Food traceability in theory and in practice

(UiT Template page)

Preface and acknowledgements

The articles presented in this thesis were written at Nofima during the years 2010-2017, but the underlying work started before the year 2000. The work has been primarily financed by the European Commission, through the Framework Programme 5 project TraceFish (#00164), the Framework Programme 6 projects Seafood Plus (#506359) and TRACE (#006942), the Framework Programme 7 projects WhiteFish (#286141) and FoodIntegrity (#613688), and the Horizon 2020 project Authent-Net (#696371).

I want to thank my co-authors and colleagues; especially those involved in the projects we had in the early years when we did not really know or agree on what traceability was or what it entailed, and we had lengthy arguments about it which eventually led to some degree of consensus, and even some papers.

When I first started looking into the then obscure field of food traceability in the mid-1990s, I was lucky enough to get to know and work with two other pioneers who knew roughly as much, or as little as I did. Together we developed the field (at least our understanding of it) more or less from scratch, we travelled to numerous meetings and conferences trying to explain to everybody how fascinating and useful this new concept was, we had some very late nights, and quite soon we were in bunch of projects together. Thanks to the other two food traceability musketeers; Tina Moe and Jostein Storøy.

In recent years, Melania Borit in particular has been extremely helpful, as she seems to read everything that is being published on food traceability, and then she points me towards the most relevant articles; a service I am very grateful for, and one I hope will continue in the future.

The biggest thanks goes to my partner Michaela Aschan who has many roles in my life; three of the least important ones are vice-dean at the faculty I am submitting this thesis to, project collaborator, and article co-author. It is fair to say that it is unlikely that this thesis would have been written without her constant encouragement (there are also other words I could use here) over a very long time.

Finally, I want to thank my parents, Gro Harlem Brundtland, and Kåre Willoch. Not because I have a close relationship with any of these two political leaders, but because I want to emphasize the importance of the Oxford comma when it comes to reducing ambiguity in written text.

Paper list

The following papers are included in this Dr. philos thesis:

I: Olsen, P.; Borit, M.; (2013): “How to define traceability”. Trends in Food Science & Technology, volume 29, issue 2, pp 142-150. doi:10.1016/j.tifs.2012.10.003.

II: Olsen, P.; Borit, M.; (2017): “The components of a food traceability system”. Submitted to Trends in Food Science & Technology June 2017.

III: Olsen, P.; Aschan, M.; (2010): “Reference method for analyzing material flow, information flow and information loss in food supply chains”. Trends in Food Science & Technology, volume 21, issue 6, pp 313-320. doi:10.1016/j.tifs.2010.03.002.

IV: Karlsen, K. M.; Dreyer, B.; Olsen, P.; Elvevoll, E.; (2012): “Granularity and its role in implementation of seafood traceability”. Journal of Food Engineering, volume 112, issues 1-2, pp 78-85. doi:10.1016/j.jfoodeng.2012.03.025.

V: Storøy, J.; Thakur, M.; Olsen, P.; (2013): “The TraceFood Framework – Principles and guidelines for implementing traceability in food value chains”. Journal of Food Engineering, volume 115, issue 1, pp 41-48. doi:10.1016/j.jfoodeng.2012.09.018.

Co-author table

Contribution to respective papers, in order of importance:

	Paper I	**Paper II**	**Paper III**	**Paper IV**	**Paper V**
Idea and initiative	PO	PO	PO	KMK	JS
Literature study and references	MB	MB	MA	KMK	MT
Development of concepts, methods or definitions	PO	PO	PO	PO, KMK	PO, JS
Application of concepts, methods or definitions, data collection and analysis	PO, MB	PO, MB	PO	KMK	PO, JS, MT
Manuscript preparation	PO, MB	PO, MB	PO, MA	KMK, PO, BD, EE	MT, JS, PO

All the co-authors have signed co-author statements agreeing to the indicated breakdown of contributions, and also agreeing to have the respective paper used as part of this thesis.

Other relevant papers

In addition to the papers included in this thesis, outlined above, the following scientific publications on food traceability which I have contributed to give additional details on the concept, and in particular on various implementations of it.

a) Karlsen, K. M.; Dreyer, B.; Olsen, P.; Elvevoll, E.; (2013): “Literature review: Does a common theoretical framework to implement food traceability exist?”. Food Control, volume 32, issue 2, pp 409-417. doi: 10.1016/j.foodcont.2012.12.011.
b) Borit, M.; Olsen, P.; (2012): “Evaluation framework for regulatory requirements related to data recording and traceability designed to prevent illegal, unreported and unregulated fishing”. Marine Policy, volume 36, issue 1, pp 96-102. doi:10.1016/j.marpol.2011.03.012.
c) Donnelly, K. A.-M.; Olsen, P.; (2012): “Catch to landing traceability and the effects of implementation – A case study from the Norwegian white fish sector”. Food Control, volume 27, issue 1, pp 228-233. doi:10.1016/j.foodcont.2012.03.021.
d) Donnelly, K. A.-M.; Thakur, M.; Forås, E.; Sakai, J.; Olsen, P.; Storøy, J.; (2012): “Mackerel supply chain from Norway to Japan - Preliminary results from an international traceability project”. Økonomisk fiskeriforskning, volume 22, issue 1, pp 11-21.
e) Donnelly, K. A.-M.; van der Roest, J.; Höskuldsson, S. T.; Karlsen, K. M.; Olsen, P.; (2011):”Food industry information exchange and the role of meta–data and data lists”. International Journal of Metadata, Semantics and Ontologies, volume 6, issue 2, pp 146-153. doi:10.1504/IJMSO.2011.046596.
f) Karlsen, K. M.; Sørensen, C.-F.; Forås, E.; Olsen, P.; (2011): “Critical criteria when implementing electronic chain traceability in a fish supply chain”. Food Control, volume 22, issue 8, pp 1339-1347. doi:10.1016/j.foodcont.2011.02.010.
g) Karlsen, K. M.; Olsen, P.; (2011): “Validity of method for analysing critical traceability points”. Food Control, volume 22, issue 8, pp 1209-1215. doi:10.1016/j.foodcont.2011.01.020.
h) Karlsen, K. M.; Olsen, P.; Donnelly, K. A.-M.; (2010): "Implementing traceability: Practical challenges at a mineral water bottling plant". British Food Journal, volume 112, issue 2, pp 187-197.
i) Donnelly, K. A.-M.; Karlsen, K. M.; Olsen, P.; (2009): “The importance of transformations for traceability – A case study of lamb and lamb products”. Meat Science, volume 83, issue 1, pp 68-73.
j) Donnelly, K. A.-M.; Karlsen, K. M.; Olsen, P.; van der Roest, J.; (2008): “Creating standardised data lists for traceability: a study of honey processing”. International Journal of Metadata, Semantics and Ontologies, Volume 3, No. 4, 2008, pp 283-291.

This thesis aims to be general in nature, and to focus on traceability concepts and methods generally applicable in the food industry. Most of the papers listed above are specific for one chain or one sector, whereas the ones selected for inclusion in the thesis are more general and conceptual in nature. Nevertheless, the papers listed above are relevant, and they can serve to illustrate that the concepts and methods outlined in the papers selected for the thesis have been tried and tested in practice.

Other relevant documents, reports, and standards

Food traceability is to a large degree an applied research field with focus on how to achieve traceability in practice, and a lot of knowledge is documented in project reports, organization reports, and international standards. Below are some of the most important ones that I have contributed to through the years.

k) Borit, M.; Olsen, P.; (2016): "Seafood Traceability Systems: Gap Analysis of Inconsistencies in Standards and Norms". FAO Circular FIAM/C1123, ISSN 2070-6065, available at www.fao.org.

l) Karlsen, K. M.; Olsen, P; (2016): "Problems and Implementation Hurdles in Food Traceability". In: Espiñeira, M.; Santaclara, F. J.; (ed) "Advances in Food Traceability Techniques and Technologies: Improving Quality Throughout the Food Chain", Woodhead Publishing Series in Food Science, Technology and Nutrition, ISBN 978-0-08-100310-7.

m) CWA 16960:2015, Batch-based Calculation of Sustainability Impact for Captured Fish Products, CEN Workshop Agreement.

n) Bhatt T.; Blaha, F.; Boyle, M.; DiMento, B.; Kuruc, M.; Matern, H. J.; Olsen, P.; Trent, S.; (2014): "Recommendations for a Global Framework to Ensure the Legality and Traceability of Wild-Caught Fish Products. Expert Panel on Legal and traceable Wild Fish Products". WWF report.

o) ISO 12875:2011, Traceability of finfish products – Specification on the information to be recorded in captured finfish distribution chains, ISO standard.

p) ISO 12877:2011, Traceability of finfish products – Specification on the information to be recorded in farmed finfish distribution chains, ISO standard.

q) Donnelly, K. A.-M.; van der Roest, J.; Höskuldsson, S. T.; Olsen, P.; Karlsen, K. M.; (2009): "Improving Information Exchange in the Chicken Processing Sector Using Standardised Data Lists". In: Sartori, F.; Sicilia, M. A.; Manouselis, N.; (eds.) "Metadata and Semantic Research, Communications in Computer and Information Science", Volume 46, 2009, pp 312-321. Doi: 10.1007/978-3-642-04590-5_30.

r) Storøy, J.; Senneset, G.; Forås, E.; Olsen, P.; Karlsen, K. M.; Frederiksen, M. T.; (2008): "Improving traceability in seafood production". In: Børresen, T.; (ed.) Improving seafood products for the consumer, Part VI Seafood traceability to regain consumer confidence, Chapter 25, pp 516-538. Woodhead Publishing Limited ISBN 978-1-84569-019-9 (book). Woodhead Publishing Limited ISBN 978-1-84569-458-6 (e-book). CRC Press ISBN 978-1-4200-7434-5. CRC Press order number: WP7434.

s) Dreyer, H. C.; Wahl, R.; Storøy, J.; Forås, E.; Olsen, P.; (2004): "Traceability Standards and Supply Chain Relationships". In: Aronsson, H. (ed.) Proceedings of the 16th Annual Conference for Nordic Researchers in Logistics, NOFOMA 2004, Challenging Boundaries with Logistics, 2004, pp 155-170. Linköping, Sweden.

t) CWA 14659:2003, Traceability of fishery products. Specification on the information to be recorded in farmed fish distribution chains, CEN Workshop Agreement.

u) CWA 14660:2003, Traceability of fishery products. Specification on the information to be recorded in captured fish distribution chains, CEN Workshop Agreement.

I was convener / leader / main writer for the three CWA standards and the two ISO standards, and the strong dependency of traceability systems on standards will be discussed in a later chapter, and the content of the standards will be shown in more detail.

Terms and abbreviations

AIDC	Automatic Identification and Data Capture
CEN	European Committee for Standardization
CoC	Chain of Custody; a way of ensuring that the information you are interested in is not lost
CTP	Critical Traceability Point; a point where information is systematically lost
CWA	CEN Workshop Agreement, a low-level, voluntary European standard
EC	European Commission
EDI	Electronic Data Interchange
EPC	Electronic Product Code; a unique code carried by an RFID tag
FAO	Food and Agriculture Organization of the United Nations
FBO	Food Business Operator, a generic name for an organization in the supply chain that handles food products
FP	Framework Programme; EC research programmes that last for roughly 7 years
GMP	Good Manufacturing Practice, guidelines issued by various organizations, including regulatory agencies, to ensure low risk and high quality when producing
GTP	Good Traceability Practice, guidelines developed as part of the TraceFood Framework, based on GMP guidelines, to ensure that relevant information was recorded, and not lost
GS1	GS1 is a non-profit organisation that develops and maintains global standards for business communication, including for number series, and for various types of bar codes
H2020	Horizon 2020, the EC Framework Programme running from 2014 to 2020
IoT	Internet of Things; inter-networking of physical devices
ISO	International Organization for Standardization
IUU	Illegal, Unreported, and Unregulated (fishing)
LCA	Life Cycle Assessment; a technique to assess environmental impacts
RFID	Radio-frequency identification (tag); a tag that uses radio waves to communicate
RTD	Research and Technical Development
SGTIN	Serialized Global Trade Item Number; a type of EPC used for identification of TRUs
TI	Trade Item, a quantity of material that is sold by one trading partner to another trading partner
TRU	Traceable Resource Unit, a generic name for the object or unit that we are tracing
TU	Trade Unit, same as Trade Item, alternative term used in some papers
WP	Work Package, a sub-project within a (large) RTD project

On "Value chain" versus "Supply chain":

The concept of value chain was introduced by Michael Porter (1985) and can be defined as the process or activities by which a company adds value to an article, including production, marketing, and the provision of after-sales service. Value chain is a business management term, and it includes links in the chain that add value to the product without physically handling the product. Supply chain is a term from logistics and operations management, and refers to the material and informational interchanges in the logistical process stretching from acquisition of raw materials to delivery of finished products to the end user (Council of Supply Chain Management Professionals, 2013). The objective of supply chain management is to manage the flow of products from suppliers to consumers. While the value chain is important, traceability is a term more closely related to logistics, and in particular information logistics, so in this synopsis the term supply chain will be used to refer to the interlinked food businesses with supplier-customer relationships where the food items we want to trace originate and flow.

Writing style

The five papers included in this thesis are not in the list of references, and will in this synopsis be referred to as "**Paper I/II/III/IV/V**". The other papers, documents, reports, and standards listed above are in the list of references if they are explicitly referred to.

The papers included in this thesis use the third person voice ("we"), indirect reference ("the authors"), or passive voice ("the analysis shows …"). The first person voice ("I") is often avoided in scientific writing, as to many it comes across as subjective and unprofessional. However, in this synopsis I have frequently chosen to use the first person voice when I refer to myself. This is not to detract from the efforts and contributions of my colleagues and co-authors; it is an attempt to take responsibility for the assumptions and the decisions that I made in the field of food traceability, and the actions that I took. In addition, using the first person voice has the advantage that the text flows better, it is simpler to write, and it is easier to read. The objective of this synopsis is to provide a narrative to explain how all this came about, what the starting point was, what decisions were made underway and why, and for this purpose the first person voice seems a better and more honest choice.

When it comes to defining terms and concepts, there are frequent references to industry standards and glossaries in this synopsis, to a larger degree than to scientific articles. This is not because these terms and concepts have not been defined in scientific literature; rather it is because there are too many conflicting definitions there. There are fewer conflicting definitions in the industry standards and glossaries, these definitions typically have backing from industry organizations, and they are more practical in nature, and therefore more applicable in this thesis.

A final point to note is that the objective of this synopsis is not to cover and refer to a significant part of the extensive literature that exists on food traceability. Where references seem to be needed I have included them, but I have not referred to all papers that says something on a given issue, nor do I cover all the different points of view that exist. The research field on traceability is fairly new, and there is no common agreement on terms and definitions, so trying to cover everything that has been published can be more confusing than enlightening. In this synopsis, I have given priority to explaining and exemplifying what my view of traceability is, rather than attempting to cover all the views that exist, and this means that this synopsis has a lower density of references than what a scientific paper normally would have.

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1 Introduction

On a wine amphorae found in Tutankhamun's grave it says "Year 5. Wine of the House of Tutankhamun Ruler of the Southern On, l.p.h the Western River. By the chief vintner Khaa" (Cerny, 1965). These amphorae were buried more than 3300 years ago, and the inscription is one of the earliest examples of product labelling that has survived. It gives the vintage and the vintner, and it shows that for several millennia there has been an interest in additional information about the food (or in this case wine) that we consume. While this inscription would not normally be referred to as traceability, it is a recorded identification and it does give us access to information relating to "that which is under consideration" which in this thesis I will refer to as a Traceable Resource Unit (TRU). Food product labelling was voluntary (and often potentially misleading or directly false) for a long time until laws and regulations appeared that established labelling requirements and penalties for violating these. The full history of food labelling requirements is beyond the scope of this thesis, but one of the first instances of a law that dealt with the issue of food labelling and misbranding was the US "Pure Food and Drug Act". It was passed in 1906 where seizure and destruction was the penalty for food that was found to be mislabelled (Wilson, 2008). Food safety and consumer protection was the background for this act, and it specified 10 potentially dangerous ingredients (including alcohol, cannabis, and morphine / opium) that if present had to be declared on the label of the food or drug.

This very brief historical summary has highlighted two drivers for traceability (or product labelling) through the centuries:

- Product information in general, to inform the consumer, to establish a brand, and hopefully to build loyalty to that brand
- Food safety and consumer protection relating to declaring the presence or absence of potentially dangerous ingredients

Roughly 20-25 years ago quite a few things happened that significantly influenced the technological possibilities and the drivers for traceability and food labelling. Some of the most important of these were:

- The widespread use of cheap and more advanced label printing technologies
- The widespread use of bar codes on products, and the corresponding widespread use of bar code readers in the business sector
- The advent of the computer with the possibility to record, transmit, and receive large volumes of information electronically
- The development and widespread use of standardised globally unique number series for company identification, product type identification, and gradually also TRU identification
- Numerous large and well published food scandals affecting various sectors in the food industry
- Increasing consumer awareness on issues relating to the environment, sustainability, ethics, fair trade, animal welfare, etc.

Up until about 25 years ago, product documentation was facilitated by writing information directly on the product, on the product label or on the packaging, and there was a practical limit to how much could be recorded (Opara, 2003). After the technological advances indicated above this limit largely disappeared, and the food scandals and the increasing consumer awareness meant that a significant demand for more information about the food product was created; a demand which the new technologies could be used to satisfy.

These technological advances led to challenges within the field of information logistics. While "logistics" is "the process of planning, implementing, and controlling procedures for the efficient and effective transportation and storage of goods including services" (Council of Supply Chain Management Professionals, 2013), "information logistics" is much the same thing, but for data and recordings rather than for goods and services. The product information was no longer physically associated with the product; the information instead resided in a ledger or in a computer somewhere, and it was sent to the next link in the supply chain through other channels, often electronically. These developments to a large degree led to the importance of traceability in the food industry. As the product information developed channels, movement patterns, and a supply chain of its own, an organizing principle was needed to keep track of the information and the exchange of it. Traceability is that principle; if you have good traceability, information once recorded should never be lost, whereas if your traceability is imperfect, you are likely to suffer from systematic information loss somewhere in your supply chain (a more formal definition follows later).

In recent times, traceability has become an obvious necessity in the food industry (and in many other industries), and there are laws, regulations, businesses, guidelines, standards, and a burgeoning research field associated with the concept. Scholarly interest in food traceability came a bit later than industry interest, but nowadays there are well over 300 scientific articles published on the subject each year; see Figure 1.

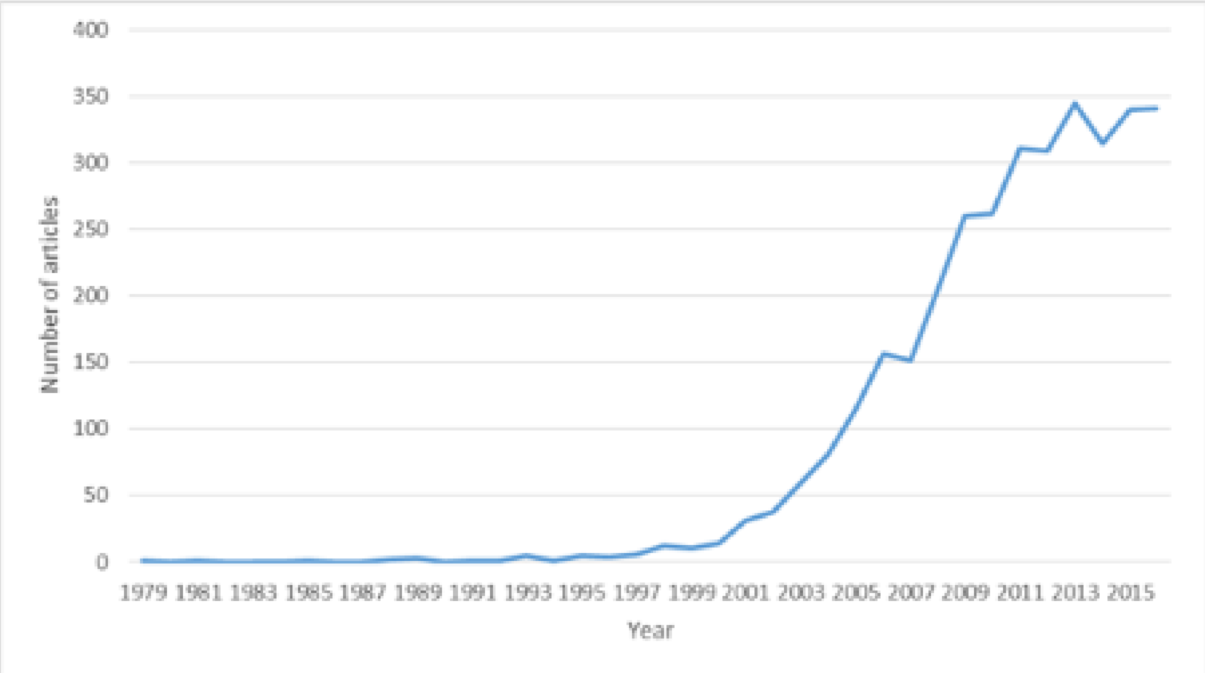

Figure 1. Scientific articles on food traceability published in the Scopus database in the period 1979-2016 (search term: "food traceability"; search date: 23.06.2017). ***From Paper 2****.*

This thesis outlines some of the overall and general developments in the field of traceability over the last years. While the oldest paper in this thesis is from 2010, the work that it reports on started before 2000, and it is still ongoing.

2 Research question and aim of the thesis

The overall aim of this thesis is to outline the theoretical background for food traceability, including how to define terms and concepts, as well as the practical application of traceability in the food industry. The thesis is based on five papers relating to different aspects of food traceability in theory and in practice, and the synopsis puts the papers into context, and provides additional information.

The papers have been selected to be as generally applicable in the food industry as possible, and they go into some detail when it comes to defining what traceability is, and what the overall components of a traceability system are. Based on these concepts, a method for analysing traceability in food supply chains is defined, and applications of this method and interpretation of the results is exemplified in a number of cases. The final paper outlines a framework for successful and efficient implementation of traceability in food chains, and to some degree summarizes the lessons learned in the work that led to the papers.

The aim of the synopsis is twofold:

1. To outline the 20+ years of work that led to this thesis and these papers, to indicate why and in which context the papers were written, and to highlight key findings, milestones and decisions along the way.
2. To serve as an introduction, or as a primer to the field of food traceability. It should be possible to read and understand this synopsis with only a minimum of pre-existing knowledge, and hopefully anyone who does so will gain insight into what food traceability is and how it works.

I have been giving university courses on food traceability since 2001; this thesis can be considered to be the extremely long and detailed version of those courses.

The associated research question underlying this thesis, loosely formulated, is "What is this thing called traceability, and how do I get it?", which logically leads to discussions of food traceability in theory and in practice. I have also worked a lot on the associated research question of "Why should I care about traceability, and what can it be used for?", but I have not attempted to answer this question in any detail here; that will be the subject of future scientific papers.

3 Personal background – From a failed PhD to a new research field

In 1993, I started working as a scientist at Fiskeriforskning in Tromsoe, which later became part of Nofima where I am now a senior scientist. My background was in computer science, systems analysis, programming, and applied mathematics. Initially I worked on projects that other people had initiated, but we were all encouraged to come up with our own ideas and to write our own applications for funding. In one of the projects, I visited numerous Norwegian fish processing plants, collecting data on production and yield. This was just a few years after electronic weighing was introduced, and there was great interest in studying factors that influenced yield, and in optimizing the production.

In the 1990s in Norway, the vessels normally delivered gutted, headless cod to the processing plants. To produce fillets the following process steps had to be undertaken:

1. Machine step – Remove the ear bone
2. Machine step – Remove the main bone, and split the fish into two fillets
3. Machine step – Remove the skin from each fillet
4. Manual step – Cut and trim the fillets, remove small bones

The project I was involved in tried to establish a benchmark for yield in the various process steps, and companies would once or twice per day select 10 or 20 fish that they weighed before and after each process step so that we could quantify the yield. Figure 2 outlines the production line for cod, with average yield numbers:

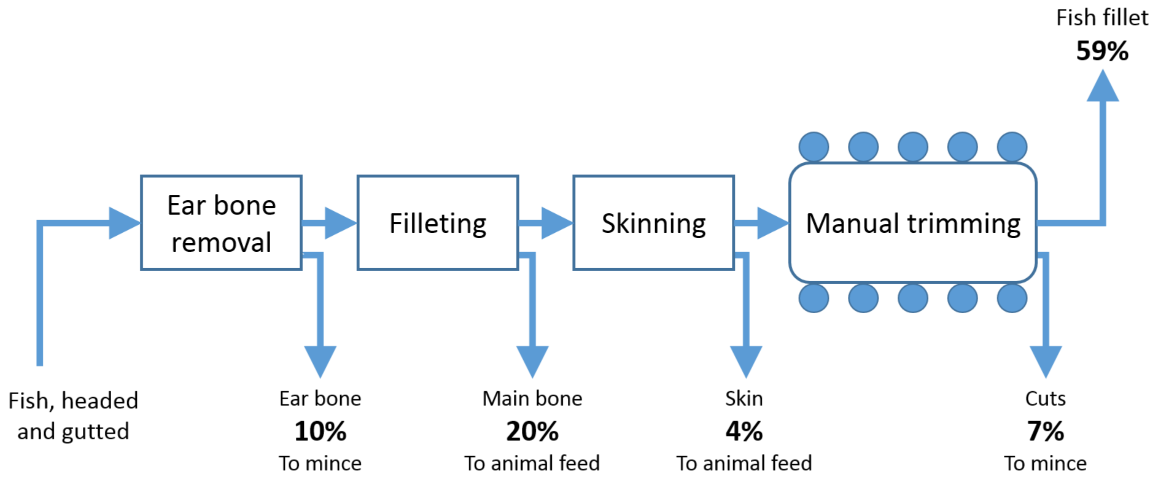

Figure 2. Material flow and yield when processing cod. From my 1995 PhD project description.

