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Research article

Traceability in food supply chains: SME focused traceability framework for chain-wide quality and safety—Part 2

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Abstract: It is relevant for traceability systems to have a common structure for information exchange. Without it, these systems lose much of their utility as they will only be usable internally and will have reduced capacity to add value to products and manage recalls. Based on extensive literature review, a non-proprietary framework for traceability was developed. This framework encompasses whole food supply chains and aims to maintain records of quality and safety while not necessitating mature IT capabilities, uncommon characteristic of SME's. As such the volume of information is divided between all stakeholders according to their necessities and funding capacities. Most of the information is stored by regulators as they have access to more funding. This improves the ease and flexibility of implementation of traceability systems by the companies. Tools were developed and simulated, and all results are presented, clearly demonstrating the capability for quality information sharing through food supply chains which in turn can increase transparency between consumers and producers as well as adjusting the quality to the desired end use.

Keywords: traceability; framework; prototype; supply chain simulation

Abbreviations: IT: Information technologies; SME: Small and medium enterprise; IMM: Inventory management module; PSMM: Processing stage management module; OMM: Order management module; UCGM: Unique code generator module; QVM: Quality validation module; QATM: Quality after transport module; RFIC: Repository of information for final consumers; HACCP: Hazard analysis critical control points; IDC: Information for direct consumers; IFC: Information for final consumers; AC: Auxiliary comparator; FC: Final consumer; QAT: Quality after transport; QV: Quality validation; UC: Unique code; IDE: Integrated Development Environment; GUI: Graphical user interface; QMP: Quality measurement parameter; TRU: Traceable resource unit; T&T: Track and trace; CIP: Critical information points; EDI: Electronic data interchange; CSF: Critical success factor; FLS: Food logistics systems

1. Introduction

Food traceability is important to both consumers and corporations. It has the potential to benefit all parties in several different manners. For companies, the monitoring necessary helps quality control and product diversity. For consumers, the added information contributes to better choices according to whichever limitations they may have or characteristics they look for.

However, implementing traceability systems is not easy. There is not a common understanding in the definition of traceability and current traceability regulations are often cumbersome to enterprises and of little use for final consumers as they do not have access to most of that information [1,2]. Due to these circumstances and based on the review presented in part one of this study, the design science research method was used to elaborate a general-purpose traceability system that allows for the transmission of quality related information throughout food supply chains independently of the number of stakeholders and number of stages. Using this method, several traceability systems and concepts were analyzed with the intent to find the most common flaws, necessities, and opportunities, using the collected information to develop the traceability system presented in this study. This system is aimed mostly to SME's but usable by all, it is intended to be scalable, thus granting immunity to the length of the chain, but still affected by the amount of information, and immune to the commodities that are being dealt with.

The structure of this study consists in a summary of the review of the state of the art detailed in Part I of the study. Then, the traceability framework is presented. The model was purposefully kept at a high abstraction level as it is intended to facilitate the transition from none/paper-based traceability systems for companies with little resources and knowledge on how to do so. This system aims to be the beginning of automatic traceability where there was none and not necessarily the end goal. Afterwards, the developed tools are described. Finally, a simulation of a simple food supply chain using the traceability system developed is shown.

2. Literature review

Starting with the application of traceability systems and their granularity, Beulens et al. [3], Borit & Olsen [4], Hu et al. [5] and Parreño-Marchante et al. [6] applied traceability systems focused on multiple stakeholders. Shared information infrastructure and quality standards were necessary as well as regulatory compliance. Wang et al. [7], Li et al. [8], Lavelli [9], Trebar et al. [10], Liu et al. [11] and Wang et al. [12] dealt with applications of traceability systems using currently available technology. Traceability systems are illustrated as tools able to reduce waste and capital loss as well as better logistics and regulation compliance. Bollen et al. [13], Skoglund & Dejmek [14], Frosch et al. [15], Thakur et al. [16] and Karlsen et al. [17] presented measures to improve traceability systems. These improvements come in the form of models for fuzzy traceability, virtualization, to determine mixing and granularity. Huang et al. [18] and Pizzuti et al. [19] studied consumer access to traceability information. Traceability systems can have a profound impact in productivity, logistics and sustainability. To achieve those benefits, it is necessary to implement traceability correctly.

Although the presented systems fulfill the applications they were destined to, they sometimes lack comprehensiveness, are applicable to a single company in its present situation or are too demanding to SME's. Thus, rises the necessity of developing a traceability model that can be applied to an entire food supply chain, that is flexible enough to allow each company to adjust granularity, with reduced investment and that is also able to be developed and adapted over time.

Table 1. Review of application of traceability systems and granularity.

Authors	Products	Granularity	Important concepts
Beulens, Broens, Folstar et al. [3]	Eggs	Undisclosed	Shared quality standards, shared information infrastructure, prototype traceability system integrated in a SME supply chain
Borit & Olsen [4]	Fish	Dependent on the records of activity	Traceability as a tool to enforce regulations and quality
Hu, Zhang, Moga et al. [5]	Vegetables	Variable, dependent on the stakeholder	Supply chain traceability
Parreño-Marchante, Alvarez-Melcon, Trebar et al. [6]	Fish	Box	Application of a traceability system in two SME's
Wang, Kwok & Ip [7]	Undisclosed	Containers	Traceability as a tool to improve distribution and minimize capital loss and waste
Li, Qian, Yang et al. [8]	Cucumbers	Terrain lot	Traceability as tool to aid production and comply with regulations
Lavelli [9]	Poultry meat	Final product lot	Traceability as a tool to comply with regulations, fuzzy traceability
Trebar, LotriI, Fonda et al. [10]	Fish	Box	Supply chain traceability based on wireless sensors
Liu, Wang, Jia et al. [11]	Eggs	Dependent on the stakeholder	Real time traceability system in a Chinese egg supply chain
Wang, Fu, Fruk et al. [12]	Peach	Undisclosed	Sensor based supply chain traceability system
Bollen, Riden & Cox [13]	Apples	Output packages linked to input bins	Mixing causes traceability information loss, model to determine and minimize mixing
Skoglund & Dejmek [14]	Milk	Output packages linked to input silos	Fuzzy traceability, batch virtualization, mixing algorithm
Frosch, Randrup & Frederiksen [15]	Fish	Output lots liked to fishing vessels	Measures to improve traceability in a manual traceability system scenario
Thakur, Martens & Hurburgh [16]	Grain	Shipment to customer	Implementation of traceability in a heavy mixing scenario, quality evaluation
Karlsen, Sørensen, Forås et al. [17]	Fish	Several tested	Impact of granularity in the usefulness and cost of a traceability system
Huang, Zhang & Zhao [18]	Red jujubes	Final product batch	Consumer access to traceability information, traceability system composed by several different subsystems
Pizzuti, Mirabelli, Gómez-González et al. [19]	Frozen vegetables	Dependent of the company	Model for frozen vegetables, supply chain traceability

