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Title

The components of a food traceability system

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Abstract

Background

Traceability of food products has become the focus of regional and national legislation, of many research and technical development initiatives and projects, and of many scientific articles. However, most of the scientific publications do not differentiate between the components of a traceability system, and those who do to some degree use inconsistent terminology and definitions. This weakens the analysis and the conclusions, and it can lead to misunderstanding in relation to what a traceability system is, what the components are, and how system functionality can be improved.

Scope and approach

This paper provides a structure for describing and analyzing a traceability system and emphasizes the difference between the system mechanisms as opposed to the attributes of the units that are traced. The basis for the classification outlined in this article is practical experience from traceability system implementations in the food industry, and participation in international standardization processes relating to food traceability. The references and the authors' experience are from the food sector, but the component description is likely to be relevant and applicable to any product traceability system in a supply chain.

'Traceability system' is used as a generic term in this article, encompassing the principles, practices, and standards needed to achieve traceability of food products, regardless of how

these are implemented. In practice in the food industry, most traceability systems are computerized and they are implemented through extensive use of information and communications technology (ICT), but in principle a traceability system could be manual and paper-based (as was indeed common practice only a few years ago), and the components hierarchy outlined in this article would still be applicable.

Key findings and conclusions

This paper identifies the general components of a traceability system to be the identification of the units under consideration, the recording of the joining and splitting of these units as they move through the supply chain (the transformations), and the recording of the unit attributes. The distinction between the different components is particularly important when describing and comparing traceability systems, and when recommending improvements. In both these cases, the respective components need to be considered separately.

Keywords

Traceability; Food traceability; Traceability system; Traceable Resource Unit; Product attribute; Product identification; Product transformation.

1 Introduction

The term “traceability” is currently used more than ever, both in the food industry, and in the production industry in general. There are many large research and technical development (RTD) initiatives and projects relating to (food) product traceability on company, national and international level. There are food traceability requirements in international legislation (e.g. the European Union (EU): General Good Law (European Commisssion, 2002)) and in national legislation (e.g. the United States: FDA Food Safety Modernization Act (FDA, 2017)), as well as in intra-company contracts, and there is an ever increasing array of electronic systems for handling traceability available on the market (Espiñeira & Santaclara, 2016). This trend is also reflected in the media articles and scientific publications about food traceability (see Figure 1).

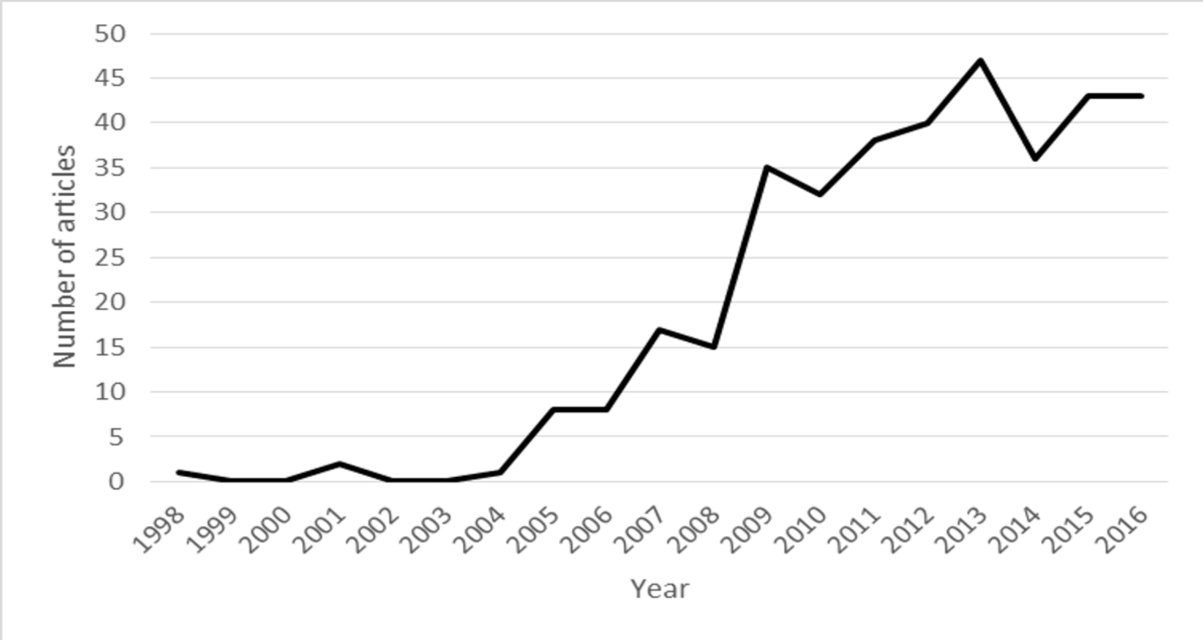

Figure 1. Scientific articles on food traceability published in the Scopus database in the period 1979-2016 (search term: “food traceability”; search date: 23.06.2017).