Unfortunately, the variation in these numbers was significant, and it depended on the gear used to catch the fish, time elapsed from catch to processing, the heading and gutting process, the storage and handling during this time, the weight, length and shape of the fish, the texture of the fish, the time of year, the type of machine, the time elapsed since the knives on the machine were sharpened, the experience of the machine operators, the experience of the people on the trimming line, etc.

With my background in applied mathematics and computer science, I got what I thought was an excellent idea for a project. I would use actual industry data from electronic weights in a number of processing plants and use multivariate statistics to develop a model that predicted yield in each process step based on the values of the parameters outlined above. Then I would write a computer program to simulate cod production, where the users could input the characteristics of the catch of the day, and play around with different options, e.g. what product to make, what machine to use, how many people to employ in the trimming process, etc.

In 1995, I submitted an application for a PhD project based on this idea to the Norwegian Research Council, and despite a lot of competition my application was funded. The PhD project would run from 1996 to 1999, and I was very happy. That did not last long. As I gradually discovered, there is a major flaw in the reasoning outlined above. I had assumed that the characteristics of the fish would be available to me both as the fish entered the processing plant and after each processing step. This was not the case. We knew, for instance, that gear type had significant influence on yield, and that fish caught in nets normally had lower yield than fish caught in trawls or on lines (Akse et al., 2012). However, the normal practice was that processing plants that received fish from net, trawl and line on the same day would grade (sort) the fish received according to size, and mix fish caught using different gear types, so there was no way to identify which gear type was used to catch a given fish after this process. Even if I focused on the properties of the fish that I could measure as they went into the first process, like weight, length or shape, there was no way to know what the original weight, length, or shape of fish (fillet) coming out of the system had been. Either the production management system did not keep track of this through the machine processes, or even if it did, the information was lost during the manual trimming process.

I had data on several thousand fish going into processing, and data on several thousand fillets coming out of processing, but the data was not connected, so I could not develop a relevant mathematical model. I could sum all the data going in and compare it with the sum of all data going out, but that would not be specific enough to enable me to do production simulation.

I did develop a computer program that simulated cod production, but as the underlying mathematical model was missing, the program was only used for education and training; not as a production planning and optimization tool as intended.

I had discovered a fundamental problem of traceability; the systematic information loss in a process in a supply chain. I came to realize that I had implicitly assumed that each fish had some sort of unique identifier associated with it, and that this identifier would be accessible to me after each process stage. This assumption is obviously wrong, but it was interesting that none of the experts that I had presented the idea to had spotted this. I got interested in traceability, which was a fairly new concept in the 1990s, and my colleagues and I submitted and got funded a number of national and international research projects; one of which was the TraceFish EU project, which is described later in this synopsis.

In 2000, I submitted the final project report to the Norwegian Research Council outlining my failure to obtain a PhD, and the closing paragraph reads as follows:

"Extensive data gathering from 6 processing plants in northern Norway and subsequent analysis showed that it was not possible to make a predictive model, and that most of the variation in yield (80% or so) are due to non-quantifiable factors or noise. … It is worth mentioning that [my] objective of obtaining a PhD within this field remains, even though the PhD as defined in this project could not be completed. The work undertaken in the projects [that were initiated as a spin-off from this project] is novel also on international level, and may provide the basis for future publications and a PhD title."

I am admittedly very late in delivering on the intention that I expressed more than 17 years ago.

4 Terms and concepts

The following constitutes a short, and by no means exhaustive, primer on traceability terms and concepts. On some of these terms where there are conflicting or ambiguous views or descriptions, the definitions most consistent with normal practice in the food industry, as indicated in key industry documents and standards, has been selected. There is some overlap between the terms and concepts defined in this synopsis and some of the papers and reports I have contributed to, including some of the papers included in this thesis. The purpose of this overlap is to increase readability, and to ensure that the synopsis can be read as a stand-alone document.

4.1 Batch

A relevant dictionary definition of batch (or lot) is “the quantity of material prepared or required for one operation” (Farlex, 2017). In supply chains for food products, we commonly refer to raw material batches, ingredient batches, and production batches (see Figure 3), but this distinction is not always applicable. Batch is an internal term in the company (or Food Business Operator (FBO), which is the general term for an actor or a process in the supply chain that handles food products). A production batch in the food industry is typically everything produced of one product type in one unit of time, e.g. a day or a shift. Batch identifiers are often locally generated in the FBO, and do not normally adhere to any external standards. Batches are not necessarily physically labelled in the FBO as long as the FBO knows what constitutes a given batch.

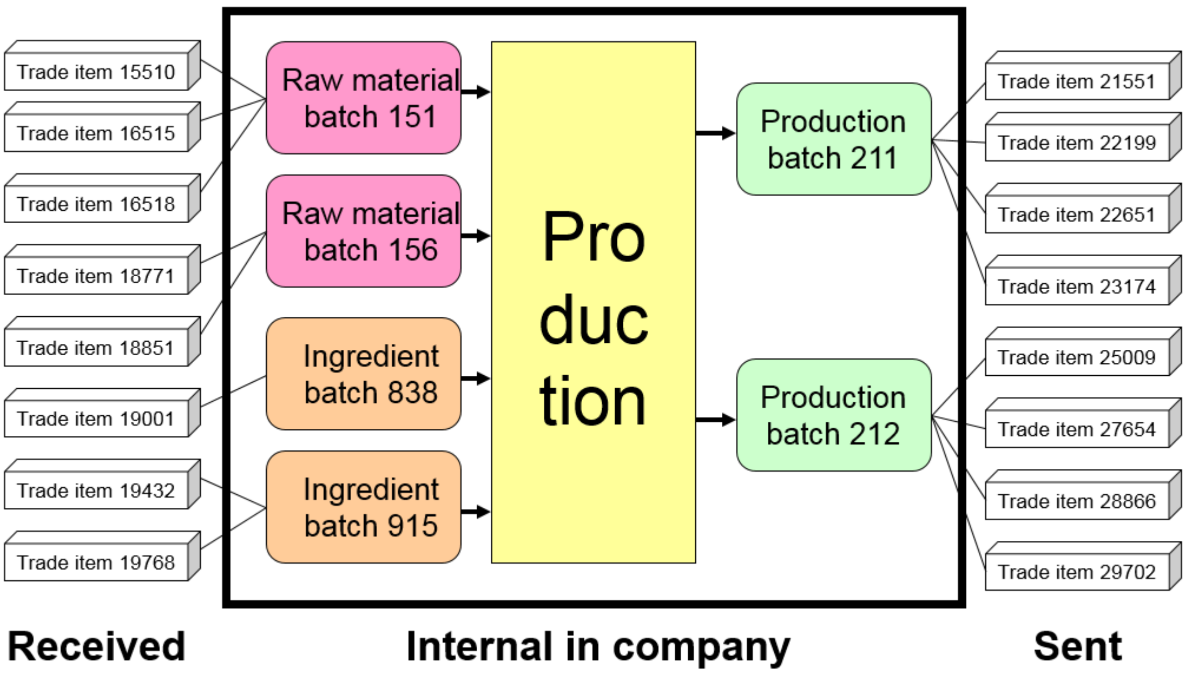

*Figure 3. Example of batches and trade items seen from the perspective of a Food Business Operator (FBO). Modified from **Paper III**.*

There is a whole research sub-field relating to traceability of continuous batches, and there are some special implementation and data recording considerations in sectors where batches are not discrete and clearly separated. I have not elaborated on this special case; for more information on this issue see the thesis of Kvarnström (2008) or Thakur (2010).

4.2 Trade item

A Trade item (TI), also referred to as Trade Unit (TU), is a quantity of material (e.g. a food product) that is sold by one trading partner to another trading partner. GS1 defines trade items as products or services that are priced, ordered or invoiced at any point in the supply chain (GS1, 2017a). Trade items received by a FBO are often merged or mixed into raw material or ingredient batches, e.g. when captured fish is sorted by size and quality before processing. Production batches are normally large, and they are often split into numerous trade items before shipping; see Figure 3 for the relationship between batches and trade items. Trade items have to be explicitly labelled and identified by the producing / selling FBO so that the receiving / buying FBO can identify them. It is not uncommon for trade items to be identified by the (production) batch number they belong to. This makes traceability more difficult and less precise, as numerous trade items will then have the same identifier. See discussion on one-to-one relationships between TRUs and TRU identifiers in section 4.7.

4.3 Traceable Resource Unit (TRU)

As indicated, batches are internal in a company, whereas trade items are exchanged between trading partners in the supply chain. A traceability system needs to keep track of both batches and trade units, and the common term for "the unit that we want to trace" or "the unit that we record information on in our traceability system" is Traceable Resource Unit (TRU) (Kim, Fox, & Grüninger, 1995) (Moe, 1998). In this synopsis, unless the internal or external nature of the food item is of importance for the discussion, the term TRU will be used, and it encompasses both internal batches and items traded in the supply chain.

4.4 TRU attributes or properties

In a traceability system, an important functionality is to keep track of are the attributes or properties of the TRU in question; see **Paper II**. TRU attributes or properties represent "that which we know about the TRU in question", which might be the TRU identification number, the product type, the product condition, the production date, the net weight, the raw material used, and so on. Different papers and documents us different words for this concept, but for the purpose of the discussion in this synopsis, "TRU attribute" is synonymous with "TRU property", and the words are used interchangeably. For a given TRU, the attributes have names and values, e.g. the attribute name might be "Fat", and the value for that attribute might be "12%". See Figure 14 in the section on "Traceability and standards" for detailed examples of attributes with name, description, example values, and categorization.

4.5 Granularity

A relevant dictionary definition of granularity is "having a high level of detail, as in a set of data" (Farlex, 2017). When the level of detail is high, we refer to "granular data", "high granularity", or "fine granularity". Granularity depends on the physical size of the TRU; the smaller the TRU, the more TRUs we have, and the higher or finer the granularity. When implementing a traceability system, companies have to make a decision on the granularity they want. A FBO typically chooses whether to assign a new production batch number every day, every shift (e.g. 2-3 times per day) or every time they change raw materials (e.g. 1-20 times per day) (Riden & Bollen, 2007). The higher the granularity, the more TRUs they will have, the more work will be involved, and the more accurate the traceability system will be. Granularity can be a particularly important consideration when planning for potential product recalls; the coarser the granularity, the more products will have to be recalled if anything goes wrong (Dabbene, Gay, & Tortia, 2014). Granularity is discussed in more detail in **Paper IV**.

4.6 TRU identifiers and uniqueness

TRUs are given identifiers in the form of numeric or alphanumeric codes. These identifiers are either assigned by the company that generates the TRU, or they are mutually agreed between trading partners, often with reference to standards. The identifiers must be unique in their context so that there is no risk of the same identifier accidently being assigned twice (Bertolini, Bevilacqua, & Massini, 2006). Ensuring uniqueness internally in a company is not too difficult; most companies have defined a coding scheme (normally used on batches) that ensures that within that company the same identifier is not used twice. Ensuring uniqueness when many trading partners are involved (typically for trade items) is more difficult, and the most common solution is to use globally unique identifiers. These are typically constructed by combining country codes with company codes that are unique within the country in question, and using this number as a prefix for TRU codes generated by the company. GS1 is the organization that keeps track of globally unique number series, and makes sure that numbers are not accidentally used again. GS1 has published a number of documents, standards, and good practice recommendations relating to this (GS1, 2007, 2017b). Se **Paper II** for a detailed description of how GS1 codes may appear.

4.7 One-to-one relationships between TRUs and TRU identifiers

While the TRU identifier must be unique within its context, practice differs in relation to whether this unique identifier can only be assigned to one TRU, or whether the same unique identifier can be applied to multiple TRUs. The first practice is referred to as the licence plate (or person number) principle. If there is a one-to-one relationship between TRUs and TRU identifiers, then each TRU will have its own unique identifier, not to be shared with any other TRUs; see Figure 5.

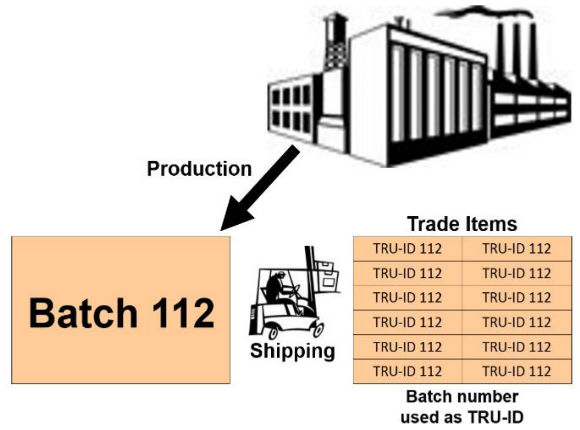

Figure 4. Batch number as TRU identifier

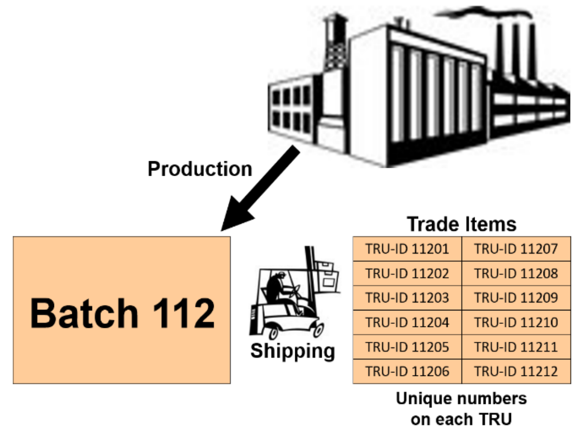

Figure 5. One-to-one relationship between TRU and TRU identifier

If the same TRU identifier is present on multiple TRUs this will limit the effectiveness of the traceability system; see Figure 4. Even if the identifier "112" is unique in a given context and has a number of properties associated with it (e.g. producer, production date, product type, raw material used, etc.) it is not possible to use the identifier to find one particular TRU. While all the TRUs that share an identifier will have the original set of properties in common (e.g. they all come from the same farm and were produced on the same dates), it is not possible to distinguish between individual TRUs. In addition, it is not possible to record further properties related to each TRU (e.g. date/time and location for that particular TRU, date/time and temperature for that particular TRU, etc.). It is not uncommon in the food industry to use the internal production batch number as identifier for each trade item that is generated and sold; this does not provide a one-to-one relationship between TRU and TRU identifier. Traceability systems that are not based on one-to-one relationships may be simpler (shorter codes) and cheaper (less generation of codes, less reading of codes), but they will inherently suffer from the limitations indicated, and there will be numerous potentially relevant TRU properties that these systems can never keep track of.

In some papers (including some papers in this thesis), a one-to-one relationship between TRUs and TRU identifiers is referred to as “referential integrity”, but after some consideration we no longer use this term, because it has a slightly different meaning in the field of computer science / database design, and this might cause confusion.

4.8 Transformations

New TRUs are created at specific times, typically when the raw material is harvested, when processes generate products in a given time period, or when existing TRUs are split up or joined together. When new TRUs are generated based on existing ones this is called a transformation; typical transformation types are joins, splits and mixes; see Figure 6.

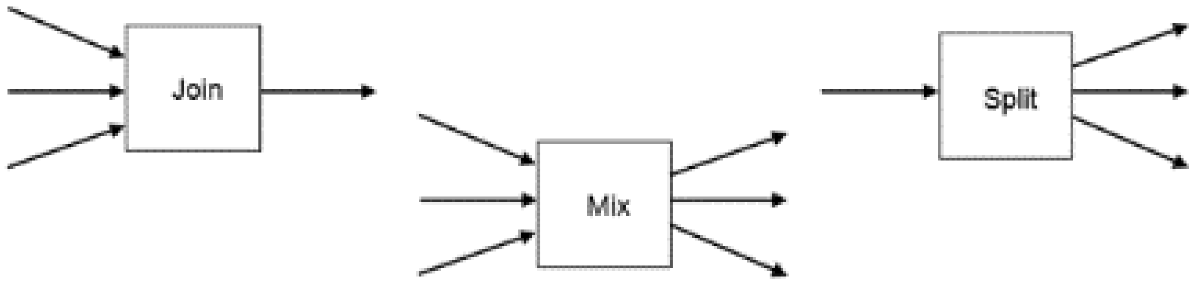

Figure 6. TRU transformation types

To document a transformation one needs to document exactly which existing TRUs were used to create a new batch or trade item; often it is also relevant to record the amounts or percentages used.

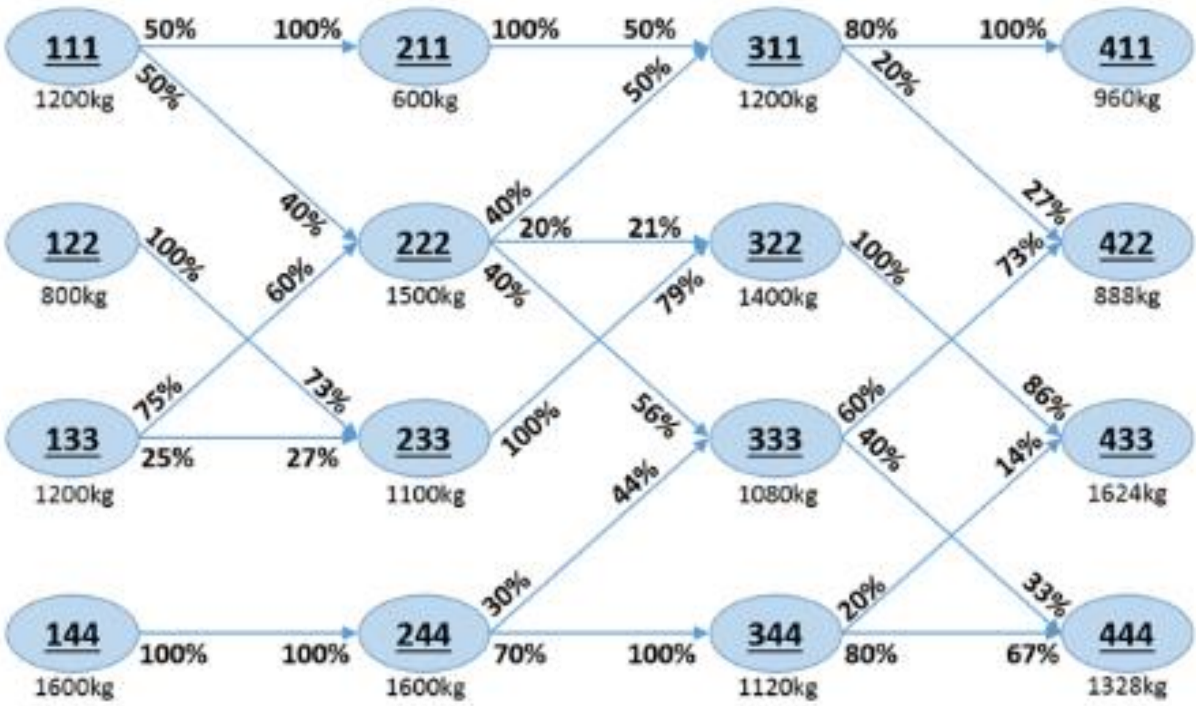

*Figure 7. An example of a traceability tree with four processing stages. From **Paper II**.*

In Figure 7, the circles are TRUs, and the underlined numbers in the circles are TRU identifiers. The arrows indicate transformations; e.g. TRU 111 is split into TRU 211 and TRU 222, and TRU 211 is joined with part of TRU 222 to make TRU 311. TRU weights, and transformation percentages are also indicated. A diagram of this type is called a "traceability tree", and while this might look complex, it only shows 4 process steps and 16 TRUs; a real life chain would have many times that number.

Normally trade items are smaller than the internal batches, which means that received trade items are often joined together to make raw material batches, and production batches are split into smaller trade units before they are sold. The overall supply chain with numerous TRUs being created, split up, and joined together can be very complex.

4.9 Traceability

There are numerous definitions of traceability (Jansen-Vullers, van Dorp, & Beulens, 2003), most of them recursive in that they define traceability as "the ability to trace" without defining exactly what "trace" means in this context. An attempt to merge the best parts of various existing definitions while avoiding recursion and ambiguity is made in **Paper I**, where we define traceability 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". This emphasises that any information can be traced, that traceability applies to any sort of object or item in any part of the life cycle, and that recorded identifications need to be involved. The latter requirement is important when it comes to differentiating between traceability and traceability control mechanisms; i.e. methods and instruments that measure biochemical properties of the food product. These are used for authentication and testing whether what is claimed in the traceability system correspond with the actual TRU attribute; see further discussion on this in chapter 5.

Traceability depends on recording all transformations in the chain, explicitly or implicitly. If all transformations are recorded, one can always trace back or forward from any given TRU to any other one that comes from (or may have come from) the same origin or process. In addition, traceability requires relevant information to be recorded and associated with every TRU in the supply chain. This makes it possible to find the origin of a given TRU (the "parents"), the application of the TRU ("the children"), and also all properties of every TRUs (when and where was it created, weight or volume, what form is it in, what species, fat content, salt content, etc.).

4.10 Chain of Custody

Traceability is related to, and sometimes confused with another term in the realm of information logistics, which is Chain of Custody (CoC). In the context of fisheries FAO defines CoC as "*The set of measures which is designed to guarantee that the product put on the market and bearing the ecolabel logo is really a product coming from the certified fishery concerned. These measures should thus cover both the tracking/traceability of the product all along the processing, distribution and marketing chain, as well as the proper tracking of the documentation (and control of the quantity concerned)*." (FAO, 2009a). Hence, while traceability and CoC to some degree have the same goal (well-documented products), the approach is rather different (Borit & Olsen, 2012) (Borit & Olsen, 2016).

Traceability is generic and non-discriminatory; the company receives trade units, splits, joins or merges trade units into raw material batches, makes production batches based on the raw material batches, and finally splits the production batches into outgoing trade units. At each stage, a spilt, join or merge can take place, which will be recorded in the traceability system so that all transformations and dependencies are documented. The golden rule in a traceability system is that "you can do 'anything' (as far as the traceability system is concerned), but you must document what you are doing".

With CoC, there is one particular set of attributes that it is desired to protect, retain, and document (e.g. fair trade, organic production, or a particular origin) while other attributes are considered to be less important. A CoC identifier will be assigned to all products produced by the FBO with the given attribute, and the same CoC number may be assigned to many different production batches, even from different suppliers. The golden rule in a CoC system is that "you can only mix units that have the same CoC number, and if you do so, the CoC number is retained".

CoC is often used when producing according to eco-label requirements; then the attributes associated with the CoC number are those which are required for certification in accordance with the eco-lablel in question. CoC can be a relevant and useful approach in some circumstances, but it is not the same as traceability. The ISO Technical Committee ISO/PC 308 was established in 2017 to standardise the definition of Chain of Custody for food products in general, and the yet unpublished ISO 22095 "Chain of custody -- Transparency and traceability -- Generic requirements for supply chain actors" is under development where the relationship between CoC and traceability will be clearly defined.

4.11 Internal traceability

Internal traceability is the traceability within a link or a company (Moe, 1998), see Figure 8. On a farm or fishing vessel the first step is recording information related to the harvest or catch; in the other links the first step is recording information related to the received trade items. Subsequently, information on all the other internal steps needs to be recorded, including all transformations that take place and all relevant properties related to internally generated batches or trade items. Internal traceability is the backbone of traceability in general; everything else depends on each company in the chain having good systems and good practices when it comes to recording all the relevant internal information. Internal traceability mainly deals with batches, but the relationship between incoming trade items and raw material (or ingredient) batches needs to be recorded, and also the relationship between production batches and outgoing trade items. Internal traceability is the domain and responsibility of a single company, data confidentiality or access is not a big issue, and several good systems, solutions, practices and standards have been developed in this area.

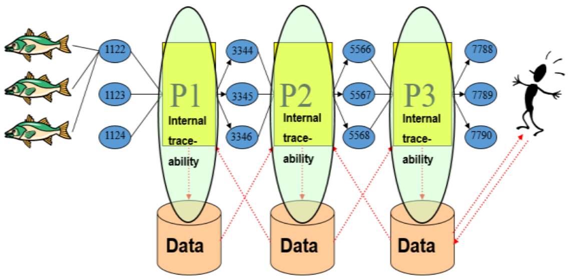

Figure 8. Internal traceability

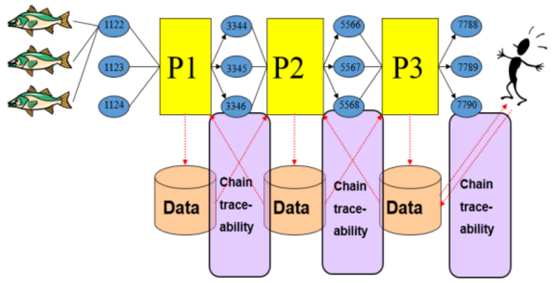

Figure 9. Chain traceability

4.12 Chain traceability

Chain traceability is the traceability between links and companies, and it depends on the data recorded in the internal traceability system being transmitted, and then read and understood in the next link in the chain (Moe, 1998), see Figure 9. Data can be transmitted in various ways; the simplest being by physically (on the label) or logically (in accompanying documentation) attaching the information to the product when you send it. A more flexible way of implementing chain traceability is for trading partners to agree on a way of identifying the trade items, and then to send the required information through another channel (fax, mail, electronically integrated systems, etc.) while referring to the trade item in question. This is commonly referred to as "information push"; as the amount of data grows ever larger, "information pull" has also gained popularity as a way of implementing chain traceability. This is when the trading partners agree that the seller should retain and make available information about the trade item in question on request (Lehr, 2013). This could be a request submitted by telephone or fax, but in modern electronic systems this functionality is typically accomplished by trading partners sharing an intranet where the supplier provides detailed data on all trade items, and the buyer can extract whatever data is needed. Chain traceability is more complex to achieve than internal traceability, because it requires the cooperation and agreement between at least two (in practice more) FBOs, and data confidentiality and levels of access are a big issues. Chain traceability is often closely related to Electronic Data Interchange (EDI), which in turn depends heavily on the agreement on -, and adoption of standards both when it comes to media, identifiers, content and structure of the data that are to be exchanged. See discussion in "Traceability and standards" section.