Some authors discuss their benefits, necessities, obstacles, and components. Gessner et al. [20], Jedermann & Lang [21], Aung & Chang [22] and Matzembacher et al. [23] discussed the need for traceability systems due to the current difficulty in dealing with food crisis. Dabbene et al. [24], Hsiao & Huang [25], Dandage et al. [26], Raak et al. [27] and Ndraha et al. [28] proposed traceability systems as tool to reduce recalls and waste and increase transparency, regulatory compliance and monitoring capabilities. Chrysochou et al. [29], Bosona & Gebresenbet [30], Asioli et al. [31], Germani et al. [32], Thakur & Forås [33] and Stranieri et al. [34] studied the circumstances that led to the adoption of traceability systems due to optimization opportunities, consumer needs and subjection of perishables to unforeseen variations. Jansen-Vullers et al. [35], Regattieri et al. [36], Donnelly et al. [37], Storøy et al. [38], Aiello et al. [39], Olsen & Borit [40] and Óskarsdóttir & Oddsson [41] studied the requirements and elements, whether conceptual or technical that should be considered and implemented in traceability systems. The necessity of traceability systems is clearly demonstrated by the need for regulatory compliance, consumer demand for safety, quality and transparency, corporate necessity to avoid fraudulent activity and inability to efficiently execute a recall. Although recalls may have several causes, being unable to adequately remove unsafe products can have severe consequences as food crisis and their associated impact on society. Thus, traceability systems can increase security and quality, optimize logistics and production, potentiate capital gains, and increase consumer satisfaction. To achieve these results, traceability systems must be able to model the supply chain, the companies using them, and all transformations associated. To have those abilities, it is necessary to identify all batches, whether inputs or outputs, document all operations over batches and communicate all information to an impartial authority able to scientifically assess the validity of the information. Still, there are several obstacles that restraint the development and deployment of traceability systems. These include, high costs, reduced available information and capacity to operate the systems, reluctance to the implementation by business partners and lack of an information sharing structure. To effectively develop and implement comprehensive chain-wide traceability systems, these issues need to be addressed, if not, traceability systems will lose most of their utility and benefits. Useful tools to incorporate in traceability systems were described by Sloof et al. [42], Hsu et al. [43], Heese [44], Xiaofeng et al. [45], Kwok et al. [46], Woo et al. [47], Hu et al. [48], Bakker et al. [49], Wang & Li [50], Verdouw et al. [51], Pahl & Voß [52], Hertog et al. [53], Qian et al. [54] and Óskarsdóttir & Oddsson [41]. Mainly, these authors describe elements that could be useful additions to traceability systems on an internal level. These elements come mostly in the form of models and algorithms for tasks as diverse as determining granularity, internal modeling, quality decay, contamination, and allocation of commodities. Bechini et al. [56], Kelepouris et al. [57], Bechini et al. [58], Thakur & Hurburgh [59], Olsen & Aschan [60] and Thakur et al. [61] presented elements that could be useful on an external level. They comprehend traceability models and methods to elaborate those same models. Van Der Vorst et al. [62], Zhou et al. [63], Karlsen et al. [64], Grunow & Piramuthu [65], Piramuthu et al. [66], Jedermann et al. et al. [67], Badia-Melis et al. [68], Saak [69] and Gaukler et al. [70] discussed pertinent topics in the context of traceability systems. These include models as First In First Out (FIFO), First Expired First Out (FEFO), Least Shelf-Life First Out (LSFO), information sharing, granularity, expiration dates and recall efficiency. It can be quite useful to be attentive to these subjects as they can substantially and positively alter a traceability system according to corporate means and necessities. Tables 1 through 3 summarize the scientific research analyzed and the main concepts that were considered relevant for the application of traceability systems. Table 1 gathers the application of traceability systems and granularity. Table 2 shows the scientific research covering the benefits, necessity, requirements, obstacles, and components of traceability systems. Table 3 includes important concepts concerning models, methods, algorithms, and supply chain management.

Table 2. Scientific research covering the benefits, necessity, requirements, obstacles, and components of traceability systems.

Authors	Important concepts
Gessner, Volonino & Fish [20]	Advantages of using IT technology to record information and necessity of traceability systems to avoid alimentary crisis
Jedermann & Lang [21]	Necessity of quality monitoring traceability systems due to the subjection of products to greater variations than expected
Aung & Chang [22]	Necessity of traceability systems due to the impact of food crisis, characterization of traceability systems and benefits of application
Matzembacher, Stangherlin, Slongo et al. [23]	Corporate inability to provide useful and timely data for the resolution of food crisis, consumers' willingness to pay for information, advantages and obstacles of food traceability systems
Dabbene, Gay & Tortia [24]	Causes and consequences of recalls, traceability systems proposed as solution, performance indicators of those systems and levels of regulation
Hsiao & Huang [25]	Need for traceability systems to increase transparency in information exchange
Dandage, Badia-Melis & Ruiz-García [26]	Traceability systems as tools to avoid waste, fraud and insecurity
Raak, Symmank, Zahn et al. [27]	Causes of waste and traceability systems as tools to avoid it
Ndraha, Hsiao, Vlajic et al. [28]	Traceability systems as tools to prevent temperature abuse in food supply chains
Chrysochou, Chryssochoidis & Kehagia [29]	Consumers' need for information and impact of that information
Bosona & Gebresenbet [30]	Increase in supply chain logistic efficiency, main driving forces behind the development of traceability systems, advantages and obstacles
Asioli, Boecker & Canavari [31]	Review on the factors that led Italian wine companies to implement traceability systems and cost benefit description
Germani, Mandolini, Marconi et al. [32]	Monitoring elements that have an impact in sustainability can lead to opportunities to process optimization
Thakur & Forås [33]	Demonstration of variations subjected to products
Stranieri, Cavaliere & Banterle [34]	Factors leading to the adoption of traceability systems and corporate necessities
Jansen-Vullers, van Dorp & Beulens [35]	Elements and requirements of traceability systems
Regattieri, Gamberi, Manzini Department [36]	Pillars of traceability systems, consequences of inadequate information exposition, benefits and requirements of efficient traceability systems
Donnelly, Karlsen & Olsen [37]	Necessity of recording information about transformations applied to products
Storøy, Thakur & Olsen [38]	General principles of traceability systems, review on the state of information exchange and necessity of safety guarantees for information exchange
Aiello, Enea & Muriana [39]	Benefits and obstacles of RFID based traceability systems and model to assess optimal granularity
Olsen & Borit [40]	Essential components of traceability systems and useful questions for performance evaluation
Óskarsdóttir & Oddsson [41]	Necessity of traceability systems to monitor quality and technology capable of being incorporated on a traceability system

Table 3. Important concepts concerning models, methods, algorithms, and supply chain management.

Authors	Important concepts
Sloof, Tijskens & Wilkinson [42]	Quality modeling through variation of inherent properties and the value consumers attribute to them
Hsu, Hung & Li [43]	Algorithm for distribution of perishables based on their deliverance at the highest possible quality
Heese [44]	Inventory management using wireless sensors
Xiaofeng, Tang & Huang [45]	Model for the correct allocation of commodities in order to maximize profit
Kwok, Tsang, Ting et al. [46]	System model and software for wireless sensor-based product authentication
Woo, Choi, Kwak et al. [47]	Model for sensor-based traceability system using the ER model adding the temporal dimension
Hu, Jian, Ping et al. [48]	Model for a traceability system usable in high probability of contamination scenarios and algorithm to determine contamination
Bakker, Riezebos & Teunter [49]	Necessity of inventory management as a part of traceability systems to monitor heterogeneous quality decay
Wang & Li [50]	Fixed expiration dates are inefficient to expose variations subjected to products; Algorithm to apply discount according to quality variation to keep demand
Verdouw, Beulens & van der Vorst [51]	Method to virtualize operations based on the IoT perspective
Pahl & Voß [52]	Algorithms to determine deterioration of food perishables
Hertog, Uysal, McCarthy et al. [53]	Algorithm to evaluate quality decay and to distribute perishables based in FEFO
Qian, Fan, Wu et al. [54]	Methodology to determine optimal granularity
Óskarsdóttir & Oddsson [41]	Methodology to select the most appropriate technology to incorporate in a traceability system
Bechini, Cimino, Lazzerini et al. [56]	Simple architecture for traceability systems
Kelepouris, Pramatari & Doukidis [57]	Model for agricultural traceability system based on RFID and EPC
Bechini, Cimino, Marcelloni et al. [58]	Model for information sharing between stakeholders in a supply chain based on XML
Thakur & Hurburgh [59]	Methods to elaborate internal and external traceability models
Olsen & Aschan [60]	Benefits of traceability systems and methodology for modeling food supply chains
Thakur, Sørensen, Bjørnson et al. [61]	Framework for traceability using EPCIS and RFID
van der Vorst, Tromp & van der Zee [62]	Comparison of LSFO versus FIFO in a supply chain, use of max., min., and avg. values to determine the quality uncertainty
Zhou, Tu & Piramuthu [63]	Review on information sharing between sellers and buyers
Karlsen, Dreyer, Olsen et al. [64]	Discussion on granularity and its effect on traceability
Grunow & Piramuthu [65]	Fixed expiration dates as inefficient means to assess product quality and models to determine quality using RFID and profit analysis
Piramuthu, Farahani & Grunow [66]	Traceability systems as tools to increase recall efficiency and model to determine economic loss reduction due to the use of those systems
Jedermann, Nicometo, Uysal et al. [67]	FIFO versus FEFO and LSFO
Badia-Melis, Mishra & Ruiz-García [68]	Review on trends and necessities of traceability systems, concept of CTE; FTTO and the TraceFood, FIFO vs FEFO and FCM to determine mixing
Saak [69]	Increase in product value due to information provided by traceability systems
Gaukler, Ketzenberg & Salin [70]	Benefits of dynamic expiration dates per opposition to fixed expiration dates

