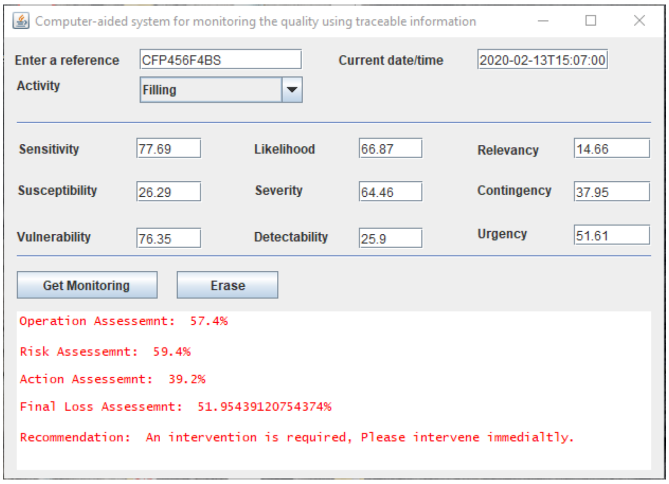

Figure 4. 14: Monitoring function results.

Next, one takes the action to correct the situation (i.e., requests the checking of the filling machine by a technician or insists operators on respecting the standards of filling).Next, to verify the accuracy of the taken action, the production responsible decides to launch another monitoring task six hours from the beginning of the first shift. The results show that the taken action helped reducing the probability of loss, although the operation (filling) requires more attention and close monitoring (level 2).

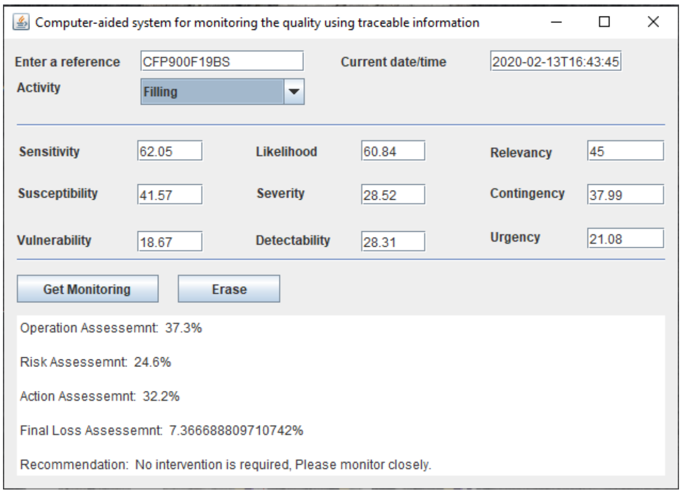

Figure 4. 15: Monitoring function results.

2.6 Practical implications

Based on the abovementioned results, applying the proposed framework has shown the effectiveness to implement an intelligent traceability in seafood industry. However, the suggested system, like any other one, has its own drawbacks.

We have confronted difficulties to ensure the integration of information from the company information system. The company uses indeed various mechanisms to gather and share its traceable data. In such a case, the system should include other functions, specifically mappings techniques that link between a relational database and a semantic one.

Another encountered challenge was related the development of fuzzy rules. We relied on both theoretical derivation and experimental results. However, while setting rules, the system effectiveness requires imperatively solid experience from field experts. Therefore, we needed several adjustments to ensure the accuracy of the characteristics, factors, and measurements used in the whole system. Moreover, by using both semantic and fuzzy reasoning, we have sacrificed some accuracy and reliability for general facts and intuition. This kind of reasoning was heavy in terms of resource computation and code development.

In addition, the particular data sample used in this research can be another limitation of the suggested system. As a matter of fact, we urge that more mixed data from various sources and different industries would certainly enhance the scope and the accuracy of the model. The inclusion of such task should be the main aspect in future research.

Though these listed limitations, the potential benefits of implementing this system are not in doubt. Accordingly, thanks to the knowledge-base, different data are integrated regardless of the heterogeneous sources. This representation enables to collect data, record information, and relate it to an identifier (ID). Furthermore, the suggested system allows implementing modalities to share the collected data among different stakeholders.

Typically, besides the identifying function, one can launch a backward-tracing of the essential information. For instance, a third-party would be able to know the key information about a supplier, which allows retracing the steps followed by a product. Moreover, the tracking function allows knowing the real-time location of a product along with its location steps forward in the supply chain (forward-tracking). Such mechanisms promote and help product recall, assist in product withdrawal, combat counterfeiting, and support supervising the product life cycle. These three functions (identifying, tracing, and tracking) are mainly important in the case of fished products or after retailing.

Moreover, the computer-aided system allows users to supervise and monitor the product during the processing tasks. By assessing variables, this tool supports recommendations that allow a user to proceed with the required action. Such tool assists a decision-maker with quality monitoring, and it allows users to carry out an accurate action. This system indeed is a modest contribution toward a completely intelligent approach expected to be useful and helpful in many cases like audit exercise, contamination investigation, and situations monitoring.

3 Intelligent Traceability in agricultural industry

The complexity of the agricultural supply chain is increasing as well as many actors are involved (i.e., farmers, processing units, pretreatment units, and transportation), and numerous technologies and procedures are used (i.e., RFID, IoT, and traceability).

3.1 Agricultural supply chain

In Morocco, most of the agribusiness is small and medium-sized enterprises (SMEs). Therefore, these units often subcontract part or the whole of some tasks. Hence, two main entities form the agricultural supply chain, the pretreatment units (i.e., plant nursery and sorting center) and the processing ones.

During pretreatment (figure 4.16), the company often delivers its seeds to the plant nursery to ensure the required quality and properties (i.e., the color, shape, and size of the cherry peppers). Next, the transplanting from the nursery bed to the farmers' growing area is done. Seeds and seedling are carefully sorted and checked before their plantation. After harvesting, the different types of crops (i.e., Olive and Bell Peppers) are also sorted (e.g., selection centers) using manual labor. Next, the appropriate raw material is transported to the processing units. Laborers do the sorting tasks which makes the quality rating utterly subjective and depends on human evaluation. Furthermore, one can see that several actors are involved in this phase, such as plant nursery, farmers, and selection centers.

When the processing unit receives the raw material (i.e., Sweet Cherry Peppers) (figure 4.17), an actor starts by weighing and registering separately the shipments coming from every selection center. During this step, traceable information is considered as the identity of the person who received the raw material (IdA), the identity of the commodities (IdR), the origin of commodities (i.e. the reference of the selection center), and initial quality evaluation for the raw material.

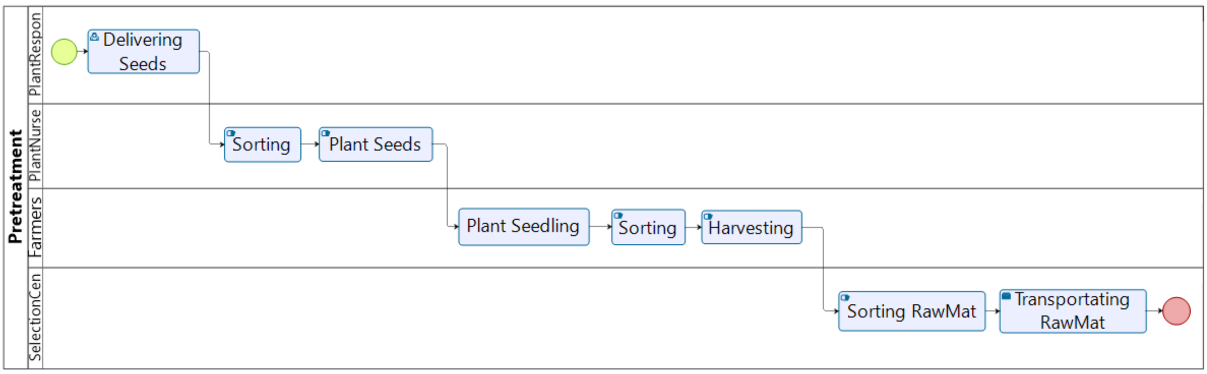

Figure 4. 16: Pretreatment process.

Next, the calibration step allows to subdivide commodities into several sizes (i.e., Medium, Small-A, and Small-B), those whom do not conform to these sizes are sent to another production process (HRISSA: a Moroccan sweet/hot recipe).

Suitable ones are washed and blanched. Afterward, another quality checking is done, it is a kind of sorting to ensure that the commodities designed for packing are still good (during blanching some product could be damaged). Afterward, a sequence of activities starts, including weighing the cans or jars, juicing by adding different ingredients, crimping, and sterilization of cans. In terms of traceability, information about these steps includes activities and properties (i.e., tasks, actors, duration, temperature, brix degree, and quality evaluation).

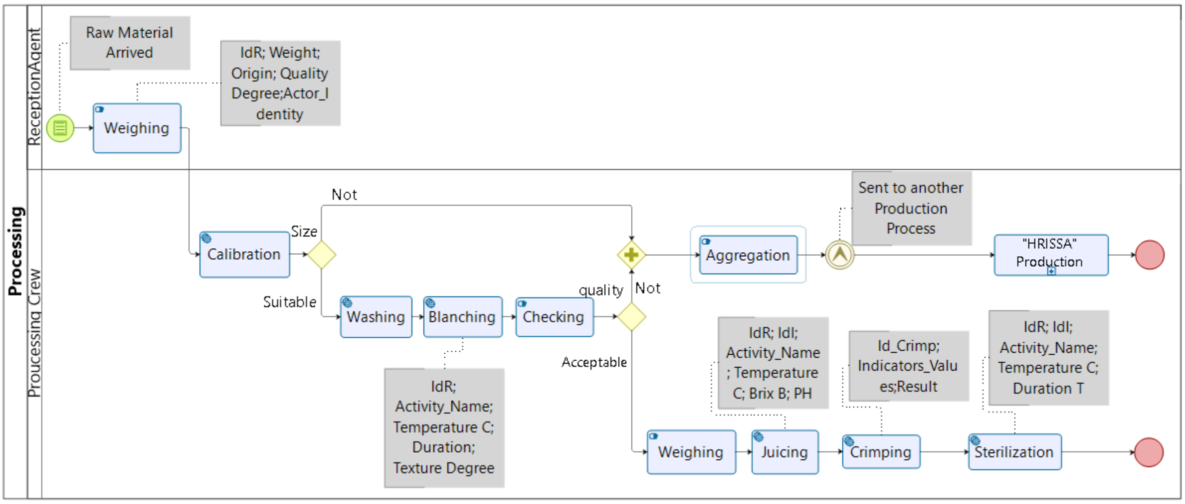

Figure 4. 17: Production processes.

3.2 *Problem statement*

One can see that the sorting tasks are present in several steps along the entire agri-supply chain. Despite their importance, these tasks executions depend entirely on human factors for procedure, protocol, and decision. Such dependence has a significant impact on production efficiency and cost. For instance, the studied agribusiness esteemed that the overall yields after the pretreatment of the raw material are approximately between 30% and 50% of the initial weight of raw material, nearly half of all raw materials are lost before starting the processing (i.e., 0.5 to 2 tons in the case of cheery red peppers).

Many and different people at many stages and places, accomplish a such sensory evaluation issue. This estimation refers to the scientific process used to evoke, measure, analyze and interpret reactions to those characteristics of foods and materials as they are perceived by the senses of sight, smell, taste, touch, and hearing (Raegert et al., 2004). The sensory evaluation can differ regarding several contexts due to differences in the individual panelist's perception of the product attributes.

The monitoring activities are expected to assess and predict the overall acceptability of raw materials to overcome this issue. Based on the sensory evaluation, this solution combines Artificial Neural Networks and fuzzy logic to enhance the standards of raw materials sorting.

3.3 Overview of the system

The proposed design is centered on a dynamic interaction between a set of activities and the knowledge base (figure 4.18). The collecting activities help to feed the knowledge base with the required raw data. These data are gathered from different sources (i.e., human agents and temperature sensors). On the other hand, information retrieval is carried out using retrieving activities that aim to extract the essential information of a product.

The knowledge base is dynamically updated and remotely queried. Several structures are integrated into this base, such as data-representation (i.e., OWL2), semantics-rules (i.e., Semantic Web Rules Language), and fuzzy-rules. Moreover, this knowledge representation is used by the monitoring tasks to ensure the supervision and diagnosis of the product.

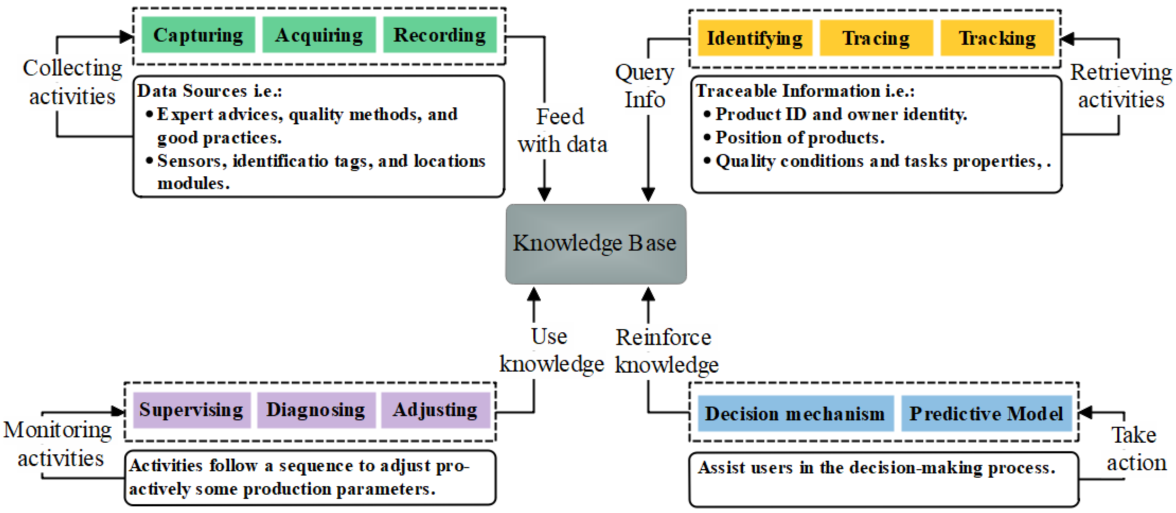

Figure 4. 18: Overview of the system architecture.

Such flow of activities aims to assist in the decision-making process by using a defined mechanism and a predictive model. As an iterative process, the expertise and results from taking actions are used to reinforce the knowledge base.

3.4 *Knowledge formalization*

The core part of the knowledge representation is a customized ontology from the general concepts and basics of Intelligent Traceability Ontology (ITO). This central element manages and integrates the necessary data for effective traceability. It describes the background context of product's information. In addition, it aims at supporting the decision-making process regarding sensory evaluation (figure 4.19).