4.13 Traceability systems

Traceability systems are constructions that enable traceability; they can be paper-based, but more and more commonly they are computer-based. Several detailed descriptions of traceability systems in various food sectors have been published, and there is general agreement on what requirements a traceability system should fulfil (Moe, 1998) (Mgonja, Luning, & Van der Vorst, 2013).

- It should provide access to all properties of a food product, not only biochemical properties that can be verified analytically.
- It should provide access to the properties of a food product or ingredient in all its forms, in all the links in the supply chain, not only on production batch level.
- It should facilitate traceability both backwards (where did the food product come from?) and forwards (where did it go?).

As indicated in **Paper I**, this means that the following activities must be carried out:

1. Ingredients and raw materials must be grouped into units with similar and defined properties, commonly referred to as TRUs (Moe, 1998) (Kim et al., 1995).
2. Identifiers / keys must be assigned to these units. Ideally these identifiers should be globally unique and never reused, but in practice traceability in the food industry depends on identifiers that are only unique within a given context (typically they are unique for a given day's production of a given product type for a given company).
3. Product and process properties must be recorded and either directly or indirectly (for instance through a time stamp) linked to these identifiers.
4. A mechanism must be established to facilitate access to the recorded properties.

In practically all FBOs we have an internal traceability system; often software with ample opportunity for browsing data, visualizing dependencies (which TRUs were based on which TRUs), and creating reports related to what happens within the company. Implementing similar functionality for a whole supply chain, where we can examine the whole chain of transformations from raw material source to consumer, is a (and probably "the") major challenge, and requires effort, motivation and cooperation, in addition to the presence of technical solutions that build on well-proven and widely adopted standards. Verification and validation of the data in the traceability system is of course also very important, but these are external processes and not part of the traceability system itself.

The terms and concepts outlined in this chapter forms the basis for the theoretical approach that my colleagues and I have developed in the field of food traceability.

5 Food traceability in theory

The theoretical work that I have been involved in has largely been based on practical project work, followed by discussions and generalizations, and only later on production of standards and publications. The theory was based on the practical implementation experience, not the other way round. Traceability was a new field in the mid / late 1990s, and although reports and publications existed, there was no widespread agreement on what terms meant, what traceability entailed, what components a traceability system should have, or how to implement it. Some other disciplines existed where the term traceability was used, or where some underlying concepts were similar. This chapter outlines some of these other disciplines which influenced our initial approach to traceability, and gives some background for the theoretical approach that my colleagues and I eventually chose, which is part of the basis for this thesis, and which led to the publication of the two papers included in this chapter.

5.1 Traceability in relation to other scientific disciplines and research areas

This section examines some of the other disciplines that influenced our way of thinking, especially in the early years. Food safety was a strong driver for traceability, and it took some time before we could convince our colleagues that traceability was not in fact a sub-field under food safety. A number of analytical methods existed, and some scientists in this field referred to what they did as "traceability", or "analytical traceability" (Peres, Barlet, Loiseau, & Montet, 2007). It was important to draw a distinction between what these scientists were doing, in contrast with those of us who were working with traceability as outlined above, where "recorded identifications" was the basis, rather than analytical measurements. Laws and regulations also referred to traceability, especially after a number of large food contamination incidents around 2000; one of which was the Belgian dioxin incident (Bernard et al., 2002) which is examined in more detail in the "Traceability and food safety" section. My background in computer science and programming also influenced my approach to traceability; especially the Object Oriented Programming (OOP) paradigm, where there are many parallels to traceability, TRUs, chains, and transformations.

5.1.1 Traceability and object oriented design

As a systems analyst and programmer, I was trained in Object Oriented Programming (OOP). This is a programming paradigm based on the concept of so-called objects, which may contain data as well as methods / procedures that do something to the object in question. If the data has several parts it is referred to as a record, and each named part of the record is referred to as a field or an attribute. For instance, the data in a given object might refer to a person, and each of the data elements we record about that person ("first name", "last name", "date of birth", etc.) is a field / attribute. An important principle is that of inheritance, so that if object B is created from object A, object B inherits all the fields that object A has. Thus, if we created an object type to represent employees, and we based this object type on the person object, the employee object would inherit the fields "first name", "last name" and "date of birth", and in addition we could add more fields (like "department" or "salary") which only applied to the employee objects, but not to the person objects. In programming terms, the original object (person) is called a "parent", and the new object created (employee) is called a "child".

For me, this way of thinking was the starting point when trying to model TRUs and traceability. Each TRU is an object, and it has many attributes; e.g. an identification number or code, a creation date, where it was created, who the owner is, the product type, the net weight, and many more depending on what type of TRU it is. Inheritance also applies to TRUs; if you use one TRU to create another TRU (for instance through a split or a join), the newly created TRU will inherit many of the attributes of the parent TRU, and also some of the attribute values. This might sound complicated, but it simply means that if you have a production batch of 1000 kg of ground beef, and you split it up into 1000 trade units of 1 kg each, then each of the created TRUs will inherit many attributes, and also some attribute values from the parent TRU (Dupuy, Botta-Genoulaz, & Guinet, 2005). For instance, the attribute value of "slaughter date" will be inherited, because the slaughter date has not changed when we created the new TRUs, but the attribute "net weight" will not be inherited, because the net weight of the created TRU is not the same as the net weight of the parent TRU. Obviously, the "parent" / "child" concepts are also immediately applicable to TRUs; we call the TRU that is split or joined "parent", and we call each TRU that is created "child".

A background in OOP is in no way required to understand traceability, but it did provide me with a very useful starting point and an approach that I believe has made it easier to think about traceability in a structured manner. This has been particularly important when formulating traceability standards, which are structured in a way that closely matches the object / record / attribute name / attribute value paradigm; see section on "Traceability and standards". These terms are also widely used in the rest of this thesis.

5.1.2 Traceability and food safety

Traceability is a principle (or tool, when implemented in a traceability system) that has very important applications in the field of food safety (J. K. Porter, Baker, & Agrawal, 2011). As the supply chains have become longer and more complex, traceability has become more and more important when it comes to ensuring food safety. However, it is worth pointing out that not only is food safety and traceability not the same thing, but they are not even the same type of concepts. Traceability in its nature is descriptive; a traceability system does not care about the values of any attributes; the objective in a traceability system is that data once recorded should never be lost. When it comes to food safety on the other hand, some TRU attribute values are very important, and will determine whether there is or might be a food safety issue or not. Seen from a traceability perspective, the attributes that are related to food safety (like "production date" or "temperature log") are very few, and most TRU attributes recorded in a traceability system have little to do with food safety. However, the main overlap between traceability and food safety is the focus on documenting transformations, which is essential in both contexts. Recording of transformations is essential in a traceability system, because when TRUs are split or joined, we need to preserve a link from TRU child to TRU parent, otherwise information is lost. Recording of transformations is essential also for food safety purposes, because if a TRU is contaminated, it may have come from the parent TRU, and it is very likely to affect all the child (and grandchild, and so on) TRUs. If contamination is discovered, one of the most important first steps is to try to identify the source of the contamination, and that means tracing backwards, from child to parent (Jansen-Vullers et al., 2003). Once the source of the contamination has been discovered, it is crucial to issue a recall, and preferably a targeted recall, which only focuses on actually contaminated food items. This means tracing forwards (also called tracking in some contexts), from parent to child (Jansen-Vullers et al., 2003).

To illustrate how traceability and food safety are connected, we can examine the so-called dioxin scandal that affected the chicken industry in Belgium and in the rest of Europe in 1999. The following is a brief summary of the sequence of events that happened (Lok & Powell, 2000) (Bernard et al., 2002) (Buzby & Chandran, 2003):

1. In January 1999 a car demolition company in Wallonia, Belgium delivered oil from a transformer to a municipal oil recycling plant. The oil contained polychlorinated biphenyls (PCBs) contaminated with about 1 gram dioxin. By accident, the oil ended up in a vegetable oil storage tank.
2. A company that produced vegetable oil collected oil from the tank, and produced contaminated oil.
3. A company that produced vegetable fat bought the oil, and produced contaminated fat.

4. A company that produced feed bought the fat, and produced contaminated feed, mainly chicken feed.
5. Egg producers noticed chicken sickness and reduced egg quality, there were numerous complaints, and the government and insurance companies got involved.
6. The “feed” company stopped selling feed, and reported the “fat” company to the police.
7. PCB / dioxin was identified as the contaminant, all feed production in Belgium was stopped, and the neighbouring countries were informed.
8. On May 27th the first public press statement was issued, and the press accused the government of attempting to cover up the case.
9. The management of the “fat” company was arrested, the management of the “oil” company was arrested, and the Belgian minister of agriculture and the minister of health were forced to resign.
10. The Belgian government estimated the direct economic loss as a result of these events at least to be 465 million Euro in Belgium alone; the European Commission estimated the total loss to be close to 1500 million Euro (Buzby & Chandran, 2003).

Now this case was obviously mainly about food safety, but as such, there have been many worse cases. The enormous costs associated with this event was not mainly because of the effect in itself; there were no human deaths associated with this, and only a limited number of animals were affected. The problem here, and the enormous cost, was related to the scope of this incident, and the fact that it was almost impossible to contain it, and this in turn relates to traceability, or lack of it. Firstly, it took a long time from when contamination was discovered until the source of the contamination was found. Secondly, after the original contamination had been identified, it turned out to be impossible in practice to recall only the contaminated feed and the contaminated food items. There was no legal requirement in the EU in 1999 to keep track of those you received food items from or those you sold food items to; that law came three years later, as a direct result of this incident (European Commission, 2002). Farmers in Belgium in 1999 bought and used feed, and when the incident was discovered a few months later, the farmers had no record of what feed they had bought (certainly not the details, like production date or batch number), and the feed producing company had no record of exactly who they had sold the contaminated feed to. In traceability terms, the transformation was not recorded, and there was no link between parent TRU and child TRU. This, coupled with the fact that the number of potentially contaminated farms and products was so large, led to the widespread recall and destruction of Belgian egg and poultry products (including Belgian chocolate, which could contain egg yolk) across Europe.

This is only one out of hundreds of food safety cases where a large part of the problem was closely related to traceability, or lack of it. Two years earlier, in 1997, the largest US recall ever (over 11.000 tons) had been issued on hamburgers originating from Hudson Foods in Arkansas, and as a result of this the value of the company was reduced so much that it was bought by a competitor shortly afterwards (Walsh, 1997). The federal report after the incident indicated “*the reason for the addition recall is that Hudson took leftover raw materials from one day’s production and used them in the next day’s production*” (CNN, 1997), which in traceability terms means that there was no separation of batches.

Today, there is still a very strong link between traceability and food safety, but it is clear that if you want a good food safety system, you need to include many other aspects and considerations in addition to traceability (hygiene, for one), and it is also clear that traceability has many other applications than food safety.

5.1.3 Traceability and methods for analysing biochemical food item properties

There are a number of methods used for analysing the biochemical properties of food items (Peres et al., 2007). These include DNA-based analyses, stable isotope and trace element analyses, analysis of lipid profiles, high-performance liquid chromatography (HPLC), gas chromatography–mass spectrometry (GC-MS), nuclear magnetic resonance (NMR) spectroscopy, near-infrared (NIR) spectroscopy, metabolite profiling, chemical profiling, proteomics, and many more. Collectively these methods are referred to as "analytical methods", and what they have in common is that they analyse a food item sample, and conclude with respect to the value of one, or set of biochemical food item properties. Properties that to some degree can be verified by analytical methods include species, geographical origin (broadly), process status (e.g. fresh or frozen), presence of additives, some aspects of organic production, remaining shelf life, and some others, depending on the type of food item (Peres et al., 2007). While the list of food item properties that can be verified analytically is extensive and growing as the methods and technologies improve, it is worth noting that this is only a small sub-set of the properties recorded in a traceability system. Analytical methods cannot tell you who the owner of the TRU is, or the name of the farm or farmer, or the route the TRU took in the supply chain, or whether the production was ethical of fair trade, or similar. While practitioners and publications sometimes refer to these types of methods as "methods for traceability" that is inaccurate, at least in relation to most definitions of traceability (including the one chosen here), because they do not deal with "recorded identifications". What these methods can be used for is to verify some of the claims in the traceability system. It is important to keep in mind that a traceability system is made up of statements that are claimed to be true, but we do not know for sure that they actually are true, so that is something we need to check.

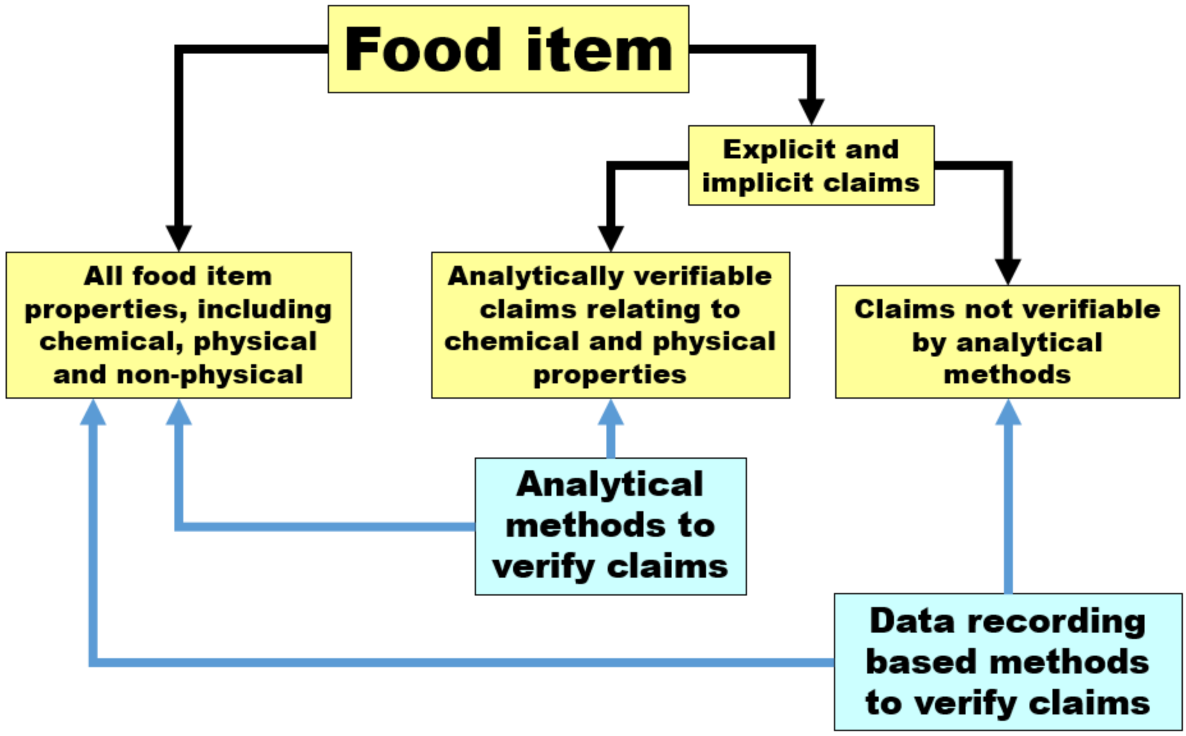

Figure 10. Relationships between claims and methods to verify them

Figure 10 illustrates the relationship between food item properties on one hand, and the claims in a traceability system on the other. Claims may be explicitly stated in the traceability system, or they may be implicit in that if the food item had that property (contained nuts, was made from genetically modified material), it should have been declared. The claims, whether implicit or explicit, fall into two categories; those that can be verified by analytical methods, and those that cannot. If we want to verify a claim in the first category ("this product is made from cod"), we can utilize analytical methods and get a true/untrue answer, or sometimes a likely/unlikely answer. If we want to verify a claim that is not related to a biochemical property ("this TRU came from the farm of Jim Jones") we need to look into the data recordings in the system, especially the transformations ("Did Jim Jones deliver to the FBO that made this TRU?"). Using methods based on analysing data recordings cannot actually verify the claim, but they can often indicate if the claim might be true or not ("No, according to the records, Jim Jones has never delivered anything to the FBO that made the food item in question").

This means that analytical methods are very important when we are dealing with traceability, but they do not in themselves provide traceability. What they do provide is a way of verifying most of the claims relating to biochemical attributes of the food item in question. While these claims are only a subset of the total number of claims in a traceability system, they are among the most important ones, because if there is a food safety problem related to a food item, it will be detectable through application of analytical methods, and food safety, as we have seen, is strongly linked to traceability.

5.1.4 Traceability, laws and regulations

In some areas laws and regulations constitute important drivers for traceability, and in some food sectors there are extensive and detailed regulations specifying exactly what information must be recorded and shared. One example of such a sector is the captured fish sector, where both the EU, the US, and other countries have regulations in place (European Commission, 2008) (European Commission, 2009) (National Ocean Council Committee on IUU Fishing and Seafood Fraud, 2014) with extensive traceability requirements designed to prevent the introduction of Illegal, Unregulated and Unreported (IUU) fish into the legal supply chain (Borit & Olsen, 2012). In this thesis, I have chosen to focus on traceability in general, so I will not go into detail on the existence of this type of national or sector-specific laws and regulations around the world, and what requirements for traceability are inherent in them. For more details on this issue, see (Charlebois, Sterling, Haratifar, & Naing, 2014) or the thesis of my colleague Kathryn Anne-Marie Donnelly (2010).

In general, the most common legal requirement for food traceability is "one up, one down" traceability. As an example, Article 18, part 2 of EU regulation 178/2002 (European Commission, 2002) commonly referred to as the Common Food Law says "*Food and feed business operators shall be able to identify any person from whom they have been supplied with a food, a feed, a food-producing animal, or any substance intended to be, or expected to be, incorporated into a food or feed*." Article 18, part 3 of the same regulation says "*Food and feed business operators shall have in place systems and procedures to identify the other businesses to which their products have been supplied*." This general requirement is fairly weak, and these days most FBOs have systems in place for recording and documenting who they buy from, and who they sell to anyway, regardless of regulations. With that said, laws and regulations containing traceability requirements for food products can be important for two reasons. Firstly, they clearly define what the minimum requirements are, and they outline penalties for violating these requirements. Secondly, they can act as drivers for implementation of traceability for small producers, and in some regions of the world. Even if these regulations do not apply in the exporting country, they have to be met if an FBO wants to sell to a market where such requirements do apply. This means that the traceability system used by the FBO, and the information the FBO provides about the product, must be more extensive than what is locally required. This has led to an interesting situation, in that often food producers in developing countries are more motivated, and have better traceability systems than in industrialised countries (personal observation in Vietnam, South Africa, and China). In some developing countries, they want market access for their products, and they are willing to do what it takes. In industrialised countries, food producers already have market access (to their home market at least), and so traceability might be less of a priority.

5.2 Theoretical approach

As indicated, the theoretical approach that my colleagues and I initially chose was partly based on the fields that were closely related to traceability (food safety, analytical methods, laws and regulations, and in my case, object oriented design) and partly on practical experience in numerous implementation projects. Our goal was to get traceability and traceability systems to work in practice, and to a large degree, we employed a trial and error approach. We did the best we could in one project, learned from our mistakes, and tried to do a better job in the next project. This worked reasonably well; with our knowledge from -, and background in the other related research fields we didn't make too many initial mistakes, and when something didn't work as intended, we improved on it the next time. Our goal was not to establish a theoretical framework; when my colleague and friend Tina Moe, who I worked closely with in various traceability projects in the late 1990s, asked if I would be interested in collaborating on a scientific paper with her (Moe, 1998), I declined, as I could not really see the point. However, my opinion changed a few years later when I got involved in some large European traceability projects, and it turned out that the people we worked with there had completely different (and in my opinion, misguided) notions of what traceability was, and what it entailed. I found that I had to explain and argue with one scientist at a time about traceability and what it was, and it would have been so much easier if I had a paper to refer to. In the TRACE project (see section on "International food traceability projects") we had to establish an internal glossary to reduce miscommunication between project participants, and several years later a part of that led to **Paper I**, outlined below. The other theoretical paper included in this thesis is **Paper II**, which names and defines the components of a traceability system. When working with applications of traceability and drivers for traceability it is relevant to examine the different components separately, because they have different purposes and constraints, and some are connected to costs, and some are connected to benefits. These two papers together outline the theoretical basis for implementing food traceability as I see it after many years of research and development. I believe that traceability should be defined as outlined in **Paper I**, and I believe it is important to distinguish between the components in a traceability system as outlined in **Paper II**.

5.3 Paper I: How to define traceability

The background for this paper was numerous discussions with colleagues on what traceability is and what it entails, in particular in some of the large EU projects on traceability. There were two misunderstandings in particular that were prevalent, and that had to be cleared up before the projects in question could progress in a constructive way:

1. Misunderstanding – "Traceability is a means of finding origin or provenance". While it is true that a common application of a traceability system is to find origin or provenance, that is not all that traceability is (Opara & Mazaud, 2001). Some FBOs claim "we have perfect traceability" when they mean "we can document the origin of our products". This misses out on two things; firstly that information relating to origin is only one attribute of the TRU; there are numerous other attributes that we want to keep track of. Secondly, that a traceability system should provide information not only on where the TRU came from, but also where it went. In some contexts, and also in some scientific articles, the word "trace" is used specifically to identify origin (looking backward), whereas the word "track" is used to identify where the TRU went (looking forward). However, this distinction is not consistently applied and can be more confusing than enlightening; e.g. traceability would then have to be defined as "the ability to trace and track". In the "GS1 Global Traceability Standard" (GS1, 2017b) GS1 writes "For

practical reasons, 'trace' or 'track and trace' may be used as equivalent terms to designate the action of ensuring the traceability", which is a view and a practice I agree with.

2. Misunderstanding – "For traceability, we need to analyse the biochemical properties of the food item in question". This was a common misunderstanding, especially among scientists that used laboratory methods and equipment to analyse and document food item properties. The problem was compounded by the fact that some of these scientists called what they did "traceability", and had made scientific publications using the word in this context. The key question here was whether traceability was necessarily based on recorded identifications or not. ISO 8402 (1994) had "by means of recorded identifications" as part of the traceability definition, and industry practice was also to use the word traceability in relation to historically recorded information rather than in relation to immediate measurements. It was clear that analytical methods were relevant and useful when implementing traceability, but it was not clear what the demarcation between the different research fields were, or how these fields related to the definitions of traceability.

In **Paper I**, my co-author and I listed and analysed all the traceability definitions we could find that were relevant for food products. We also examined how frequently each of these existing definitions were referred to in 101 selected scientific articles, and outlined developments over time for this frequency. Our original intention was to write only a descriptive article, ending with a recommendation for which the "best" definition was, or at least what the disadvantages and limitations of each of them were. However, every single definition had obvious weaknesses; the two most common ones were defining traceability as "ability to trace" without defining what "trace" meant, or unnecessarily limiting what and where you could or should trace. In the end, we combined the good parts of several existing definitions, and came up with the following:

Traceability (n)
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

In our opinion, this is at least a less bad definition than the other existing ones, and it has been referred to a few times in scientific publications. However, the use and relevance of it obviously suffers from the fact that it has no official status or backing.

For the full paper, see appendix.

5.4 Paper II: The components of a food traceability system

This is the newest paper that I have initiated the writing of, and it contains terms and concepts that it was useful to formulate explicitly before writing this synopsis. There are now literally hundreds of food traceability papers, but many of them (including several I have contributed to) focus only on individual companies, chains or systems, or they focus only on one aspect or one application of food traceability. A generic and robust model of traceability, where the overall components are named and identified, is not present in most of these papers, and terminology use in this area is often inconsistent and confusing. As **Paper I** highlights, traceability is about record-keeping, and you can keep records relating to any type or number of attributes of the TRU in question. Many papers on traceability focus mostly on particular attribute types, like the biochemical food item properties, or the attributes relating to food safety or food quality. However, this is not really what traceability is about; these attributes are simply carried by the traceability system, and once we have the traceability system in place we can carry anything. When teaching courses on traceability, I use Figure 11 to try to explain this concept.

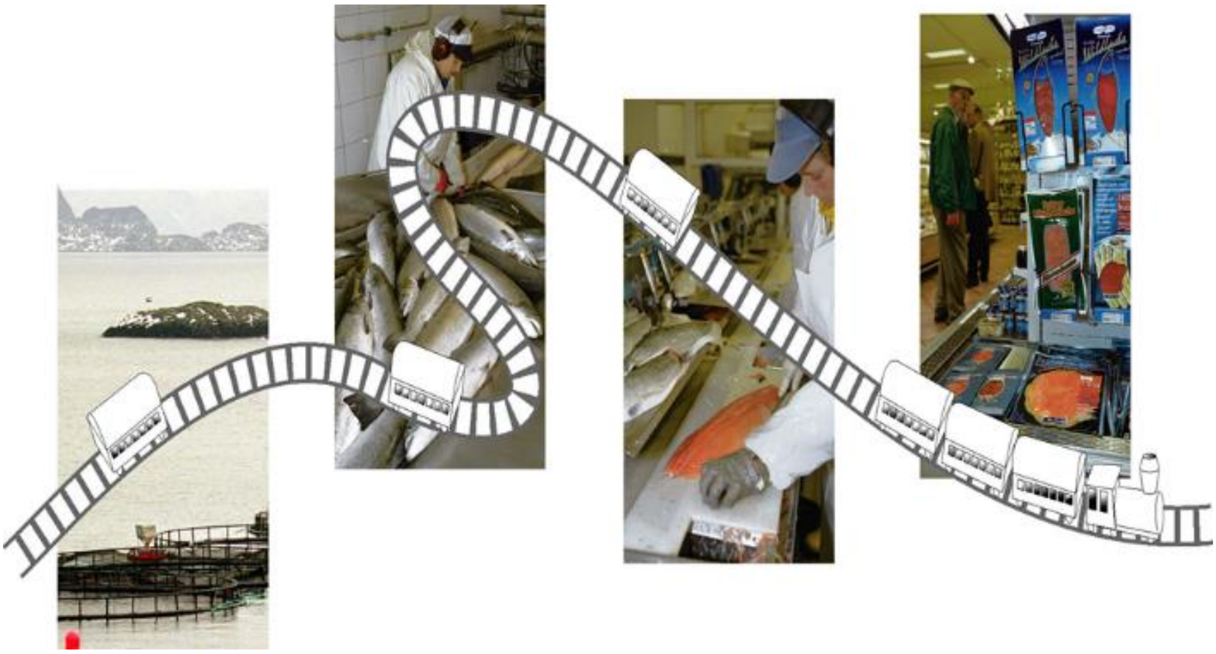

Figure 11. Visualizing traceability as a railroad track. Graphics by Oddvar Dahl, Nofima.