3. Traceability framework

3.1. Overview

This model aims to include consumers, enterprises, and regulators. As enterprises produce, they also monitor quality. When a company wishes to sell their products that information is relayed to regulators. Regulators will then recalculate quality according to the information given and will validate or not the transaction of certain products according to the result of the calculation. Consumers have a repository of information in which they can view the cumulative history of a product if they wish to. The traceability system defines at each stage the "Quality" and the "algorithm used to assess quality" to increase transparency in the food chain as anyone would be able to identify how quality was determined. To organize the model, it was divided into layers, according to the stakeholder involved, and into segments, each meaning to divide productive activity according to the most significant means of acquisition of materials. The only exception is the fourth segment whose purpose is to identify final consumers and their interaction with the rest of the stakeholders. Figure 1 shows the model. In this model are several modules, each responsible for certain tasks according to the manner of reception and transmission of information. The inventory management module (IMM) is responsible for accompanying all variations in quality of items resting in inventory.

The processing stage management module (PSMM) is responsible for accompanying all variations in quality of materials being processed.

The order management module (OMM) is responsible for the handling of orders by predicting transport routes and quality variations during transport.

The unique code generator module (UCGM) is responsible for identifying validated items for sale.

The quality validation module (QVM) is responsible for evaluating data and validate or not items for sale.

The quality after transport module (QATM) is responsible for the determination of quality of materials at arrival. The repository of information for final consumers (RIFC) is responsible for allowing access to product history to consumers.

3.2. First segment

The first segment functions by obtaining raw materials, identifying them, evaluating their quality, and keeping quality using scientific methods and using all that information as input to the IMM. As materials are required for processing, the PSMM fetches data from the IMM, which kept records of inventory conditions and their impact in quality and keeping quality for as long as the items remained in inventory and uses that data and process relative data to identify processing stage exits and their quality and keeping quality and uses that data as new input for IMM. It is recommended that should be one PSMM per HACCP flow chart stage or equivalent. As orders are received the OMM handles all information requests and fetches data form both IMM and PSMM to generate the information for direct consumer (IDC) and the information for final consumer (IFC) files. The first contains more technical information relative to constituents of a product and its quality/keeping quality history. The second is composed by data comprehensible by the final consumers. The OMM relays this data to the QVM, which will compare all commonly indexed data between files and recalculate all quality and keeping quality evaluations to detect the existence of non-compliant or fraudulent activity. According to the result of that evaluation the products marked for validation may or may not be accepted by the QVM. If any is valid, the QVM will relay information to the UCGM which will uniquely identify valid products and the IFC will be relayed to the RIFC. IDC and IFC will be relayed back to OMM to inform the respective company of the ability to trade the products validated. The OMM will then pass the IDC file to the buyer in the second segment. Figure 2 presents the first segment.

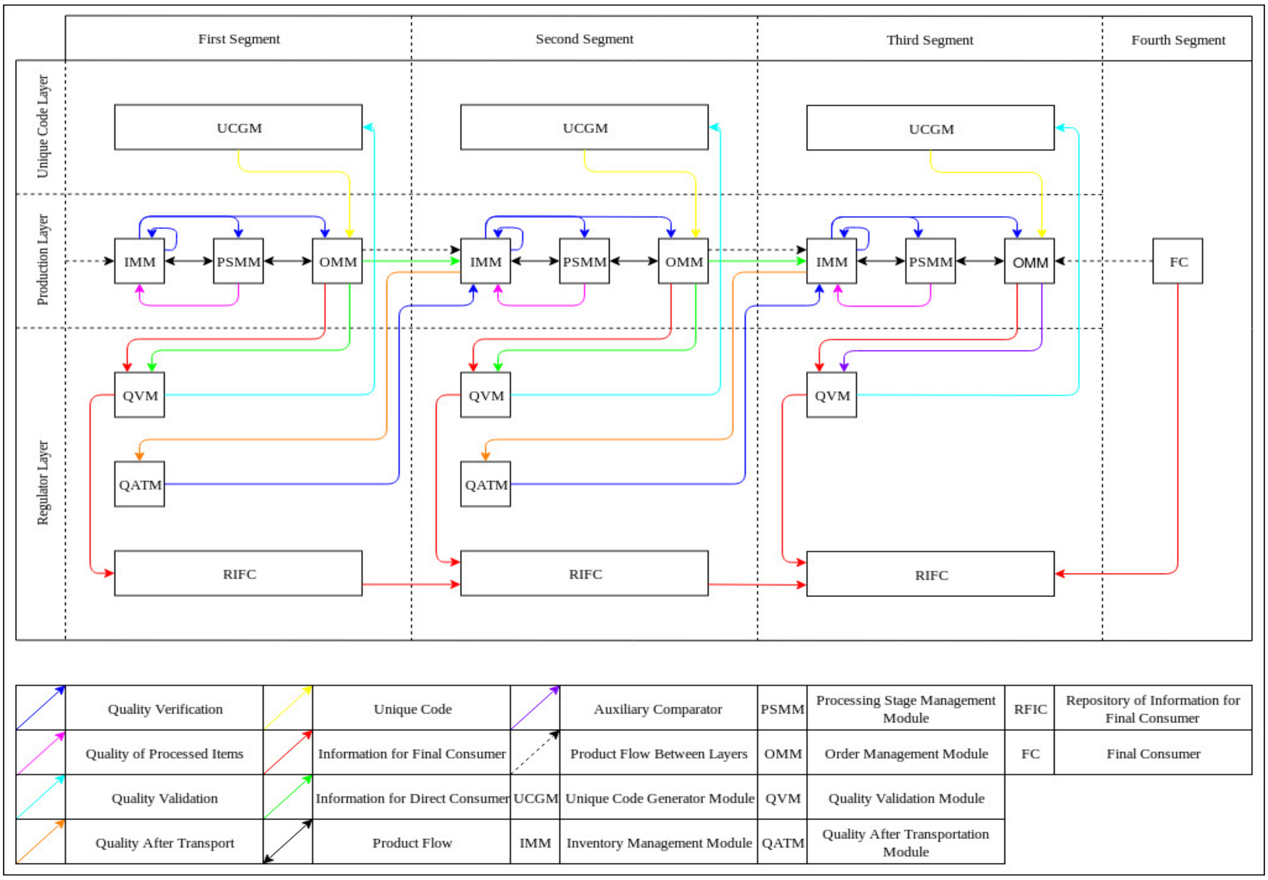

Figure 1. Traceability framework complete model.