However, many of these scientific publications use inconsistent terminology and definitions, not only when it comes to traceability in itself, but also to traceability-related terms and concepts, and to the components of a traceability system (Jansen-Vullers, van Dorp, & Beulens, 2003; Borit & Olsen, 2016; Olsen & Borit, 2013). This article addresses this last issue, and provides a general description of the components of a traceability system on overall level. This article is partly intended as a suggested glossary for how to name and refer to components of a traceability system, especially in reports and in scientific articles where a certain level of consistency and rigour is required. An important application of this article is to enable systematic study and classification of the components of specific traceability systems so that the defining features are highlighted, and the system in question can be compared to -, and to some degree benchmarked against other similar systems. Benchmarking traceability systems is relevant when considering costs and benefits in relation to various options, when comparing systems in different organizations or in different parts of the same organization, and when analysing strengths, weaknesses, opportunities, and threats related to product traceability, or lack thereof.

The basis for the classification outlined in this article is practical experience from traceability system implementations in the food industry, and participation in international standardization processes relating to food traceability. For more than 20 years, the first author has worked with traceability systems and implementations in various sectors of the food industry, including meat, chicken, honey, mineral water, and seafood. During this time, the first author has participated in the development of the general food traceability standard ISO 22005 (ISO, 2007), led the development of the seafood traceability standards ISO 12875 (ISO, 2011a) and ISO 12877 (ISO, 2011b), and together with the co-author, is participating in the ongoing development of ISO 22095 (ISO, 2017). The terminology used and the concepts and practices outlined in this article are in line with common practice in the food industry, and also in line with the indicated standards.

2 Traceability and traceable resource units

Before going into details on what the components of a traceability system are, we need to define what traceability is (Section 2.1), and we need to define what it is we are tracing (Section 2.2).

2.1 Definition of traceability

There are numerous definitions of (food product) traceability in international regulations (e.g. EU Regulation 178/2002) and standards (e.g. ISO 22005), as well as in some scientific articles (e.g. (Moe, 1998)). The authors have published a comprehensive analysis of definitions of traceability found in legislation, in international standards, in some dictionaries, and also the most cited standalone definition formulated in a scientific article according to a systematic literature review of the field of food traceability (Olsen & Borit, 2013). As demonstrated in this previous research, most of these definitions suffer from recursion, i.e. defining “traceability” as “the ability to trace”, without defining “to trace”, or from not being consistent with common usage, i.e. focusing on only some properties or only on part of the supply chain. After describing and analyzing in details the problems identified with all these definitions, the authors have proposed an improved definition, which is used as basis for the analysis and discussion here. Thus, traceability is defined as “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 & Borit, 2013). The content of this current article does not depend on that particular definition; the components of a traceability system are the same regardless of which definition is chosen.

2.2 Definition of Traceable Resource Unit (TRU)

In this article we refer to “that which is under consideration” in the traceability definition as a Traceable Resource Unit (TRU). This is a well-established general term, used in many scientific articles (Kim, Fox, & Gruninger, 1995; Kelepouris, Pramatari, & Doukidis, 2007; Pizzuti, Mirabelli, Sanz-Bobi, & Goméz-Gonzaléz, 2014). As far as the traceability system is concerned, a TRU can be any traceable object, and typically it is a trade unit (e.g. a case, a bag, a bottle, or a box), a logistic unit (e.g. a pallet or a container) or a production unit (i.e. a lot or batch). An important distinction is between internal units, which are defined by the company in question (e.g. production lots or batches) and normally identified using company-specific, internal codes that are not generally understood outside the Food Business Operator (FBO), as opposed to trade units, which pass between companies and have to be identified in a way that both trading partners can understand (Karlsen, Olsen, & Donnelly, 2010; Thakur, Martens, & Hurburgh, 2011). There is also often a hierarchy of TRUs, in that a box may be part of a pallet that in turn may be part of a container, and all these are considered to be TRUs in their own right. The main focus in this article is to analyze the components of a traceability system, thus we will not go into further detail when it comes to TRU types.