The background shows some links in a supply chain for food (farmed fish), and the carriages represent the data that is recorded in each link of the chain, i.e. the TRU attributes. However, for traceability, we want to “access any or all information relating to that which is under consideration”, so this means that the information recorded in the first link of the chain must somehow be made available in (or transported to) the next link of the chain. This is what the traceability system does; it makes sure that the recorded information is made available elsewhere, and not lost. In Figure 11, the traceability system is the railroad track itself, and the implementation of it consists of assigning identifiers to the TRUs, and recording the transformations. This means that if we want to describe or analyse the properties of a traceability system, we need to distinguish clearly between the following component types:

- The systems and processes that relate to the identification of the TRUs, which includes choosing a code, deciding on uniqueness and granularity, and associating the identifier with the TRU
- The systems and processes that relate to the documentation of the transformations in the chain, which includes recording of the TRU transformations, the weights or percentages, and the related metadata
- The recording of the attributes of the TRU, which can basically be anything that describes the TRU

Paper II describes each of these components in more detail, as illustrated in Figure 12, and also discusses how each of these component types can be improved, and what the overall effect of this improvement might be.

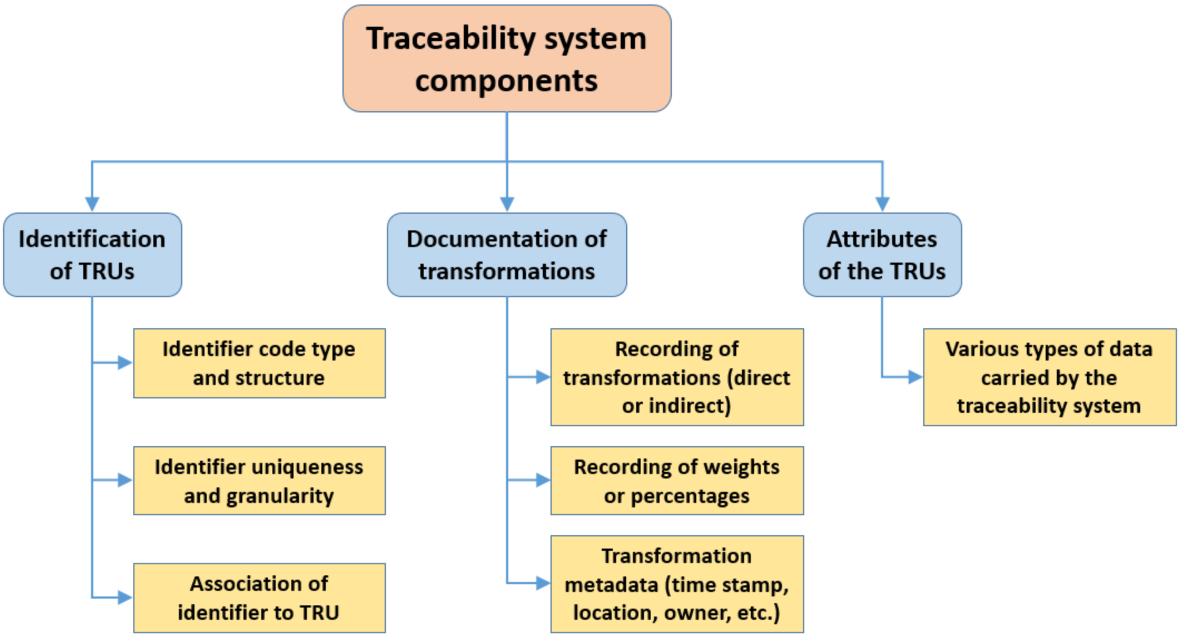

*Figure 12. The components of a traceability system, from **Paper II***

For a holistic view of how a traceability system works, this distinction is crucial, especially if you want to examine costs, benefits, drivers, or constraints. The components are there for different reasons, and to a large degree TRU identification and documentation of transformations is a cost, whereas the ability to access TRU attributes gives us benefits. It is difficult to find scientific publications on food traceability that makes this distinction clearly and consistently, and it is difficult to write coherently about traceability without referring to this overall classification. For this reason, **Paper II** is the most general of the papers included in this thesis, and the classification that it makes underlies all the other papers on traceability included here.

For the full paper, see appendix.

6 Food traceability in practice

Food traceability in practice starts with implementation projects, and this chapter starts with an overview of some of the most significant international traceability projects I have been involved in. The implementation projects always involved industry partners, so one of the first things we had to learn was how to analyse traceability in existing supply chains. I developed a methodology for this, which was extensively used also by others, and with my co-author I wrote **Paper III** to outline the methodology and explain how it should be applied, and how to interpret the results. After analysing traceability in existing supply chains, the next step was to aid and advice the companies on how to improve their systems. My colleagues and I did this in several dozen supply chains, and **Paper IV** outlines implementations in three different chains, and some lessons we learned. We discovered how important standards were when implementing traceability, especially chain traceability, and this led to many of the projects developing first internal standards and guidelines, and then gradually official international standards on European (CEN) or global (ISO) level. To highlight the dependency of traceability on standards, my co-authors and I wrote **Paper V** where we outlined what we called the TraceFood Framework, which describes what type of standards are needed when implementing traceability, and also outlines what we called "Good Traceability Practice" (GTP) guidelines, inspired by many examples of "Good Manufacturing Practice" (GMP) guidelines that already existed (US Food & Drug Administration, 2004).

6.1 International food traceability projects

Food traceability was, at least initially, an applied research field where projects and implementation was more important than scientific publication. In the mid and late 1990s, my colleagues and I were involved in a number of smaller local, national, and Nordic projects focusing on food traceability. When the European Commission in the 5th Framework Programme under "Quality of life and management of living resources" indicated funding available for a project on "Quality monitoring and traceability throughout the food chain", we decided to apply. The project type was not specified, and we decided to apply for a network project (a so-called Concerted Action) rather than an implementation project. We called the project "Traceability of fish products" (short name TraceFish), and in the project application we wrote:

> *The overall objective of this concerted action is to go some way towards establishing a broad consensus for what traceability data should be recorded and transmitted for fish products, and how these data should be coded. To accomplish this, we will establish a forum where representatives from various parts of the fish/product industries and research institutes can meet to discuss traceability related issues.*

In retrospect, I am glad we went for a network project which focused on standardization, rather than on yet another implementation project. Not only because we got the application funded, but mostly because our experience from the implementation projects we had already been involved in indicated that we could not keep solving the problems in one chain at a time; we needed a broader approach, and we needed to come up with more generically applicable solutions.

As project coordinator, I am biased, so it is difficult for me to objectively evaluate TraceFish, but it is clear that:

- We delivered the two European standards (CEN Workshop Agreements or CWAs), CWA 14659:2003 "Traceability of fishery products. Specification on the information to be recorded in farmed fish distribution chains" (CEN, 2003a) and CWA 14660:2003 "Traceability of fishery products. Specification on the information to be recorded in captured fish distribution chains" (CEN, 2003b).

- The standards were used by the industry, also outside Europe. CWAs last for three years, and after that they can be renewed if they are still used and seen as relevant, which the TraceFish CWAs were. In 2007, ISO established a Fisheries and Aquaculture (TC234) working group on traceability (WG1), and the first task of this working group was to make ISO standards based on CWA 14659 and CWA 14660. ISO standards are global, and do not expire unless they are retracted, so to a large degree the TraceFish CWAs from 2003 still live on today as part of ISO 12875 (ISO, 2011a) and ISO 12877 (ISO, 2011b).
- The TraceFish network was valuable to us, and the discussions we had there led to greater insights, a broader view, and a better understanding of traceability.
- The competence that we acquired from this project and the network also led to several other projects, many on European level.

Table 1: List of EU food traceability projects, my role, and what came out of them

Project full name	Short info	My role	Traceability relevance
Traceability of fish products	EU 5FP TraceFish 2000-2002	Coordinator, overall responsibility for constructing project and writing proposal	Defined some terms and concepts Produced the CWA 14659 and 14660 traceability standards which is the basis for the ISO 12875 / 12877 standards
Health promoting, safe seafood of high eating quality in a consumer driven fork-to-farm concept	EU 6FP Seafood Plus 2004-2008	WP leader, assisted with constructing project and writing proposal, responsible for methodology development	Produced and applied first version of the "Reference method" (**Paper III**) to analyze traceability in supply chains
Tracing Food Commodities in Europe	EU 6FP TRACE 2005-2009	WP leader, significant responsibility for constructing project, writing proposal, as well as concept and methodology development	Applied the "Reference method" (**Paper III**) in several chains Numerous discussions on how to define traceability which resulted in **Paper I** Developed sector-specific ontologies Produced the "TraceFood Framework" (**Paper V**)
Automated and differentiated calculation of sustainability for cod and haddock products	EU 7FP WhiteFish 2012-2014	Coordinator, overall responsibility for constructing project, writing proposal, concept and methodology development	Produced the CWA 16960 sustainability standard which builds on the traceability standards
Ensuring the Integrity of the European food chain	EU 7FP FoodIntegrity 2014-2018	WP leader, significant responsibility for constructing project, writing proposal, concept and methodology development	Using traceability to document food authenticity and to detect food fraud Linking claims in a traceability system to analytical methods that can be used to verify them

AUTHENT-NET – Food Authenticity Research Network	EU H2020 Authent-Net 2016-2018	WP leader, significant responsibility for constructing project, writing proposal, concept and methodology development	Using traceability to document food authenticity and to detect food fraud Producing CWA standard on food authenticity, and how it relates to traceability

A summary of the most important EU food traceability RTD projects that I have been part of is shown in Table 1.

I would especially like to emphasize the importance of the TRACE project which finished in 2009, and the FoodIntegrity project which finishes in 2018. In these projects my colleagues and I applied the methods and principles that we had largely developed in the seafood industry on several other foodstuffs, including mineral water (K. M. Karlsen, Donnelly, & Olsen, 2010), honey (Donnelly, Karlsen, & Olsen, 2008), chicken, (Donnelly, van der Roest, Höskuldsson, Karlsen, & Olsen, 2012) and meat (Donnelly, Karlsen, & Olsen, 2009). We were happy to find that while there were particular considerations in some sectors, the challenges were largely the same, and the principles and methods we had developed were generally relevant and applicable.

6.2 Analysing traceability in supply chains

To properly understand food traceability you need to engage with the industry and investigate what systems and needs they have, and how these match. This requires detailed study and analysis of various supply chains, using a number of techniques for gathering and representing data. If you do this a number of times, it makes sense to develop and gradually refine a robust methodology to ensure that you ask the same questions and gather the same type of data in the same way each time so that the results are comparable. **Paper III** outlines the development, application, and refinement of such a methodology.

6.3 Paper III: Reference method for analyzing material flow, information flow and information loss in food supply chains

A lot of the early work on traceability was in individual companies or chains. There was significant food industry investment in traceability systems in the 1990s and early 2000s, and expertise in this area was sought after. My colleagues and I initiated numerous projects where we would visit a single company or a supply chain for a given product, collect data and conduct interviews, describe and analyse material flow, information flow, and information loss, and identify weaknesses and potential for improvement. I developed a set of forms that we used when interviewing the companies, and also some instructions for how to use these forms, how to plan and carry out the interview overall, and how to represent and interpret the results. This worked well, the forms were used in practically all our projects, and I released several new and improved versions of the forms. When I distributed version 10 of the forms and the accompanying guidelines to my colleagues, I took the initiative to publish the methodology. Scientific publication had not been a priority for me up to that point; the industry was more interested in specific recommendations, and some of the reports that we produced and some of the analyses that we did were confidential. There were three main reasons why I nevertheless decided to initiate the writing of a scientific article outlining the methodology and the accompanying guidelines:

- The method was robust and well proven to work, and had been applied by numerous scientists in a variety of food chains

- My colleagues who had applied the method urged me to publish it so that that they had a proper reference to give to it when they wrote reports and publications
- Hopefully the method could be of use to other scientists and food industry professionals who wanted to analyse material flow and information flow, and in particular to anyone who wanted to identify systematic information loss

The method was based on breaking each process down into an alternating sequence of durations and transformations, and assigning one set of questions and a form to be filled out for each of them. Duration was defined as "the time between transformations when nothing happens to the integrity of the unit; that is it is not split up, joined, or grouped with other units". The transformations were typically reception of ingredients and raw materials, application of them, batch production, and splitting of batches into trade items before shipping. Before and between each of these transformations there was a duration as illustrated in Figure 13, so there were nine sets of questions and nine forms to be filled in for each process we analysed.

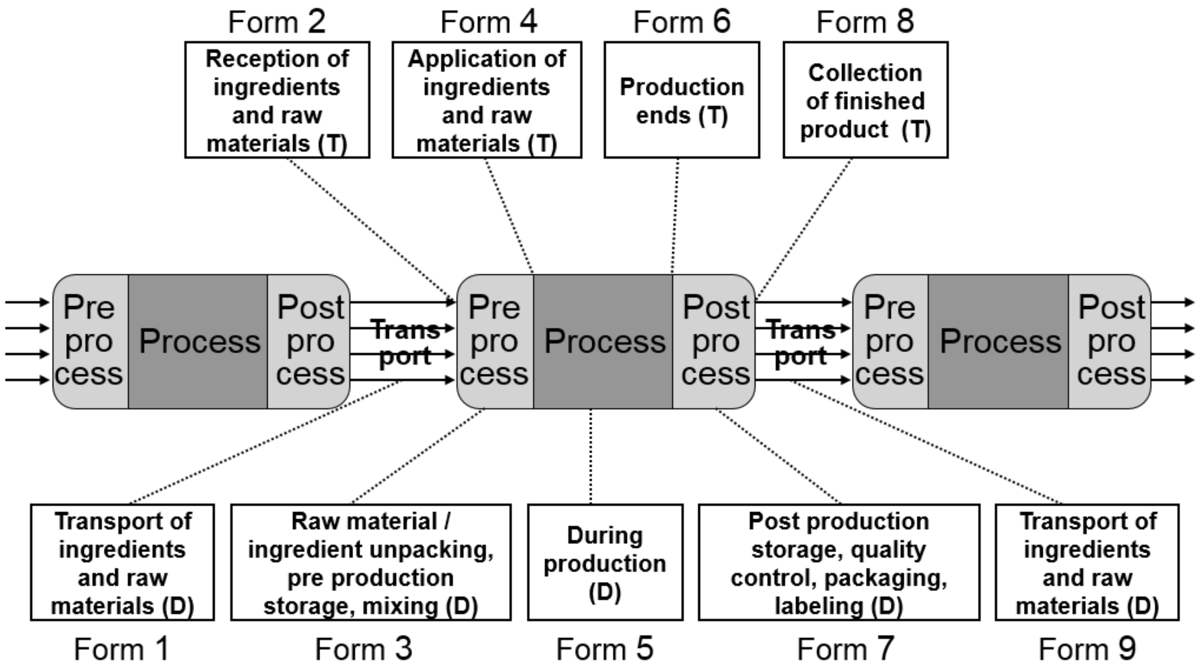

*Figure 13. Transformations (T), durations (D), and forms for each process. From **Paper III**.*

Description of the whole mapping process, examples of the forms, and an indication of how to interpret the results can be found in **Paper III**. An interesting fact that we discovered was that the method was most efficient if we went against the flow, both internally in each process (starting with the questions on form 9 and ending with form 1) and in the supply chain where we started downstream (near the consumer) and then gradually mapped the processes further upstream (closer to the original raw material). The reason was that we normally knew what end product we wanted to analyse, but we did not necessarily know all the ingredients it contained or all the processes it had been through. When we first started using the method, we started upstream, but then we found that we often had to revisit links that we had mapped before, because there were ingredients or processes we did not know about, and relevant questions we had not asked. When we went against the material flow, starting with product questions and ending with raw material questions, this was less of an issue.

For the full paper, see appendix.

6.4 Implementing and improving traceability in supply chains

Using the method outlined in **Paper III**, my colleagues and I analysed a large number of chains. We found systematic information loss in every chain we analysed; this could of course be related to the fact that our pilot companies were interested in traceability and considered investing in better traceability systems, which meant that their existing systems and practices were less than perfect. In general, we found that:

- Our pilot companies had good practices when it came to systematic and extensive recording of relevant data
- Our pilot companies varied when it came to how much of this recorded data they sent or made available to their customers
- Our pilot companies had significant potential for improvement when it came to how they treated data that was sent to them, and how they integrated received data into their own systems

We found, for instance, that information-rich labels with many data elements were produced, but that these labels were largely ignored when the TRU arrived at the next link in the chain. We also found that the companies that received TRUs normally recorded (a very limited number of) TRU attributes, rather than the TRU identifier. This meant, for instance, that in their own system they could find out, for a received TRU, who had produced it, and the production date, but not the identifier on it. In addition, the identifier on the received TRU was normally the production batch number which was an internal number meaningless to anyone outside the producing FBO, and it was used on all trade items that came from that batch, so there was no one-to-one relationship between TRU and TRU identifier. All this led to systematic information loss, and for all the chains that we analysed we could outline potential for improvement, and indicate what the benefits of this improvement might be.

What became clear however, especially as technology and standards improved over time, was that the main reason for systematic information loss was lack of motivation in the company (McEntire, Arens, Bernstein, & Ohlhorst, 2010). Most of the technical problems were solvable, but a combination of financial investment and change of internal practices would be required. In the view of many companies, their traceability was good enough, and they could not see tangible benefits of investing in improved systems, or of changing their established practices (Banterle & Stranieri, 2008). It is worth pointing out that this observation is not meant as criticism of the FBOs in question; it is reasonable for a company to avoid spending time and money on something that they do not think that they need. The question remained, however, whether the companies knew what benefits an improved traceability system could bring, or what risks and limitations were connected to their existing systems. This issue is discussed further in the "Discussion and conclusions" chapter.

My colleagues and I produced numerous papers and reports outlining the analysis we had done, and the recommendations we had made in various FBOs and chains; see sections on "Other relevant papers" and "Other relevant documents, reports, and standards". To exemplify the implementation efforts we were involved in, I have included **Paper IV** in this thesis, where existing and improved traceability systems in three seafood chains are outlined, together with some observations and conclusions regarding how the selected granularity influences the traceability. For more details on this last issue, see the thesis of my colleague Kine Mari Karlsen (2011).

6.5 Paper IV: Granularity and its role in implementation of seafood traceability

This paper illustrates how my colleagues and I worked in implementation projects in specific chains. It was selected for inclusion in this thesis for the following reasons:

- It describes three implementations, not only one, so it is more representative, and it is easier to generalise from
- The reference method outlined in **Paper III** was used to analyse several of the chains
- The principles from the TraceFood Framework outlined in **Paper V** was used as basis for the traceability implementations and the recommended improvements in the supply chains
- There are relevant overall conclusions to draw from this paper and the implementations it outlines, relating to Critical Traceability Points (CTPs, points where systematic information loss occurs (A. F. Bollen, Ridena, & Cox, 2007) (Kine Mari Karlsen & Olsen, 2011)) and in particular to granularity

The three supply chains were:

1. Three suppliers of salmon feed ingredients -> One salmon feed producer -> One salmon farm
2. Fishing vessels -> Wet salted cod producer -> Dried salted cod producer
3. Fishing vessels -> Landing and filleting link -> Packing and distributing link -> Supermarket

The conclusions from the analysis were:

- There was systematic information loss in all chains because the same TRU identifier was used on many TRUs; there was no one-to-one relationship
- There was systematic information loss in all chains because transformations were not explicitly recorded
- Granularity was largely decided by production preferences, not by information preferences. This means that even if the sales department or the customers would prefer to be able to distinguish between fish from different vessels, or geographical areas, or fish caught with different gear types, they could not, because in the batch size chosen, fish with different attributes were mixed. Even though changing to a smaller batch size and finer granularity was technically possible, and might even be quick, simple, and practically without cost, many FBOs are reluctant to do so. Partly because they prefer not to change established practice, but also because the connection between granularity and potential for profiling product characteristics is not clear to them. If the batch size is large, and everything is mixed together, all you can sell is “fish”. If the batch size is smaller, and traceability is present, there is a potential to sell “line caught fish”, or “fish from vessel ABC”; either of which may fetch a higher price than the generic product in some markets.

These conclusions are in line with the conclusions from many other implementations based on similar principles. As a consequence, **Paper IV** highlights the need for cost-benefit analysis related to implementation of improved traceability in general, and finer granularity in particular. As in many other implementations and as mentioned above, the limiting factor was not the technology; it was the motivation of the company that was lacking.

For the full paper, see appendix.

6.6 Traceability and standards

Standards are often useful to ensure unnecessary duplication of effort, to establish and represent consensus, and to facilitate error-free communication (Bechini, Cimino, Marcelloni, & Tomasi, 2008). For traceability, standards play a particularly important role, because the recorded identifications need to be shared in the supply chain, and often this sharing is done electronically (Dupuy, Botta-Genoulaz, & Guinet, 2002). Before the advent of computers, when product information was physically attached to the food item, standards were less important. The information was sent physically along with the TRU, and the recipient and intended reader was human. When product information is recorded and sent electronically, standards are essential, for two reasons:

1. As both the sender and the receiver are computer programs, and it is not necessarily the same computer program, we need a clear specification of a protocol for Electronic Data Interchange (EDI). We need to define exactly, without room for misinterpretation, how the messages are to be coded so that the sender can construct a message and the receiver can understand it. If there are only two trading partners, these could agree on some way of coding messages that suited them, but the supply chain is very complex, and there are many-to-many relationships between suppliers and customers. The most practical way of communicating is to decide on a standard for EDI that everyone supports. A parallel here is fax machines, which became popular in the 1980s. If each fax machine producer had insisted on their own standard, faxes could only have been sent to other machines from the same producer, which would have significantly limited their utility. Instead, all fax machine producers agreed on a common standard, buyers knew that regardless of what brand of fax machine they bought they could send faxes to anyone, and fax machines became very popular. This is similar to the standard for EDI that is needed to facilitate electronic exchange of product information. There are a number of to some degree competing standards in this area. Some of the most prominent are the EDIFACT standards (UNECE, 1987) and the ebXML standards (OASIS & CEFACT, 1999) developed by the United Nations, the Universal Business Language (UBL) (OASIS, 2006) which is based on ISO/IEC 19845:2015, and EPCIS (GS1, 2016) which is supported by GS1. These are standards with different functionality, maturity and intended areas of application, but it is beyond the scope of this thesis to go into more detail on this issue.
2. To facilitate EDI, we also to some degree need standards for the contents of the messages; we need to agree on what the words mean (Folinas, Manikas, & Manos, 2006). If trading partner A uses an EDI standard and sends the message "TRU 1234 has 12% fat" (or more formally, "TRU 1234 has an attribute called "Fat", and the value of that attribute is "12%"), this might not be unambiguous to trading partner B. Fat may be measured in different places, in different processes, and using different methods. Communication and understanding requires not only the exchange of electronic messages, but also a clear agreement on what the words and values in these messages mean. A standard for content is needed, where the meaning of words are defined (the TRU attributes in particular), and also the meaning of the attribute values. This type of standard is commonly referred to as an ontology (Pizzuti, Mirabelli, Sanz-Bobi, & Goméz-Gonzaléz, 2014), and there are some broad international efforts in this area. The UN organization FAO has developed the structured, hierarchical vocabulary AGROVOC (FAO, 2009b) where more than 32000 words and concepts related to food, nutrition, agriculture, fisheries, forestry, environment, etc. have been defined. Smaller, sector specific standards for content and meaning has also been developed, e.g. ISO 12875:2011 "Traceability of finfish products - Specification on the information to be recorded in captured finfish distribution chains" (ISO, 2011a) and "ISO 12877:2011 "Traceability of finfish products - Specification on the information to be recorded in farmed finfish distribution chains" (ISO, 2011b).

Data element		Description	Examples	Categorization		
				Shall	Should	May
Source						
CLA203	Previous food business ID	Country prefix plus unique national identification number for the organization, as well as name and address of the food business from whom the unit was received (vessel or transporter, etc.)	GB – 123467890 Humber Trawlers, Albert Dock, Hull, HU1 7AR, UK		x	
CLA204	Date and time of reception	Date and time of transfer from previous food business, ISO 8601 format	2010-06-28T04:00		x	
Control checks (related to the logistic or separate trade units, as appropriate)						
CLA205	Temperature of unit when received	Temperature of unit °C	1,0 °C		x	
CLA206	Unit temperature record	Temperature/time log (manual/automatic) (if there is a recording device affixed to the unit)	Series of temperature (°C)/date and time points in ISO 8601 format		x	
Transformation information (for each trade unit that is transformed by landing business or auction)						
CLA207	Related created trade unit IDs	List of the UTUIs of the created trade units that may incorporate part of the received trade unit	978817525.0766.00001 0123 978817525.0766.00001 0131 978817525.0766.00001 0272	x		

Figure 14. A page from the ISO 12875 standard

As an example of a content standard, see Figure 14 from ISO 12875 intended for use by landing businesses and auction markets. Each row defines a data element that can be recorded and transmitted, and there is a unique identifier for each data element, a name, a description, and an example or a specification of the content. In addition, each data element is categorized as “shall” (mandatory to record), “should” (recommended, according to good practice guidelines), or “may” (optional). Using a standard like this, trading partners can agree on exactly how data elements should be named and measured, and how messages should be constructed and understood.