The proposed ontology describes four main concepts, including Object, Process, Environment, and TraceableElement. Object refers to the entity that is under traceability (i.e., commodity). Process describes the principal activities and tasks taking part in a supply chain (i.e., sorting and washing). The environment includes persons and the surroundings (i.e., sensors and actuators) that evolve or exist in a context such as the production line, sorters facilities, and storehouse. Traceable Element involves entities related to even an object, environment, or process. This class includes the most noticeable traceable information. It could have links with a person (i.e., technician, manager, and owner), products (i.e., product ID), process, or an entity that performs changes (i.e., actuator).

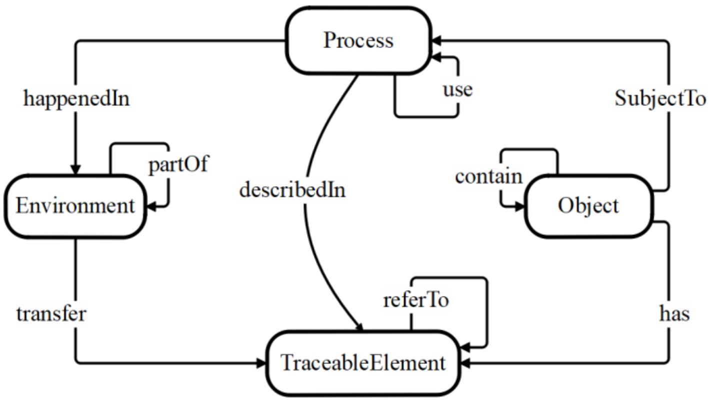

Figure 4. 19: Main concepts of the knowledge representation.

Besides these concepts, relationships link between the ontology classes and elements. Each object can contain another one "contain". For instance, a product contains some ingredients. In a real case, an object has several interactions with the process "subjectTo". For instance, peppers (objects) are subject to blanching (process), which can "use" another process. In addition, an object has several elements linked by "has" (i.e., an object has an owner and an ID). Likely, each traceability information might refer to another one "refer" (i.e., product ID refer to the product owner). The processes happened in a specific environment "happenedIn". For instance, during storage (process) that happens in a store (environment), the stock agent transfers the operations properties to the knowledge base as a traceable element.

The mentioned relationships are the main ones. However, one can add other sub-properties. For example, the link "has" could include "hasId" to express that an object (product) has an identifier ID (TraceableElement). Moreover, one can add the link "hasOwner" to express the company that possesses the product.

3.5 Decision-making process

The proposed system predicts the rating of the raw material acceptability, which assists users in sorting. This evaluation supports the decision-making process that revolves around a decision mechanism and a predictive model.

3.5.1 Mechanism

3.5.1.1 Sensory properties

The suggested evaluation encompasses the description, measurement, and interpretation of product characteristics that can be perceived by human sensory organs using four sensory attributes (appearance, texture, flavor, and convenience) (Barrett, 2010).

Appearance is a visual quality factor that may include size, shape, color, gloss, and freedom from defects and decay. Generally, defects are damage that occurs before or after harvest and results from insects, diseases, birds, morphological, physical, physiological, or pathological. On the other hand, textural is a feel quality factor, which includes firmness, crispness, juiciness, mealiness, and toughness, depending on the type of commodity. The ability to assess this factor is important for several tasks such as cooking and shipping a commodity.

The flavor attribute is an eating quality factor that involves sweetness, sourness (acidity), astringency, bitterness, and aroma. These elements depend on the perception of the tastes and aromas of many compounds. Another important attribute is convenience, which fresh-cut products. This factor is simply referring to the freshness of raw materials (Raegert et al., 2004). The four mentioned attributes are the input of the proposed model and the acceptability is its output ($Y_{predicted}$).

3.5.1.2 Data preparation

The collection of information and necessary data, for red cherry sweet peppers, was conducted in line with the basis of the collecting activities (capturing and recording). The proposed solution uses indeed a labeled data (dataset contains the values of both inputs and desired output).

The individual panelist's perception of these variables differs from one worker to another one. For this subjective evaluation, we proposed an internal procedure for sensory evaluation. The sensory measurement is done using a scale between 1 and 9. Intervals are described as poor and excellent, where these terms are used to describe the predicted output. The following scale refers to the red cherry sweet pepper (figure 4.20). Between the terms "***poor***" and "***excellent***", one can define other ones, such as "***fair***" and "***good***".

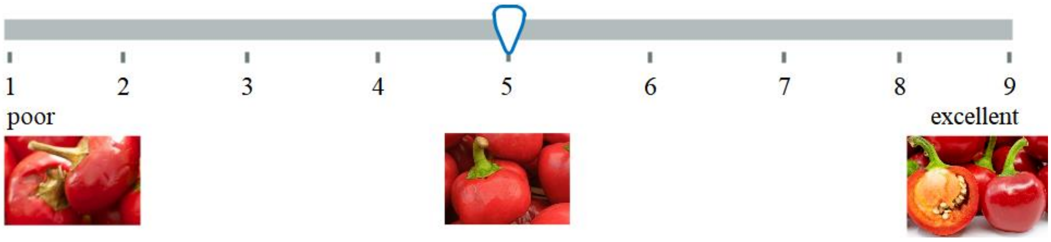

Figure 4. 20: Scale used for collecting and evaluating information about acceptability.

This representative sample is established based on the experts of the quality manager, the production engineer, the manager of the sorting centers, 3 farmers, and 3 workers from the sorting centers. To that end, this committee has treated 100 reference and standard samples to provide the necessary dataset, including training, checking, and testing. The following table provides some examples from the experimental dataset.

Samples	Appearance	Textural	Flavor	Convenience	Experimental Acceptability
s1	1	3	5	1	2
s2	7	2	6	4	5
.	.	.	.	.	.
.	.	.	.	.	.
s100	9	4	3	4	6

Table 4. 5: Example of experimental data of acceptability evaluation.

3.5.1.3 Implementing modality

The decision mechanism combines fuzzy logic techniques (Zadeh, 1965) and artificial neural network (ANN) (Buckley and Hayashi, 1994). This combination provides advantages of both methods in a single structure. Using fuzzy sets, we overcome vagueness about variables' dependence, incomplete information about properties, and subjectivity in establishing values. With ANN, we ensure that the proposed system can learn and fit its prediction results (figure 4.21).

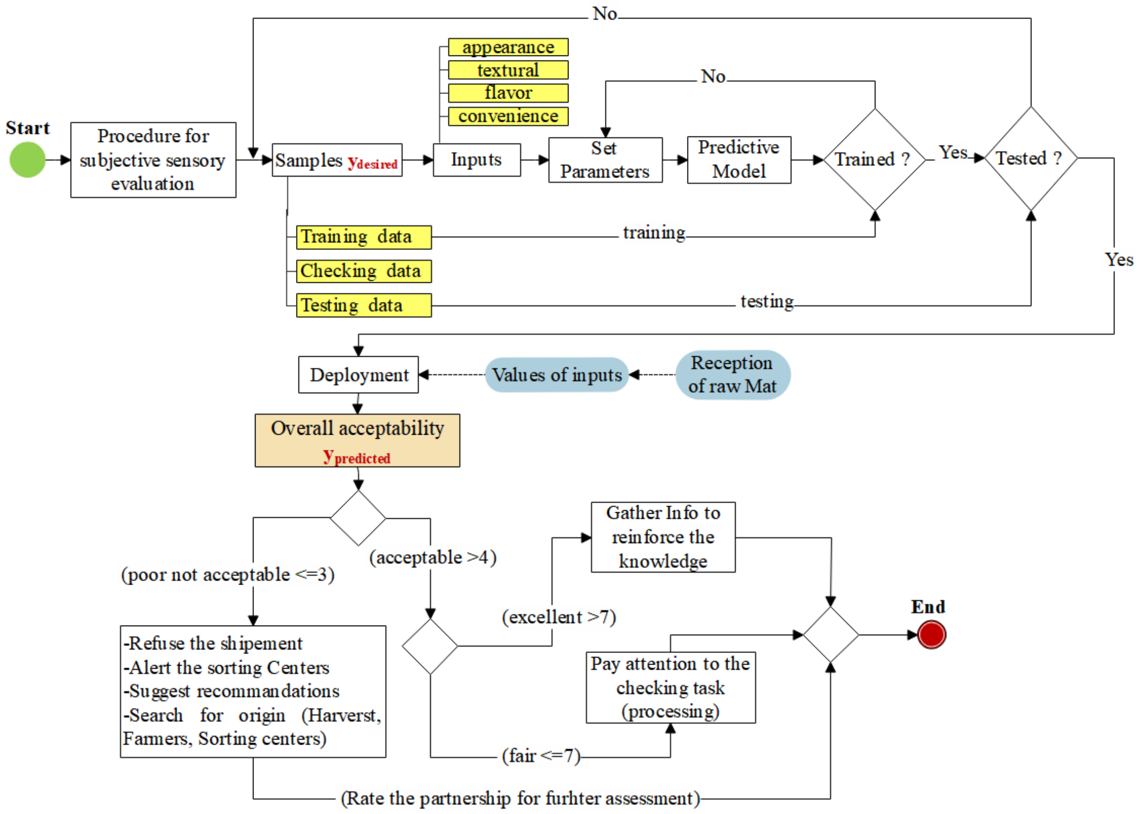

Figure 4. 21: Decision- making process.

This Neuro-Fuzzy model (Jang, 1993) is a chain of inference that starts with the fuzzification of the inputs and setting initialization of the parameters (i.e., rules and memberships function). First, a primary model of prediction is constructed. Next, the data are used to establish an accurate model. Otherwise, the process is repeated until obtaining an accurate model.

Once the accurate model is deployed, it is used to predict the acceptability of raw material and making decisions upon these predictions. If the acceptability *poor*, the shipment would be declined. If the acceptability *fair*, the reception responsible should alert the production unit to monitor the quality (i.e., during blanching's step). Information about excellent shipments can be gathered and studied as a reference.

3.5.2 Predictive model

Let consider the following statements:

- X: x_1, x_2, x_3, x_4 refer to appearance, texture, flavor, and convenience, respectively.
- x_1, x_2, x_3, x_4 are inputs to the i^{th} node, and A_i, B_i, C_i, D_i are the defined linguistic variables associated with an input.
- The architecture is based on the first-order Takagi-Sugeno fuzzy inference system (Takagi and Sugeo,1985). Hence, the consequent of a rule is a function $f_i(x_1, x_2, x_3, x_4)$.

- There are 16 rules used by the proposed system $N_{rules}=2^4$ where 2 is the number of linguistic labels (poor and excellent) for each inputs (x_i) and 4 is the number of inputs.
- A typical rule set can be expressed as the following example:

$$If \quad (x_1 = A_1) \quad and \quad (x_2 = B_1) \quad and \quad (x_3 = C_1) \quad and \quad (x_4 = D_1)$$

$$Then \quad f_1 = p_1x_1 + q_1x_2 + r_1x_3 + s_1x_4 + u_1 \qquad (6)$$

Where, p, r, q, s, u are linear output parameters and A_1, B_1, C_1, D_1 are nonlinear parameters.

- We use the sigmoidal membership function:

$$\mu_{M_i}(X) = \frac{1}{1+e^{-a_i(X-c_i)}} \qquad (7)$$

Where *M: A, B, C, D*, *i*= 1,2, and a_i, c_i are the linear parameters of the sigmoid function.

- During learning the sigmoid function is parameterized using the set $\{a_i, c_i\}$.

3.5.2.1 Architecture

The predictive architecture comprises five layers (figure 4.22); (1) the fuzzification of inputs, (2) the determination of the firing strength of rules, (3) the normalization of rules, (4) the consequents evaluation, and (5) the summation of functions to pass the prediction value.

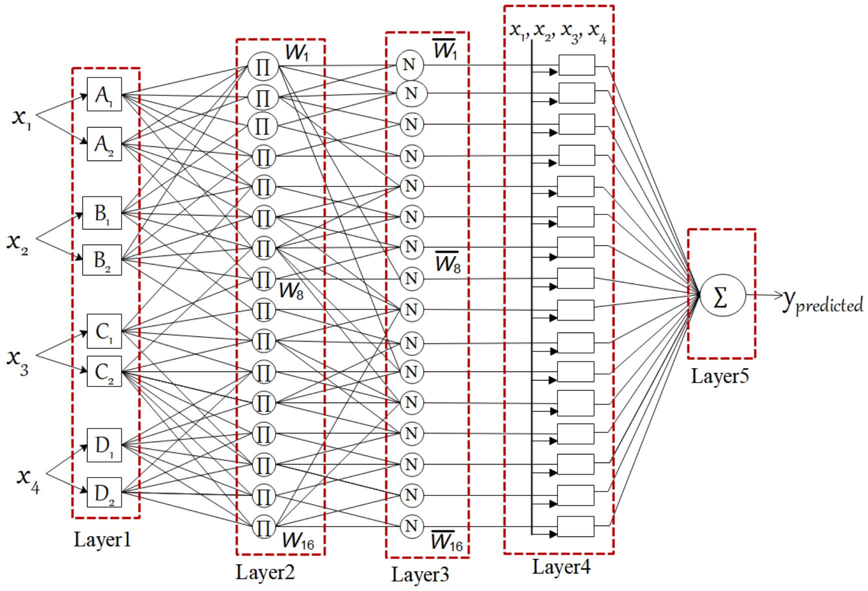

Figure 4. 22: Architecture of the predictive model.

In the figure, the circular nodes are fix, while the square nodes have parameters to learn are adaptive. Adaptive nodes are those changing each learning iteration. The output of the i^{th} node is denoted as Y_{ki} , where *k* refers to the layer number *k*= 1,2,3,4. Yet, the output in layer 5 is referred as $Y_{predicted}$, which is the final output of the predictive model.