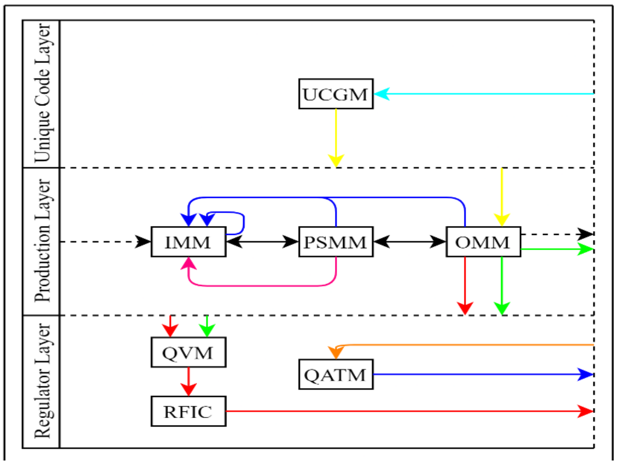

Figure 2. First segment.

3.3. Second segment

The only difference of this segment the former is the use of the QATM to compare if the quality and keeping quality of a delivered product corresponds to what was promised by the seller. Data provided from the QATM becomes input for the IMM. Figure 3 presents this segment.

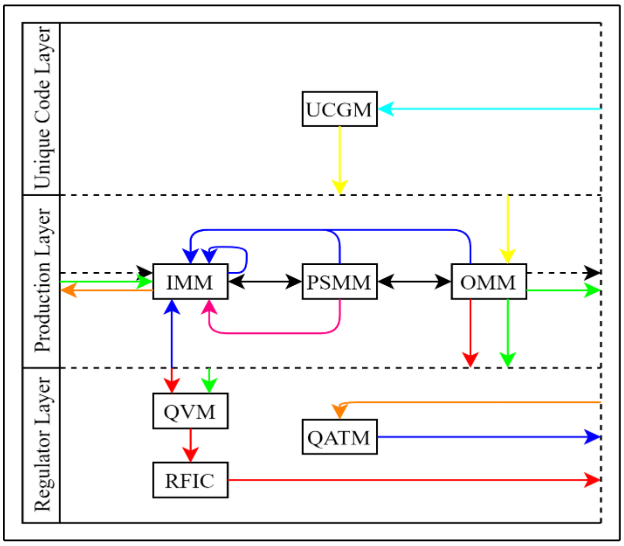

Figure 3. Second segment.

3.4. Third segment

As in this segment the final consumer is also the direct consumer, it is not considered reasonable to generate both IDC and IFC. As such only IFC is generated, but this causes an issue, the absence of commonly indexed data for external evaluation. To resolve this problem, an auxiliary comparator (AC) is generated just to inform the QVM which data to evaluate and validate. Figure 4 presents this segment.

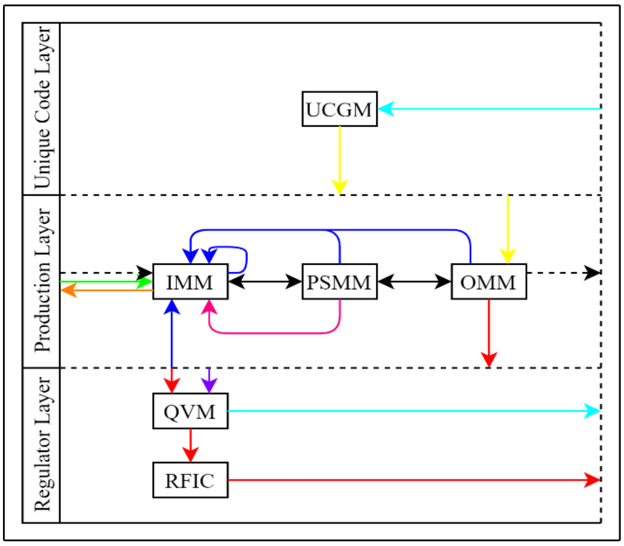

Figure 4. Third segment.

3.5. Fourth segment

This segment is composed solely by the final consumer (FC). The FC will make use of the RFIC to access the cumulative history of a process and will “hop” from IFC to IFC using the external identifiers provided by the UCGM.

3.6. Archetypes for shared files

This section aims to illustrate the structure of the files that should be shared to comply with the framework such as the IFC, IDC, QAT, QV and UC. However, the files as presented are not the maximum limit of information that is acceptable but, instead, a generalized minimum as different supply chains have different needs. Thus, it may be necessary to modify the structure of the files according to the application context. Even though each chain is subjected to different rules and regulations that does not necessarily mean that the information collected is understandable by the consumers. Also, it cannot be expected, especially from end consumers, be aware of all the vocabulary and meanings used in any given chain. So, to remove cumbersome technicalities, a simpler format of information was developed. However, all that technical information should still circulate between interested stakeholders and comply with the full extent of the law.

3.7. Information for final consumers

This file is the less strict in terms of structure and can be used as a marketing tool since the quality and history of the product is verified externally. Marked in red in Table 1 are the mandatory fields. However, it is highly recommended to include a description of all stages of production and their effect on quality. To facilitate the comprehension of the table, three materials will be turned into products in a one-to-one relationship. Raw material X will become A, then D and finally G; similarly, Y and Z will become B and C, then E and F and finally H and I, respectively. Also, only two production stages are demonstrated. If more stages exist or if mixing is to be considered, one will need to add more columns to the table with the same structure as presented in the Table 4 or have a one-to-many relationship, i.e., three components and one exit, or vice-versa.

The fields of the file are:

- Component ID—this mandatory field indicates the entry ID of a component. With this ID a consumer can look for the history of that component on the IFC file of the company who sold it.
- Company ID—this field indicates the company who accepted the commodity, and for that reason, is mandatory.
- Start Date—indicates when the goods entered the inventory of the above company. This provides the consumer with a better perspective of the age of the perishable, hence its mandatory nature.
- Start Quality—indicates the quality of the goods when they entered inventory. It is also an instrumental value to illustrate the quality of raw materials and so is mandatory.
- Description—simply serves to describe the commodities.
- Inventory QMP—presents the value of the quality measurement parameter in the inventory when the goods enter it. For the sake of simplicity, only one quality measurement parameter was

used to illustrate this field. If more parameters were used, then more columns would have to be added to the table and each correctly identified.

- Inventory Algorithm—presents the identifier of the algorithm used to assess quality.
- Inventory Exit Quality—presents the quality of the goods when they leave inventory to enter processing.
- Production Stage 1 Components—identifies the goods that enter the first stage of processing.
- Production Stage 1 Description—describes what happens in the first stage of production.
- Stage 1 Date—indicates when the goods enter the first processing stage.
- Stage 1 QMP—indicates the value of the quality measurement parameter relative to this first stage. Likewise, to Inventory QMP, more columns would have to be added and identified if more quality measurement parameters were used.
- Stage 1 Algorithm—identifies the algorithm used to assess quality during this stage.
- Stage 1 Exit Quality—presents the quality of a perishable when it leaves the first stage.
- Stage 1 Exit ID—presents the identifier attributed to the perishable when it leaves the first stage and enters inventory as an intermediary product.
- Production Stage N Components—identifies the goods that enter the last stage of processing.
- Production Stage N Description—describes what happens in the last stage of production.
- Stage N Date—indicates when the goods enter the last processing stage.
- Stage N QMP—indicates the value of the quality measurement parameter relative to this last stage. Likewise, Inventory QMP, more columns would have to be added and identified if more quality measurement parameters were used.
- Stage N Algorithm—identifies the algorithm used to assess quality during this stage.
- Stage N Exit Quality—presents the quality of a perishable when it leaves the last stage.
- Stage N Exit ID—presents the identifier attributed to the perishable when it leaves the last stage and enters inventory as a final product.
- End Date—indicates when the product leaves the company.
- End QMP—indicates the value of the quality measurement parameter when the product leaves the company.
- End Algorithm—identifies the algorithm being used for the final product in inventory at the moment the commodity exits the company.
- End Quality—indicates the quality of the product when it leaves the company. This is another instrumental parameter for an end user to assess and then decide what to buy and so, it is mandatory.
- Exit Internal ID—identifies the commodity internally at the moment of departure from inventory.
- Exit External ID—identifies the commodity as it leaves inventory. This value is crucial for the end user as it is the code that the user will use to search for the history of the product and because of that it is a mandatory field.