3 Components of a traceability system

The definition above refers to “recorded identifications”, so in a traceability system there must be some way of identifying the TRUs, it refers to “throughout its entire life cycle”, so there must be some way of keeping track of TRU relationships as they move through the supply chain, and it refers to “any or all information relating to that which is under consideration”, so there must be some way of recording TRU attributes. Thus, we can broadly identify the components of a traceability system to be as follows:

1. a mechanism for identifying TRUs; (Section 3.1)

2. a mechanism for documenting transformations, i.e. connections between TRUs; (Section 3.2)
3. a mechanism for recording the attributes of the TRUs; (Section 3.3).

3.1 A mechanism for identifying TRUs

When choosing how to identify TRUs, we have to choose the identifier code type and structure (Section 3.1.1), we have to make choices with respect to granularity and uniqueness of the code (Section 3.1.2), and we have to find a way to associate the identifier with the TRU in question (Section 3.1.3).

3.1.1 Identifier code type and structure

When choosing a code or structure for the identifier, there are many options. Most often, the TRU identifier is numeric or alphanumeric, and the length can vary from a few characters (used for internal batch identification) to a couple of hundred (used, for example, for electronic product identification where the code is read from a computer chip associated with the TRU). The code can be a simple sequential code with no inherent structure (e.g. batch number 1 is produced on day number 1) or it can have a structure where different parts of the code have different meanings. On global level, the international, non-profit organization GS1 defines codes and number series to avoid accidental re-use of numbers (Storøy, Thakur, & Olsen, 2013). GS1 also defines how the numbers can be printed in various machine-readable formats, including bar-codes. An example of a rather advanced and lengthy code for TRU identification is indicated in Table 1.

Table 1. A code structure example from the 96 bit GS1 Serialized Global Trade Identification (SGTIN) code used for electronic identification of products and business-to-business transactions. TRU = Traceable Resource Unit.

Bit 1-8	**Bit 9-11**	**Bit 12-14**	**Bit 15-51**	**Bit 52-58**	**Bit 59-96**
Header	Filter	Partition	Company prefix	Item reference	Serial number
Indicates	Indicates	Indicates	Indicates globally	Indicates a	Indicates a

what type of code it is.	what type of item it is.	how the rest of the code is structured.	unique identification of FBO, including country.	uniquely identified product type within the company.	unique serial number for the TRU in question (given the product type).
Example: 0011000 means that this code is a SGTIN.	Example: 001 means it is a Point of Sale item.	Example: 001 means the next 37 bits is the company prefix, then 7 bits for item.	Example: 000100000000011 100011011100000 1000100 is the Abarta Coca Cola Beverages company.	Example: 1010101 is some item type that the company produces.	Example: 101010101… is the unique serial number of the TRU that this code is affixed to.

In practice, most codes used in the food industry (and in the production industry in general) are shorter and simpler than this, and contain fewer fields. For instance, the fields “Header”, “Filter”, and “Partition” are only relevant if several different types of codes use the same structure, “Company prefix” is only needed for codes that will be used outside the organization in question, and “Serial number” is only used if each TRU has a unique identifier (as opposed to several TRUs sharing the same identifier, see Section 3.1.2). Simpler and shorter codes for TRU identification are commonly used in the food industry; the SGTIN code was selected as an example because it is fairly comprehensive, and the fields in the shorter codes will often be a subset of the fields outlined in Table 1.

There are numerous schemes and standards describing different types of code structures that can be used, and details on this could warrant a whole article in itself. For traceability purposes, the uniqueness and granularity of the code are the most important attributes, as explained below.

3.1.2 Identifier uniqueness and granularity

For an identifier to serve as intended, it must be unique within the context where it is used (Regattieri, Gamberi, & Manzini, 2007; Senneset, Forås, & Fremme, 2007; Storøy et al., 2013). The context can be the individual production facility, the parent company, the supply chain, nationally or globally. GS1 issues codes that are unique on national or global level, and most trading standards refer to these codes, including at point of sale to the consumer where Global Trade Item Number (GTIN) codes are widely used.