- Layer 1: Nodes are adaptive, the parameters to be fit are called premises. As the values of these parameters ($\{a_i, c_i\}$) change, the shape of the membership function varies (sigmoidal functions). Outputs of this layer are the membership grade of inputs. In other terms, $y_{1,i}$ is the membership function of A_i, B_i, C_i, D_i

$$Y_{1,i} = \mu_{A_i}(x_1) \quad \text{for } i\text{=1,2} \qquad Y_{1,i} = \mu_{B_{i-2}}(x_2) \text{ for } i\text{=3,4}$$

$$Y_{1,i} = \mu_{c_{i-4}}(x_3) \text{ for } i\text{=5,6} \qquad Y_{1,i} = \mu_{D_{i-6}}(x_4) \text{ for } i\text{=7,8} \quad (8)$$

- Layer 2: Nodes are fixed and labeled as Π, which indicates a multiplier (it is a T-norm performing generalized "AND"). In this layer, each i^{th} node calculates the firing strengths of each rule via multiplying the incoming signals and sending the product out:

$$Y_{2,i} = w_i = \mu_{A_i}(x_1) \times \mu_{B_{i-2}}(x_2) \times \mu_{c_{i-4}}(x_3) \times \mu_{D_{i-6}}(x_4) \quad (9)$$

- Layer 3: Nodes are fixed and labeled as N. In this layer, the i^{th} node calculates the normalized (N) ignition level of each rule. It is the ratio of the i^{th} rules firing strength to the sum of all rule's firing strengths: $Y_{3,i} = \overline{w}_i = \frac{w_i}{\sum_{i=1}^{16} w_i}$ (10)
- Layer 4: Nodes are adaptive and the parameters in this layer are consequent parameters. The output of each node is the product of the normalized firing strength and a first order polynomial function f_i . Here, the values of all inputs are also considered:

$$Y_{4,i} = \overline{w}_i\ f_i = \overline{w}_i\ (\sum p_i x_1 + q_i x_2 + r_i x_3 + s_i x_4 + u_i) \quad (11)$$

Where the variables p_i, q_i, r_i, s_i, u_i are the consequent parameters to fit.

- Layer 5: The single node in this layer is an adaptive one labelled as ∑ that computes the overall model output as the summation of all incoming nodes' signals:

$$Y_{predicted} = \sum_i \overline{w}_i\ f_i = \frac{\sum_i w_i f_i}{\sum_i w_i} \quad (12)$$

3.5.2.2 Learning process

The learning of the model consists in tuning the parameters of the system until reaching an accurate model. The suggested model has two types of parameters, including non-linear parameters (premises parameters in layer 1) and linear ones (consequent parameters in layer 4).

We use a hybrid method to train the system. This method uses the least-squares estimation (LSE) for the parameters associated with the output membership functions (consequent parameters) and backpropagation for the parameters associated with the input membership functions (premises).

The least squares estimation is applied to the consequent parameters in layer 4. The contribution of these parameters to the network output is a linear equation:

$$Y_{predicted} = \sum_i \overline{w}_i\ \sum_i p_i x_1 + q_i x_2 + r_i x_3 + s_i x_4 + u_i \ (13)$$

Let $\beta_0, \beta_1, \beta_2$ .... be the unknown values of the parameters in the regression function $f(\vec{x}, \vec{\beta})$. They are estimated by finding numerical values for the parameters that minimize the sum of the squared deviations between the observed responses and the functional portion of the model (Astrom et al., 1971). The least squares criterion is minimized to obtain the parameter estimates, it is expressed as:

$$\varphi = \sum_{i=1}^{n}(Y_{measured} - f(\vec{x}, \hat{\beta}))^2 \quad (14)$$

To emphasize the fact that the estimates values are not the same as the true values of the parameters, they are denoted $\hat{\beta}_0 \widehat{\beta}_1 \ldots$. For linear models, the least squares minimization is usually done analytically using calculus (Astrom et al., 1971). This whole mechanism (LSE) is referred as the learning forward pass.

The backpropagation is a neural network algorithm that employs a gradient descent procedure to minimize an objective function (error function) (Rumelhart et al., 1986). Here, the used error function is the sum-of-squares that is given by:

$$E_t = \frac{1}{2}\sum_{i=1}^{n}(Y_{predicted} - Y_{measured})^2 \quad (15)$$

This function measures the error for t= 1…m where m is the number of iterations and n is the number of nodes. To optimize the error function, the backpropagation algorithm uses this rule:

$$NewValue_{p_i} = OldValue_{p_i} - \eta \frac{\partial E_t}{\partial P_i} \quad (16)$$

η is the learning rate $0 < \eta < 1$ and P_i refers to the set $\{a_i, c_i\}$ that shapes the sigmoid function.

The learning mechanism is based on updating the values of different parameters (from oldValue to NewValue). Hence, we should find the alter in the parameters P_i of the input M_i. However, they are not represented directly in the equation E_t . Therefore, we use the differentiation chain rule to reach this parameter:

$$\frac{\partial E_t}{\partial P_i} = \frac{\partial E_t}{\partial Y_{predicted}} \frac{\partial Y_{predicted}}{\partial \bar{w}_i} \frac{\partial \bar{w}_i}{\partial w_i} \frac{\partial w_i}{\partial \mu_{M_i}(x_i)} \frac{\partial \mu_{M_i}(x_i)}{\partial P_i} \quad (17)$$

Note that the learning rate is expressed as: $\eta = \frac{K}{\sqrt{\Sigma(\frac{\partial E_t}{\partial P_i})^2}}$ (18)

Where k is the step size that determines the speed of error convergence.

When the partial derivatives are computed, the linear equations can be used to update the consequent parameters. The learning starts from the output layer and moves backward until the input layer. This mechanism is referred as the learning backward pass (backpropagation).

3.6 System deployment

The deployment task involves the compliance with the training and evaluation requirements.

3.6.1 System training

For the system training, we use the representative data that contains 100 samples. We select randomly a 70% of the data for training, 15% for the test, and 15% for validation. In this supervised learning, the training data helps to fit the model parameters (premises and consequents), whereas the validation data is necessary to prevent the overfitting of the model. The testing data is used to evaluate model performance and accuracy.

During the training, the premise parameters are held fixed, while the functional signals are propagated forward and the error (E_t) derivatives are propagated backward. This forward-backward pass is called an epoch, where the training dataset is offered to the system cyclically. We use the software "MATLAB R2018a" to visuals the system training and checking steps.

All the training data passes through the different nodes to find the appropriate adjustment in the relationships between input/output, and consequently to minimize the errors (figure 4.23).

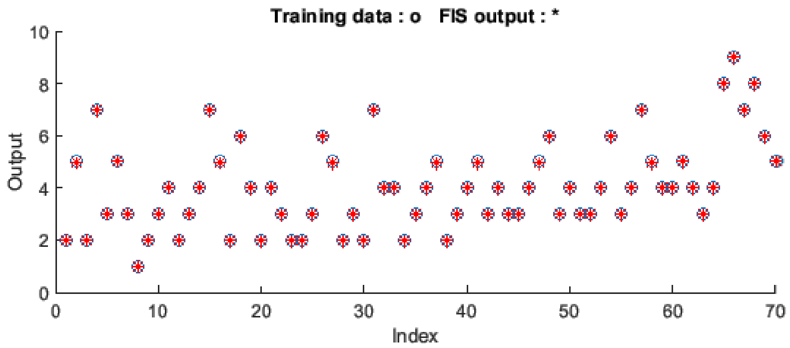

Figure 4. 23: Measured and predicted outputs for training data.

Since every trained data set has indeed its maximum number of epochs before the predicted output will be over its accuracy (overfitting issue), we used two techniques to avoid the overfitting problem.

First, we set different values for the training epoch numbers. This will allow us to determine the optimal epoch number with the lowest training (figure 4.24).

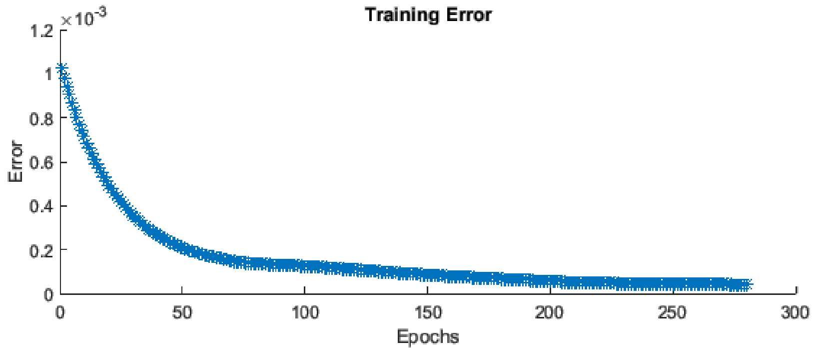

Figure 4. 24: Training error Vs. Epoch.

The root mean squares error (RMSE) was the function used to monitor the training errors. This function aims to minimize the sum of all difference (error values) between the actual outputs and the predicted outputs. RMSE is defined as:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Y_{predicted} - Y_{measured})^2} \quad (19)$$

Where N is the number of data points.

Second, we use the checking data (unseen data for the model) to verify the avoidance of the overfitting problem, analytically (figure 4.25) the prediction performance of the checking data is high since the most predicted value are close matches of the actual ones.

Finally, the training has needed 280 epochs to reach the best structure with the lowest value of RMSE = 0.000046.

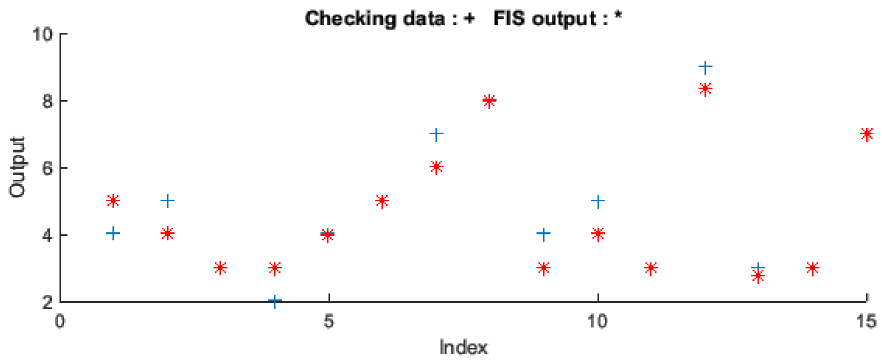

Figure 4. 25: Measured and predicted outputs for checking data.

3.6.2 System evaluation

The evaluation of the predictive model performance is done according to accuracy and precision, sensitivity, and efficiency. This evaluation step is conducted using the testing data where each predicted value was compared with the experimental one (table 4.6).

Appearance	Texture	Flavor	Convenience	Measured acceptability	Predicted acceptability	Error	Squared Error
8	5	7	7	8	7,49	+0.49	0.2401
7	2	6	4	5	5	00	0
6	5	6	8	8	8,11	-0.11	0.0121
5	5	4	8	5	5,45	-0.45	0.2025
3	7	3	9	5	4,4	+0.40	0.16
3	9	3	9	5	5,6	-0.60	0.36
4	6	2	3	2	1,11	+0.89	0.2601
6	5	2	6	5	5,1	-0.10	0.7921
4	7	5	3	3	3,41	-0.41	0.1681
3	4	8	4	4	4	00	0
8	5	6	4	7	7	00	0
3	2	5	3	2	2,66	-0.66	0.4356
6	3	5	5	4	4	00	0
5	4	3	4	3	3,62	-0.62	0.3844
7	3	4	5	5	5,83	-0.83	0.6889

Table 4. 6: Comparison between measured and predicted outputs (testing data).

Regarding the model accuracy and precision, RMSE and Mean Average Error (MAE) are used because these indicators provide a numerical description of the goodness of the estimated values. In case of testing data, RMSE=0.494 which measures the performance of the proposed model in terms of the possible error between predicted and observed values.

MAE is expressed as: $MAE = \frac{1}{N}\sum_{i=1}^{N}\left|Y_{measured} - Y_{predicted}\right|$ (20)

Thanks to MAE, we can take into consideration the fact that our model generates two type of errors; predicted values can be lower (+) or higher (-). Hence, we ensure that both contribute to the overall error correction, otherwise the positive and negative errors would cancel each other. Consequently; it was shown that our model makes good predictions with a small variation in possible errors (MAE=0.3858).

The comparison between the measured and the predicted outputs (using RMSE and MAE) shows that the system is well-trained to model the acceptability of cherry red peppers. In terms of precision, these results signify that the number of correct outputs is high compared to all made outputs**.** Both accuracy and precision should be considered simultaneously (model can be very precise but inaccurate or be accurate but imprecise).

Regarding sensitivity, we have confirmed the stability and reliability of the proposed model by attempting changes in its parameters. For example, instead of the sigmoid function, we tried to use the bell-shaped function, which showed a higher RMSE and more epochs for training. However, attempting to use more linguistic variables (poor, fair, good, and excellent), the number of rules became higher (256), and the numbers of premises (32) and consequent parameters explode (1280). At this level, the model became complex and time-consuming, which require more computing capacity.

Besides these criteria, the efficiency indicator ties to answer the question: how close the predicted output is to the actual output. The correlation coefficient (*r*) provides insight into how well trends in the predicted values follow trends in past actual values. This coefficient of efficiency (determination) is expressed as:

$$r = \sqrt{1 - \frac{\sum_{i=1}^{N}(Y_{measured} - Y_{predicted})^2}{\sum_{i=1}^{N}(Y_{measured} - S_i)^2}} \quad (21)$$

Where N number of data and S_i is given by: $S_i = \frac{\sum_{i=1}^{n} Y_{measured}}{N}$ (22)

The calculated correlation coefficient (*r*) is 0,9643, which shows a high correlation between predicted and experimental values and demonstrate how much the learning was efficient and successful. This regression relation is plotted in the following figure.

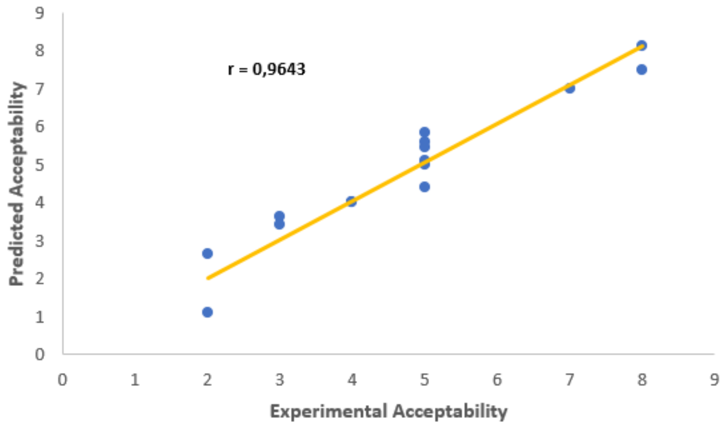

Figure 4. 26: Correlation between experimental and predicted values.

3.7 Practical implications

After training and evaluating the model, we maintain the developed version that proved the highest accuracy and efficiency. This final version is chosen for implementation along with the decision mechanism and the knowledge representation. To show the applicability of this solution, we give illustrative examples. Typically, the proposed intelligent traceability ensures not only the classical functions like identification and tracking but also helps to solve the issue of raw material selection. The proposed system is designed to be a sorter tool that support the decision makers.