The work we did on standards, in particular in the TRACE project, resulted in a paper where we attempted to outline good traceability practice guidelines based on extensive use of standards.

6.7 Paper V: The TraceFood Framework – Principles and guidelines for implementing traceability in food value chains

After having analysed a number of chains and recommended system improvements, we attempted to generalise our recommendations, and to outline what constituted good practice in relation to implementing traceability. We called our recommendation “The TraceFood Framework”, and we illustrated it as follows; see Figure 15.

The TraceFood Framework has six components, as follows:

- Unique identification; one-to-one relationship between TRUs and TRU identifiers. This issue has been discussed above, and the advantages of this approach has been described.
- Documenting transformations. This issue has been discussed above, and the advantages (or even necessity) of doing this has been described.

- Use of an EDI standard for exchanging messages, as outlined above. In the TRACE project we developed our own standard called TraceCore XML and demonstrated that the approach was viable. In practice, it does not matter much what EDI standard is used, as long as it supports the required functionality, and as long as enough FBOs (trading partners in particular) use it.
- Development and use of a sector-specific standard for defining the meaning of terms, and to establish how to measure them. In the TRACE project, we made such standards for mineral water, honey, and chicken; for seafood we used the existing CWA 14659 (CEN, 2003a) and CWA 14660 (CEN, 2003b) standards.
- Generic guidelines for Good Traceability Practice (GTP). We split the recommendations into how to implement internal traceability, how to implement chain traceability, and how to implement electronic data interchange.
- Sector-specific guidelines for implementation where we dealt with issues that were unique for the commodity in question, for instance parameters or production methods that influenced traceability, or the presence of commodity-specific regulations.

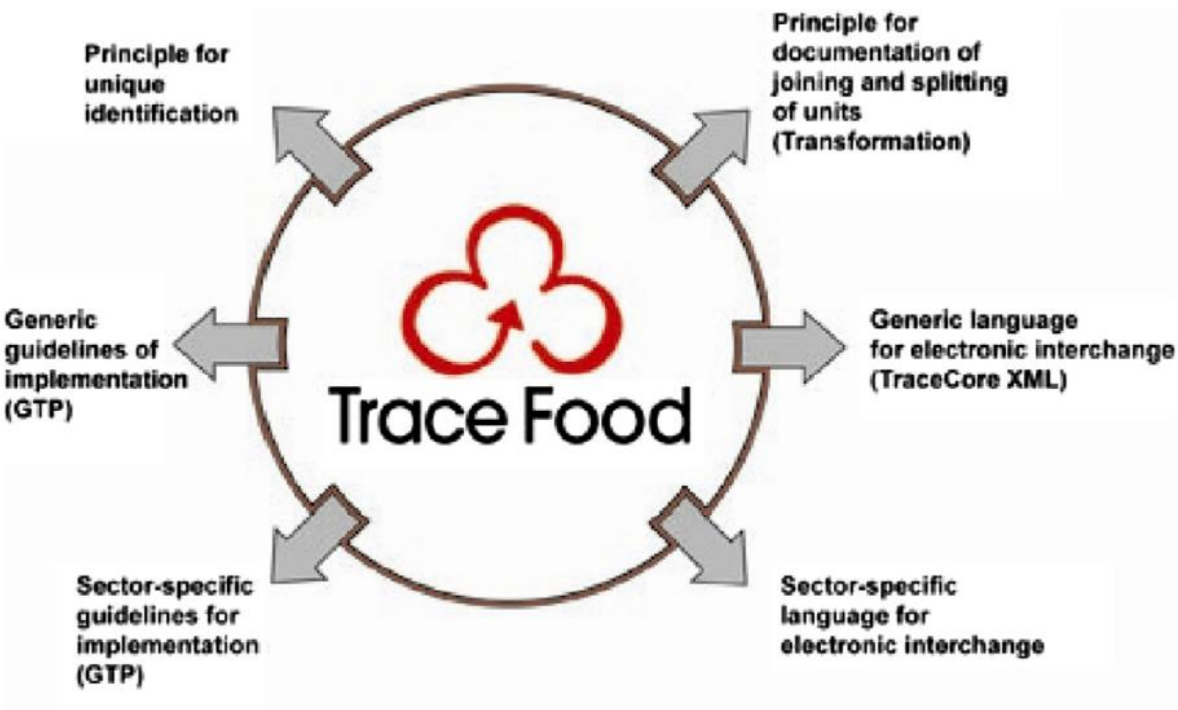

*Figure 15. The TraceFood framework components, from **Paper V***

To formulate, implement, and test the TraceFood framework was for us a very useful exercise. The TraceCore XML was hardly used after the project finished, but by then the publicly available standards for EDI had improved, so companies used these instead. The sector-specific standards for mineral water, honey, and chicken were not used after the project finished; mainly because there were no follow-up projects in these sectors, and the standards had been made with input from only a small number of companies. For the seafood standard we had input from a large number of companies, and the fact that ISO initiated a process to get the original European CWA standards upgraded to ISO level shows that the concept is sound, and seen as relevant by the industry.

For the full paper, see appendix.

7 Discussion and conclusions

To summarize the thesis, I want to first examine the current situation, and then look a bit into the future. While food traceability has come a long way in the last 20 years, there are still gaps in various areas, which I will identify and discuss. There are also new and exciting developments and technologies emerging that will influence and most likely improve traceability, and I will present and discuss some of these. Finally, I will indicate the most important lessons learned, and attempt to give useful advice to scientists and food industry professionals who may be involved in future traceability implementation projects.

7.1 Status on implementation of food traceability, gaps identified

Although there is improvement in the implementation of chain traceability in recent years, we still face some mayor challenges (Forås, Thakur, Solem, & Svarva, 2015) (Bai et al., 2017). Based on the research outlined in this thesis, it is useful to examine where we are now with respect to food traceability, and where the gaps and unsolved problems are. It is possible to identify traceability-related gaps both when it comes to awareness, implementation, technology and standards; the most important are indicated below. These gaps mainly apply to the food industry, but some of the awareness gaps also seem to apply to the scientific community.

7.1.1 Awareness gaps

- There is a lack of understanding of what traceability is, and how it differs from other concepts that are viewed to be similar, e.g. Chain of Custody, or methods for analysing biochemical food item properties. Hopefully **Paper I**, **Paper II**, and some of the standards developed can go some way towards reducing this gap.

- There is a lack of understanding of what the difference between internal and chain traceability is, and why this distinction is important. Many of the potential benefits of having traceability in place comes from chain traceability, but the focus of many implementation projects is on single FBO, internal traceability improvements. Improving the internal traceability is fine and relevant, but it only gives you some of the benefits. To get the benefits from chain traceability implementation, the focus must be on the communication between the trading partners, not only on the data recording in each of them (**Paper IV** and **Paper V**).

- There is a lack of understanding of the fact that a traceability system can cover the entire food chain, from farming or catch through all types of processing and transport all the way to the retailer and the consumer, and also that any attribute may be recorded in the system. The legal requirement is often one-up, one-down traceability, but the commercial requirements, and some of the benefits depend on the ability to trace all the way back to the original source of the raw material, and all the way forward to the eventual application or sale of the finished product. Some proposed definitions of traceability limit the scope of traceability, or they limit the type of data that may be recorded, see **Paper I**. It is difficult to see why, in a definition, it should be desirable to limit what can be traced or where tracing can occur; once the traceability components are in place, any TRU attributes or transformations can be recorded in the system.

- There is a lack of understanding of the importance of having a one-to-one relationship between TRUs and TRU identifiers. If many TRUs have the same identifier, it is impossible to record further information in the chain relating to one particular TRU. We have asked many FBOs about why they put the same identifier on each TRU when it is comparatively simple and cheap to generate unique identifiers. The answer is normally that for the FBO in question, the

TRUs are indistinguishable when they are generated; they are trade units coming from the same production batch, and they share all the same attributes and most of the attribute values. This is true initially, but this reasoning only applies as long as the TRUs are kept together. In practice, they will be transported and stored apart from each other, and they will be sent to different destinations using different means of transport. The fact that there is no unique code on each TRU significantly limits the possibility to record more information related to it (**Paper IV** and **Paper V**).

- There is a lack of understanding of the importance of documenting transformations, and how the chain of transformations is essential if we want to trace back or forward to or through companies (Badia-Melis, Mishra, & Ruiz-García, 2015). There is a significant difference between recording "I used 1000 kg meat from supplier ABC and DEF with the following attributes (and then a list of attributes and values) to make my hamburger batch 1234" as opposed to "I used raw material batch 111 and 112 to make my hamburger batch 1234". Even though more information is recorded in the first case, it will lead to systematic information loss, because the input TRU IDs were not recorded. In the second case the transformation is explicitly recorded, which means that as long as the attributes of raw material batch 111 and 112 are also somehow available, no information will be lost. If something happens (a complaint or a food safety incident), the recorded transformation will make it possible to trace back to the supplier (who hopefully also recorded the transformations that made the produced batches, and so can trace to the previous link in the chain).
- There is a lack of understanding of the fact that many of the main obstacles for adoption of traceability in food chains are cultural and organizational rather than technical. Some FBOs have been under the impression that an improved traceability system can be installed and used without changing the existing manual procedures and processes. In general this is not true; the efficiency, accuracy, and granularity of the traceability system depends on the production processes, and if these are not changed (e.g. if the batch size remains "everything produced of a product type on one day") then this will seriously limit the utility of the traceability system. Successful adoption of a new traceability system requires motivation both in management and among the operators, and this in turn requires training, and explanation and demonstration of what the new system can do, and what the advantages are.
- There is a lack of understanding of how traceability can streamline internal company processes and improve financial performance. This is probably the biggest awareness gap, and it represents the biggest obstacle for widespread implementation of better traceability systems. The FBOs are aware of the costs of improved traceability, but they do not see sufficiently large benefits to justify these costs (Mattevi & Jones, 2016). When it comes to chain traceability, this relates to the fax machine parallel outlined in the "Traceability and standards" section; there is little benefit from buying a fax machine if hardly anyone else owns one. When it comes to internal traceability, there is evidence both from confidential industry reports and from scientific literature (Alfaro & Rábade, 2009) that an improved traceability system pays for itself in less than two years, mainly due to the streamlining of internal processes which result in better industrial statistics, faster turnover of ingredients, raw materials and products, and reduced amount of goods on storage. However, either the food industry does not believe that it is profitable to invest in an improved traceability system, or they do not know it. Either way, more case studies, more data, and more research in this area is needed to establish exactly what the expected benefits of an improved traceability system are, and to what degree, and under what circumstances, investment in such a system is profitable.

These awareness gaps are significant, and they serve to prevent more widespread implementation of improved traceability systems in general, and the uptake of new technologies in particular.

7.1.2 Implementation gaps

- There is a significant gap related to lack of implementation of (improved) food traceability systems, and to a large degree this is a consequence of the awareness gaps. While there are still challenges related to availability of technology, solutions, and standards, it is clear that most companies have less traceability than they could have. They also probably have less traceability than they should have, given their strategy, their priorities and their own economic interests. There is increasing documentation of the fact that not only can a good traceability system reduce operating costs and fulfil legislative and commercial requirements; it can also underpin company branding and marketing strategies, and give the company a competitive advantage.

- There is an implementation gap related to the use of standards, or rather to the fact that too many solutions and implementations rely on proprietary data recording and communication protocols rather on the standards that exist. This is connected to the awareness gap related to the lack of understanding of what the difference between internal and chain traceability is. If the focus is on a single company, standards are less relevant. If the focus is on having traceability in the whole chain, between all the interconnected actors, standards are needed both for EDI and for content.

- There is an implementation gap related to the lack of integration of received data into own system. As indicated above, the biggest systematic information loss in the existing systems happens when data is recorded and sent, but more or less ignored by the recipient. FBOs need to consider the data they receive about a TRU to be a valuable aspect of the TRU; one that they pay for, and must take care of upon reception, the same way they take care of the food item itself.

- There is a gap related to the lack of widespread implementation and use of new technologies for automatic identification. Both for TRU identification and for representation of attribute values, bar codes still dominate in the food sector. Bar codes have significant limitations compared to e.g. RFID tags; they need to be read physically with a scanner, they can only store a limited amount of information, and they are not well suited to support one-to-one relationships between TRUs and TRU identifiers. The time and work involved in reading a number of bar codes is significant, whereas RFID tags can be read instantaneously and from a distance. The cost of reading is a very important factor which to some degree prevents the introduction of finer granularity, and in particular it makes it difficult to implement one-to-one relationships between TRUs and TRU identifiers. RFID tags inherently provide this functionality; no two tags ever have the same identifier, and the efficiency of the traceability systems will be significantly improved when the bulk of the industry adopts RFID tags as common practice. Nevertheless, use of bar codes is still the dominating technology; a fact that is connected to several of the awareness gaps outlined above.

- There is a gap related to the lack of widespread implementation and use of new technologies for automatic data capture. Automatic Identification and Data Capture (AIDC) is the common term and abbreviation for these last two technology types, and it refers to methods for automatically identifying objects, collecting data about them, and entering them directly into computer systems, without human involvement. A significant cost related to the running of a traceability system is associated with initial data entry that is frequently performed manually.

It would simplify and speed up the process, and reduce the number of errors, if technologies existed that could automatically extract the relevant data, enter them into the traceability system, and associate them with the TRU in question. Electronic weights on the processing line can be considered AIDC technology when they record the weight of a TRU and associate this weight with the TRU identifier in the system. More advanced sensor types (for temperature, location, pressure, humidity, etc.) exist, but they are still not widely used. See section on "New technologies" for more information on some of these.

The food industry would argue that many AIDC technologies are too expensive, not robust enough, and not value-adding enough. This is not completely untrue, and it brings us to some technology gaps.

7.1.3 Technology gaps

- There is a lack of cheap, functional and robust radio-frequency identification (RFID) tags and technologies (Regattieri, Gamberi, & Manzini, 2007) (Aung & Chang, 2014). Price is probably the main constraint preventing more widespread use of RFID tags, but there have also been issues related to reading distance, reading problems when the tags have the wrong orientation, and reading problems in some environments (cold or frozen products).

- There is a lack of cheap, functional, robust, and integrated technologies for automated data capture. Price is again a major constraint, but another problem is that for the data captured to be associated with the TRU in question, the TRU needs to have an identifier that is known to the sensor. Also, if the TRU identifier is not unique for that TRU (if we do not have a one-to-one relationship), it is difficult to attach sensor data to the TRU. If the TRU identifier is on a bar code (which is still common), it is difficult to read it in real time, as the sensor operates. The widespread introduction of RFID codes would solve most of these problems, which means that automatic data capture technologies will become more common when RFID is more widely implemented.

- There is a lack of instruments and technologies that can verify claims in the traceability system related to the biochemical properties of the food items. As indicated, a traceability system consists largely of claims in relation to food item properties, but mistakes or fraud might cause erroneous claims to be entered into the system. Ideally, for the most important biochemical attributes, we would like to be able to verify the claim in question, but currently it is difficult, expensive, and time-consuming to do so.

As indicated, even if we narrowed the technology gaps and the implementation gaps, if we wanted chain traceability we would have to make extensive use of standards to make sure that information was communicated and shared, and that it was understood by all in the same way. While standards do exist, there are still some gaps also in this domain.

7.1.4 Standards gaps

- The "Traceability and standards" section outlines a number of EDI standards that can be used for data communication and integration. One problem is that there are several of these standards, and that to some degree they are competing. A bigger problem is that they do not enforce or even encourage "good traceability practice". The EDI standards are like enormous menus with numerous choices; they can support whatever type of EDI the user wants. This flexibility might seem like an advantage, but it means that not only do the trading partners need to use the same EDI standard if they want to communicate; they also need to use the standard in the same way. There are no uniform requirements for how to use the standards in a way that supports good practice when it comes to chain traceability (Bosona & Gebresenbet, 2013). This gap to some degree inhibits interoperability of technology systems along the supply chain, increasing business risks and costs when choosing and adopting traceability and information systems.

- While there are a number of ontologies developed for various food sectors (Pizzuti et al., 2014), they cannot be said to be widely used, and most of them do not have official status or significant backing. Once EDI becomes more prevalent, the need for sector-specific ontologies that clearly define what attribute names and values mean (see Figure 14 for an example) will become more acute. Even for some animal species there is confusion; different countries may use different names to refer to the same species, or different countries may use the same name to refer to what is two different species (e.g. an anchovy in Peru is not the same species as an anchovy in Sweden).

Some of the gaps identified will be narrowed when some novel technologies become more widespread in the food industry.

7.2 New technologies and future developments

Paper II describes the components of a traceability system to be identification of TRUs, documentation of transformations, and recording of TRU attributes. There are emerging technologies in each of these fields; some of the most relevant are outlined below.

7.2.1 New technologies for identification of TRUs

The main gap in relation to identification of TRUs is to go from one-to-many relationships between TRU identifier and TRU to one-to-one relationships; the unique license plate principle outlined earlier. The GS1 Electronic Product Code (EPC) is designed as a universal identifier that provides a unique identity for every physical object anywhere in the world, for all time. EPC can be used to carry information about locations, shipments or assets, but for traceability purposes it is most relevant to use it to carry information about TRUs, and that is what the 96 bit Serialized Global Trade Identification (SGTIN) code is for. SGTIN is designed for globally unique identification of trade units in general, not only of food items. For a detailed description of SGTIN with examples, see **Paper II**. One-to-one relationships between TRUs and TRU identifiers already exist in some sectors (for instance when tracking parcels online); there is significant potential for value adding when this principle becomes widespread for food items in general. If you scan the barcode of a food item now, all it will tell you is what product type it is. If you scan or read a unique code, it can link to any relevant information pertaining to the uniquely identified TRU in question, e.g. the best before date, or the transaction in the chain that produced the TRU. This will simplify storage and handling both for the industry and for consumers, and intelligent cold storage rooms or refrigerators can scan or read codes automatically, and tell you when the best before date is approaching.

7.2.2 New technologies for documentation of transformations

Blockchain technology in its current form has been around since 2008; it is what underlies the digital currency called Bitcoin, and it can be used to document transformations in the supply chain in a secure and transparent manner. Blockchain technology is best described as one that enables records to be shared by all network nodes, updated by miners (system users who, for a fee, keep track of transaction records), monitored by everyone, and owned and controlled by no one (Swan, 2015). A significant problem in traceability is that it is difficult to verify that the stated transformations actually took place. If a FBO claims "we split TRU 111 into TRU 222 and TRU 223", this is difficult to check, because we do not have access to the internal recordings of the FBO, and even if we did, the records might not be accurate or complete. Using blockchain technology, the record of all transformations would be in the public domain, openly visible to anyone (although most of the TRU attributes would not be visible)

(Tian, 2016). If a buyer received a TRU where the transactions were documented using blockchain technology, every single transaction from the TRU in question back to the original farming or harvesting would be available for inspection, also for the other TRUs that came from the same source. This to some degree prevents FBOs from introducing undocumented raw materials or products into the supply chain; if they did, the mass-balance accounting would not add up (you cannot produce 1200 kg fillet from 1000 kg meat or fish). It also prevents anyone from overwriting the transaction once it has been recorded, which means that if the original data recorded is correct (and it is normally in the interest of high quality producers to record the initial data correctly, to protect their brand and to justify the higher price they get) it becomes very difficult for FBOs later on in the chain to counterfeit or dilute the product. Blockchain technology will not guarantee accurate recordings, but it will certainly remedy some weaknesses that currently exist, and it will be interesting to see what happens when the technology becomes prevalent.

7.2.3 New technologies and trends for recording of TRU attributes

There are two significant developments in this area; one is related to technologies for Automatic Identification and Data Capture (AIDC) and the Internet of Things (IoT), and the other is related to the interest in recording new attribute types.

AIDC is by no means a new concept, but use of AIDC is increasing, the technology is becoming simpler, cheaper, and more accurate, and there is increasing interest in the attributes that AIDC can record (Trappey, Trappey, Hareesh Govindarajan, Chuang, & Sun, 2016). AIDC covers a broad range of technologies; what they have in common is that data is generated and recorded without the need for human effort. Various types of sensors in the production plant can be examples of AIDC, and they can record weight, location, speed (if on a conveyor belt), room temperature, process temperature, other process parameters, pressure, humidity, or other attributes that it is relevant to associate with the TRU in question. A more recent, and more advanced version of AIDC technology is when the sensor is not in the production plant, but embedded in the TRU itself. Embedded time/temperature loggers have existed for many years, but more advanced embedded sensors can also measure e.g. pressure, humidity, or exact GPS coordinates (Bai et al., 2017).

The Internet of Things (IoT) is the inter-networking of physical devices and other items embedded with electronics, software, sensors, actuators, and network connectivity which enable these objects to collect and exchange data (Trappey et al., 2016). The advent of IoT can significantly increase the utility of AIDC technologies. We can envisage, for example, a TRU with an RFID chip embedded, travelling on a conveyor belt in a production facility. On the conveyor belt there is an electronic weight that the TRU passes over, and nearby there is a time-temperature sensor that monitors the environment. If these three sensors are connected through IoT, the traceability system can automatically, without human intervention, assign the recorded weight and temperature at the given place and time to the TRU in question by linking the data to the unique TRU identifier. Interoperability and connectivity is unproblematic; all these sensors communicate through a predefined protocol. This functionality is achievable today, but it will become cheaper and more widely used as more devices are IoT-enabled. As with traceability, the limiting factor is not the technology, it is the utility, and the degree these technologies add value to the product (Pang, Chen, Han, & Zheng, 2015).

Another significant development the recording of new attribute types; especially so-called secondary attributes that are not related to the biochemical properties of the food item. This is largely a consumer driven development, where a small, but increasing part of the consumers show interest and willingness to pay for information relating to various aspects of sustainability or ethics (Miller et al., 2017). Examples of attributes that it might be relevant to record include:

- Exact origin, name of farmer or fisherman, documented local production
- Organic production status, organic certification
- Alternative production methods, like biodynamic production, no additives, special recipes
- Religious attributes, halal or kosher production
- Social sustainability attributes, like absence of child labour or slave labour, freedom to join a union, fair trade principles in place
- Environmental sustainability attributes, like resource use, emissions, or transport distance

A particularly relevant application of improved traceability is in relation to environmental accounting where the principle is that based on Life Cycle Assessment (LCA) principles, the emissions and resource use related to all the processes and ingredients that went into making and transporting the final product will be quantified. This means that the buyer, whether a FBO or a consumer, can see, on a specific product, how much emission (measured in carbon dioxide equivalents, or CO_2e) went into the production and transport of that product. Widespread environmental accounting would require the CO_2e of each TRU to be recorded in the traceability system, and for an updated CO_2e to be calculated in each process that generated new TRUs. The European standard CWA 16960:2015 "Batch-based Calculation of Sustainability Impact for Captured Fish Products" outlines the principles of environmental accounting in the captured fish sector based on recordings of resource use in the traceability system (CEN, 2015).

7.3 Summary and lessons learned

To conclude, I will attempt to briefly summarise what I believe to be the most important lessons learned after working for many years in the field of food traceability. I have focused on what I hope constitutes useful advice to scientists and food industry professionals who might get involved in future traceability implementation projects.

- In any project or endeavour related to implementation of food traceability, you should clearly define the terms and concepts so that everybody involved has the same understanding, and uses the same definitions. In some of our early traceability projects, a lot of time was wasted on misunderstandings, and sometimes when we seemed to disagree, it turned out that we were just using the same word in different ways. Hopefully **Paper I**, **Paper II**, and some of the standards developed have helped bring clarity, rather than confusion, in relation to this.
- Unique identification of TRUs, and one-to-one relationships between TRUs and TRU identifiers is very important. If several TRUs have the same identifier, you are not making a traceability system for the future. Many of the emerging technologies, and many of the value-adding applications depend on the ability to associate data with one particular TRU. If you are not assigning unique identifiers to each TRU, you are building a system where the focus is on a single FBO rather than on the chain, and it is a system where you cannot avoid systematic and significant information loss.
- In implementation projects, you should focus on chain traceability, and you should involve more than one partner. Chain traceability is the real challenge; improving internal traceability does not necessarily improve chain traceability. Firstly, it is important to know what chain traceability and internal traceability is, and what the difference is. Secondly, it is important to

realise that in general, you cannot implement good systems for chain traceability by yourself; you need to collaborate closely with your trading partners. Many of our first traceability projects were based on single companies that were interested, motivated, and willing to invest in improved traceability, including hardware and software. In these projects, we managed to improve their internal traceability, but many of the benefits generally associated with traceability were not achieved. We had numerous examples of companies implementing excellent procedures and systems for traceability, but when the TRU was sent, often with a product label overflowing with information, including a code that could give access to more, it was largely ignored by the trading partner. This obviously yielded frustration and the investment in improved traceability seemed to some degree to be wasted. After experiencing this situation a number of times, we established the requirement that in industry implementation projects, we would require (or at least strongly prefer) the involvement of at least two FBOs who had an existing supplier-customer relationship. A related piece of advice is to be aware that it is not enough to record and send relevant information; it is necessary that the receiver actually reads and processes the information, and incorporates it into their own systems.