GS1 offers a wide range of codes. Some of these codes are meant for many TRUs (e.g. all bottles of a certain brand from a given producer will have the same GTIN code), whereas some are meant to be used on only one TRU. A one-to-many relationship between codes and TRUs is quite common in the food industry, when one single code (unique within a context) is found on many TRUs. This happens, for example, when the code describes a production run or production batch that results in many TRUs. In the traceability system, this is problematic, because the code in question does not point to one, and only one, TRU. Thus, as far as the traceability system is concerned, the TRUs are indistinguishable. In the real world, the TRUs are of course not indistinguishable, and while they may initially share many properties (e.g. origin, location, environmental attributes), they are physically separate entities and may have different paths through the supply chain. With the advent of longer codes, and media that can carry longer codes (RFID chips in particular), one-to-one relationships between codes and TRUs are becoming more common (Dabbene, Gay, & Tortia, 2016). This is similar, for example, to the relationship between cars and license plate numbers, or between people and social security numbers, in that in a given context there is only one unit (TRU in our case) with a given code. A one-to-one relationship between codes and TRUs allows for a more powerful traceability system. As the code remains associated with the TRU, new attributes of the TRU can be linked to the unique code in the traceability system. If a one-to-one relationship between codes and TRUs does not exist, it is difficult to record attribute values for the TRU in question in the system, as the code in question is shared by several TRUs, whereas the attribute value in question may not be shared by all of them (e.g. exact location at a given date and time).

To illustrate what the problem is in the absence of a one-to-one relationship between codes and TRUs, if a red and a green truck both transported TRUs with identical codes from production to storage and unloaded them there, it would be impossible to identify which TRU came from the red truck, and which came from the green truck. It could be that the cooling system on the red truck broke down, and the TRUs in that truck were subjected to high temperature for a significant time. If the red truck and the green truck deliver their TRUs to the same recipient, after delivery the TRUs that came from the red truck can no longer be distinguished from the ones that came from the green truck, and later it would be impossible to find out what route the TRUs took to get there, and which ones had been subjected to high temperature. Even if the truck drivers wanted to record information pertaining to the TRUs in their truck, they could not do so, because there was no identifier that the recording could be linked to.

In this context, granularity refers to the amount of product referred to by the identifier (Bollen, Riden, & Cox, 2007; Karlsen, Dreyer, Olsen, & Elvevoll, 2012). Fine granularity means that an identifier refers to a relatively small amount of product; coarse granularity is the opposite. For the food business operator (FBO), this is a trade-off; fine granularity means more work and more cost related to data recording and physical separation of batches, but it also means more accurate traceability, and a smaller amount to recall if anything should happen.

3.1.3 Association of identifier to TRU

There are various ways to associate an identifier with a TRU. The most common is through some sort of physical marking directly on the TRU or on its label (Dabbene, Gay, & Tortia, 2014). Part of the marking is normally in plain text and readable by humans, but it is often supplemented by machine-readable codes such as barcodes or Quick Response (QR) codes. In business-to-business transactions, radio-frequency identification (RFID) technology is also increasingly used (Badia-Melis, Mishra, & Ruiz-García, 2015; Costa et al., 2013), with the chip either physically attached to the TRU or to the packaging that the TRU is in (e.g. box). Passive RFID tags require no battery and are becoming very cheap, but a number of technical challenges (e.g. sensitivity to deployment environment) still needs to be overcome in order to harness the full potential of this technology (Bolic, Simplot-Ryl, & Stojmenovic, 2010). In addition, this type of tag normally only carries a pre-defined code. Active RFID tags use a battery and can also record environmental parameters (e.g. temperature, pressure, humidity, Global Positioning System (GPS) location etc.), but they are more expensive. The identifier may also be associated with the TRU indirectly, for instance when a computerized traceability system keeps track of exact TRU location (e.g. on a conveyor belt), and the identifier is known in the IT system, but it is not physically associated with the TRU in any way.

3.2 A mechanism for documenting transformations

Once we have selected what type of identifier to use, and we have found a way to associate the identifier to the TRU, we need to document what happens to the TRU as it moves through the supply chain. The supply chain for food products is often long and complex, and TRUs do not necessarily last long; they are constantly split up, or joined together with other TRUs. These splits and joins are referred to as transformations, and the ability to document the sequence of transformations is one of the most important function of the traceability system (Dillon & Derrick, 2004; Olsen & Aschan, 2010).