For example, by analyzing a random sample of sweet red cherry peppers intended to be sent to the production unit, a sorting manager can supervise and check the tasks done by workers.

Given his estimation (5,6,5,6), the system's return an assessment of the sample acceptability (acceptability=6,20) (figure 4.27).

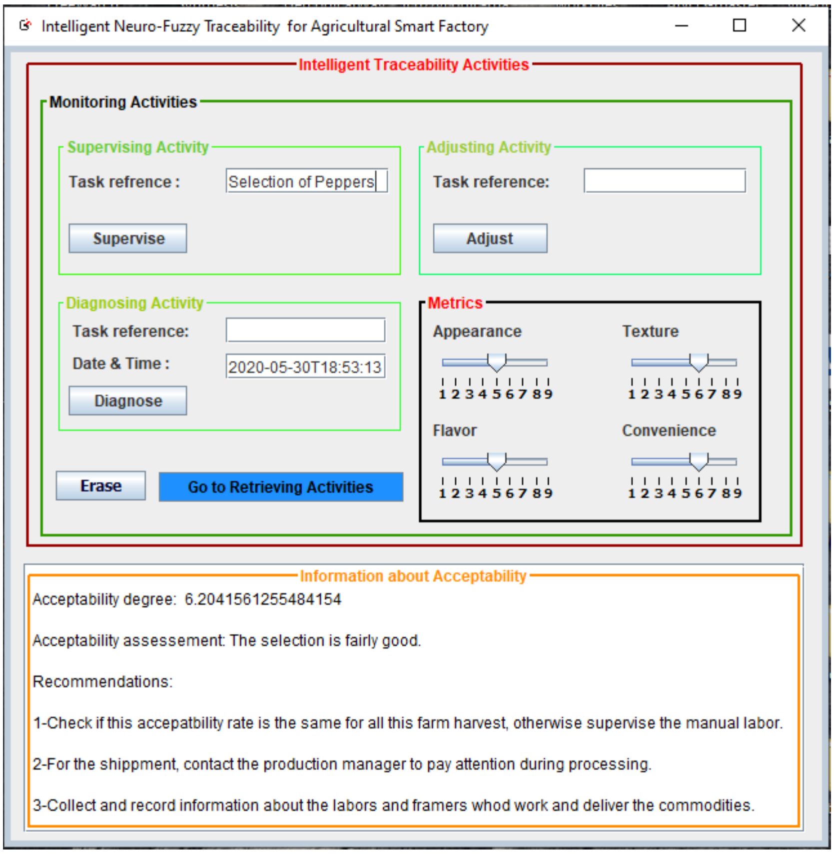

Figure 4. 27: Supervising activity to check the raw material acceptability.

Although this degree is fairly acceptable, the system proposes some recommendations due to the specificity of such commodities (i.e., during summer, this commodity is sensible to high temperature). Thus, it is recommended to check the accuracy of manual labor and give guidelines, if it is needed. Also, it is recommended to revise the harvesting tasks and alert the production unit (i.e., monitor closely the blanching step).

Now, let us consider the arrival of a raw material shipment, where the agent tried to get a decision on the acceptability level of the shipment. The user enters parameter values (appearance, texture, flavor, and convenience) and obtained a predicted acceptability poor (acceptability= 2.5) (figure 4.28).

Based on this diagnosis, the system automatically recommends to reject the shipment, to alert the sorting center, and to retrace the path of this shipment for further investigation and assessment. The reception agent uses the retrieving activities to identify involved entities and to trace information about the shipment. Figure 4.29 and 4.30 provide insight into some examples of identification and information's tracing.

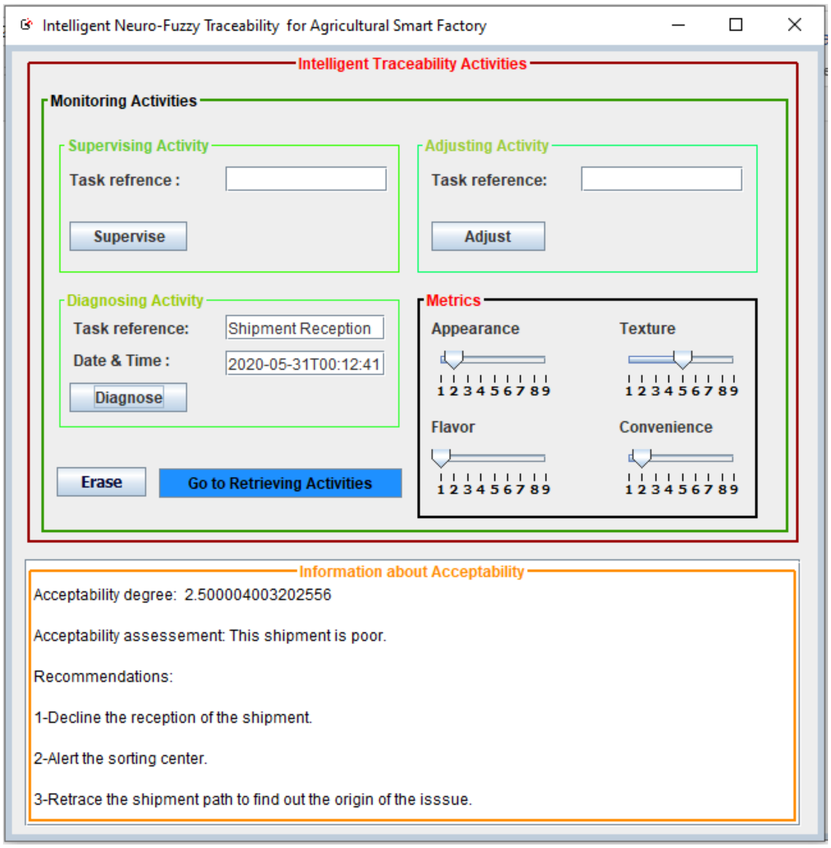

Figure 4. 28: An example of a diagnosis activity during shipment reception.

One can see the content of the shipment (cherry peppers) and its owner's identity and address (figure 4.29).

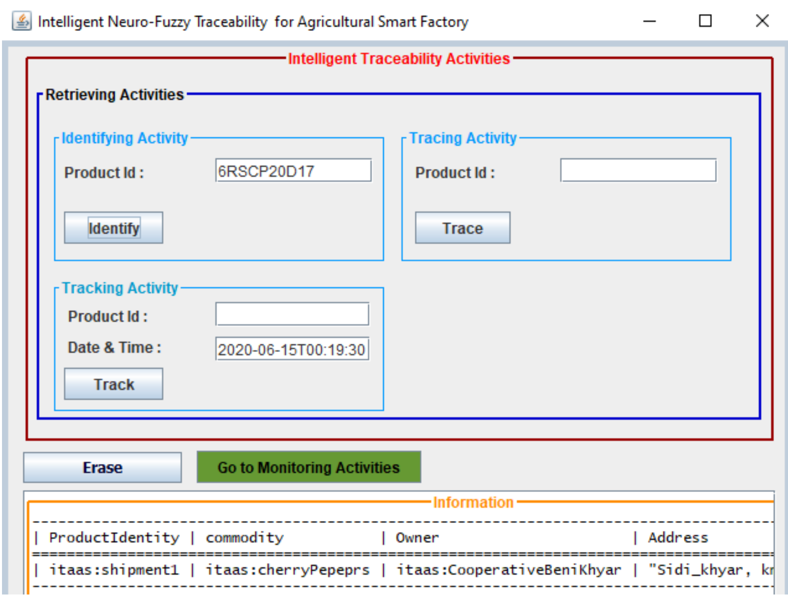

Figure 4. 29: Identification information about the shipment1 (6RSCP20D17).

In addition, a user can see the tasks and the person involved in the shipment processing before it arrives in the production facility (figure 4.30). Such information helps to conduct a backward analysis to apprehend the causes of such poor shipment.

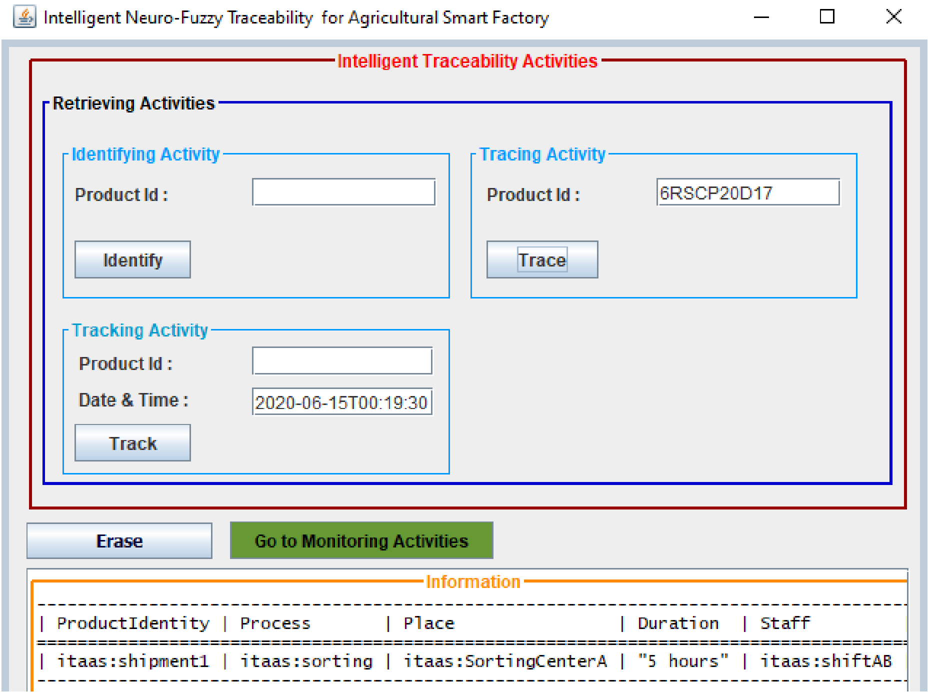

Figure 4. 30: Tracing information about the shipment1.

By attempting to understand the origin of the poor acceptability, the company might be able to rate its partnerships with farmers and sorting centers, to reward and penalize based on quality, and to improve protocol and procedures for daily practices and selection standards.

Depending on the model, companies can successfully sort raw material in different stages. Such functionalities assist in detecting unwanted size, shape, and defects raw material. The system is expected to unify standards of raw material selection, especially in the agriculture supply chain.

The scale, used for taking representative samples, plays a key role in standardizing the selection's parameters and criteria. Based on a more collaborative partnership, this scale would be improved and used for comparison between scales as a basis for improving existing ones, or even the development of new ones for other commodities.

With continuous enhancements, the model is expected to form a basis for several sorting operations, including those done in farms, selection centers, and even during the production checking. Such references and standards might be used not only for cherry peppers but also for other commodities such as olive and truffles.

The evaluation of the predictive model showed that the predicted values are close matches of the measured ones. It is noteworthy to mention that such results are due to the representative samples that are sufficiently accurate thanks to the collaborative and considerable efforts of the field experts. However, for better performance, the system might still need more learning and training using a large amount of data that could be collected from different companies, for different commodities, in different areas, and at different seasons of the year.

This intelligent traceability solution uses the adaptive neuro-fuzzy inference (ANFIS), which proved its ability to overcome the issue of sensory evaluation (e.g., incomplete data and subjective evaluation). It was found that combining fuzzification to face variable vagueness and learning to enhance the prediction accuracy was an excellent strategy in our case study. Most of the results showed indeed that the system was not only particularly good in learning but also in reproducing and simulating the sensory experts' opinions.

This intelligent traceability has other implications. Instead of being a simple classifier, i.e., a commodity is accepted or is not accepted (a binary way), the model allows predicting a crisp value that helps to conduct more and deep analysis. Hence, it enables to support a sustainable decision-making process. Based on the predicted values, decisions have either a short-term goal, medium-term, or long-term one. For example, when the acceptability is poor, the manager would take some decisions like refuse the shipment of raw material, alert the sorting manager, and recommend enhancements. Besides this short term, other long-term steps such as rating the source of this shipment (sorting centers, workers, and farmers) for future assessment of the partnership with different stakeholders are taken.

4 Intelligent Traceability in Automotive Industry

Over the past decade, the automotive industry, particularly the wire harness and assembly manufacturing has become an important asset to the Moroccan industrial sector. This is how the last implementation of intelligent traceability took place in an automobile wiring factory.

4.1 Overview of wire industry

A wire harness is an assembly of wires, cables, and connectors that transmit electric power or signals. Such manufacturing involves several operations such as cutting, stripping, crimping, soldering, as well as the assembly of wires in a wide range.

The cable harness processing could involve simultaneously various assembly lines. Generally, the production’s activities include reception of the raw material, cutting, pre-assembly, assembly, packaging, and shipping. The reception of the raw material from the supplier goes through a checking control managed by the company’s Information System (IS). In our case, the company uses the SAP system (Systems, Applications and Products for data processing), in which, the different functions of the company (i.e., accounting, finance, production, supply chain management, and marketing) are linked together by the use of a client-server configuration. SAP prepares also the needed stock for the next 24 hours of production.

During the cutting, the electrical wires are sized using automatic machines. These machines allow also wires stripping, crimping, and insertion of plugs. Once cut, wires go through several operations (pre-assembly) such as manual crimping, ultrasonic joint, twist, and mass soldering. Finally, all the components are assembled to obtain the final cable, destined for using.

4.2 Issue statement

In the production line, we have observed that sometimes there are shortage of stocks in the supply of raw materials (i.e., connector, jacket, and terminals) or there are overstocks of these raw materials. According to the supply chain manager, the data provided by the company’s IS did not show any unconformity in the supply of items, there are neither ruptures nor overstocks.

At this level, this problem results in a mismatch between the recorded information about raw materials and their real status, which shows that the synchronization between the information flow and the physical one is lost. Moreover, such issue affects negatively the entire supply chain visibility. Due to this situation, another issue is raised with respect to the shelf life of products and how much that influences the material’s quality.

4.3 Situation analysis

Before moving forward, the present situation of raw materials requires a critical evaluation with respect to the way raw materials are distributed, causes, and consequences of the unknown status of raw materials.

4.3.1 Distribution process

The conducted investigation has shown that malfunctions in raw materials supplying often happen within an intermediate area between the main warehouse and the production line. We have precisely identified this discordance as raw materials move from an area, namely ‘the supermarket' to the assembly lines. Therefore, we focused on the distribution process as it is the principal source of malfunction in supplying. The supermarket is the intermediate storage area between the main warehouse and the production lines. It represents the miniature image of the quantities and references (items) of the store, as well as the image of the references requested by the different production lines (figure 4.31).