- If they exist; use standards. If they do not exist; develop standards. There is a strong dependency between standards and traceability, and some of the challenges of traceability can only be solved through the development and widespread use of standards. In addition to defining what the terms and concepts related to food traceability means, we need standards on different levels to operationalise traceability in an efficient manner. For Electronic Data Interchange (EDI), there are a number of standards to choose from, many with backing and support from major corporations. For efficient and widespread implementation of chain traceability, we need these standards to be used extensively. Above, the exchange of data in a traceability system was likened to a fax machine. An interesting rhetorical question is, who was stupid enough to buy the very first fax machine? That person or company had no one to send to and no one to receive from, and the first fax machine was basically useless. The same is true for EDI standards, both in general, and in relation to traceability. The more FBOs start using EDI standards for exchanging information on TRUs and transformations, the larger part of the chain we can cover, and the more valuable the information will become. The same is true for content standards where attributes are named and defined. When use of EDI becomes more widespread, the availability of information that was received electronically will increase, and the need for standards that define what the attribute name and values mean will increase. In some form, it is likely that standards similar to the content standards developed for seafood (ISO, 2011a) (ISO, 2011b) will have to be developed, at least for the other major food sectors, as outlined in **Paper V**.
- When you are doing supply chain mapping and analysis, go against the product flow. Start by defining where in the supply chain your mapping will end, and what food item or items you will look at there. Interview the last link first, find out about suppliers, raw materials, and ingredients, and gradually move against the product flow. This was not obvious to us when we started, but the mapping going with the product flow (which intuitively seemed to be the way to do it) turned out to be inefficient, and we often had to revisit already mapped FBOs with supplementary questions, because of something we discovered further downstream in the supply chain. Also, the buyer of a product normally has more power in the trading relationship than the seller has, so when we went with the product flow, the seller had to introduce us to the buyers and ask them to spend time answering our questions, which wasn't always popular. When we went against the product flow, the buyer had to ask the supplier to spend time

answering our questions, and as the suppliers wanted to accommodate their customers, this was far less of a problem. For more details on this, see **Paper III**.

- Be aware that improving the traceability system will improve the internal logistics significantly, even for companies that thought that they already had optimised this area (F. P. Bollen, Riden, & Opara, 2006). Practically every company that we worked with that did an *ex post* evaluation of costs and benefits related to the investment in a new traceability system reported benefits related to better control, better industrial statistics, better ability to optimise production, faster through-put, less raw material storage, and less product storage. It is difficult to document this scientifically; partly because *ex post* cost-benefit calculations may be biased so that they defend the investment decision.
- Be aware that the main bottleneck for successful and widespread implementation of food traceability is economics and motivation. Although there are some gaps, such as missing standards and unresolved technical issues, these are not what prevents investments and implementation. The problem is that most FBOs see the costs associated with investing in improved traceability, but they do not see the benefits (Mattevi & Jones, 2016). Cost-benefit analysis of investment in improvement in traceability systems is normally performed by the companies themselves, and the reports are confidential. Through the years, my colleagues and I have been allowed to see a few of these confidential reports with *ex-post* analysis of the investment, and they all indicated that the traceability system paid for itself in less than two years; a timeframe that is confirmed by other observations (Alfaro & Rábade, 2009).

In my view, we are now in the third implementation wave of food traceability systems. The first wave was driven by the advent of computers and other related technologies, and resulted in data being recorded electronically rather than in ledgers; the focus was on improving data recording and internal traceability. The second wave was driven by the advent of the internet and communication technology, and resulted in systems, procedures, and standards for sharing data electronically, mainly through point-to-point messaging. In the third wave where we are now, the main obstacle is no longer lack of technology or lack of standards. Networked, interoperable food traceability systems are viable, and technologies are emerging for cheap and efficient globally unique identification of TRUs, automated data entry from external and embedded sensors, and publicly available and validated records of TRU transformations. The focus now is on using all this functionality and this data to add value to the food product, either for the food business or for the consumer. It is an exciting time to work in this still developing field, but my guess is that the food traceability scientists of the future to a larger degree will come from the fields of economics, marketing, and even psychology, although there will hopefully still be some use for those with a background in computer science and applied mathematics.

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9 Appendix – The papers

9.1 Full text version of Paper I

Paper I

Olsen, P.; Borit, M.; (2013): “How to define traceability”. Trends in Food Science & Technology, volume 29, issue 2, pp 142-150. doi:10.1016/j.tifs.2012.10.003.

Trends in Food Science & Technology 29 (2013) 142–150

TRENDS IN FOOD SCIENCE & TECHNOLOGY

Viewpoint

How to define traceability

Petter Olsen[a,*] and Melania Borit[b,1]

[a]Nofima, Muninbakken 9-13, Breivika, Postboks 6122, N-9291 Tromsø, Norway (Tel.: +47 776 29231; fax: +47 776 29100; e-mail: petter.olsen@nofima.no)

[b]University of Tromsø, Norwegian College of Fishery Science, N-9037 Tromsø, Norway (e-mail: melania.borit@uit.no)

While food product traceability has become increasingly important in recent years, there is no consensus on what the term "traceability" means, and several conflicting definitions exist. This paper gives an overview of relevant traceability definitions, outlining similarities, differences, and the consequences of choosing one definition over another. To ascertain which definitions are most commonly used, 101 scientific articles relating to food traceability were reviewed. All the definitions commonly referred to in these articles are shown to have weaknesses. By combining the best parts of the existing definitions, this paper offers a new possible definition of traceability as pertaining to food products.

Introduction

Background

In recent years there has been an increased focus on product traceability in food supply chains. Around the turn of the century the main driver for improved food product traceability was the many tragic and costly food scandals that received wide media attention around the world at that time. These included the Bovine Spongiform Encephalopathy (BSE, or mad cow disease) case in the early and mid-nineties (Wales, Harvey, & Warde, 2006), the massive Hudson Foods recall in the US in 1997 (USDA, 1997), and the dioxin contamination of chicken feed in Belgium in 1999 (Bernard *et al.*, 2002), to mention but a few. These scandals resulted in massive press coverage, and increased demands from business partners and consumers relating to documentation and traceability of food products. As a result, traceability requirements appeared or were strengthened in national legislation and in commercial standards for food production. In recent years, electronic systems and standards for food product traceability have improved a lot. This has led to a potential for benefits associated with investing in better traceability systems, beyond reducing risk and meeting requirements. These potential benefits typically include:

- Reduced cost and labour related to better information logistics and less re-punching of data internally.
- Reduced cost and labour related to exchange of information between business partners through better integration of electronic systems.
- Access to more accurate and more timely information needed to make better decisions in relation to how and what to produce.
- Competitive advantage through the ability to document desirable product characteristics, in particular relating to sustainability, ethics and low environmental impact.

This means that traceability has become an important tool in a variety of areas and sectors, and traceability is being referred to in many disciplines and scientific articles. Unfortunately, as this article shows, the definitions used and the respective interpretations of what traceability is are neither precise nor consistent. This article discusses the various ways traceability is defined, what the definitions mean and entail, and also offers a recommendation for how traceability, as pertaining to food products, should be understood and defined.

For the rest of this article, "traceability" should be understood to have the suffix "as pertaining to food products". There are many other meanings and applications of the term, including "measurement traceability" and "transaction traceability", but this article does not attempt to analyze or expand the term "traceability" in contexts other than the one just specified.

Structure of this paper

As we cannot assume that the reader is familiar with all the various definitions of traceability that exist, we begin by listing each of them in Section 1.3. The methodology for the systematic review of scientific papers published in the

* Corresponding author.

[1] Tel.: +47 776 20934.

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area of food product traceability is described in Section 2. Section 3 outlines the outcome of the literature study, and based on this five existing definitions are chosen for further study. This section also includes a brief overview of definitions of -, and references to traceability systems in scientific articles, and the properties these systems have. In Section 4 the definitions of the term "traceability" are analyzed in more detail and compared with the properties and functionality commonly assigned to traceability systems, as outlined in Section 3. Finally, by combining parts of various existing definitions, a new definition is suggested; a definition hopefully without the weaknesses present in the existing alternatives.

Existing definitions of traceability

When we started our investigation we did not know exactly which definitions we would find in frequent use, but to increase consistency and readability we have chosen to include all the pre-existing definitions referred to in this article in this section. This includes traceability as defined in international standards, in legislation, in some dictionaries, and also the most cited standalone definition formulated in a scientific article according to our literature review.

Traceability as defined in international standards

Traceability defined in ISO 8402. An old, practical and often used definition of traceability is found in the International Standardization Organization (ISO) 8402 (ISO, 1994) where traceability is defined as: "*The ability to trace the history, application or location of an entity by means of recorded identifications.*" This definition clearly states what should be traced (history, application and location) and also how the tracing should be done (by means of recorded identifications). It suffers, however, from recursion and thus incompleteness related to the fact that "traceability" is defined by using the term "trace", and the term "trace" is not defined here. It has this recursion in common with many other definitions, as indicated below. In this paper, and in particular related to the definitions we analyze, we understand "trace" to mean "find", "follow" or "identify". An additional problem is that ISO 8402 was withdrawn by ISO and superseded by ISO 9000 which uses a different definition of traceability.

Traceability defined in ISO 9000 and ISO 22005. ISO 9000 (ISO, 2000) has a slightly less specific definition of traceability: "*The ability to trace the history, application or location of that which is under consideration*". Note that in this newer definition, the fragment "*by means of recorded identifications*" has been removed, and this has consequences as discussed in Section 4.

The ISO 22005 (ISO, 2005) definition is word for word the same as the ISO 9000 definition, but ISO 9000 is a standard for quality management systems in general whereas ISO 22005 is a specific standard for traceability in the food and feed chain. ISO 22005 adds that "*Terms such as document traceability, computer traceability, or commercial traceability should be avoided.*"

For all these ISO definitions (ISO 8402, ISO 9000, ISO 22005), there is an additional clause which states that when relating to products, traceability specifically entails "*the origin of materials and parts, the processing history, and the distribution and location of the product after delivery.*"

Traceability defined in Codex Alimentarius. The Codex Alimentarius Commission Procedural Manual (FAO/WHO, 1997) defines traceability as "*the ability to follow the movement of a food through specified stage(s) of production, processing and distribution*". This definition reduces traceability to the following of the movement only, and if taken literally, this definition is very different from all the others outlined here which use at least potentially more comprehensive verb phrases. Codex Alimentarius is recognized by the World Trade Organization as an international reference point for the resolution of disputes concerning food safety and consumer protection, so the traceability definition there is of special importance, even though it is (as shown in Section 3) not commonly referred to, at least not in scientific articles.

Traceability as defined in legislation: the EU GFL (Regulation 178/2002)

The EU General Food Law (EU, 2002) defines traceability as "*The ability to trace and follow a food, feed, food-producing animal or substance intended to be, or expected to be incorporated into a food or feed, through all stages of production, processing and distribution*". This definition is often referred to in scientific articles, and it is quite detailed with respect to what should be traced and followed, and where. It is, however, less detailed when it comes to describing what type of properties are relevant or how the traceability might be implemented. Also, substituting the "trace" phrase used in other definitions with "trace and follow" does not solve the recursion problem.

Standalone definitions of traceability in scientific articles: traceability defined in Moe (1998)

The most commonly referred to definition of traceability that comes from a scientific paper is in Moe (1998). It says "*Traceability is the ability to track a product batch and its history through the whole, or part, of a production chain from harvest through transport, storage, processing, distribution and sales*". Moe specifies that this is "chain traceability", and defines "internal traceability" as the same thing, but "*internally in one of the steps in the chain*"; a useful distinction not made in most other definitions. "Track" is used as the verb here which avoids recursion, but does not really add clarity as the term is not clearly defined. "Product batch" is that which is being traced here which introduces the question related to what a product batch is, and whether all food product traceability is necessarily done on product batch level. For further discussion on this, see Section 4.

Traceability as defined in dictionaries

While dictionary definitions of traceability in general are too imprecise for our purposes and not frequently referred to in scientific articles, we decided to perform a brief examination of these definitions anyway, to get an indication of what the general meaning of the term "traceability" is.

Most dictionaries offer only generic definitions of traceability, and typically "traceability" is only defined as "the ability to trace". This is the case of Dictionary.com (Dictionary.com, 2012), The Free Dictionary by Farlex (Farlex, 2012), Merriam-Webster (Merriam-Webster, 2012) and the Oxford Dictionaries Online (Oxford University Press, 2012). The verb "trace" in turn has a plethora of meanings, and the most relevant for our purposes are "*to follow the footprints, track, or trail of*" and "*to follow or study out in detail or step by step*" (Merriam-Webster, 2012). "Trace" is reported as being a word where the first known use is in the 14th century and the origin is from the Anglo-French *tracer* (Merriam-Webster, 2012), the Vulgar Latin *tractiare* – to drag, and the Latin *tractus* – past participle of *trahere* – to pull (Farlex, 2012).

Only a few dictionaries offer relevant definitions of "traceability" beyond "ability to trace". Cambridge Dictionaries Online (Cambridge University Press, 2012) defines the term as "*the ability to discover information about where and how a product was made*" which, while being fairly generic, is still a suitable definition for our purposes, and it manages to avoid the recursion present in many other definitions.

The most extensive dictionary definition of "traceability" is found in Webster's Online Dictionary (WOD) (Webster's Online Dictionary, 2012), where domain definitions, speciality expressions and extended definitions are given. Under the domain "Environment" WOD mentions "*The ability to trace the history, application, or location of an item, data, or sample using recorded documentation*", which is very close to the ISO 8402 definition, recursion included. Under "Extended definitions" WOD adds:

1) "*Traceability refers to the completeness of the information about every step in a process chain.*"
2) "*Traceability is ability to chronologically interrelate the uniquely identifiable entities in a way that matters.*"
3) "*Traceability is the ability to verify the history, location, or application of an item by means of recorded identification.*"

Extended definition 1) in particular seems to be a fair attempt at avoiding the recursion while still providing a non-trivial definition. Extended definition 2) pre-supposes uniquely identifiable entities which, in the context of food products, is beyond definition and into implementation of traceability. Extended definition 3) is in contrast with common usage of the term "verify" as pertaining to attributes of food products; see discussion on this in Section 4.

Methodology

Literature search strategy

The key objective of this paper is to examine the use of the term "traceability" in scientific articles relating to food products and food production, and to point out relevant definitions, including their properties and mutual inconsistencies. To establish which definitions are used in scientific papers, a systematic literature review was needed. To accomplish this, a search strategy was developed as outlined in Table 1. Given the search criteria in the table ISI Web of Knowledge provided in total 243 hits and all were included in the preliminary documents list. Google Scholar and Science Direct delivered too many results; therefore 100 articles were picked out randomly from the top hits of each list. After eliminating documents that did not meet the inclusion criteria listed in Table 2, 101 articles remained for analysis. These remaining articles were then investigated using the coding scheme outlined in Table 3, and the data was recorded in a database. The final coding question was expanded as the literature study proceeded. Initially ISO 22005 was not a separate option, but as several papers referred to it, it was given a separate code in the investigation.

Results

Overall results of the literature search

Most of the analyzed articles (65%, $n = 101$) mentioned a traceability definition, which means that one third of scientific articles in this field took the definition of traceability for granted, at least in that they did not provide a definition for the term. Out of those referring to a definition, 66% used a single definition, while the rest referred to at least

Table 1. Databases, keywords, and search strategy used to identify scientific articles to be included in the review of traceability definitions.

	Database	Keywords	Where	When
1	Google Scholar	a. Products, traceability, definition	Articles and patents AND legal opinions and journals	All times
		b. Food traceability	Articles and patents AND legal opinions and journals	All times AND since 2008
2	ISI Web of Knowledge	a. Food traceability	In topic AND title	All times
		b. Food traceability AND traceability	In topic AND title	Since 2005
3	Science Direct	a. Food traceability	In all fields	All times

Table 2. Criteria used to include scientific articles in the final analysis list. Documents not fulfilling these criteria were excluded.

Inclusion criteria	Why this criterion?
Published in English language	English is by far the most common language for scientific publication in this field
Published as an article in a scientific journal	Articles published in scientific journals have passed a rigorous quality control
Refers to food and food products	This paper refers to traceability as pertaining to food products
Includes references to traceability	This paper is about traceability

two definitions. The fact that more than 20% of all scientific articles in this field referred to at least two definitions might indicate that the definition of traceability should not be taken for granted. The most common definition used in all the assessed documents was EU GFL (24%), followed by ISO 8402 (17%) and ISO 9000/ISO 22005 (8%/5%). It is worth noting that the ISO 8402 definition continued to be used even after the standard was withdrawn in 2000, as indicated in Fig. 1. 14% of the articles provided their own definition of traceability, and 14% of the articles referred to definitions found in other scientific articles. Among these, the one devised by Tina Moe in 1998 was the most referred to (5%); no other definitions from scientific articles were referenced in more than two papers. Despite being an international reference point for the resolution of disputes concerning food safety and consumer protection the Codex Alimentarius definition of traceability was referred to in only 5% of the articles. For a discussion on the Codex definition of traceability and its limitations see Section 4.

An additional observation from the literature study is that in several scientific papers, the term "traceability" was used in a way which does not correspond to any of the definitions listed above. Phrases like "labels with different degrees of traceability information" and "to find out about the traceability of a product" were not uncommon. From the context, it was clear that many of these articles used the word "traceability" when they meant "product properties", in particular properties relating to origin. We have chosen not to provide a reference to these articles here, partly because there were many of them and singling out a few would be unfair, but also because the concept of traceability is not trivial and the definitions are contradictory, so some confusion is understandable. However, a shared feature of all the definitions above is the fact that traceability is not a type of information; it is the means by which information is retrieved and hence also stored and arranged. Conceptually, a traceability system is quite similar to a filing cabinet in that they both deal with systematic storing and retrieving of data. Importantly, neither a traceability system nor a filing cabinet care about what types of data are being stored. There is no special relationship between traceability and origin; information relating to the origin of a food product should be recorded along with any and all other types of information. In some articles, the terms "traceability information" or "traceability data" were used to refer to the product properties recorded in a traceability system, and this also has the potential to cause confusion. The reason is that practical implementation of traceability necessitates the introduction of codes or numbers whose sole purpose it is to provide identification and enable traceability, and these codes are often referred to internally as "traceability codes" or "traceability numbers" and collectively as "traceability data", and this is then of course a different meaning of the same term.

Table 3. Coding questions and guide used to analyze the scientific articles included in the systematic review of traceability definitions.

1.	Does the article include or refer to a definition of traceability? *Yes/no.*
2.	If yes, is it one single definition or several? *Single definition/multiple definitions.*
3.	If yes, which definition(s) does it include or refer to? *ISO 8402/ISO 9000/ISO 22005/Codex Alimentarius/EU General Food Law/other author's definition/own definition/other.*

Properties of a traceability system

The scientific articles included in the systematic literature review described above contained several detailed descriptions of traceability systems in various food sectors. Many of the articles went into great detail outlining what properties these traceability systems could or should have, and in this area there did not seem to be significant disagreement. Opara (2003) indicates that "*With respect to a food product, traceability represents the ability to identify the farm where it was grown and sources of input materials, as well as the ability to conduct full backward and forward tracking to determine the specific location and life history in the supply chain by means of records*". For this to happen in a supply chain, a traceability system must have the following properties:

1. Ingredients and raw materials must somehow be grouped into units with similar properties, what Moe (1998) and Kim, Fox, and Grüninger (1999) refer to as "traceable resource units".
2. Identifiers/keys must be assigned to these units. Ideally these identifiers should be globally unique and never reused, but in practice traceability in the food industry depends on identifiers that are only unique within a given context (typically they are unique for a given day's production of a given product type for a given company). Expanding on this issue is beyond the scope of this paper; see Karlsen, Donnelly, and Olsen (2011) for a more detailed discussion on this.

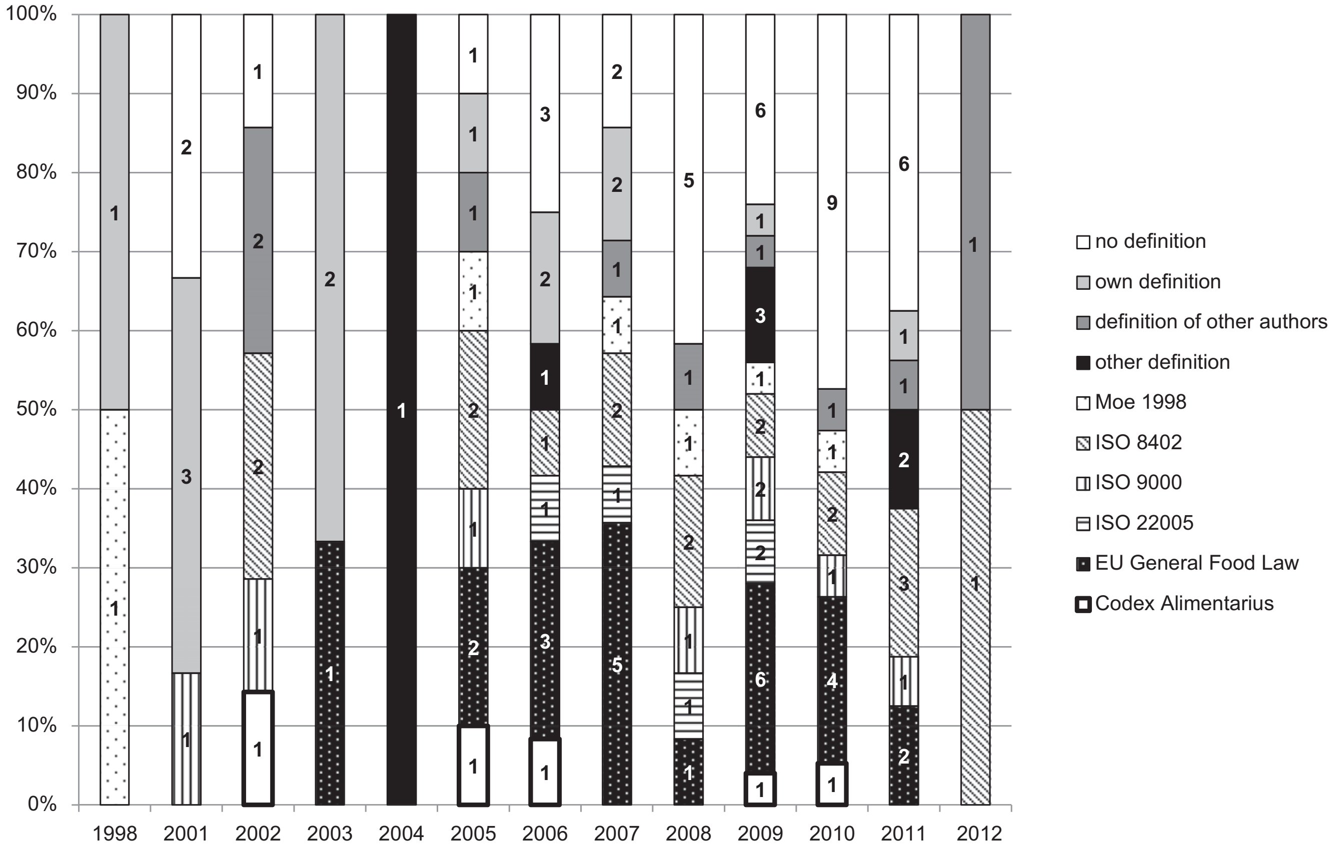

Fig. 1. Traceability definitions and their usage in scientific articles. The numbers in the columns indicate how many articles were using that specific definition. A total of 101 articles were analyzed.

3. Product and process properties must be recorded and either directly or indirectly (for instance through a time stamp) linked to these identifiers.
4. A mechanism must exist to get access to these properties.

All these requirements are necessary for food product traceability. If there is no grouping of ingredients and raw materials; if no distinction is made between what one uses or produces today and what one used or produced many years ago, there is no traceability. If no identifiers are assigned to the traceable resource units, one can only access immediate properties physically attached to the units (for instance on the label), and all properties that one wants to have access to would have to be copied every time a process converts an input to an output. This could work for very short and simple supply chains, but in general traceability depends on assigning identifiers to units, and recording properties that are linked to these identifiers.

This overview of traceability system properties provides us with a benchmark for the traceability definitions. There is general consensus on what a traceability system is, and what properties it could and should have. As basis for our discussion we compare the traceability definitions with the properties of a traceability system. A traceability definition can be classified as too narrow if it does not include or allow for functionality that must be provided by a traceability system. A traceability definition can be classified as too broad if it allows for systems that do not satisfy the minimum requirements for a traceability system.

Discussion

As basis for our discussion, it is useful to make a structured comparison of the different definitions, see Table 4.

As an aid to evaluating the differences between these definitions, we describe two hypothetical systems which offer at least some degree of food product traceability.

Hypothetical system 1 (HS1) – A perfect online location tracking system for food products and all their ingredients. This could in theory be implemented by a multitude of GPS transponders (Zhang, Liu, Mu, Moga, & Zhang, 2009), which would identify location of all products and ingredients at any given time so the ability to follow the food product geographically would be perfect. HS1 would include the functionality for continuous monitoring and permanent recording of the position data, so that even after the fact one could see exactly where a product and all its ingredients came from and went.

Hypothetical system 2 (HS2) – A rapid instrument for accurate analysis of all analytically verifiable properties a food sample may have. This could be implemented if one managed to combine into one instrument all the

Table 4. Selected traceability definitions broken down in constitutive elements.

Defined in	Verb phrase	Product properties	Trace what	Trace where	Trace how
ISO 8402	Trace	History, application or location	An entity	–	By means of recorded identifications
ISO 9000 and ISO 22005	Trace	History, application or location	Of that which is under consideration	–	–
Codex	Follow	Movement	A food	Through specified stage(s) of production, processing and distribution	–
EU GFL	Trace and Follow	–	A food, feed, food-producing animal or substance intended to be, or expected to be incorporated into a food or feed	Through all stages of production, processing and distribution	–
Moe (1998)	Track	–	A product batch and its history	Through the whole, or part, of a production chain from harvest through transport, storage, processing, distribution and sales or internally in one of the steps in the chain	–

methods and instruments currently in use to measure analytical properties of food products, such as DNA fingerprinting (Ogden, 2008), Magnetic Resonance (Renoua *et al*., 2004), and Isotope analysis (Renoua *et al*., 2004).