3.2.1 Types of transformations

A transformation is an instant or a duration of time where, at a given location, a process uses a set of inputs (TRUs) to generate outputs (new TRUs). Examples of simple transformations can be (Dillon & Derrick, 2004; Donnelly, Karlsen, & Olsen, 2009; Thakur & Hurburgh, 2009):

- "one input TRU, one output TRU", where only one input TRU is used to produce one output TRU (e.g. one whole fish (input TRU) is filleted and placed alone in a single fish box (output TRU));
- "merging of input TRUs", where a number of input TRUs are used in (mixed) conjunction to produce one output TRU (e.g. two different feed bags (several input TRUs) are poured into one feed silo (one output TRU));
- "splitting of output TRUs", where one input TRU is used as basis for production of a number of output TRUs (e.g. one meat producing animal (one input TRU) are cut into numerous fillets that are placed in different boxes (several output TRUs)).

In practice, the actual transformations in a supply chain are often a complex mixture of the simple types indicated above, and there is often a very large number of transformations in a given chain, involving many suppliers and many TRUs. Software implementations of traceability systems often contain the functionality for visualizing the sequence of transformations as a directed graph, referred to as a traceability tree. An example of such a graph is depicted in Figure 2.

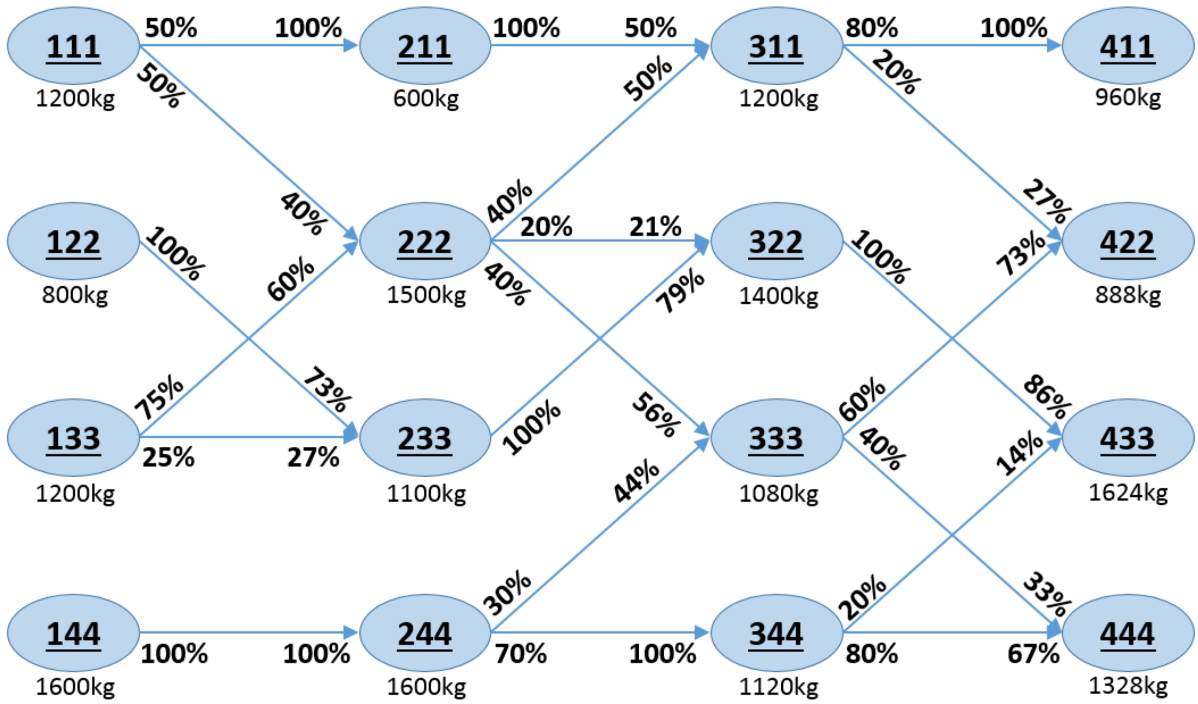

Figure 2. An example of a traceability tree with four processing stages.

The nodes are TRUs, the weights are indicated below the nodes, and the incoming and outgoing amounts (percentages) from and to the respective processes are indicated on the vertices. As an illustration, the diagram indicates that 600 kg of TRU 111 was combined with 900 kg of TRU 133 to make TRU 222. The 1 500 kg TRU 222 in turn went into TRU 311 (600 kg), TRU 322 (300 kg) and TRU 333 (600 kg). For a given TRU, the TRUs that was used to produce it is commonly referred to as "the parent TRUs", and the joint collection of all parent TRUs, grandparent TRUs etc., going all the way back to the start of the chain, are referred to as "the ancestor TRUs" or just "the ancestors". Thus, the ancestors of TRU 333 are TRUs 222, 111, 133, 244, and 144. For a given TRU, the TRUs that it produced is commonly referred to as "the child TRUs", and the joint collection of all child TRUs, grandchild TRUs etc., going all the way forward to the end of the chain, are referred to as "the progeny TRUs" or just "the progeny". Thus, the progeny of TRU 244 are TRUs 333, 422, 444, 344, and 433. Knowing the ancestors and progeny is particularly relevant if some sort of contamination is identified in the TRU in question; the ancestors must be examined to identify where the contamination originated from and, thus, help identify which other TRUs might be contaminated, and the progeny are considered contaminated, and must be recalled.