Table 4. Information for final consumer (IFC) example.

Component ID	Company ID	Start Date	Start Quality	Description	Inventory QMP	Inventory Algorithm	Inventory Exit Quality
X ID	Company ID	dd/mm/yy h:m	X hours	Description of X	X QMP value	X Algorithm ID	X hours
Y ID	Company ID	dd/mm/yy h:m	Y hours	Description of Y	Y QMP value	Y Algorithm ID	Y hours
Z ID	Company ID	dd/mm/yy h:m	Z hours	Description of Z	Z QMP value	Z Algorithm ID	Z hours
Production Stage 1 Components	Production Stage 1 Description	Production Stage 1 Date	Production Stage 1 QMP	Production Stage 1 Algorithm	Production Stage 1 Exit Quality	Production Stage 1 Exit ID	
X ID	In this stage X was done	dd/mm/yy h:m	X QMP value	X Algorithm ID	A hours	A ID	
YID	In this stage Y was done	dd/mm/yy h:m	Y QMP value	Y Algorithm ID	B hours	B ID	
Z ID	In this stage Z was done	dd/mm/yy h:m	Z QMP value	Z Algorithm ID	C hours	C ID	
Production Stage N Components	Production Stage N Description	Production Stage N Date	Production Stage N QMP	Production Stage N Algorithm	Production Stage N Exit Quality	Production Stage N Exit ID	
A ID	In this stage A was done	dd/mm/yy h:m	A QMP value	A Algorithm ID	D hours	D ID	
B ID	In this stage B was done	dd/mm/yy h:m	B QMP value	B Algorithm ID	E hours	E ID	
C ID	In this stage C was done	dd/mm/yy h:m	C QMP value	C Algorithm ID	F hours	F ID	
End Date	End QMP	End Algorithm	End Quality	End Internal ID	End External ID	Mark For Validation	
dd/mm/yy h:m	D QMP value	D Algorithm ID	D hours	D ID	G ID	YES	
dd/mm/yy h:m	E QMP value	E Algorithm ID	E hours	E ID	H ID	YES	
dd/mm/yy h:m	F QMP value	F Algorithm ID	F hours	F ID	I ID	YES	

3.8. Information for direct consumers

The structure of this file is more rigid. It must include the processing stages and more detailed, less end consumer friendly information about the processes that any given good was subjected to.

The structure of this file is identical to the Information for final consumers, albeit with all fields being mandatory. Some of its fields can be used as a marketing tool, but in a different, more appropriate manner since its target is a company and not an end consumer.

Such is not done in the information for final consumers file to prevent it from being overbearing to the end user.

3.9. Quality validation and unique code

This file is the same as IFC and IDC but with the products marked for validation given a unique code if external quality evaluation returns valid.

3.10. Quality after transport and quality verification

The quality after transport (QAT) file is to be started at a destination and to be finished at the QATM in the regulator layer. The objective of this communication is to externally and scientifically assess the quality of goods that arrived at a company. This allows the company an unbiased evaluation and verification if the quality of goods matches the one that was supposed to be delivered.

The fields to fill in this file are, also shown in Table 5:

- Seller Company ID—identifies who sold the perishables.
- Buying Company ID—identifies who bought the perishables.
- Product ID—identifies the products to be evaluated.
- Expected Quality—presents the quality that goods were supposed to have at arrival.
- Algorithm Used—identifies the algorithm used to assess quality.
- Evaluated QMP at Arrival—presents the value of a quality measurement parameter when the product was tested at arrival. As seen before, if more parameters are used, more columns must be used and correctly identified.
- Calculated Quality—this column is filled by the quality after transport module and contains the level of quality as evaluated using the previous field.
- Delta—indicates the difference between the expected quality and the real quality. This column is also filled by the quality after transport module.

Table 5. Quality after transport file example.

Seller Company ID	Buying Company ID	Product ID	Expected Quality
Seller ID	Buyer ID	Product ID	X hours
Algorithm Used	Evaluated QMP at Arrival	Calculated Quality	Delta
Algorithm ID	QMP value	Y hours	X-Y hours

Quality is easier perceived in the same way of keeping quality. For example, it is easier to coordinate operations knowing that a given material can be worked on to produce a product within the desired quality standards for a given number of hours instead of an amount of quality. Even still, quality is declared as it is necessary for calculations, including keeping quality calculations.

4. Materials and methods

4.1. Development environment

To choose the language to develop all modules presented in the traceability model, some requirements must be met. The language must be simple to learn and to teach, extremely versatile as it will be used for a multitude of different tasks and not be inherently computationally intensive. It is considered that the best language that fulfils those criteria is Python. There is a wide variety of free material that can be effectively used to learn the language and its syntax is quite simple and easy to begin using. It is widely used for very diverse functions including the web apps and servers, graphical interfaces, and data analysis.

Although Python 2 is still widely used, support ended in 2020, and Python 3 was used to future proof this project.

The only other required software is an Integrated Development Environment (IDE). In this case there is no selection process as Python is an interpreted language thus not needing a compiler. This means that any text editor can be used for development and testing can be done in a terminal. Microsoft Visual Studio Code was used to develop this prototype. It operates as a text editor with a direct connection to a terminal, making development less time consuming.

As an operating system (OS) Ubuntu 18.04 LTS was used. This choice not to use Windows was simply made due to the stability of this OS which is quite useful for testing purposes and to deploy servers. Although this change is not necessary, it is recommended.

Concerning the hardware used, a CPU Intel Core i7 3630QM with a frequency of 2.4GHz and 8GB of RAM. Although resource consumption was not measured, it was always considered by verifying the usage of those two components. It was never close to exceeding hardware capabilities at any given time.

As simulation will demonstrate, even by restricting the environment quite heavily, the system managed to operate correctly, thus testifying that traceability systems must be neither expensive nor hard to operate.

4.2. Production layer

As seen before, the production layer is divided into segments to better illustrate information flow. This layer is the most affected by the nature of the templates as there will have to be, in the very least, as many PSMM's as stages in the HACCP diagram. All others do not require extensive replication and adaptation to operate properly.

To avoid unnecessary repetition only the first segment will be discussed as it is very similar to the other segments.

4.3. Inventory management module

This GUI is composed by a window with three tabs. The first tab concerns new entries in inventory and the record of initial conditions. This submission tab is very simple in its constitution, requiring only quantity, class, the value of the quality measurement parameter and initial quality as inputs for new entries in inventory.

Submitting a new entry will cause a window to pop-up. This window contains data from the submission form show all gathered and calculated data, such as the identifier given to the new entry, necessary parameters for the determination of the keeping quality and its value.