The question now becomes: if one has either one or both of these instruments, does one then have traceability?

Very few would argue that HS1 could be a good enough food traceability system in itself. The only properties HS1 could give us access to would be exact location at a given time, and according to most definitions that is only one aspect of traceability. It is worth noting that if we used the Codex Alimentarius definition of traceability, HS1 would offer traceability as defined there, which serves as an illustration of how narrow that particular definition is.

HS2, especially if combined with HS1, would give a much broader picture. If we look at the "Product properties" column in Table 4, HS1 would give location, and HS2 would give quite a lot of information about origin, application and life history. Still, regardless of how good HS2 was, it would be limited to giving information about the analytically verifiable properties of the food sample. For many applications of traceability, it is relevant also to have access to food product properties that cannot be analytically verified. These include properties such as identity of food business operator or owner at various stages in the chain, processing conditions that did not directly influence the food properties, data on yield and economics, properties relating to ethics, sustainability and legality, and so on. HS1 + HS2 would only partly satisfy the ISO definitions; there are aspects of "history, application or location" relating to a food product that you cannot get through tracking movement and instantaneous measurements. Moe (1998) also refers to "ability to track ... history", so again HS1 + HS2 would not be sufficient. The EU GFL definition does not indicate which properties the traceability system should provide access to, but the same regulation that contains the traceability definition also contains the legal requirements for traceability of food products in the EU in general. In the EU GFL "Article 18 – Traceability" these requirements include "... *identify any person from whom they have been supplied with a food, ...*" and ... *identify the other businesses to which their products have been supplied*." Identification of persons and businesses cannot be done analytically (at least not in this context), so it is clear that a system consisting of HS1 + HS2 would not satisfy any of the definitions analyzed here (with the exception of Codex Alimentarius). Note that HS2 is an instrument for instantaneous measurement; one gets to know the properties of a food sample by measuring it there and then. This is as opposed to a system of record keeping throughout the chain (the "recorded identifications" mentioned in the ISO 8402 definition) where one assumes that if A has some property and A goes into B, then B will also have this property, and one knows this without needing to measure B. Note also that the analytical methods, when utilized, provide data that it is very relevant to record and attach to the food product for future reference. This means that record keeping is not something one does instead of using analytical methods; it is something one does to keep track of all data, including the data that comes from using an analytical method or instrument.

Looking at the many examples of traceability systems described in the analyzed scientific articles, it seems clear that even the combination of HS1 and HS2 would not be sufficient for a perfect or even adequate food product traceability system and that access to the properties that HS1 + HS2 could not provide us with is essential in modern food production. With this as a basis, we can conclude that a traceability system for food products should have the following properties:

- It should be able to provide access to all properties of a food product, not only those that can be verified analytically.
- It should be able to provide access to the properties of a food product or ingredient in all its forms, in all the links in the supply chain, not only on product batch level.
- It should facilitate traceability both backwards (where did the food product come from?) and forwards (where did it go?).
- The traceability must be based on systematic recordings and exchange of these; there are many relevant properties that will be lost if there is no record-keeping system and a way of distributing/sharing the information.
- In practice, this means that a unit identification system or numbering scheme must be present; without it one cannot achieve many of the goals listed above.

It is worth noting that when traceability is based on systematic recordings and record-keeping, there is no guarantee that the recordings are true. Both error and fraud may lead to untrue claims with respect to properties of the food product. There is a clear need to verify these claims, and in this area analytical methods and instruments play a crucial role. See Borit and Olsen (2012) for a discussion of this issue.

Given these properties of a traceability system, we can go back to the traceability definitions and evaluate them against the list outlined above. This evaluation is included in Table 5.

Some comments on this evaluation:

- Ideally, the verb phrase should not be recursive, and if it uses a different verb than "trace" it should explain it, or refer to an explanation of it.
- It may be relevant to keep track of any or all properties a food product may have. Therefore the definition should not limit this.
- It may be relevant to keep track of the properties of any unit size, so "of that which is under consideration" is good, whereas focussing only on products or product batches is an unnecessary limitation.
- It may be relevant to keep track of the properties of these units anywhere in the supply chain.
- There is no traceability without recorded identifications and a record-keeping system, and a good definition should spell this out clearly, in order to avoid confusing the issue.

In the choice between the definitions above, ISO 8402 is the only one which has incorporated this final and essential property, so of these it is the recommended definition to use. Nevertheless, as already mentioned, ISO 8402 suffers from the recursive verb phrase, and also from the fact that the standard has been superseded, so an ideal definition does not currently exist. Such an ideal definition should combine the best parts of the definitions above, and could be phrased as follows:

Traceability (*n*)

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.

This definition has the following advantages:

- It does not suffer from the weaknesses outlined above, associated with the other definitions.
- It closely matches the properties of traceability systems as used in the production industry in general, and in the food production industry in particular.
- It states that one needs to make recorded identifications if one wants to call what one is doing traceability, and also that one needs to provide access to these recordings. This is in line with the properties that traceability systems used in the production industry have.
- It can serve as demarcation between different scientific disciplines. There is a significant difference between having traceability ("ability to access any or all information") and verifying the claims in a traceability system. Both are very useful tasks and interesting scientific disciplines, but they are quite different. The literature search revealed that many articles did not make this distinction, and it was easy to get the impression that if one wanted traceability, one needed analytical tools and methods. Our view is that if one wants traceability, one has to systematically record properties of "that which is under consideration", and some of these properties can be verified by analytical tools and methods (and indeed some of these properties are obtained through using analytical tools and methods). The point

Table 5. Evaluation of the traceability definitions against the properties of traceability systems. Light shading indicates a problem as identified in Section 4; darker shading indicates a significant limitation or shortcoming in the definition as compared to the properties of a traceability system.

Defined in	Verb phrase	Properties	Trace what	Trace where	Trace how
ISO 8402	Recursive	All	A general food related entity	–	Recorded identifications
ISO 9000 and ISO 22005	Recursive	All	A general food related entity	–	–
Codex	Vague	One only	"Food" is undefined	Specified stages	–
EU GFL	Recursive	–	A general food related entity	All stages	–
Moe (1998)	Vague	–	A product batch	All stages	–

is that it is the recording of information, and the giving access to the recorded information that constitutes traceability, and this definition spells this out in detail.

Note that this definition is similar to the old ISO 8402 definition, and like ISO 8402 it can potentially apply to traceability of any products, not only food related.

While recording of information in itself is not too difficult, getting access to the information later on might be challenging in practice. This is especially true for products with many ingredients, for large production runs with many inputs, for deeply processed products with extensive supply chains, and for products where it is difficult to link inputs that go into a production process to the respective outputs. In all these cases tracing back from a finished product to all its ingredients and raw materials and all the associated recordings will result in an overwhelming amount of information which will be difficult to communicate or analyze (Olsen and Aschan, 2010). Therefore computerized traceability systems are needed to keep track of this information, as well as tools for data mining, analysis and visualization. Process re-engineering can help significantly with this problem, especially if it involves introducing smaller production batches with fewer and more clearly defined inputs. However, this practical problem does not change the fact that if one wants access to all properties a product and its respective ingredients and raw materials have, then extensive record keeping is needed.

Conclusion

Traceability is not a trivial term, and the systematic literature review shows that even in scientific papers there is a lot of confusion and inconsistency. With basis in the properties of a traceability system for food products as described in numerous articles, we have concluded that record keeping is an essential aspect of traceability, and that attempts to implement or define traceability without record keeping will lack significant components. Of the definitions analyzed here, the only one to specify that record keeping is an essential part of traceability is ISO 8402, so with respect to phrasing, it is the most accurate definition. Unfortunately, the ISO 8402 standard has been withdrawn, and the definition suffers from the fact that it defines traceability as "the ability to trace", without defining the term "to trace". This means that currently scientific papers do not have an existing standard or definition without obvious weaknesses to refer to. By combining parts of existing definitions, we have suggested our own definition which hopefully will be seen as an improvement over the alternatives that currently exist.

Acknowledgements

The discussion that underlies this paper started in the Nordic Council of Ministers project "Traceability and electronic transmission of qualitative data for fish products" and the EU 5FP TraceFish project. It continued in the EU 6FP projects Seafood Plus and TRACE where arguments were repeated and refined several times until finally there was some consensus on various terms and their meanings, at least within the respective projects. Thanks to the Nordic Council of Ministers and the European Commission for funding these projects, to the Norwegian Ministry of Fisheries and Coastal Affairs for funding a significant part of the writing of this article, and special thanks to the project members who were most eager and willing to exchange views on this issue; in particular Tina Moe, Jostein Storøy, Marco Frederiksen, Paul Brereton and Heiner Lehr. The second author wishes to thank the EWMA project (Norwegian Research Council project number 195160) for facilitating this work.

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9.2 Full text version of Paper II

Paper II

Olsen, P.; Borit, M.; (2017): "The components of a food traceability system". Submitted to Trends in Food Science & Technology June 2017.

The components of a food traceability system

Authors
Petter Olsen[a,*] and Melania Borit[b]

Affiliations
[a] Nofima, Muninbakken 9-13, Breivika, Postboks 6122, N-9291 Tromsø, Norway (Phone: +47 776 29231; fax: +47 776 29100; e-mail petter.olsen@nofima.no)
[b] University of Tromsø (UiT) - The Arctic University of Norway, Norwegian College of Fishery Science, N-9037 Tromsø, Norway (e-mail: melania.borit@uit.no)
[*] Corresponding author

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, these scientific publications to some degree use inconsistent terminology and definitions related to the components of a traceability system.

Scope and approach
This study names, describes and makes a clear distinction between the different components of a traceability system. The basis for the classification outlined in this article is partly practical experience from traceability system implementations in the food industry, and partly 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.

Key findings and conclusions
This study distinguishes between the underlying mechanisms in a traceability system related to identifiers and transformations, and the Traceable Resource Unit attributes that one wants to get access to. The distinction between the mechanism and the Traceable Resource Unit attributes are 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

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

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) and in national legislation (e.g. the United States, Japan), as well as in intra-company contracts, and there is an ever increasing array of commercial systems available on the market. This trend is also reflected in the media articles and scientific publications about food traceability (see Figure 1).

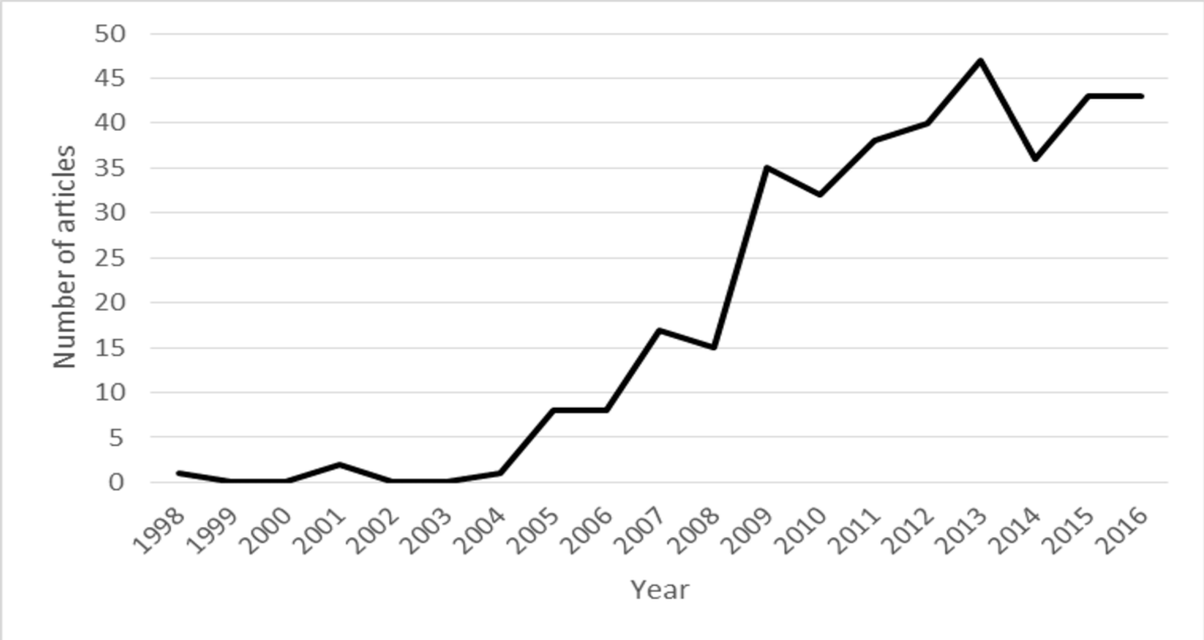

Figure 1. Scientific articles on food traceability published in the Scopus database in the period 1979-2016 (search term: “food traceability”; search date: 23.06.2017).

However, despite common traceability requirements and drivers that generally extend across industries (Jansen-Vullers, van Dorp, & Beulens, 2003), these scientific publications to some degree use inconsistent terminology and definitions, not only when it comes to traceability in itself, but also to related terms and concepts, and to the components of a traceability system (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 study 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, which are documents that require a certain level of consistency and rigour. When discussing topics such as drivers for traceability or the potential for improvement related to traceability, it is important to distinguish between the various mechanisms that exist in a traceability system as opposed to the data carried by the traceability system. Another 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.

The basis for the classification outlined in this article is partly practical experience from traceability system implementations in the food industry, and partly 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 led the development of the seafood traceability standards ISO 12875 “Traceability of finfish products - Specification on the information to be recorded in captured finfish distribution chains” and ISO 12877 “Traceability of finfish products - Specification on the information to be recorded in farmed finfish distribution chains”, and participated in the development of the general food traceability standards ISO 22005 “Traceability in the feed and food chain - General principles and basic requirements for system design and implementation” and, together with the co-author, ISO 22095 “Chain of custody - Transparency and traceability - Generic requirements for supply chain actors”; the last standardization process is still ongoing. 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, and we need to define what it is we are tracing.

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 12875), as well as in some scientific articles (e.g. (Moe, 1998)). However, most of these definitions suffer from recursion (defining “traceability” as “the ability to trace”) or from not being consistent with common usage (focusing on only some properties or only on part of the supply chain). The authors have described and analyzed these problems in detail in a previous article (Olsen & Borit, 2013), and 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).

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 (Kelepouris, Pramatari, & G. Doukidis, 2007; Kim, Fox, & Grüninger, n.d.; 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. often a case or 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 meaningful only to the company in question (i.e. production lots or batches), as opposed to trade units, which pass between companies and have to be identified in a way that both trading partners can understand. 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 TRU types.

3 Components of a traceability system

Based on the definition above, we can broadly identify the components of a traceability system to be as follows:

1. a mechanism for identifying TRUs;
2. a mechanism for documenting connections between TRUs (i.e. the so-called transformations);
3. the attributes of the TRUs, which is normally what we want to trace.

These components are examined more in detail below.

3.1 A mechanism for identifying TRUs

The traceability definition refers to recorded identifications, which means that there must be some way of identifying a TRU. When choosing how to identify TRUs, we have to choose identifier code type and structure, we have to make choices with respect to granularity and uniqueness of the code, and we have to find a way to associate the identifier with the TRU in question.

3.1.1 Identifier code type and structure

When choosing 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 96 or even 198 bits (used 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. 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. 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.

Table 1. A code structure example from the 96 bit GS1 Serialized Global Trade Identification (SGTIN) code used for electronic product identification 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 what type of code it is.	Indicates what type of item it is.	Indicates how the rest of the code is structured.	Indicates globally unique identification of food business	Indicates a uniquely identified product type	Indicates a unique serial number for the TRU in question

			operator (FBO), including country.	within the company.	(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: 00010000000001 11000110111000 001000100 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.

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 (Borit & Olsen, 2016). 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 e.g. 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 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, in that as long as the code remains associated with the TRU, new attributes of the TRU can be linked to the unique code in the traceability system.

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. Even if the trucks wanted to record this information, they could not. As the TRU did not have a unique identifier, it would not be possible to distinguish one of them from the other.

In this context, granularity refers to the amount of product referred to by the identifier (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 the label. 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 utilized (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 reading distance, especially in harsh environments, is still an issue. In addition, this type of tag normally only carry a pre-defined code. Active RFID tags use a battery and normally often 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 internally, 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 aspects of the traceability system (Dillon & Derrick, 2004; Olsen & Aschan, 2010).

3.2.1 Types of transformations

A transformation is an instant or 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:

- "one input TRU, one output TRU", where only one input TRU is used to produce one output TRU (e.g. one whole tuna fish (input TRU) is filleted and placed into a new 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. cod fish from two different vessels (several input TRUs) is mixed in one single fish box (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. anchovies from one single fishing vessel (one input TRU) are pumped in three different basins at the landing site (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 can look as in Figure 2.

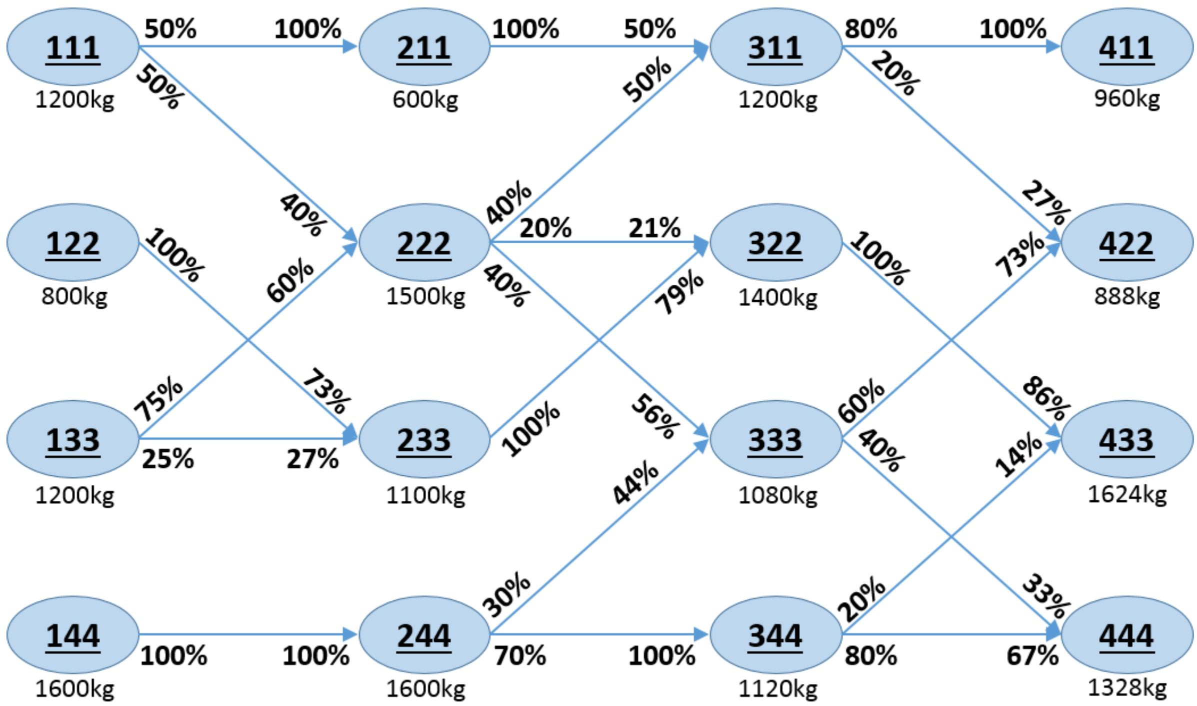

Figure 2. An example of a traceability tree with four processing stages.

The nodes are TRUs, the weights are indicated below the nodes, and the incoming and outgoing amounts (percentages) from and into 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).

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 to visualize the entire traceability tree.

3.2.2 Direct or indirect recording of transformations

Keeping track of the transformations and the traceability tree is at the core of a traceability system. 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. In many processes the details of the transformation are not explicitly known, either because of undocumented mixing, or because data is 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. 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 frequent in the food industry.

3.2.3 Recording of weights or percentages

For food safety purposes, we are mainly interested 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. Traceability systems primarily designed for food safety therefore frequently only record the connections, not the weights or percentages. If we also want to study yield, quality or other production properties, it is also useful to record the quantities or percentages that went into, and came out of each transformation. This will provide better industrial statistics, it will enable us to identify dependencies, and it will aid in production optimization.

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; this may include environmental attributes like temperature, pressure, humidity, or other environmental parameters. If we want access to these parameters, we also need to record the data in question.

3.3 Documentation of TRU attributes

Our definition of traceability is “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”. “That which is under consideration” is the TRU, and it is the TRU attributes that the traceability system is designed to give us access to. Choosing an identifier, associating an identifier with the TRU, and documenting transformations are just means to an end; all we are really interested in are the TRU attributes throughout the life cycle. A relevant analogy may be railroad tracks and carriages; the mechanisms related to identifiers and transformations in a traceability system may be likened to a railroad track that connects everything together, whereas the data recorded may be likened to the carriages that move on the tracks. If the existing mechanism in a given traceability is good, adding more attributes is fairly trivial. There are TRUs in place, they are identified, and so are the transformations. From a system perspective there is no limit to the number of attributes that can be linked to a given TRU; below are some examples from the ISO 12877 standard “Traceability of finfish products - Specification on the information to be recorded in farmed finfish distribution chains” indicating attributes for fish coming from a fish farm. The TRU in question is typically (a large number of) 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). 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, the mechanism part of the traceability system represents costs for the FBOs. The assigning of identifiers and the documentation of transformations is not in itself what a FBO is interested in; such an entity is more interested in getting access to the attributes of all TRUs in the system. 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 mechanisms indicated, we would not have access to the TRU attributes that we are interested in.

4 Discussion

To summarize the components outlined above, a traceability system can be illustrated as in Figure 3.

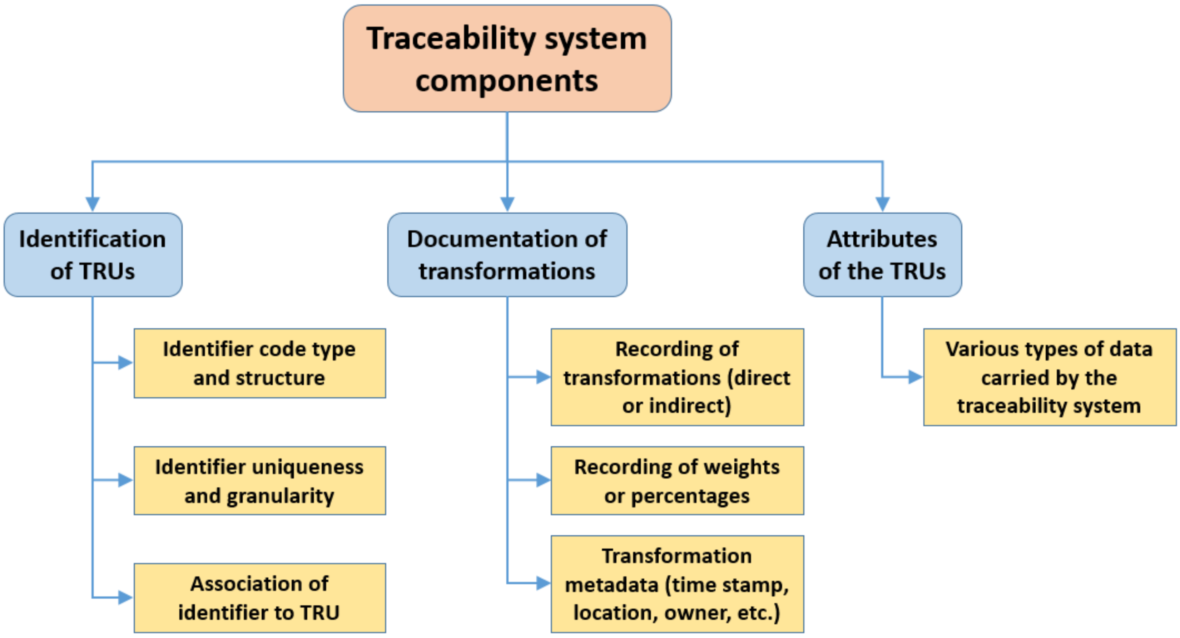

Figure 3. The components of a traceability system. TRU = Traceable Resource Unit.

As indicated above, the most important distinction is between the identification of TRUs and transformations on one hand, and the TRUs attributes on the other; i.e. between the railroad tracks and the carriages. To implement the identification and documentation, the TRUs need to be identified, and the transformations need to be documented. 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 uncover the mechanism part 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 mechanism and TRU attributes is particularly important when discussing potential for improvement of the system. If there are obvious shortcomings related to the current mechanism, it might not be useful to record more attributes. Elaborating all possible traceability system weaknesses and possible improvements is beyond the scope of this article, but a broad overview is included in Table 3.

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

Traceability system component		How the system may be improved
Identification of TRUs	Identifier code type and structure	Use code standards so that the code may be understood also outside the company. Incorporate frequently used data in the code itself.
	Uniqueness and granularity	Finer granularity to 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, which means that TRU attributes can be linked to the code in question, throughout the supply chain.
	Association of identifier to TRU	Faster reading of code, use of barcode, QR-code, RFID chip.
Documentation of transformations	Recording of transformations	Explicit rather than implicit recording of transformations. Smaller input batches or production batches so that the transformation involves a smaller number of TRUs.
	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).
	Recording transformation metadata	Recording transformation metadata more accurately than in existing system. Record more transformation metadata. Allow searching and filtering based on transformation metadata.
Attributes of the TRUs	Various types of data carried by the traceability system	Record more TRU attributes. Record TRU attributes more accurately. Record TRU attributes faster, e.g. through automatic data capture.

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, and there is no separation of TRUs; dairy and grain production are typical examples. 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 underlying mechanisms in a traceability system related to identifiers and transformations, and 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 between the mechanism and the TRU attributes are particularly important when describing and comparing traceability systems, and when recommending improvements. 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 issue.