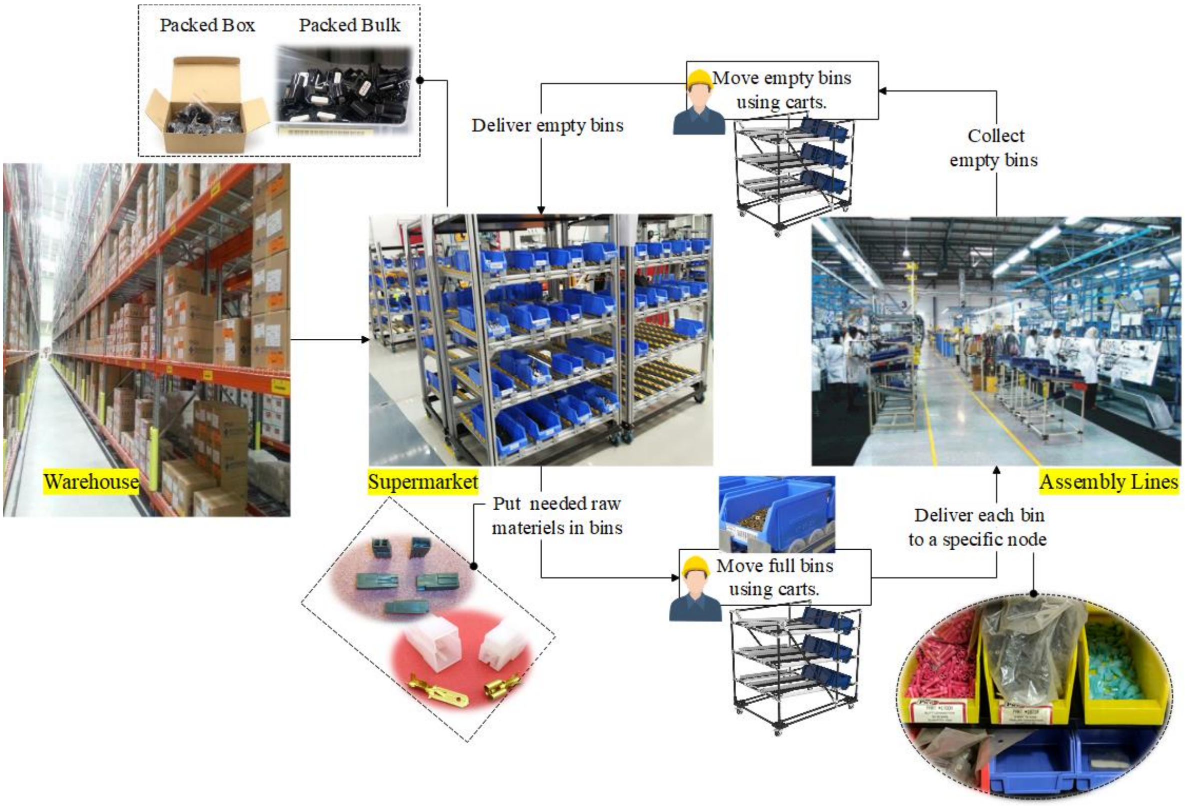

Figure 4. 31: Distribution process from supermarket to assembly lines.

During the distribution flow, the warehouse feeds periodically the supermarket with necessary raw materials either as packed box, or as packed bulk. This activity is under full control (IS records all information about the delivered materials). In the supermarket, raw materials are put in bins, which are arranged in storage shelves. Here, a distribution agent can freely fill bins with materials as much as needed by the assembly lines. This activity is done cyclically (back and forth), which handicaps any effort to keep the number of material quantities under count and control.

4.3.2 Data processing

This conducted case study uses the collected information form the domain's experts and the raw data coming from several internal audits' reports (between 2017and 2018). Most of data is captured during a shift (8 hours) where three shifts exit (morning, afternoon, and evening). This data reports on four assembly lines (Rears Family), where 50 workstations exist. For instance, rears manufacturing requires 311 types of connectors that are indicated by theirs references (figure 4.32). In addition, during a shift, 418 items “7287317030” (120, 116,76, 106 for line1, line2, line3, line4, respectively) are consumed.

Figure 4. 32:Items’ designation (references).

The following graph depicts the difference between raw materials delivered by warehouse and the actual needed quantity. One can see a clear gap between two quantities, especially for certain items (i.e., 7047754830).

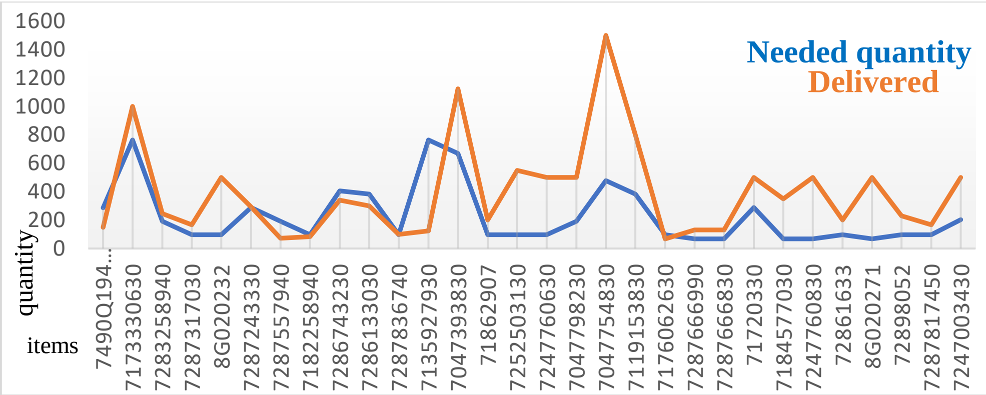

Figure 4. 33: Needed and delivered components per 4 hours.

In 4 hours, a distributor performs two distribution cycles. As an average, a cycle can last between 55 min to 1hour 27 min. Information about the duration of each operation (seconds) has been calculated for 8 times (T1,…,T8). (Table 4.7)

	Timing (s)								
	T1	T2	T3	T4	T5	T6	T7	T8	Mean
Collection of empty Bins	2123	1890	2183	1815	1689	2025	1885	1995	1950,625
Fill the empty cart	2412	2352	2703	2405	2470	2412	2430	2459	2455,375
Feed the assembly line	1935	1983	1745	2056	1935	1930	1901	1599	1885,5
Supermarket-workstation	136	135	128	137	135	155	145	137	138,5

Table 4. 7: Timings of distribution operations.

The used bins for distribution differ according to their internal volume (Table 4.8).

Bin designation	Volume (cm3)
G	10 864
A	10 230
B	4 557
C	810

Table 4. 8: Internal volume of the bins.

The following figure shows the size, designation of items, and type of package.

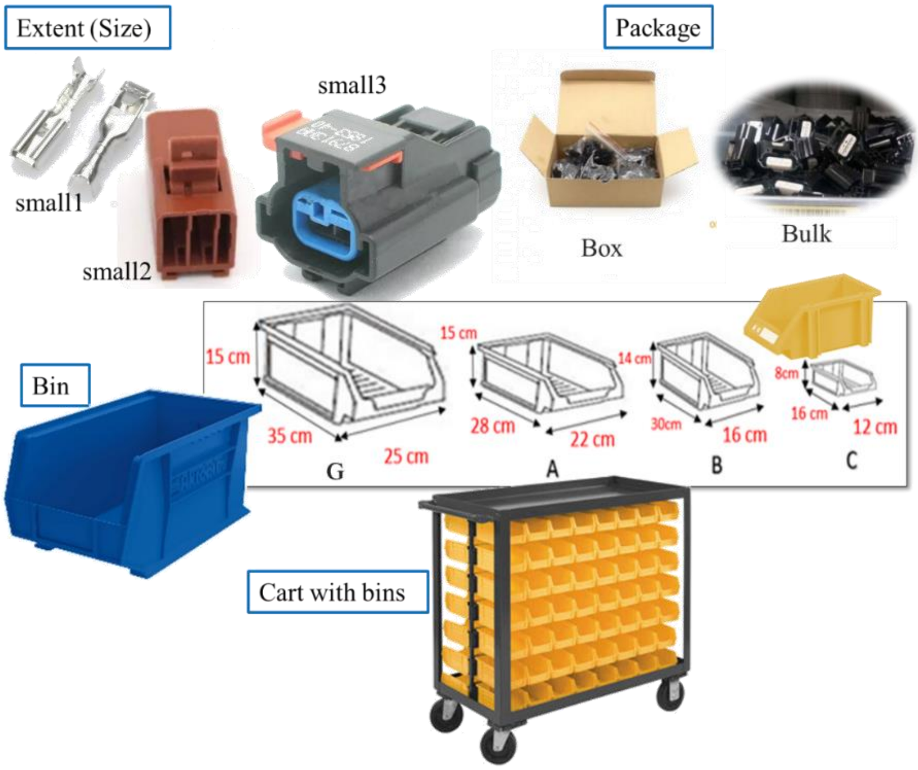

Figure 4. 34: Items size, package, and bins.

4.3.3 Status of raw materials

Practically, when moving items from supermarket to assembly lines, it is almost impossible to know their exact number (status). For example, a distribution agent opens a bulk packaged of connectors, fills in the bins until their limits, and carry them to different workstations. Unless spending all the day counting thousands of small items, who could know exactly how many ones are in these bins and how many of them are left in shelves? If one had wanted to do so, such counting would have taken hours and delayed the cadence of work in progress.

It is worth mentioning that this company, through other academic's and professional partnerships, has tried several solutions, among others, are now in progress. A first one was to adjust some supply parameters (i.e., define a lager interval for minimal stock before triggering an alert for shortage or overstocks).

Other propositions attempted to use external methods and tool (i.e., Kanban and Excel data sheet) to follow the movement of raw materials and integrate manually this data into IS modules (SAP). Other approaches suggested the idea of weighing the full bins and estimation of the numbers of raw materials, or RFID bins' tagging to enhance the monitoring of materials.

Here, intelligent traceability approaches this issue from a different perspective. Generally, it is widely known that "Treating the original causes of an issue is the best way to eliminate its consequences"; here we think, "Mitigating the consequences to a tolerable or acceptable level is the best way to transform this issue into a trivial matter". Thus, instead of trying to find the exact status of raw materials, we attempt to get knowledge about dependencies of attributes involved in the distribution flow, the direction of causations, and the estimation of uncertainty.

4.4 Problem solving strategy

Assuming the following phenomenon: "the status of raw materials is unknown during the distribution flow"; knowing most of the phenomenon's attributes, the way they affect each other, and the occurring probabilities of each attribute, one can find at least one path to avoid and reduce damaging consequences (tolerable or acceptable) that come from the unknown status of raw materials.

In the production line, we have noticed that most of relationships between causes and effects are not deterministic, but probabilistic. That means if we observe a cause or many ones, it does not systematically indicate the occurrence of the effects that depend on these causes. Such observation only modifies the probability of observing the effects where the occurrence remains always random, but their probability of occurrence depends on the identified factors (causes).

We can conclude that the studied environment is uncertain, and thus any chosen approach should deal with probabilistic events and allow reasoning under uncertainty. Bayesian network proved efficient for solving such issues (Xueyou et al., 2018; Scanagatta et al., 2019). A Bayesian Network (BN) is a probabilistic graphical model representing a set of variables and their conditional dependencies (Pearl, 1988). It is probability theory (Kjærulff and Madsen, 2008) and graph theory (Faudree, 2003) based. It also assumes the Markov property (Nakaoka, 2018) (i.e., no direct dependencies, being modeled, are not already explicitly shown via arcs in the graph).

All things considered, our strategy is indeed aiming to apprehend and represent this phenomenon that is not observable directly (in terms of materials count) while its possible consequences are tangible (i.e., ruptures of stocks). Henceforth, the focus becomes on how do we get knowledge about the status of raw materials (structure of knowledge) and how can we use this knowledge to make this issue trivial (solution's deployment).

4.5 Knowledge structure

The proposed knowledge's structure consists of (1) a set of variables, (2) a graph that describes the causal relationships between variables, (3) the probability that an event occurs given the occurrence of another one.

4.5.1 Variables determination

We assume that the management of raw materials is difficult due to the nature of the materials distribution flow. This process is indeed significantly influenced by the size and quantity of materials, the used tools (i.e., bins and carts), the usage of either bulk or box package, the human factors, and the management of continuous production tasks "Work In Process" (WIP).

Therefore, 15 variables are defined. Each variable refers to either a cause or a consequence (continuous or discrete). In case of discrete variables, states are determined (i.e., narrow). For continuous variables, we use "expert discretization" technique to define thresholds and intervals. Compared to other methods (Chen and Pollino, 2012), this one is based on theoretical knowledge and expert interpretation, it also does not need additional discretization algorithm or additional computational capabilities. Attributes are defined as follows:

S: Status of raw materials, type: discrete, states {***unclear, irregular, regular***}.
D: Distribution's flow of raw materials, type: discrete, states {***disordered, organized***}.
V: Visibility of supplying activities, type: discrete, states: {***blurred, maintained***}
L: Lifespan of items (shelf life), type: discrete, states: {***affected, safe***}.
O: Orchestration between information and physical flow, type: discrete, states: {***lost, achieved***}.
G: Gap between planned and actual situation, type: continuous, discretization: $]-\infty; -200; -50;\ 50; 200;\ +\infty[$.
I: Item's number delivered from the stock, type continuous, discretization: [0;1125; >= 1125].
E: Extent of raw materials (in terms of size), type: discrete, states: {***small1, small2, small3***}.
B: Bins used for filling raw materials, type: discrete, states: {***typeA, typeB, typeC, typeG***}.
C: Carriage of raw materials (carts), type: discrete, states: {***bad, fair, good, excellent***}.
A: Agents responsible for distribution, type: discrete, states: {***a1, a2, a3, a4***}.
P: Package used for feeding supermarket, type: discrete, states: {***bulk, box***},
F: Frequency of raw materials distribution, type continuous, discretization: [0, 4; step: 1].
M: Manner of raw materials distribution, type: discrete, states: {***random, standardized***}.
W: Work in progress conditions, type: discrete, states: {***inprocess, completed***}.

4.5.2 Probabilistic graphical modeling

We conduct the modeling according to three steps (1) determination of the probability distribution of each variable (prior), (2) determination of the conditional probability distribution between them, (3) determination of the joint distributions of variables.