The second tab in the GUI contains a table of all items in inventory. To further reduce resource consumption, the tab only shows a button at first. Pressing the button will display the table containing all items and the updated quality and keeping quality values.

The third tab contains an animated plot of the inventory QMP. For illustration purposes temperature variation is plotted as is the most common relevant parameter in agri-food supply chains. As the update interval can be freely changed, this tab functions as soon as the GUI is started. This means that the respective resource consumption can be easily controlled.

4.4. Processing stage management module

This module is very similar to the previous in the sense that the first tab queries the user for information relative to an operation stage. The second tab keeps record of all operations and the third shows a live plot of quality measurement parameters. To fully link product information throughout entire processes it is necessary for a PSMM to exist per HACCP flowchart stage or equivalent health and safety method. Doing so means that a cumulative product history can be kept. To create a new operation, it is simply necessary to press the "New Operation" button in the first tab.

Doing so causes a simple confirmation window to pop-up. This serves as a mere confirmation that a new operation was created.

After an operation is created, it will remain on standby until a new operation is created and will associate all entries and exits of that stage to that operation. As information is submitted, top level windows will appear and will contain all information recorded upon submission.

Like IMM's second tab, to access operational history a button must be pressed.

As mentioned, the third tab is a live plot of parameters that influence quality in a specific stage. This tab has the exact same appearance as IMM's third tab.

4.5. Order management module

This module consists of a web application made using the Flask framework. The rationale behind this choice is simple. Making a web application guarantees access anytime, anywhere with practically any modern device. Adding to that, Flask is very simple to learn and use, making possible for any entity to deploy a fully featured application easily and cheaply. As this is a prototype, this module contains only all the functionalities deemed essential for application in an enterprise following the traceability model proposed. This module is divided in two, between users and non-users. This division makes greatly increases the organization of this module, which is, by far, the most complex of this layer. Non-users are all persons who do not have a login credentials, i.e., individuals or entities not belonging to any given company. All non-users are restricted to simple functions in the application.

They have access to a homepage and a search page. The homepage consists in a simple presentation of a company via price table. Due to the possibility of scaling prices with quality, the price table has three columns. The first, a class identifier, the second a description of item class and the third contains the price per quality interval. This is, however, a mere example of how to present a company in a simplistic manner and can easily be altered to better suit each corporation's necessities.

The only other function available for non-users is a search function to search for products currently in inventory. This search has two required parameters, the class identifier, and the time interval until delivery. The search returns a table with all available products that meet the specified conditions.

For users, meaning persons or entities related to a company and with login privileges, more varied functions are available. These functions are locked behind a login screen. By providing valid credentials a user is taken to a personal page. This page serves only as a place in which user only functions are aggregated via hyperlinks in a sidebar.

The inventory page shows inventory in the exact same manner as the IMM. The Stage N page shows the operational history in the exact same manner as the PSMM and, just as the aforementioned module, needs to be replicated per production stage described in an HACCP flow chart or equivalent health and safety mechanism.

The order page allows for a user to process an order when requested. To do so a form must be filled. This form has three steps, the first two querying the user about the order and the third with a final review of all information given and a final submission button. Pressing the final submission button, creates several files necessary for an order and shows them to the user via tables. Some of the files correspond to user input and though they may seem unnecessary due to every input being shown in the application, its intent is to create a history of all orders. All the other files contain processed information that is necessary for the completion of an order.

The Summary file shows all perishables to deliver and to which destination. Table 6 presents the structure of this file.

Table 6. Summary file structure.

	Destination 1	Destination 2	Destination 3
Goods to deliver	ID1 ID2 ID3	ID1 ID2 ID3	ID1 ID2 ID3
Quantity to deliver	Q1 Q2 Q3	Q1 Q2 Q3	Q1 Q2 Q3

The Conditions file shows the conditions expected to be subjected to an order. These include, number of destinations, number of possible routes, exit and delivery dates and the relevant conditions inside the transport vehicle, temperature is the most relevant QMP for this study. Table 4 shows this file.

Table 7. Conditions file structure.

Order name	Number of destinations	Number of arcs in graph
OrderName	3	3
Exit date	Travel QMP	Delivery date
2019/12/30 23:59:59	−2	2019/12/31 23:59:59

The graph file shows the origins, destinations, and relative cost between origin destination pairs. This file is necessary for the application of Prim's algorithm. This algorithm determines the best path for distribution. The structure is shown in Table 8.

Table 8. Graph file structure.

Origins	Destinations	Relative cost
Home Destination 1 Destination 2	Destination 1 Destination 2 Destination 3	1 1 1

The IFC and IDC files are also created. Due to their structure already being discussed, it is considered that there is no necessity to further expose them.

The quality file contains the expected quality and keeping quality of products at delivery using the predicted exit and delivery dates plus the expected travel conditions. Table 9 illustrates the structure of this file.

Table 9. Quality file structure.

ID	Exit date quality	Exit date keeping quality	Delivery date quality	Delivery date keeping quality
ID1	EDQ1	EDKQ1	DDQ1	DDKQ1
ID2	EDQ2	EDKQ2	DDQ2	DDKQ2
ID3	EDQ3	EDKQ3	DDQ3	DDKQ3

The route file contains the result of the application of the Prim's algorithm to the given graph and, in this case, returns the cheapest path through all destinations. Table 10 shows the structure of this file.

Table 10. Route file structure.

Origin	Destination	Relative cost
0	1	1
1	2	1
2	3	1

4.6. Regulator layer

This layer has simpler functions than the production layer. This layer must provide access to information to consumers, validate transactions and verify received materials. However, this layer is the one that necessitates the most investment to deal with large volumes of information safely and correctly.

4.7. Quality validation module

For both this function and the next a login is required, and a user is presented with a personal page just as in the OMM. This function consists of a form that asks the user for the IDC and ICF files and returns them filled with unique codes for validated products.

4.8. Repository of information for final consumers

This function is available to all and consists in a simple form that requests a product ID and returns the cumulative history of a product. To search for the history of a component of a certain product, a new search must be made.

4.9. Quality after transport module

This function queries the user on how many products to verify. After that the user is again queried on the product IDs, the QMP value and the remaining keeping quality. In the end the user is shown a table with the resulting values.

4.10. Unique code layer

In this scenario, the development of a prototype, there is no graphical interface. This module consists in a simple script that generates random codes that are twelve digits long. As mentioned before, the generated codes serve the purpose of identifying items externally, on order for a consumer to be able to search for their history.

5. Simulation results

To test the created tools three materials will be followed throughout a virtual supply chain based on the data presented by Tijskens & Polderdijk [71]. This supply chain encompasses three different companies, one per segment. As this simulation aims to illustrate quality and keeping quality variations over time and temperature, the materials were subjected to different entry parameters to better observe their impact in quality and keeping quality. Temperature data from Tijskens & Polderdijk [71] was used in this specific case study.

First the equations used in the created modules are presented. However, due to the simplicity of the supply chain simulated, the routing algorithm is irrelevant for simulation.

Following that presentation, the simulation itself is shown segment by segment.

5.1. Quality and keeping quality variation equations

The linear reaction equations described by Tijskens & Polderdijk [71] were used. Although this equation was determined considering constant temperature, which is not realistic in the context of food supply chains, they can still be used to evaluate quality and keeping quality since the temperature intervals are small. Even though this induces some error in the evaluation of those parameters, it is considered acceptable for prototyping purposes. For the decay of quality Equation 1 (Eq.1) is used:

$$Q = Q_0 - kt \qquad (1)$$

Where Q is the value of quality, Q_0 is the initial quality, k is the decay rate and t is the time elapsed.

For the evaluation of keeping quality Equation 2 (Eq.2) is used:

$$KQ = \frac{Q_0 - Q_l}{k} \tag{2}$$

Where Q_l is the quality limit.