This traceability tree is very simplified, with four clearly defined stages of production (indicated by the first digit of the TRU identifier), only one interchangeable type of raw material / product, 100% constant yield (no loss), a very short chain, and very few nodes. In general, a real life traceability tree for an actual supply chain will be a lot bigger and a lot more complicated. Also, unless the FBOs are vertically integrated through the supply chain and share information freely, it may not be possible for anyone to visualize the entire traceability tree, but respective subsets of the tree can be visualized in each company in the supply chain.

3.2.2 Direct or indirect recording of transformations

Recording of a transformation is simplest when we know the input TRUs identifiers and the output TRUs identifiers; then the relationship between inputs and outputs can be recorded directly. However, in many processes the details of the transformation are not explicitly known, either because of undocumented mixing, or because data are not recorded. An example of undocumented mixing is when feedbags are added to a non-empty feed silo, and feed from that silo is used as input into a process (for more examples see (Skoglund & Dejmek, 2007)). A transformation happens in the silo from numerous feedbag inputs to numerous “feed extracted from the silo” outputs, but even if we know the input and output TRUs identifiers, we do not know the details of the transformation. What normally happens is that the silo is emptied regularly, and then we can identify a transformation from all the feedbags that were added since the silo was last emptied to all the feed extractions that happened in this period. This is indirect recording of transformations; it is normally connected to a time span, and it is quite common practice in the food industry.

3.2.3 Recording of weights or percentages

Some implementations of traceability systems record weights or percentages relating to how much went into, and how much came out of each transformation. If it is relevant to study yield, quality or other production properties, it is useful to record these quantities or percentages at each transformation (see the example in (Borit & Olsen, 2012; Thakur, Sørensen, Bjørnson, Forås, & Hurburgh, 2011)). This will provide better industrial statistics, it will enable the identification of dependencies, and it will aid in production optimization. For food safety purposes, however, the main interest is in the presence or absence of connections in the traceability tree. If TRU 144 in Figure 2 turns out to be contaminated, TRUs 244, 333, 344, 422, 433, and 444 need to be recalled, regardless of the amounts involved.

3.2.4 Recording of transformation metadata

The transformation is the actual joining or splitting of TRUs, whereas the transformation metadata are all the data relating to -, or describing the transformation. A transformation may happen at an instant, or it may be associated with a duration, and the time or duration of the transformation is an example of transformation metadata often recorded in the traceability system (Olsen & Aschan, 2010). Normally the transformation happens in a given location; data relating to the location is another example of transformation metadata; these may include environmental attributes like temperature, pressure, humidity, or other environmental parameters. If these parameters are considered relevant (for example, see (Zhang, Liu, Mu, Moga, & Zhang, 2009)), the data in question also have to be recorded.

3.3 A mechanism for recording TRU attributes

Once we have selected what type of identifier to use, and we have found a way to associate the identifier to the TRU, we have the ability to record attributes associated with the TRU in question, and to link these attributes to the TRU identifier. For most FBOs, the value of a traceability system lies in getting access to the many TRU attributes. Choosing an identifier, associating an identifier with the TRU, and documenting transformations are just means to an end; the main interest lies in the TRU attributes throughout the life cycle (Epelbaum & Martinez, 2014), and, especially for food safety purposes, also lists of ancestor TRUs and progeny TRUs. The traceability system facilitates information flow in much the same way that a system of railroad tracks and carriages facilitates material flow; in this analogy the carriages contain recorded data rather than physical products. The mechanisms related to identifiers and transformations in a traceability system may be likened to the railroad track that connects everything together, whereas the attributes recorded may be likened to the carriages that move on the tracks. The traceability mechanisms (the railroad track) is what ensures that data once recorded (the carriages) are connected, and can be moved from place to place without loss. If the necessary mechanisms are in place (the railroad track), adding more attributes (carriages) is fairly trivial, and, from a system perspective, there is no limit to the number of attributes that can be linked to a given TRU. Table 2 gives some examples from the ISO 12877 standard "Traceability of finfish products - Specification on the information to be recorded in farmed finfish distribution chains" (ISO, 2011b), indicating attributes for fish coming from a fish farm. The TRU in question is typically fish in a cage or in a well-boat.