Most of initial probabilities (prior) are filled by expert domain based on their professional experience. For example, the following table shows the usage of a sample of 100 bins during different shifts. Here, we search to find out the probability of using a bin over another one.

	shifts						
Bins	s1	s2	s3	s4	s5	s6	s7
typeA	15	8	6	20	10	4	14
typeB	13	60	30	30	42	28	10
typeC	56	12	48	10	21	64	46
typeG	16	20	18	40	27	4	28

Table 4. 9: Usage of bins in different shifts.

Using experimental probability (Relative Frequency=Number of times the event occurred/Total number of trials), we find the prior probabilities: p(B=typeA) = 0.11, p(B=typeB) = 0.30, p(B=typeC) = 0.37%, p(B=typeG) = 0.22. Between shift1 and shift2, we can see also that the probability of using bin typeB increased from 13% to 60 %. This wide range of change shows the influence that the type of bin could have on the choice of a carriage kit (i.e., cart).
Next, we deign the relationships dependencies between the defined variables. Hence, let T be the topology that represents our knowledge structure (figure 4.35).

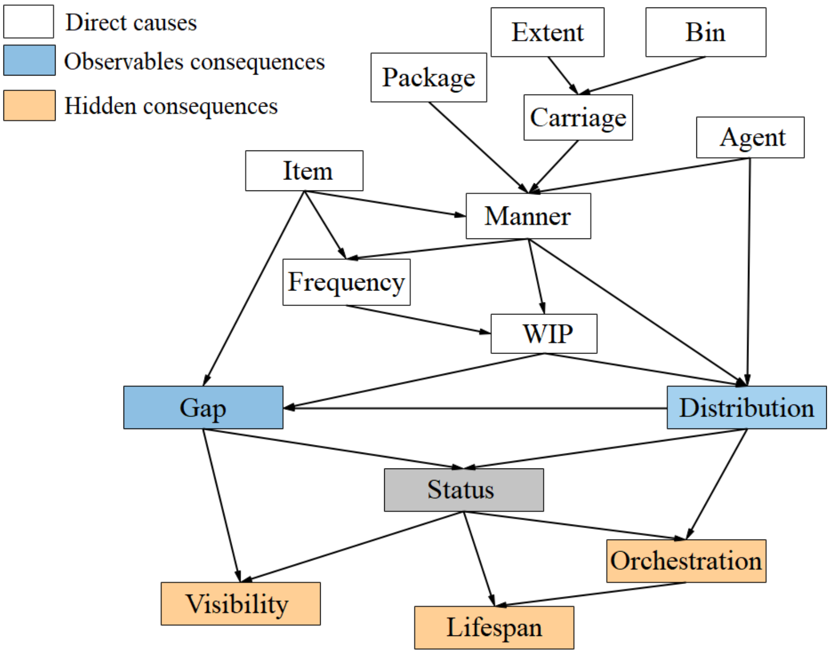

Figure 4. 35: Proposed knowledge’s structure.

T= (G, θ), where G is a directed acyclic graph (DAG) and θ a set of probabilities for nodes. Also, $G = (X, E)$ where nodes (i.e., Status) are associated with a set of random variables $X = \{x_1, \ldots, x_n\}$ (i.e., x_1=completed) and E a set of edges that relate nodes.

In the graph, directed arrows (edge) go from a parent node (i.e., Manner) to a child one (i.e., WIP), whereas a node without any parents is a root node (i.e., Bin). A direct link (arrow) means that one node directly influences the other node (no directed link means no dependence). The parent's effect on a node is expressed as a conditional probability distribution:

$$p(x_i \mid parent(x_i)) \quad (23)$$

Where, "*parents* (x_i)" represent the set of parent nodes of a node x_i. It is the probability of x_i given the probability of its parent. Using the following Bayes' rule (Jensen, 1996), for example, we can calculate the probability that a WIP will be completed (W=completed) given that we know the manner of the raw material distributions (M=organized):

Likelihood, Prior, Posterior

$$p(W \mid M) = \frac{p(M \mid W).\,p(W)}{p(M)} \quad (24)$$

Evidence

We can see that the Bayes' rule (2) allows to get new information (posterior) based on the likelihood of event occurring (likelihood) and what is originally believed (prior) before new evidence is introduced (evidence). An evidence can be an observation of a variable's state, or a scenario or potential actions that may take place. Thus, Bayes' theorem is a tool to update a previous belief once a new information obtained.

For example, the conditional probability table (CPT) of the node Distribution *p(D |WIP,A,M)* is shown in table 4.10.

WIP	Agent	Manner	p(Distribution=disordered) (%)	p(Distribution=organized) (%)
completed	a1	random	41.6169	58.3831
completed	a1	standardized	78.5049	21.4951
completed	a2	random	19.534	80.466
completed	a2	standardized	75.8879	24.1121
completed	a3	random	9.31348	90.6865
completed	a3	standardized	49.67	50.33
completed	a4	random	45.1665	54.8335
completed	a4	standardized	41.8534	58.1466
inprocess	a1	random	15.6145	84.3855

inprocess	a1	standardized	58.7429	41.2571
inprocess	a2	random	31.6714	68.3286
inprocess	a2	standardized	88.3115	11.6885
inprocess	a3	random	81.5689	18.4311
inprocess	a3	standardized	48.6702	51.3298
inprocess	a4	random	61.9168	38.0832
inprocess	a4	standardized	96.9417	3.05827

Table 4. 10: Conditional probability table (CPT) of the node Distribution.

As of right now, based on the specified graph and formulas (1 and 2), we have modeled our knowledge as a network. However, we still need the joint probability distributions to encode the total knowledge. These joint probabilities are written as:

$$p(x_1, x_2, \dots, x_i) = \prod_{i=1}^{n} p\big(x_i \big| parents(x_i)\big) \qquad (25)$$

Thus, the graph can be expressed as set of probabilities multiplication:

p(O,L,V S,D, WIP, G, F, I, M, A, P, C,B)

=p(O| L,V S,D, WIP, G, F, I, M, A, P, C,B)*p(L,V S,D, WIP, G, F, I, M, A, P, C,B)

= p(O| L,V S,D, WIP, G, F, I, M, A, P, C,B) * p(L|V S,D, WIP, G, F, I, M, A, P, C,B)* p(V S,D, WIP, G, F, I, M, A, P, C,B)……… (26)

4.6 Solution deployment

The implementation of intelligent traceability using Bayesian network requires a training stage and the usage of inference tools to support the decision-making process.

4.6.1 Model training

Based on the mentioned elements, the proposed Bayesian Belief Network (BBN) allows us to encode the knowledge about the issue as a probabilistic graphical model. We use the software Netica 6.07 (Beuzen et al., 2018) to represent and supervise the training of this network. Figure 4.36 shows initial probabilities, conditional, and joint probabilities of each node.

This model is built on initials beliefs that allow to have a first big picture of causes and consequences regarding the studied phenomenon (status of raw material). For example, if we set the probability of a gap (p (G=trivial) = 80,3%), we can have the influence on the status and visibility (the probability distributions), i.e., p (S=regular) = 48,1%) and p (V=maintained) = 65,8% (figure 4.37).

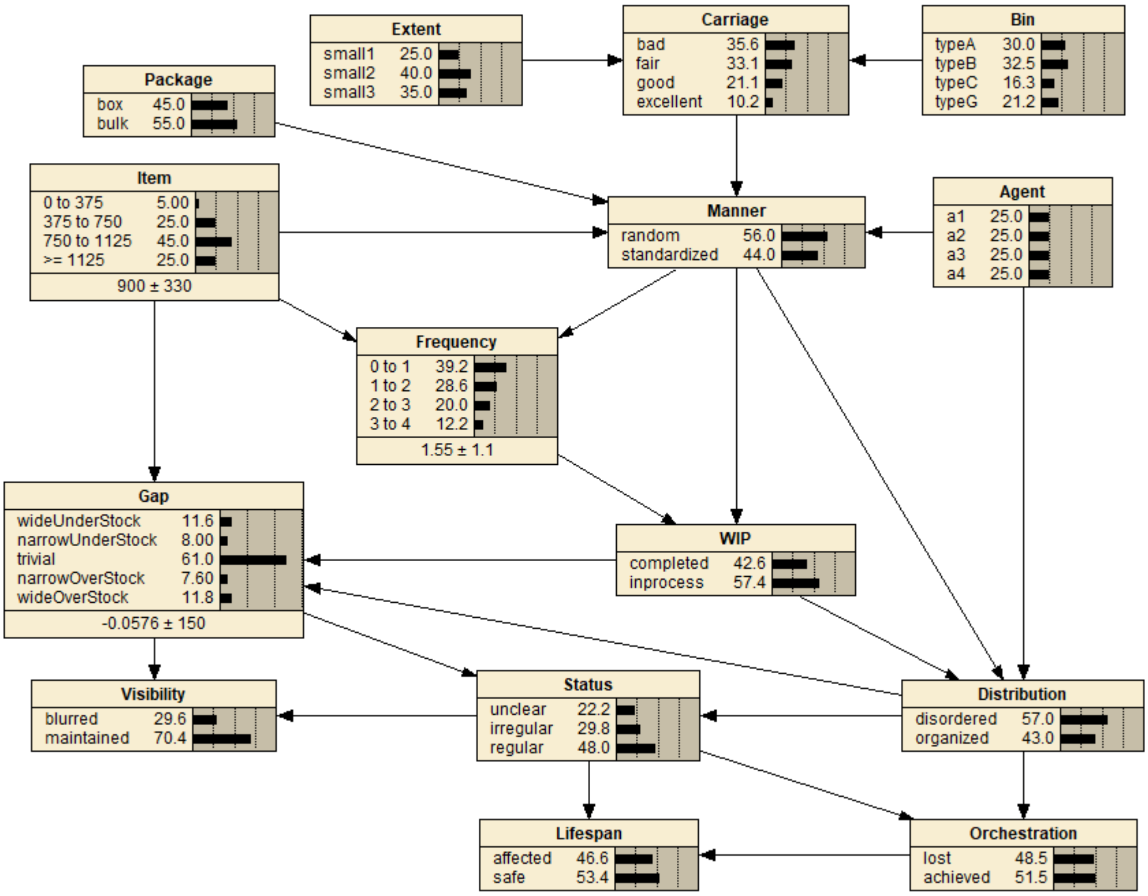

Figure 4. 36: Proposed Bayesian Belief Network.

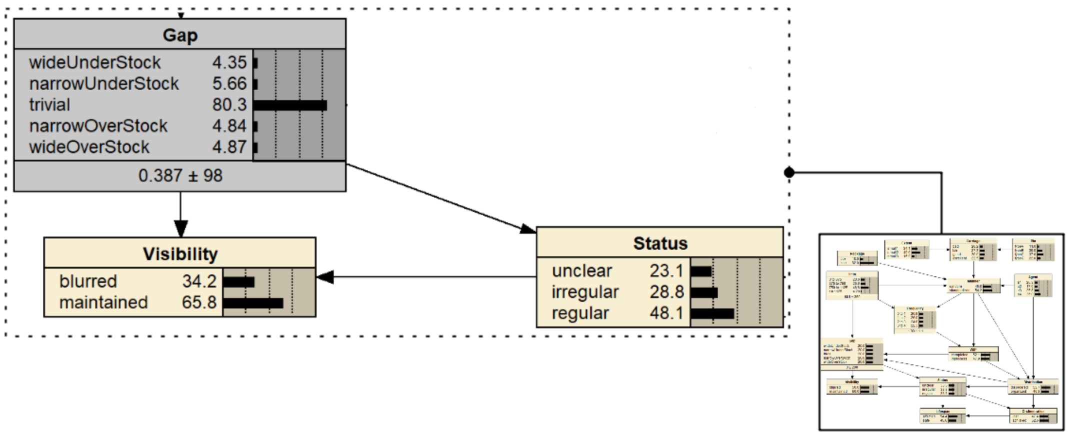

Figure 4. 37: Example from the proposed BBN.

This naïve Bayes network still need training to produce accurate information and perform efficient computation. This supervised learning process involves parameters and structure learning, and it aims to update the conditional probabilities tables (CPT).

Given a set of training data D= {u_1,…, u_n} that is composed of instances U (variables), the training should find a network B that best matches D. Two main approaches, including those based on conditional independence tests and on a scoring function and a search model are used for learning (Acid et al., 2004).

Here, we use the expectation–maximization (EM) technique since it tolerates incomplete and missing data (Tembo et al., 2016). This iterative algorithm starts with an estimation of missing variables in the dataset (E-Mode). Next, during the "M-mode", the parameters are optimized until the model fits the best possible explanation of data.

For data training, we fuse the knowledge from domain experts and the collected data. The following table shows the data used for training (100 patterns), where incomplete data are shown as (*). For the sake of visibility, the provided table is a screenshot from xlsx datasheet.

IDnum	Extent	Bin	Carriage	Package	Agent	Item	Manner	Frequency	WIP	Gap	Distribution	Status	Visibility	Orchestration	Lifespan
1	small1	typeG	good	bulk	a2	7888	standardized	3	completed	14	organized	regular	maintained	lost	safe
2	small1	typeB	fair	box	a2	232	standardized	1	inprocess	14	organized	regular	maintained	achieved	safe
3	small2	typeB	bad	box	a4	2784	random	3	inprocess	1304,5	disordered	irregular	blurred	lost	affected
4	small2	typeB	fair	bulk	a3	1624	random	4	inprocess	1209	disordered	irregular	blurred	lost	affected
5	small1	typeA	fair	bulk	a1	464	random	1	inprocess	209	disordered	unclear	maintained	lost	affected
6	small2	typeC	fair	box	a1	5232	standardized	3	completed	1114,5	organized	irregular	blurred	lost	affected
7	small2	typeC	good	box	a1	1856	standardized	2	inprocess	1022,5	organized	irregular	blurred	lost	affected
8	small1	typeC	good	box	a4	1624	random	4	inprocess	809	disordered	irregular	blurred	lost	affected
9	small3	typeB	bad	box	a4	2326	random	4	inprocess	809	disordered	irregular	blurred	achieved	safe
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
100	small2	typeG	good	box	a4	3232	standardized	3	completed	704,5	organized	irregular	blurred	lost	affected

Table 4. 11: Patterns used for training the prosed model.