The value of k varies with temperature and is calculated using the following Equation (Eq.3):

$$k = k_{ref}\, \mathrm{e}^{\frac{Ea}{R}\left(\frac{1}{T_{ref}} - \frac{1}{T_{absolute}}\right)} \tag{3}$$

Where k_{ref} is the reference decay rate (has the value of one), Ea is the energy of activation, R is the gas constant, T_{ref} is the reference temperature (has the value of 10 ℃) and $T_{absolut\ e}$ is the measured absolute temperature.

5.2. Routing algorithm

To determine transport and distribution routes the Prim's algorithm is used. To use this algorithm a graph must be made. The graph contains nodes, which are locations, and arches, representing all possible relationships between the nodes. This algorithm determines a route that passes through all nodes in the graph with the lowest relationship between them. Usually, the arches represent the travel cost between nodes and so the algorithm will determine the cheapest route that passes through all nodes. Although the arches can symbolize whatever a company values most, here the travel cost was the relevant parameter.

5.3. Entry data

Three materials were followed throughout a supply chain. For the time intervals, data of Tijskens & Polderdijk [71] was used.

The initial conditions were as follows:

- Material 1: initial quality is 100, quality limit is 60 and was subjected to a temperature range between 0 and 5 ℃.
- Material 2: initial quality is 70, quality limit is 60 and was subjected to a temperature range between 0 and 5 ℃.
- Material 3: initial quality is 100, quality limit is 60 and was subjected to a temperature range between 2.5 and 7.5 ℃.

The possibility that two products are mixed to generate a single new product is not considered. This illustrative case study uses a relationship of one-to-one to simplify the analysis. However, the system is not limited by it. One-to-many or many-to-one also operates correctly, being the difference either more inputs that outputs or vice versa.

5.4. First segment quality and keeping quality

In this segment, the following sequence of events was simulated:

- Materials rested in inventory for 1 hour.
- Materials were processed for 1 hour.

• Materials were transported for 4 hours.

Table 11 shows all variations subjected to the materials throughout this segment. Temperature is represented by T. Quality is represented by Q and keeping quality is represented by KQ.

Table 11. First segment data from simulation.

	Hour 0			Hour 1			Hour 2			Hour 6		
	T	Q	KQ	T	Q	KQ	T	Q	KQ	T	Q	KQ
Material 1	8	100	55.48	4.46	99.60	100.25	1.24	99.14	173.91	4.41	97.62	101.01
Material 2	8	70	13.87	4.46	69.60	25.06	1.24	69.14	43.48	4.41	67.62	25.25
Material 3	8	100	55.48	6.47	99.44	71.42	7.04	98.77	65.04	5.61	97.09	82.47

5.5. Second segment quality and keeping quality

In this segment the following sequence of events was simulated:

• Materials were received with different conditions than expected. A 1 ℃ higher than expected was assumed.
• Materials did not rest in inventory. Instead, they were immediately allocated for processing for 4 hours.
• Materials spent 2 hours in transit.

Table 12 shows data obtained through simulation.

Table 12. Second segment data from simulation.

	Hour 6			Hour 10			Hour 12		
	T	Q	KQ	T	Q	KQ	T	Q	KQ
Material 1	5.41	97.19	85.29	2.03	96.13	140.87	0.88	95.89	171.38
Material 2	5.41	67.19	21.32	2.03	66.13	27.23	0.88	65.89	33.13
Material 3	6.61	96.56	69.81	5.75	94.58	73.71	3.60	94.49	105.97

5.6. Third segment quality and keeping quality

In this segment the following sequence of events was simulated:

• Again, a difference is assumed between expectation and the actual delivery. This difference is 1 ℃ bellow expected,
• Materials did not rest in inventory. Instead, they were processed for 2 hours,
• Materials spent 48 hours until they reached the final consumer.

Table 13 shows the data relative to this segment.

5.7. Limitations and performance analysis

Although this template traceability system was developed with comprehensiveness, restrictiveness and low cost in mind as mean to emulate conditions subjected to MSE's and SME's, it is still a prototype and requires further development to become a finished product more valuable to MSE's or SME's than the prototype presented.

Table 13. Third segment data from simulation.

	Hour 12			Hour 14			Hour 62		
	T	Q	KQ	T	Q	KQ	T	Q	KQ
Material 1	−0.88	96.24	227.93	2.54	95.66	125.83	1.68	83.79	145.54
Material 2	−0.88	66.24	39.25	2.54	65.66	21.67	1.68	0	0
Material 3	2.60	94.81	119.62	4.69	93.98	83.88	6.83	65.11	58.60

With the plethora of information available about traceability systems, some pertains to the evaluation of their performance. Although some adaptations were made to fit the evaluation methods presented in scientific literature to this prototype, it is still possible to make a general assessment of the capabilities of this prototype.

It is possible to include other elements in this traceability system due to its modular structure. However, it is considered that not all elements should be included in a template like this. That does not mean that those elements are of secondary importance to a MSE or SME, it simply means that their inclusion limits the application range of this prototype by reducing its abstraction as some elements could be useful to an enterprise but not to another. As to demonstrate the potential additions to this traceability system, some potentially useful methods will be described.

5.8. Limitations

This prototype has three main flaws. First and foremost is security. As it is out of scope of this study, the security of information collection, storage and transmission was not considered. If applied in a real scenario, a fair number of precautions would have to be made to ensure the safety of privileged data. The second greatest flaw is the manual input of information which greatly limits the input of material flows. The third major flaw is the manner the quality and keeping quality was applied. As temperature varies continuously, assuming a constant temperature through a long period of time induces an error in quality determination. To correctly apply the algorithm, the following formula should be used instead (Eq.4):

$$\frac{dQ}{dt} = -k \tag{4}$$

Where dQ/dt is the variation of quality over time and k the decay rate. This, however, implies constant monitoring which was deemed unfeasible to MSE's and SME's due to the added investment in technology capable to handle continuous monitoring and large data volumes.

One minor flaw is the connection of the regulator layer with the unique code layer as if the first fails, there is no access to the second and products will not be able to receive unique codes. However, such can easily be countered by the existence of several regulator servers.

5.9. Performance analysis

From Mgonja, Luning & Van der Vorst [72] several criteria can be used to assess the performance of the prototype presented in this study.

Table 1 from the aforementioned study refers to contextual factors. As the prototype is a general template the criterion in this table is not applicable to the system presented in this study.

Table 2 from the aforementioned study contains indicators that allow to assess the design of the system. However not all of them are applicable to this system.

The first indicator is types of TRU identifiers, mode of data registration and location of data storage. Although all data is to be managed electronically, companies are always given a choice on how and how much information to manage for as long as it complies with all legal requirements. This means that all answers presented by the authors are possible including the lowest ranking, paper-based systems if the amount and quality of information is low enough to make a fair equivalent. This question is more appropriate to a specific application of a traceability system. The second indicator is appropriateness of the location of information collection point. As the prototype implies a segmentation of the process based on the HACCP system, the most appropriate classification is the highest, T&T information is collected at all appropriate CIP and it is based on HACCP system.

The third indicator is determination of the TRU. All classifications are applicable to fish products only, making this indicator inadequate to assess the design of the prototype.

The fourth indicator is mode of information communication. Due to the necessity external validation and identification for a product to be sold, the highest-ranking classification is the most adequate, system design allows communication via printed material and via electronically e.g., EDI.

The fifth indicator is degree of data standardization. Again, due to external identification, the best possible result, use of international standards such as EAN.UCC standards are the most adequate as is it even possible to use it on an internal level.