Table 2. Examples of attributes that can be linked to a given Traceable Resource Unit (TRU) in the supply chain for finfish products. Source: ISO 12877. FBO = Food Business Operator.

TRU attribute type	**Example**
Attributes of the producing FBO	FBO name, address, national identification number, certification schemes etc.
Quality control checks undertaken on the TRU	Results from organoleptic, physical, chemical or microbiological tests.
Temperature record for the TRU	Time/temperature log.
TRU description	Size distribution (weight per size grade), condition factor, fat content, color, texture, net weight, average weight, total weight per quality grade etc.
TRU production data	Starving period, fish density record, disease record, treatment record, feeding record etc.

In general, assigning identifiers and recording transformations represent costs for the FBOs; the FBO is mostly interested in getting access to the attributes of all TRUs in the system, and in knowing the ancestor TRUs and the progeny TRUs. Perhaps for this reason many publications and reports on traceability focus almost exclusively on the TRU attributes. However, if we want to describe, analyse or improve a traceability system we need to take all the components into consideration because without the other components indicated, we would not have access to the TRU attributes that we are interested in.

4 Discussion

Based on the discussion above, the relationship between the components of a traceability system and their respective implementation options can be illustrated as in Figure 3.

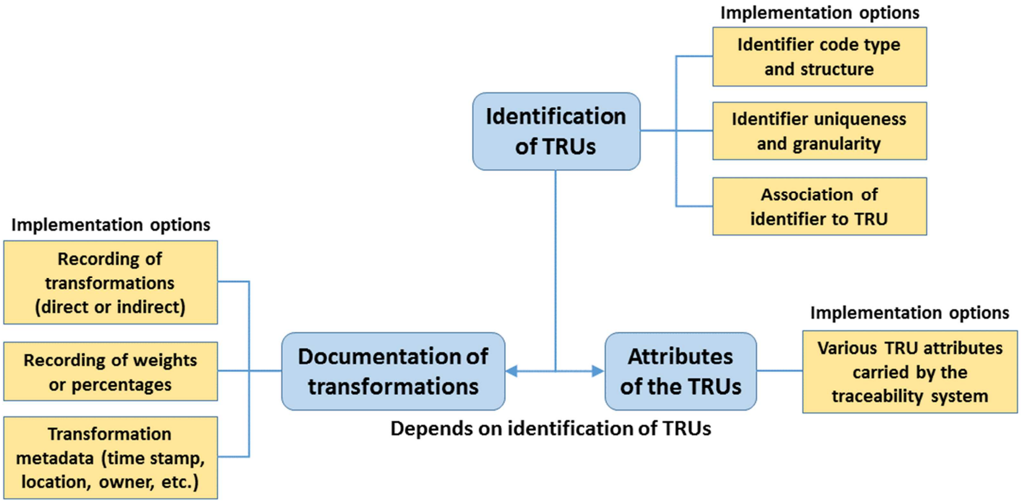

Figure 3. The components of a traceability system and the respective implementation options. TRU = Traceable Resource Unit.

As indicated above, identification of TRUs is the key component that the other two build on. Without TRU identification transformations cannot be documented, and TRU attributes cannot be recorded. The other two components are in principle independent; it is possible to record transformations, but no attributes (Figure 2 illustrates this), and it is possible to record attributes, but no transformations. In practice, however, all three components are part of food industry traceability systems, and the components need to be examined separately if we are studying the system. For each of the three components there are a number of options related to practical implementation, as also indicated in Figure 3. The implementation options represent questions to ask, or decisions to make when deciding on how a particular component is implemented. When analyzing a traceability system, Figure 3 can be used as basis for a structured investigation, and yields initial questions like:

- How is the identifier associated with the TRU?
- What is the identifier code type and structure?
- In what context is the identifier unique; is there a one-to-one relationship between the identifier and the TRU?
- How are transformations recorded?
- How are weights or percentages recorded?
- What transformation metadata are recorded?

This initial analysis will highlight the identification and transformation components of the traceability system, and will of course have to be followed by a thorough investigation of what attributes are recorded, and how they are associated with the TRUs.