Using, the software "Netica", the performance of training according to three criteria confusion matrix, scoring rules, and sensitivity is evaluated (figure 4.38). Note that the used data for test is called cases, which are randomly generated from the network. The following figure sum up the main obtained results.

```
Confusion:
  .......Predicted......
  unclea  irregu  regula    Actual
  ------  ------  ------    ------
       2       1       0    unclear
       1       3       1    irregular
       0       0      92    regular

Error rate = 3%
```

```
Scoring Rule Results:
  Logarithmic loss = 0.04229
  Quadratic loss   = 0.03087
  Spherical payoff = 0.9821
```

```
Sensitivity of 'Status' to a finding at another node:

Node                     Mutual      Percent    Variance of
----                     Info                   Beliefs
Gap                      0.38933     34.3       0.0666138
Distribution             0.12219     10.8       0.0243731
WIP                      0.06057     5.34       0.0119078
```

Figure 4. 38: Performance criteria as shown in Netica.

In the blue shape, the table shows (for Status node) the actual and the predicted states. The error rate (3%) indicates a high performance of the trained model.

For scoring rule (Pearl, 1978) (in red shape), the results show how well the actual belief levels agree with those in the testing case. This rule allows measuring the accuracy of probabilistic predictions. In our case, given the logarithmic and quadratic losses are close to 0, and the spherical payoff is close to 1, the proposed model provides best performance.

In case of sensitivity analysis (yellow shape), we measure the independence between various nodes, specifically a node could change the beliefs at another (posterior probability). For example, the status is most influenced by the Gap (Mutual Info=0,38933), which make the most variance in beliefs compared to Distribution and WIP.

4.6.2 Usage scenarios

Using the developed Bayesian network, the proposed intelligent traceability solution now endowed with several inference tools such as diagnosing inference and decision graph. These capabilities are illustrated through the following two plausible scenarios, where we used BayesServer API (Scanagatta et al., 2019) to show simple using interfaces.

- **Scenario 1:** One can supervise continuously the whole attributes related to the status of raw materials, and thus determine approximatively if an unconformity would exist (diagnostic).

During the morning shift, the production manager suspects that the manner, in which the distribution is done, is random (p (M=random) = 100%). Based on such belief, the manager wants to supervise the status of other activities (i.e., WIP and the number of cycles needed to perform this task) to anticipate any possible actions.

By querying the system (figure 4.39), it is shown that these activities would present some dysfunctional issue for the whole distribution process, especially if distributors are making more or less than 4 distribution cycles, in this case the work in progress in the assembly line is likely to be incomplete (in process). Given this new information, the manager could intervene to adjust the situation (i.e., demand more distributors for the specified assembly line to maintain the cycles around 4).

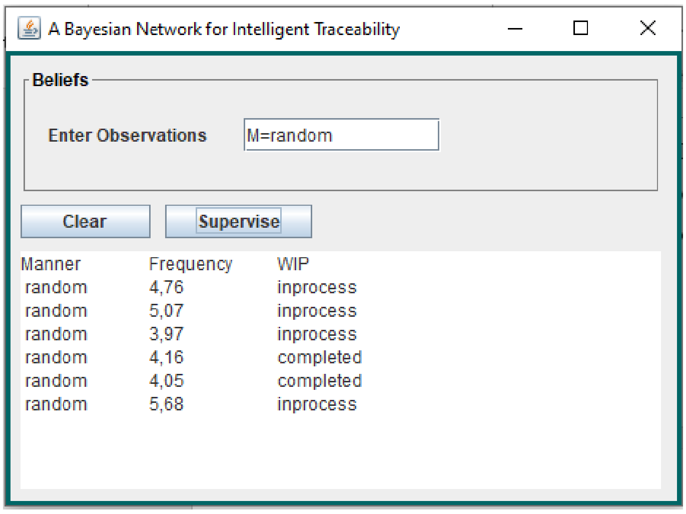

Figure 4. 39: Probabilities for a random manner of material distribution.

- **Scenario 2:** One can make predictions to support the decision-making under uncertainty. This scenario uses a decision graph derived from the structure of knowledge (figure 4.40). Note that the blue node represents the decision to make and the utility gain/cost are in red color.

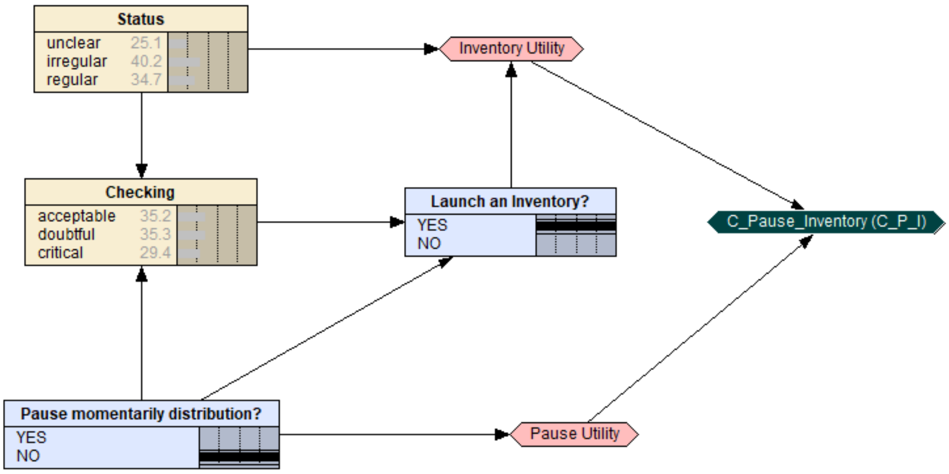

Figure 4. 40: Decision graph for launching inventory.

Now, assuming, a supply manager must decide either to launch an inventory of raw materials or not. In this case, He is uncertain whether the status of raw materials is regular, irregular or unclear. One option, among others, is to pause shortly the distribution flow between the supermarket and the assembly lines. Such an action will give the manager a closed reflection about the situation.

Thus, we see that the manager has indeed two decisions to make, whether to pause the distribution flow, then costing a delay, and whether to go directly to inventory gaining in time and effort. The developed decision graph assists the manager in taking the appropriate decision.

Here, the profit or loss depends on the quality of the decision he made. Solving the decision problem became a question of weighing the costs and gain with the probability distributions of variables.

Figure 4.41 shows a simple code where, a manager can request prediction from the developed decision graph. Here, the manager wants to know the status of the raw materials and upon this information take the appropriate decision. The status is unclear, the system recommends to launch an inventory, since the utility (C_P_I) is high. Here, the benefit is maximum expected utility, which combines both Pause and Inventory utility (benefits).

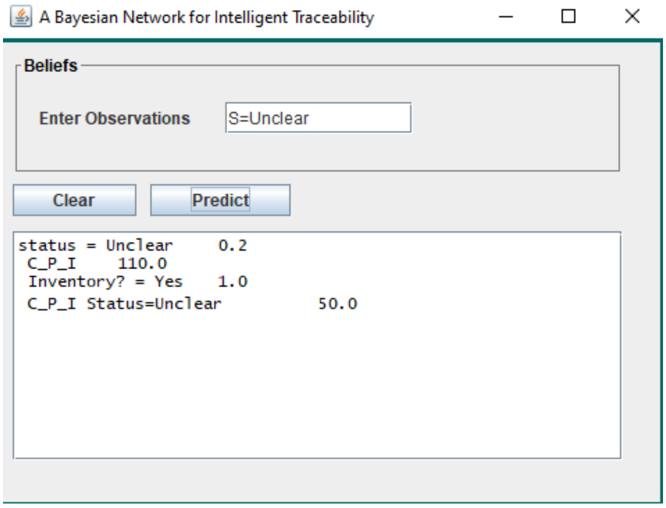

Figure 4. 41: Decision-making process using the decision graph.

4.7 Practical implications

The proposed solution is able to enhance different aspects of the supply chain of automotive assembly, especially vis-à-vis the supply and assembly operations (figure 4.42).

Besides, regulating the manner of collecting information in the supermarket zone (main source of the studied issue), the collecting activities might enhance the accuracy of the collected information and support the data management handled by the information system.

Another significant improvement related to the extraction of essential traceable data is obtained, specifically for tasks in progress (i.e., distribution of raw materials). Hence, using the knowledge-base (ITO), an operator can search for missing information rapidly and independently of the main information system (i.e., SAP), such feature would improve distributors' performance.

In addition, some issue, related to the mismatch between type or quantities of raw materials, can be solved as possible as they are detected thanks to the immediate retrieval activities (i.e., identification) that use the intermediate knowledge-base. Typically, standardizing the data-gathering process and optimizing the information retrieval sequence would have a significant and positive impact on the way of conducting the distribution process.

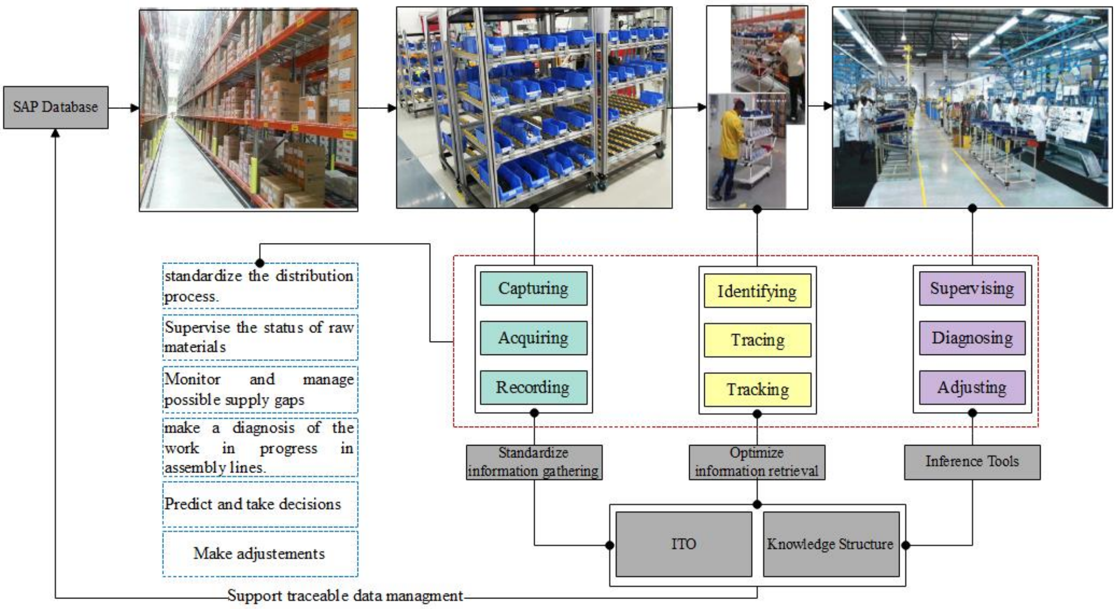

Figure 4. 42: Implications of intelligent traceability based on Bayesian network.

It has been confirmed that the status of raw materials remains unexpected, random, complex, and latent. Thus, prior suggested solutions were inefficient at combining all the available information and interactions to come to a rational decision.

Using Bayesian approach, intelligent traceability has intuitively identified and quantified causes, consequences, and preferences (probabilities). Such model can also learn new information based on observed data, update its knowledge about the dependence and independence of variables, and suggest a direction of causation.

This representation of knowledge was efficient for encoding the expert knowledge about this issue by the calculation of a probabilistic value that predict essential information for dealing with the status of raw materials. Therefore, taking into account a priori knowledge of experts based on premises known or assumed, the proposed solution can derive logical conclusions to be true. Such conclusions are useful to improve the supply system for assembly lines, reduce overstocks, eliminate production ruptures, reduce non-value added and waste in the supply system of assembly lines, and ensure the traceability of raw materials leaving the supermarket.

5 Conclusion

These implementations have proven the effectiveness of the prosed generic model from an empirical stand point since the suggested intelligent traceability model was able to meet several challenges within different industrial environments. For examples, the developed prototypes have merged information from different supply chain stakeholders, also they were an effective way for handling critical situations (i.e., quality monitoring, technical assistance, and decision-making under uncertainty).

These solutions have also confirmed that the representation of knowledge and the inference mechanism are essential for designing intelligent traceability. Moreover, the generic model flexibility and scalability have been demonstrated thanks to the usage of soft computing techniques to solve the real-world problems (non-linear).

General Conclusion

General Conclusion

This study aimed to investigate traceability implementation, particularly in modern supply chain. This investigation was confronted with the various and sometimes conflicting notions from the research field of traceability. Therefore, the thesis has addressed this research field from three different perspectives, including theoretical, technological, and empirical. These angles of approach have been effective in understanding and clearing up many confusions (i.e., the usage of the general sense of traceability or using the words tracking, tracing, and traceability interchangeably).

The thesis has confirmed the general consensus on how much traceability is important for manufacturing (i.e., Industry 4.0) as well as the supply chain management, but it has also shown a few disagreements about what it is traceability and what are the properties that could and should have. Between this necessity for traceability and the divergence between its forms, this doctoral research has drawn a line that underlined the difference between a traceability system, as a solution for a situation, and the traceability as a set of concepts and standards. This distinction has proven the existence of a gap between the conceptualization and the implementation of traceability.

In the current work, it was found that there was a lack of consistency in using intelligent traceability systems, since there is no unanimous version of intelligent traceability. From researchers to practitioners, a few agreements were found on how intelligent traceability properties could be properly implemented. This research has also shown that no common framework to design or even compare these solutions exists. Such a situation might lead to confusion with respect to several aspects such as characteristics and implementation techniques.

Therefore, one major finding in this thesis is that the proposed generic model played a key role in facing both the theoretical and the practical challenges of traceability. With the help of the proposed model, the implementation process would be more goal-oriented, standardized, and efficient. Moreover, the proposed definition and characterization of intelligent traceability will help to extend the core-knowledge of traceability.

Also, the results have proven that the implementation of a general, interoperable, and intelligent traceability should be a central feature of a solution to ensure product monitoring and supply chain visibility. The generic model has proven its ability to provide a formal and structured way of viewing a traceability solution before and during its development and deployment, it has also shown effectiveness in fulfilling the need for establishing general traceability foundations.

Since, the model can operate independently of the product or the industry specificity, the bases would bridge the gap between a solution engineering and the traceability requirements. Also, the separation between aspects is essential when describing and comparing traceability systems. This distinction is also helpful when recommending solution improvements.

One can see that the implications form the thesis findings cover the theoretical and methodological aspect as well as the practical one. By combining methods from soft computing, systems engineering, and practical expertise, this study has confirmed the veracity of the hypothesis, responded to the research questions, and addressed several traceability challenges. Also, this whole five-year work has proven the necessity of cooperation between the academic branch and the industrial sector in order to achieve substantial and fruitful results.