The final indicator from Table 2 is level of using HACCP system during T&T system design. As the entire system was developed around the usage of HACCP to segment any given process, the highest-ranking indicator is the one that suits best, HACCP system is entirely used easily and correctly in all stages of T&T system design and during execution.

Table 3 refers to the operation of the traceability system by humans. This implies an internal evaluation which cannot be applied in this study.

Table 4 from the aforementioned study contains performance indicators relative to performance and food safety.

The first indicator is how long does it take to trace product information within the company? Although all information relative to each module is kept within the module, the order management module aggregates all information in one place making possible to verify product information with ease. This implies the best possible answer to this question, within four hours.

The second indicator is what is the level of reliability of procedures, tools and information used in the company? Since the presented system is a prototype template for a traceability system meant to be derived by each company to better suit individual needs but needs to follow national and international directives, the most adequate performance metric is the intermediate, use of both local and international approved tools, procedures, and information.

The third indicator is what is the degree of accuracy/precision of product batches? All data from operations over any given batches is always recorded by the Processing Stage Management module. As such, the most adequate indicator is the highest ranking one, the actual batch size is known and is constant at all the times.

Shankar, Gupta & Pathak [73] modeled Critical Success Factors (CSFs) for Food Logistics Systems (FLS) by questioning persons capable of evaluating and classifying the CSFs. From the initial sixteen proposed CSFs, twelve were the most relevant and the remainder was excluded.

Although the relationships between CSFs is also studied it has no use for the prototype presented in this paper as it aimed to template traceability systems. Instead, for evaluation, each of the twelve most relevant CSFs will be individually discussed.

The first CSF is effective transportation management. The order management module is responsible for this task. As is, it only finds the route with the lowest cost and predicts quality and keeping quality at arrival. Route prediction is the most trivial of the described functions but the prediction of quality and keeping quality is not. By being capable of doing it automatically, this module can increase the effectiveness of transportation management by taking in heavy and morose workloads from company employees.

The second CSF is manufacturer branding. Properly using both the IDC and IFC files can help brands distinguish themselves from one another and more easily captivate their target audience.

The third CSF is safe and quality food. As this entire study is built around the HACCP system and regulation enforcement, this CSF is an inherent characteristic of the system.

The fourth CSF is sustainable agricultural practices. As the developed framework and tools are not specific to agri-food products, this CSF cannot be used to evaluate the success of the prototype.

The fifth CSF is government regulations. Again, as the third CSF, this is an inherent characteristic of this system.

The sixth CSF is increased marketing and trading. Increased marketing happens due to the existence of the IDC and ICF files. This, however, does not guarantee increased trading as is dependent on the efficiency of the marketing made in those two files which is impossible to evaluate outside a specific application.

The seventh CSF is proper coordination and transparency. By enforcing external verification and validation using scientific methods, transparency becomes an inherent characteristic. Coordination is dependent on the specific relationships between stakeholders and cannot be evaluated in the context of this study.

The eighth CSF is control of collusive behavior in food logistics. External verification and validation once again takes the role of this CSF. Verification and validation before transaction can heavily hinder this type of behavior that could promote the dissemination of improper products throughout a food chain.

The ninth CSF is logistics competitiveness. This again implies a more specific application of a traceability system as is heavily dependent on particular use. Still, automatic quality and keeping quality assessment can be extremely useful to accelerate logistic processes within a company.

The tenth CSF is risk management strategies in food logistics. This CSF has implications on both internal and external levels. Internally the use of the HACCP to segment a process and monitor each stage has a big influence in reducing risk. Also, internally, the identification of all materials and operations can help the detection of abnormal circumstances or correctly identify products that must be recalled. Externally, again due to mandatory verification and validation, risk is reduced as improper products are unable to be commercialized between companies.

The eleventh CSF is use of transportation technology. This is dependent on a specific application and cannot be used to evaluate the prototype described.

The final CSF is consumer satisfaction. As consumers value information, providing a tool that helps them access externally and scientifically validated information has the potential of in-creasing their satisfaction.

Bendaoud et al. [74] lists several functions that a traceability system must be able to perform in Table 1 of the study.

The first function is to create product lots. Both IMM and PSMM are capable of such.

The second function is to create lot identifiers. Both IMM and PSMM identify lots and operations over them.

The third function is to mark the identifier on the product. This function implies the evaluation of a specific case.

The fourth function is to use identification carriers. Again, this implies the evaluation of a specific case.

The fifth function is to collect traceability data. IMM, QATM and RFIC are capable of such.

The sixth function is to generate product traceability data. IMM, PSMM and OMM can do so.

The seventh function is to record traceability data in an external support. The mandatory communication between producers and regulators performs this function.

The eighth function is to restore product traceability data. According to the communication module, information cannot be lost.

The final function is to communicate product traceability data. This is mandatory according to the framework.

There can be seen that all functions that do not require internal evaluation are performed by the prototype presented.

The system's approach can deal with distribution and production chains. However, as pointed out, each chain has specific regulations that need to be complied with. As such, it is necessary to have some flexibility for internal traceability. That is the reason why internal traceability is illustrated and external traceability is better detailed and enforced. As quality decays with time and depending on the environmental conditions, it is very important to deliver the product in a timely manner to avoid potential issues.

6. Conclusion

The model described in this paper solves several issues associated with traceability, thus potentially leading to increased food safety. This model is not, however, completely free of flaws, the most obvious being the interchangeable nature of companies. This means that it is difficult to assign them to a specific segment as there may be the need to purchase products from another company. Because of this difficulty, segmentation is made by what constitutes the most significant mean of acquisition of raw material. Another major issue is the amount of power possessed by companies in the first segment as the initial quality and keeping quality of a raw material as those values are not those dictated by the QATM. Such is an open door to fraudulent activity as all that is necessary in the input of false data. The solution of this issue depends on the parameters used by the QATM to evaluate quality and these in turn depend on the parameters used by the second segment enterprise.

Still, there are several advantages to this model. As information monitoring is required, implementation costs will be offset by the validation of the quality and by the consequent ability to better compose a product line according to corporate capabilities and objectives. Information monitoring also translates into process optimization as the parameters that affect any given stage are monitored and so flaws and defects can be effectively counteracted due to the disclosure of their causes. Being able to transmit externally validated information also allows to better price products according to target audience which will translate to more consumer satisfaction and trust as well as to reduce losses from waste. In a final note traceability models must be able to increase profit. If such does not happen there is not enough incentive to adopt a model and the corporations will combat the implementation of a model as in those circumstances, it will only make operations more cumbersome. Therefore, cooperation between all stakeholders in mandatory and regulators must become an active agent, this concerns security and crisis management as well, and help regulatory compliant corporations to profit and punish noncompliance. By helping companies profit sustainability increases as there will be significantly less waste either from operational residue, disposal of unsafe goods and less garbage from final consumers.

Simulation and performance analysis clearly demonstrate the capabilities of this system to correctly enforce and disseminate scientific based quality and keeping quality information. Unfortunately, it was not possible to include this system in a real case scenario due to time and resource constraints. As is, a system based on this model can be readily implemented in scenarios where batch mixing is easy to assign, i.e., a certain amount of product comes from X and the remainder comes from Y. In cases where mixing is difficult to determine, liquid food products for example, it is not advised to apply this system without modifying the mixing determination method.

Augmenting the readability and availability of traceability information can be beneficial to both consumers and companies due to the possibility of purchasing products better adequate to the intended purpose as well as discarding improper products with increased ease and celerity. Also, as internal corporate logistics increase, it becomes possible to optimize processes and determine the cause of anomalies as well as producing commodities better adjusted to the target market by analyzing the information that consumers prefer.

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Conflict of interest

All authors declare no conflicts of interest in this paper.

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