The distinction between the different components is particularly important when discussing potential for improvement of the system. Elaborating on all possible traceability system weaknesses and possible improvements is beyond the scope of this article, but a list of examples is included in Table 3, Table 4, and Table 5.

Table 3. Overview of possible improvements in the identification component of a traceability system. TRU = Traceable Resource Unit; QR = Quick Response; RFID = Radio-frequency identification.

Implementation option	**How it may be improved**	**Benefit from improvement**
Identifier code type and structure	Use established standards for code type	Increase chance of code being recorded and understood in next link
	Incorporate important attributes (e.g. species) in the code itself	Direct and quick access to important attributes
Uniqueness and granularity	Finer granularity	Reduce size of possible recall
	Establish a one-to-one relationship between codes and TRUs so that the code uniquely points to one, and only one TRU	Information that applies only to the TRU in question can be recorded (red truck / green truck example, Section

		3.1.2)
Association of identifier to TRU	Faster reading of code, use of barcode, QR-code, RFID chip	Faster reading Multiple simultaneous reading Distance reading

For more information on identification of TRUs, see (Bolic et al., 2010; Borit & Santos, 2015).

Table 4. Overview of possible improvements in the transformation component of a traceability system. TRU = Traceable Resource Unit

Implementation option	**How it may be improved**	**Benefit from improvement**
Recording of transformations	Explicit (linked to the TRU identifier) rather than implicit recording of transformations	Explicit recordings are findable in the traceability system; implicit recordings are generally not persistent
	Smaller input batches or production batches so that the transformation involves a smaller number of TRUs	Smaller potential recalls, reduced risk
Recording of weights or percentages	Recording weights or percentages more accurately than in existing system (often relates to reducing the size of the input batches and production batches).	Better industrial statistics; improved ability to study variations in yield and quality
Recording transformation metadata	Record (more) transformation metadata	Ability to identify the transformation attributes
	Allow searching and filtering based on transformation metadata	Ability to analyze transformations related to, for example, locations or time frames, identify commonalities

The advent of blockchain technology has obvious applications when it comes to transparent and persistent recording of transformations in a supply chain (Swan, 2015), but it is beyond the scope of this article to discuss the potential of this technology, and its limitations. For more information on transformations of TRUs and TRU types, see (Mai, Margeirsson, Stefansson, & Arason, 2010).

Table 5. Overview of possible improvements in the recording of attributes component of a traceability system. TRU = Traceable Resource Unit.

Implementation option	How it may be improved	Benefit from improvement
	Record more TRU attributes	More information on the TRU in question
Various attributes carried by the traceability system	Record TRU attributes more accurately	More accurate information on the TRU in question
	Record TRU attributes faster, e.g. through automatic data capture.	Faster recording, no need for human effort, fewer recording errors

For more information on recording of TRU attributes, see (Bosona & Gebresenbet, 2013).

A complicating factor is that everything in a traceability system must be considered a claim, not a fact, which means that we are also going to need mechanisms for verifying and validating the claims. Erroneous claims may occur, e.g. because of production errors, recording errors or deliberate fraud. See (Borit & Olsen, 2012) for a discussion of this issue.

For some types of production, in part of the supply chain the production is continuous, there is no separation of TRUs, and discrete TRU identifiers are not necessarily defined; dairy and grain production are examples of this. This type of production requires a slightly different type of traceability system and also some other components, but these particular challenges have not been dealt with in this article.

The references and the authors' experience are from the food sector, but the components description is likely to be relevant and applicable to any product traceability system in a supply chain.

5 Conclusion

This main objective of this article is to name, describe, and make a clear distinction between the different components of a traceability system. In particular, to distinguish between the mechanisms in a traceability system related to assigning identifiers and recording transformations, as opposed to the TRU attributes that we want to get access to. This is a distinction not always made in previous articles, reports and other documents relating to food traceability, and this omission has in some instances led to unclear or incomplete analyses and conclusions. The distinction is particularly important when describing and comparing traceability systems, and when recommending improvements to a given system. In both these cases, the respective components need to be considered separately. Hopefully the distinctions made in this is article can serve as a useful starting point for future work on this topic.

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Highlights

- A traceability system has three main component types with different functionalities
- A traceability system needs to identify the unit that is being traced
- It needs to document the joining and splitting of units in the supply chain
- It needs to record data describing the unit in question and the environment it is in
- When analyzing traceability systems, each component type must be considered