The present research has indeed proven that traceability is an interdisciplinary research field that involve several natural sciences as well as social sciences. It is noteworthy that the implications and benefits of traceable information are still a clear area for further studies. While traceable information is relevant for production as well as supply chain, one could wonder about the scheme and the benefits of a "Big Traceable Data", especially for data sciences, Business Process Reengineering, and Business Intelligence. Also, when the treatment of traceable information can be helpful to support decision-making processes, it is presumed that the next research steps would more investigate a scheme of "Ambient-aware traceability". The current thesis focused and emphasized the importance of technological concerns. However, some studies could be done regarding further study angles (e.g., legislation, safety, and quality concern).

Scientific works and publications

Publications

- Bougdira, A., Akharraz, I. and Ahaitouf, A. (2020) *A computer-aided system for monitoring quality using traceable information*, International Journal of Computer Aided Engineering and Technology, Ahead of print.
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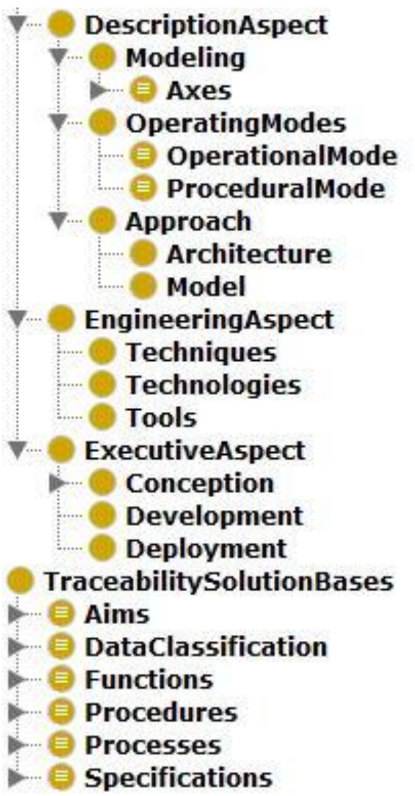
Appendix 1

Framework Formalization

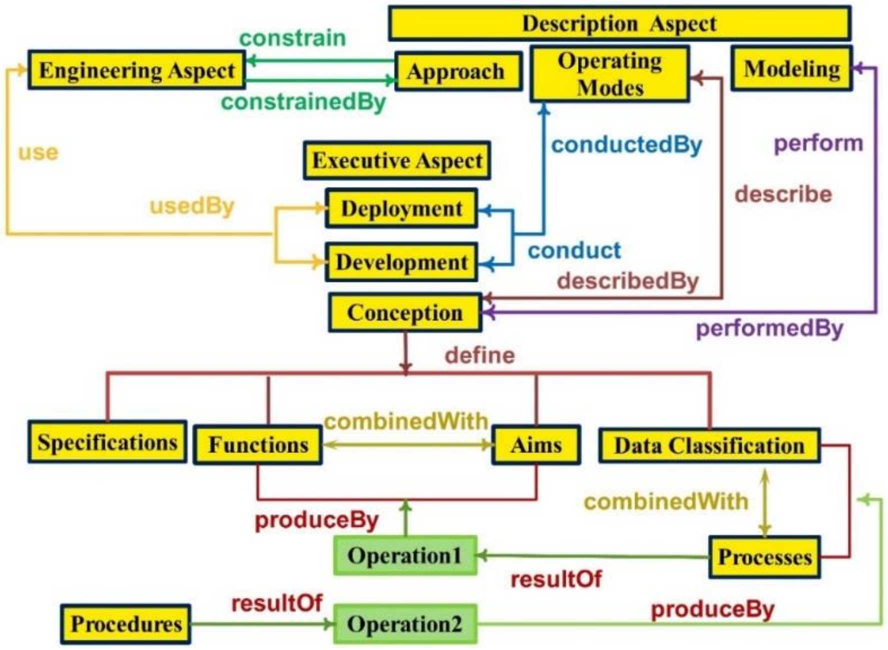
Formalizing the framework, in a logical way, eases its utilization and facilitates its adoption among different solution developers. Practically, the development of a traceability solution often requires different contributor and interdisciplinary analyzes and work. Hence, technical expertise and competences might be exchanged internally or externally, and also across several stakeholders (i.e., inside the same company or industry domain, and between different company or industry sectors).

The presented links are expected to simplify the usage of the framework. To this end, we intend to express these relationships using logical links. Therefore, we use Description logic (DL) and Ontology Language Web (OWL2) to formalize the framework. Due to the limitations of each one, the combination between languages enables user to define more expressive and decidable axioms that formulate the concepts (components and elements) and roles (framework links). Thus, one can fill the requirements for each framework component (i.e., Axes), and then launch the reasoning on framework functioning.



The proposed framework represented as an ontology.

Therefore, we construct an original ontology that represents the framework domain and the links between its entities. This ontology seeks to ensure optimal use and description of the framework components and functioning. The following shows the framework taxonomic hierarchy. Moreover, it shows the main framework relationships that are included inside the ontology. These links are the detailed using relationships formalized as DL links.



The links between aspects as described inside the ontology.

The suggested ontology can also describe the solution bases and provide a basis for product data management and information retrieval. Therefore, the ontology represents a considerable part of the needed data for traceability (figure 13). In this context, Magliulo et al. (2013) proposed to use ontology for managing the product data.

Thus, the framework as ontology is an important asset in establishing a common language and sharing standardized packages of data. The bases as ontology form the basis of a traceability knowledge base. This tool eases data management and helps to ensure semantic interoperability. Lusiantoro et al. (2018) noticed that the ability to share product information plays a key role, particularly in perishable product supply chains. Several publications have suggested using ontology as a core element of traceability systems (Salampasis et al., 2012; Pizzuti et al., 2017). Practically, each solution might have a specific knowledge base; hence, a user can interrogate the knowledge base and launch automated reasoning on data. The solution bases can express product data and its surroundings. Therefore, an application can be deployed using this knowledge base. This system can perform traceability tasks and communicate product information. The procedures can be used to question the knowledge base about information. If one needs product data, one uses the accessing procedure (users' authentication). Next, the identifying procedure indicates the product identity, owner and origin. The tracing procedure provides access to all product properties (i.e. ingredients and processing history). The tracking procedure enables users to follow the product geographically; hence, one could precisely know where an item came from and went. In addition to retrieving product information, these procedures help to monitor the product life cycle. For example, during storage, the controlling procedure permits supervising the temperature, making the proper diagnosis and taking the right decisions to ensure the product quality. Also, this traceability solution is expected to help stakeholders with both backwards and forwards analysis.

Examples of the framework formalization as relationships ontology (DL and OWL2):

Based on Figures 4 and 12, if a traceability system has to meet three requirements (a, b, c) and use
two axes (X, Y), three sets of modeling would exist, i.e. (Xa, Yb), (Xa, Yc) and (Xb, Yc). Using the syntax of SROIQ(D), the framework links can be described using the following examples:

$$(X_a \sqcup Y_b) \sqsubseteq \text{Axes} \sqsubseteq \text{DescriptionAspect}\top$$
$$(X_a \sqcup Y_c) \sqsubseteq \text{Axes} \sqsubseteq \text{DescriptionAspect}\top$$
$$(X_b \sqcup Y_c) \sqsubseteq \text{Axes} \sqsubseteq \text{DescriptionAspect}\top$$

The three equations signify that each union (⊔) of axes forms a set (i.e., Xa ⊔ Yb). Moreover, a set is a subclass (⊑) of Axes that are also a subclass of the top (⊤) class description aspect.

Next, a user performs the analysis of sets using a conception principle (the first stage of conception). Therefore, the analysis results in Aims, Functions, DataClassification, Specifications, OperationalMode, and ProceduralMode. The role (define) links conception to modeling and (describe) relates conception to operating modes. Assuming the scenario presented in subsection (3.3.1 Modeling: Axes and Principles), figure 13 shows the carried-out analysis represented as it is represented in the ontology. Herein, A correlation (i.e. correlation 1) means the application of the analysis to a group (BR, OR). Therefore, we can state:

$$\text{Conception} \equiv \text{ExecutiveAspect} \sqcap \exists\text{define.}(\text{Aims} \sqcup \text{Functions} \sqcup \text{DataClassification} \sqcup \text{Specifications}) \sqcup \exists\text{describe.OperatingModes} \sqcap \forall\text{perform.Axes} \sqsubseteq \text{Description Aspect}\top$$

Note that, conception is equivalent (≡) to the executive aspect' intersection (⊓) with [at least (∃) define one "base" which is the union (⊔) of (aims, functions, data classification, and specifications)], all these are the union (⊔) with [at least (∃) describe one operating modes that intersects (⊓) with only (∀) things (conception principles) that perform axes that are subclass(⊑) of the description aspect (top concept ⊤)].

$$\text{Processes} \equiv \text{Bases} \sqcap \exists\text{resultOf.Operation1} \sqcup \exists\text{producedBy}(\text{Aims combinedWith. Functions})$$

Next, one should use two other conception principles. The first principle performs operation1 that results in processes (the first operation in the second stage of conception). The processes belong to the bases and result from combining aims with functions.

$$\text{Procedures} \equiv \text{Bases} \sqcap \exists\text{resultOf.Operation2} \sqcup \exists\text{producedBy}(\text{Processes combinedWith.DataClassification})$$

The second principle performs operation2 that results in procedures (The second operation in the second stage of conception). The procedures belong to the bases and result from combining processes and data classification.

$$OperationalMode \equiv OperatingModes \sqcap \forall conduct.\ Development \sqcap \exists use.\ EngineeringAspect \sqcap \exists constrainedBy.\ Approach \sqsubseteq DescriptionAspect \top$$

In the same context, the operational mode provides the appropriate description (based on processes) to start the development step, which uses the engineering elements. These elements are conditioned by the defined approach.

$$ProceduralMode \equiv OperatingModes \sqcap \forall conduct.\ Deployment \sqcap \exists use.\ EngineeringAspect \top \sqcap \exists constrainedBy.\ Approach \sqsubseteq DescriptionAspect \top$$

The procedural mode provides the appropriate description (based on procedures) to start the deployment step that uses the engineering elements. These elements are conditioned by the defined approach

Appendix 2

Certification of implementation in New Peppers.

« INTELLIGENT TRACEABILITY FRAMEWORK »

Validation et Implémentation en Milieu Industriel

La présente attestation certifie que Mr **Abdesselam Bougdira** doctorant au Laboratoire des Sciences de l'Ingénieur (LSI), attaché au Centre d'Etudes Doctorales en Sciences et Techniques de l'Ingénieur (FST), a procédé à la modélisation et l'implémentation d'un système de traçabilité au profit de l'entreprise NEW PEPPERS (Pepp Africa).

Représentée par : Mr **El Mehdi Bennouna** En qualité du : **Directeur d'usine**

Date 23/07/2019

signature

Appendix 3

Certification of implementation in FrigoBouchata.

FRIGO BOUCHTA

Sté FRIGO BOUCHTA S.A.R.L
Zone Extra Portuaire
TAN-TAN PORT
RC N° : 475
Agrément N° : PP.68.4021.18

« INTELLIGENT TRACEABILITY FRAMEWORK »

Validation et Implémentation en Milieu Industriel

La présente attestation certifie que Mr **Abdesselam Bougdira** doctorant au Laboratoire des Sciences de l'Ingénieur (LSI), attaché au Centre d'Etudes Doctorales en Sciences et Techniques de l'Ingénieur (FST), a procédé à la modélisation et l'implémentation d'un système de traçabilité intelligente au profit de l'entreprise FRIGO BOUCHTA SARL.

Représentée par : Mr **AKHARRAZ Mohamed** En qualité du : **Directeur d'usine**

Date : 18/01/2020

signature

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Appendix 4

Certification of implementation in YAZAKI Morocco Meknes.

« INTELLIGENT TRACEABILITY FRAMEWORK »

Validation et Implémentation en Milieu Industriel

La présente attestation certifie que Mr **Abdesselam Bougdira** doctorant au Laboratoire des Sciences de l'Ingénieur (LSI), attaché au Centre d'Etudes Doctorales en Sciences et Techniques de l'Ingénieur (FST), a procédé à la modélisation et l'implémentation d'un système de traçabilité intelligente au profit de l'entreprise YAZAKI MOROCCO MEKNES………

Représentée par : Abdelhak BENFEDDOUL

En qualité du : Superviseur Logistique

Date 23/06/2020

signature

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كلية العلوم والتقنيات فاس
FACULTÉ DES SCIENCES ET TECHNIQUES DE FÈS

Centre d'Etudes Doctorales : Sciences et Techniques de l'Ingénieur

Titre de la thèse : A Generic model for Intelligent Traceability.

Nom du candidat : BOUGDIRA ABDESSELAM

Discipline : Sciences de l'Ingénieur

Spécialité : Systèmes intelligents

Résumé de la thèse

Ce mémoire de thèse a été consacré au développement d'un modèle générique pour l'implémentation de la traçabilité dans l'industrie moderne dont la tendance actuelle est à l'usine intelligente et à l'échange croissant de données hétérogènes et distribuées. Parallèlement, chaque solution de traçabilité est spécifiquement dédiée à un produit particulier et la plupart des solutions de traçabilité intelligente se différencient au vu des techniques et des technologies d'implémentations déployées. Dans ce contexte, nous avons avancé l'idée d'existence d'un écart entre la conceptualisation et l'implémentation d'une solution de traçabilité.

A cet effet, nous avons proposé un modèle générique qui vise à garantir une traçabilité générale, interopérable et intelligente. Ce modèle implique deux outils ; un Framework conceptuel et une caractérisation de la traçabilité intelligente. Le Framework introduit les bases d'une solution de traçabilité et conduit sa réalisation. La caractérisation de la traçabilité intelligente s'est appuyée sur la modélisation des informations de traçabilité et la mise en place du processus de prise de décision (apprentissage et raisonnement). Sur la base de ce modèle générique, nous avons développé une solution typique de traçabilité intelligente, comprenant des bases, une modélisation contextuelle des informations de traçabilité, une ontologie à usage général et un mécanisme de prise de décision. La faisabilité théorique du modèle a été démontrée par comparaison avec trois systèmes différents (pharmaceutique, céramique et bois), tandis que la faisabilité pratique a été démontrée par implémentation en milieu industriel (trois secteurs différents : industrie alimentaire, agriculture et automobile). À cette fin, trois prototypes de traçabilité intelligentes ont été développés et validés à l'aide de la logique floue, des réseaux de neurones artificiels, et des réseaux bayésiens.

Mots Clés : Intelligence Artificielle, Intelligence Ambiante, Soft Computing, Industrie 4.0, Traçabilité.

Laboratoire où la thèse a été préparée :

Laboratoire Sciences de l'Ingénieur (**LSI**)**, F**aculté **P**olydisciplinaire de **T**aza (**FTP**)

Université **S**idi **M**ohamed **B**en **A**bdellah, Fès