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9.3 Full text version of Paper III

Paper III

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TRENDS IN FOOD SCIENCE & TECHNOLOGY

Viewpoint

Reference method for analyzing material flow, information flow and information loss in food supply chains

Petter Olsen[a,*] and Michaela Aschan[b,1]

[a]Nofima Market, Muninbakken 9-13, Breivika, Postboks 6122, N-9291 Tromsø, Norway (Tel.: +47 776 29231; fax: +47 776 29100; e-mail: petter.olsen@nofima.no)

[b]University of Tromsø, Norwegian College of Fishery Science, N-9037 Tromsø, Norway (e-mail: michaela.aschan@uit.no)

This paper describes a well-proven process mapping method designed for structured investigation of material flow and information flow in a food producing company or a whole supply chain. The material flow is viewed as an alternating sequence of durations and transformations, and a pre-determined set of questions is associated with each phase. These questions constitute a structured investigation which in turn translates into an overview of the relevant flows and serves to identify systematic information loss. The concept the method is based on, instruction on how to use it, and guidance on how to interpret the results is described in detail in this paper. Finally, some overall results from previous application of the method are presented. The conclusion so far is that the companies investigated are very good at data recording, they range from fairly bad to quite good on data sending, but there is a lot of room for improvement when it comes to data receiving.

* Corresponding author.
[1] Tel.: +47 776 469 53.

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Introduction

Background

Traceability in the supply chain has become a major issue in recent years, in particular related to the production of food. Many international food scandals have given rise to legislation and to commercial requirements relating to traceability (Carriquiry & Babcock, 2007; Opara, 2003). Companies have also in increasing degree recognized the benefit side of a good traceability system. Such benefits include rationalization of information logistics, less repunching of data, competitive advantage through improved documentation, profiling of desirable product characteristics as well as documentation of resource use, environmental load and degree of sustainability in the product supply chain (Korthals, 2008).

For the reasons indicated above, the production industry in general, and the food production industry in particular are investing in traceability systems as never before. Traceability is becoming an integral component of modern supply chains both in the food industry (Dupuy, Botta-Genoulaz, & Guinet, 2002; Moe, 1998; Riden & Bollen, 2007), and in other industries (Kim, Fox, & Gruninger, 1995; Kvarnström, 2008). Although the supply chains vary in length and complexity, the material and information flow in and between links in the chain are based on the same principles. In each link of the supply chain the raw materials, ingredients and products are grouped as batches or lots and usually assigned an identifier. When the products move between the links in the supply chain they are generally referred to as trade units (TUs) or logistic units (LUs, trade units grouped for storage or transport, for instance on a pallet) and given an identifier, possibly different from the batch identifier. Recordings are made that are either directly or indirectly (for instance through a time stamp) linked to these units and their identifiers. Typical material flow in one link of the supply chain can be illustrated in a simple diagram (Fig. 1).

The method described in this paper is applicable to all processes where the material flow in and between links of the supply chain in its simplest form looks as described.

Note that in principle, from the perspective of supply chain management and information logistics, there is no difference between raw materials and ingredients. Also, the product of one link in the chain is frequently the raw material or ingredient for the next link in the chain. However, experience has shown that the diagram is easier to

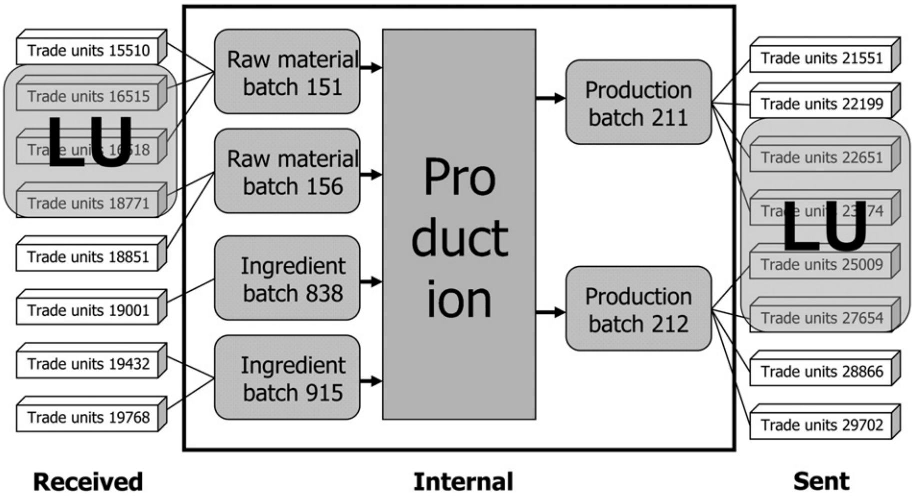

Fig. 1. Relationship between batches, trade units (TU) and logistic units (LU) in one link in the supply chain.

understand and use as basis for discussion if we stick to the terms commonly used in the production industry.

The important question for food business operators (and for production companies in general) is: "Do we, for the product in question, have good enough traceability in our company or our supply chain?" The need for traceability depends on several factors such as type and size of company and supply chain, type of product, legal and commercial requirements, the risk of food safety related incidents, the likelihood of recalls, etc. The method described in this paper is descriptive, not normative, so it will not answer the question above directly. What application of the method will provide is answer to the question "What information do I record, what information can I retrieve, and exactly where is my systematic information loss for this product?". With this knowledge, the company can make an informed assessment, taking the factors above into consideration and judge whether the traceability for the product in question is good enough.

Definitions

Fundamental concepts related to traceability have previously been well defined (Moe, 1998), so we here only present the definitions of particular relevance for the process mapping method. The most precise definition of product traceability is given in the old ISO 8402 standard, where it states that traceability is the ability to trace the history, application or location of an entity by means of recorded identifications, and it adds that for products, traceability may relate to the origin of materials and parts, the product processing history and the distribution and location of the product after delivery (ISO 8402, 1994).

An important concept is that of 'Transformation' (Riden & Bollen, 2007), also called 'batch-dispersion' (Dupuy, Botta-Genoulaz, & Guinet, 2005). It is the common term for joining, splitting, grouping or ungrouping of units. "Grouping" is like "joining", only the individual identities of the units that are grouped together is retained. The typical example of grouping is putting boxes on a pallet. "Ungrouping" is the opposite process; it is the dismantling of a grouped unit (for instance a pallet) and the re-establishment of the individual units (for instance the boxes on the pallet).

An important term which is defined and used in this article is that of 'Duration'. 'Duration' in this context is the time between transformations when nothing happens to the integrity of the unit; that is it is not split up, joined or grouped with other units. 'Duration' is a state that lasts, for instance 'in transport', 'in storage', 'on the production line', etc. As the name implies, a duration always has a span of time associated with it, where as a transformation in principle may happen almost instantaneously.

Overall objective of the method

If we take a closer look at the generic and simplified process outlined in Fig. 1 we can identify the alternation between durations and transformations (Fig. 2).

The actual material flow may be more complicated than this, with sequences of pre-processes, production processes

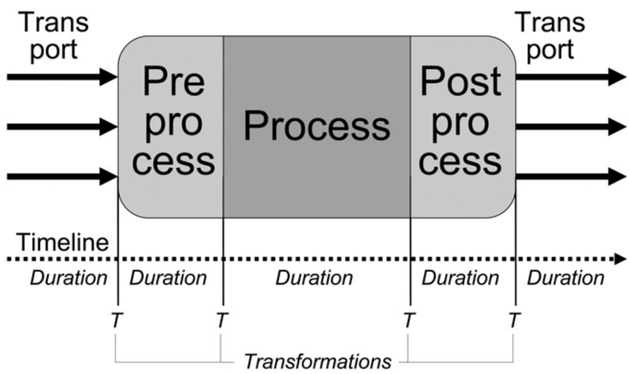

Fig. 2. Transformations and durations in one link in the supply chain.

or post-processes, but the principle of alternating durations and transformations remain the same.

A common feature of research and development projects, especially when some sort of process re-engineering in the supply chain is planned, is the modeling of the present system. Most scientific articles on this subject do not go into specifics on exactly how this modeling should be performed. Dupuy *et al*. (2002) is one of the few exceptions, and propose and describe in some detail a 10 stage approach for modeling the present system. In stage 1 the unit to be traced is defined. In stage 2 the paper says "After defining the Traceable Resource Unit, we suggest reconstituting their chain in a graph…". This is a crucial step in the modeling of the present system, and the aim of this paper is to describe in detail a well-proven process mapping method designed for this type of structured investigation. The focus of this paper is on what questions to ask, and how to interpret the answers. The material flow uncovered by the process mapping can be visualized using any of the many standard notations designed for this purpose, for instance Petri Net graphs (Horvath, 2001), UML activity diagrams (Eshuis & Wieringa, 2002) or Business Process Modeling Notation (White & Miers, 2008). The analysis of information flow will serve to identify systematic information loss and areas where the information logistics can be improved.

The history and use of the process mapping method

The first version of this method was developed as part of the EU-funded 6th Framework Programme "Seafood Plus" project in 2004. It was used for analyzing supply chains for herring in Denmark, salmon in Norway and tuna in Spain (Karlsen *et al*., 2007). The method has been further developed and applied several times, especially within the EU-funded TRACE project, where it was applied on mineral water in Spain (Karlsen, Olsen, & Donnelly, 2010; Karlsen, van der Roest, & Olsen, 2008; Olsen & Karlsen, 2005), honey in France (Donnelly, Karlsen, & Olsen, 2008), and chicken in China (Olsen & Foraas, 2008). The method has also been applied in national projects mapping the supply chain of fish meal and fish oil (Olsen, 2005), salt fish (Donnelly & Karlsen, 2010) and lamb (Donnelly, Karlsen, & Olsen, 2009) in Norway, soy bean in Serbia, cod, herring and salmon in the Nordic countries (Fredriksen *et al*., 2007) and in various other supply chains around the world. Adjustments to the method have been made through the years and now the method is considered robust and stable in its present shape (version 10).

Structure of this paper

In Section 2 "Methodology" the method itself is described, with some recommendations for preliminary work needed to ensure success described in Section 2.1, the questions and the forms used described in Section 2.2, and some practical advice on how to use the method given in Section 2.3. Section 3 "Results" is divided into general advice on how to interpret the answers to the questions asked (Section 3.1) and some overall results, conclusions and recommendations based on around 20 applications of the method so far. Strengths, weaknesses and limitations of the method as well as possible extensions are discussed in Section 4 "Conclusions".

Methodology

Preparing and setting up for the process mapping

This is not the main focus of this article and it is difficult to standardize this part of the procedure, but there are some common steps usually undertaken before starting the actual investigation:

- Sending information to the company that is to be mapped in advance, describing what is going to happen and who needs to be involved.
- Agree time for process mapping interview, ensure that the people who can answer the questions are present and available.
- Either at meeting or before, let the company decide on exactly which process, product or ingredient to map. The company should be encouraged to choose something that is relevant for them in terms of improved documentation and traceability, for instance a product that they have had to recall or one where their customers are requesting more information.
- Either at meeting or before, collect overall information about the object of study (the chosen process, product or ingredient). Who are the suppliers, who are the customers, what is the volume, frequency, and lead time of production. Are they producing for storage or are the products already sold? Is this a supply-driven production where access to raw materials is the bottleneck? Is this a demand-driven production where ability to sell is the bottleneck? The relevance of this information is in determining the possible applications of an improved traceability system for the company or chain in question. If access to raw materials is the bottleneck then any improvement in yield would be very welcome, and it might be valuable to use the information in the traceability system for better industrial statistics, decision support, production optimization, simulation, or similar. If market access is the bottleneck then recording and disseminating data that possibly adds value to the product might be relevant. This can be more details about the farmer or fisherman, the geographical origin, the distance travelled or the resources used, or similar. Several companies have successfully profiled their products in this manner, putting additional data on the label, in the accompanying documentation to the buyers or openly on the company web site. To establish which of these additional drivers or benefits that might exist, it is important to get the whole picture, which is why these questions are relevant, even though they do not directly constitute part of the process mapping.

- Either at the meeting or before, agree on access to data and privacy issues. What parts of the report and conclusions may be published? May photos be taken and included in the report?
- At the meeting, but before the detailed interview, do a production process walk-through. Our experience has indicated that it is most efficient to meet up first, decide exactly which processes are going to be mapped, draw a high level diagram on a whiteboard or similar, and then do the production process walk-through on the factory floor.

A crucial task is to establish the motivation for the company; what do they hope to get out of this? The analysis is of the present situation, and it is important to ascertain if there was a 'before' situation or if there is going to be an 'after' situation, and what the difference is. If benchmarking the old system against the new system is desired, it will be necessary to collect quantitative data that might change after implementation. This includes data on how much time is used on different tasks, expected speed and size of recall, level of detail/granularity of the data, lead time in production, amount of raw material and product on storage, etc. If the process mapping is a prelude to process re-engineering it is important to establish why a new system is being implemented. Typical motivations for the company may be desire to reduce recalls, improve internal logistics, document sustainability, increase sales or use traceability information as part of product branding. The motivation may influence the level of detail chosen when asking the questions. For instance, if improved food safety is not part of the motivation for the company it is not necessary to go into details on the questions relating to these issues.

The questions to ask and the grouping into forms

The core of this process mapping method is the grouping of questions into forms, with each form relating to one specific duration or transformation for the ingredient or product.

For the simple case indicated (Fig. 2), a linear production with one ingredient being transformed into one product, the alternating duration/transformation phases will be:

1. D − Transportation of ingredient from supplier
2. T − Reception of ingredient
3. D − Pre production storage of ingredient
4. T − Application of ingredient
5. D − Duration of production
6. T − Production ends
7. D − Post production storage
8. T − Shipping/collection of finished product
9. D − Transportation of finished product to customer

Each of these phases corresponds to a set of questions to be asked about the ingredient or product in that particular phase. This gives us 9 sets of questions or 9 forms (Fig. 3).

1 is identical to form 9 in nature (in the questions to be asked, not in the ingredient or product to be mapped) in that it is the transport between links that is being investigated. The 9 forms contain on average about 10 questions each; some of them fairly detailed with possibility for multiple responses (for instance parameter lists linked to identifiers). To list each form and each question is beyond the scope of this paper, so only typical questions and a sample form of each type (duration and transformation) has been included here.

Typical questions related to durations (example in Fig. 4):

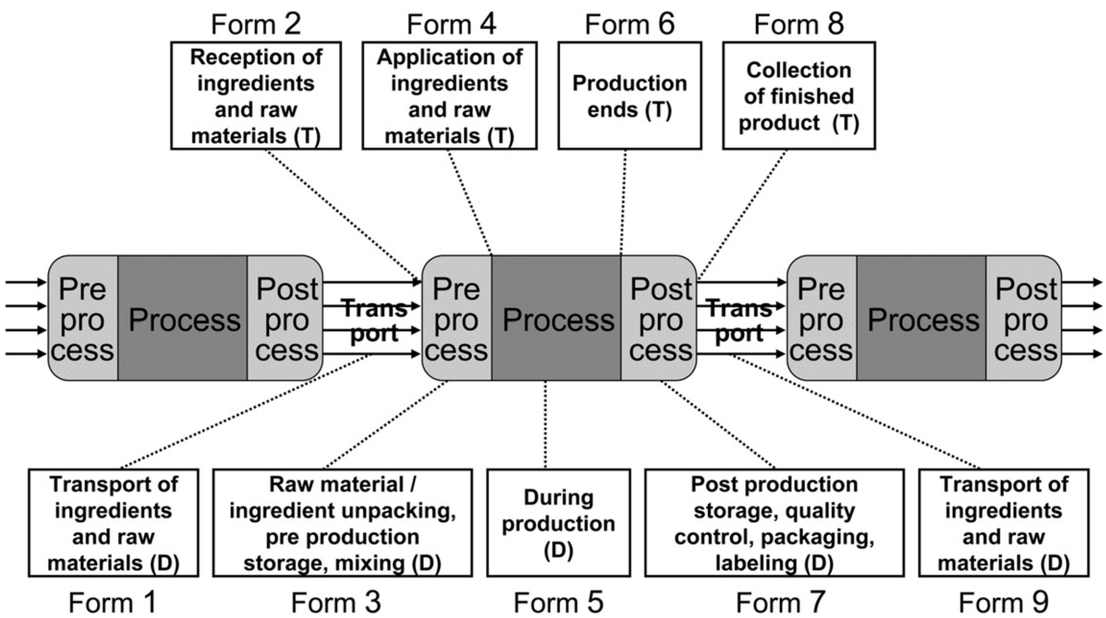

Fig. 3. The grouping of the forms containing the questions.

Process mapping no:	Previous form no:	This form no:	Next form no:

Table 1: Transport of ingredients and raw materials (duration) - Each type one table

	Question to transporter of ingredients and raw materials	Answer, fill in	Description or example
1.M01	What type of transport is used?		Truck / vessel / air plane / post / courier / etc.
1.M02	What type of delivery is it?		Distribution terminal or directly from supplier, either
1.K01	How is the vehicle identified?		Registration number of vehicle or name and address (or GLN)
1.K02	How is the trip identified?		SSCC, transporter code, delivery code, freight code, etc.
1.T01	Is there a link from vehicle / trip to delivery?		No / Yes, indirectly / Yes, directly
1.P01	What parameters are linked to this transport? How are they recorded; on Label, Paper, Fax, Electronically, Other? Are they received but ignored, re-recorded for own use only, given to the buyer or given back to the supplier?	1.P01.1 1.P01.2 1.P01.3 1.P01.4 1.P01.5	List of parameters. For each parameter, indicate L/P/F/E/O for type of transmission. For each parameter, indicate "Ignore", "Own", "Buyer" or "Suppl". Alternatively provide a link to a form, a screen-shot, a report or similar.
1.F01	Which temperature control method was used?		None / iced / iced and refrigerated / refrigerated / etc.
1.F02	Is temperature logged during transportation?		No / Yes manually / Yes electronically

Hierarchy digit 0 refers to the whole transport.

Fig. 4. Sample duration form – "Transport of ingredients and raw materials".

- What is the nature of the duration? How is the vehicle/trip/tank/store identified?
- What is the nature of the product in this duration? The name? The type? The size?
- What is on the product label in this duration?
- Who is responsible for the product?
- How are products separated in this duration?
- What common parameters are linked to all products in this duration?
- What quality control checks are performed in this duration?

Typical questions related to transformations (example in Fig. 5):

- Why and where did the transformation happen?
- What is the frequency of this, what amounts are involved?
- How do inputs relate to outputs? (one-to-one, one-to-many, many-to-one, many-to-many)
- What is the relationship between LU and TU?
- How are parameters that describe inputs connected to parameters that describe outputs?

Process mapping no:	Previous form no:	This form no:	Next form no:

Table 4: Application of ingredients and raw materials (transformation) - Each type one table

	Transformation questions, into production	Answer, fill in	Description or example
4.T01	Can the producer link from identification of ingredients and raw materials to identification of lot / batch?		No / Yes indirectly / Yes directly (ingredients and raw materials ID recorded under production)
4.T02	If the answer above is yes, how is it linked?		Electronic / manual
4.T03	Is the ingredient / raw material split up, joined together or kept as one?		Split up / joined together / kept as one
4.P01	What parameters are recorded to document the application of this ingredient / raw material? How are they recorded; on paper, punched into computer system, automated data gathering?	4.P01.1 4.P01.2 4.P01.3 4.P01.4 4.P01.5	List of parameters. For each parameter, indicate "Paper", "ComPunch" or "ComAuto". Alternatively provide a link to a form, a screen-shot, a report or similar.

Hierarchy digit 0 refers to one instance of application of one ingredient / raw material batch.

Fig. 5. Sample transformation form – "Application of ingredients and raw materials".

If anyone is interested in applying the method please contact the corresponding author or go to www.nofima.no/marked/en/person/petter.olsen where the newest version of the forms are available for download.

Obviously, the alternating sequence of durations and transformations indicated above is a simplified model. Fig. 3 does not illustrate the fact that several different types of raw materials and ingredients may be joined together to make the finished product and it does not illustrate that several products and bi-products may come out of the same process. This has been compensated for by making it possible to fill out multiple copies of each form. If, for instance, the method is used to map the material flow and information flow of multiple ingredients, one copy of form 1, 2, 3 and 4 is filled out for each ingredient, and the same form 5 identifier is indicated in the "Next form no" box in the heading. If the method is used to map a series of sequential processes, form 5, or 4&5, or 3&4&5 can be repeated for each process step, again using "Previous form no" and "Next form no" to indicate the sequence.

Application of the process mapping method

The forms (Figs. 4 and 5) contain the question (and answer) identifier, the question itself, a description of what type of answer is sought, and a space where the answer is filled in. This can be done manually on paper forms or electronically on a computer. The process mapping is assigned an identifier and each form used in the process mapping is also assigned an identifier. In addition, especially if the chain is non-trivial and multiple copies of some forms are needed, it is important to identify the form immediately preceding this one, and the form immediately following this one in the material flow.

If you know in advance exactly what ingredients and products you are going to map, and what processes they go through mapping can be done going with the material flow or against the material flow. If you know the raw materials and ingredients, but not the product, you should go with the material flow and fill out forms 1–9 in that order. If you know the product you want to map, but you do not necessarily in advance know all the raw materials and ingredients that went into it (this is often the case in practice), it is better to go against the material flow, that is start with form 9 and work back to form 1. This is to reduce revisits; if you start filling out the ingredient reception form before you know all the relevant ingredients you might have to revisit this step later. If you go against the flow you will come from the side that is known (the product) and gradually discover what is unknown (all the ingredients).

Our experience is that it is most efficient if two people jointly conduct the process mapping, with one doing the interview and the other recording the answers and ensuring that all relevant forms are used and that all relevant questions are answered.

Results and discussion

How to interpret the results in general

As indicated by the letter in the left column of Figs. 4 and 5 the questions are categorized into 5 types, and the answers to the questions of each type are interpreted together. The question types are:

- Material flow (M) questions, asking about type of duration, source or destination, product or ingredient name, type, condition, location, amount, collection frequency etc. The answers to these questions are used to get a picture of the overall material flow which in turn can be represented in a suitable graphical notation.
- Questions about existing or possible keys (K), establishing what identifiers are used for deliveries, amounts, TUs, LUs, shipments, vehicles, trips, etc. The answers to these questions are used to ascertain whether explicit identifiers exist, whether they are (globally) unique and what type and media is used for the identifiers.
- Parameter (P) questions, asking which parameters are recorded, which identifiers these parameters are linked to, what media/software is used for recording, whether the recordings are temporary or permanent, etc. The parameter lists are used to get a picture of all the information that is recorded in the existing system, and to what degree it is linked to well-defined identifiers and available also after the product has been shipped.
- Transformation (T) questions, asking about link between input and output, between TU and LU, whether there is mixing, how joins and splits are documented, etc. This is a crucial question type and will reveal systematic information loss. A common question type here is "Is there a link between A and B?" with possible answers "No", "Yes, indirectly" or "Yes, directly". For every "No" or "Yes, indirectly" answer (the latter typically indicating an indirect link with time or place as the common factor) a potential for improving the existing system has been identified.
- Food safety (F), questions about temperature, temperature control methods and temperature logs. This question type is optional, and may be replaced or supplemented by other quality control type questions depending on what is relevant for the ingredient or product in question.

As indicated above, the material flow questions are used mainly to get a picture of the overall material flow, and the food safety questions are optional. The core of the investigation into the current traceability system is through the questions relating to keys and transformations. The key-related questions will uncover missing, implicit or non-unique keys, and the transformation questions will uncover to what degree traceability exists both ways (from given ingredient to all products where ingredient was used; from given product to all ingredients included). The parameter questions will uncover what information the traceability system can be used to retrieve, but in general the parameters will only be available if the keys are explicit, unique and retained also after the product has left the company.

Results obtained by using the method

In the introduction, we refer to some published cases where the method was used. In total the method has been applied in more than 20 supply chains, but some of the results are not published, and others are not published yet. All the companies investigated were voluntary partners in some sort of traceability implementation project, and as such they are not necessarily representative for the whole industry. With these limitations in mind, here are some overall conclusions from the studies undertaken so far:

- In some instances information loss was a direct consequence of limitations in the material flow itself, revealed by the M type questions. For instance, in one company palleting of trade units was physically impossible after production because of size restrictions in the production facility, which meant that palleting had to be done in the next link of the chain, and it was in practice impossible to establish a link between TU IDs and LU IDs as reading/scanning each TU at this stage would take too much time. However, this was the exception, and in general the questions on material flow did not uncover information loss. In the cases where the method was used both before and after implementation of an improved (and in practice electronic) traceability system it was seen that regardless of what the original driver for investing in the new system was, the material flow was affected. The companies that undertook an ex post cost/benefit analysis of the investment in the new system reported that the biggest quantifiable benefit of the new traceability system was the unforeseen lower lead time in production and the reduction of raw material and product in storage.
- The K questions on existing and possible keys are very important, and a wide range of answers and situations have been uncovered. In a perfect system all TUs and LUs are allocated externally generated globally unique keys. So far, we've only come across one company (of around 20) that has this system. In 2–3 companies we found internally generated unique keys on TUs and LUs, typically internal batch number plus a sequential number on each TU or LU. In practice this means information loss, as none of the companies we've mapped have systematically entered the batch number from the previous link into their own system. The most common situation seen in at least 75% of the companies is non-unique TU identification, typically only internal batch number, production date or best-before date, and this obviously makes it impossible to record or trace any information related to one specific TU, for instance where it was at a given time. In most companies we also found extensive use of indirect keys, that is data recorded and only implicitly keyed to the TU or LU. Typically the indirect link was through date or time, so that some property (for instance temperature) was recorded at a given time, and to link this property to specific units some sort of analysis had to be performed to find out which units were involved.
- The P questions on parameters recorded revealed that practically all companies analyzed were diligent in this area, and recorded the necessary and recommended data faithfully. In the companies investigated, it was rarely possible to point out obvious omissions with respect to what data was recorded.
- The T questions on transformations are also very important, and again a wide range of answers and situations have been uncovered. In a perfect system any application of a raw material or ingredient should be explicitly documented, with link to the unique ID of the ingredient in question. We found no companies that did this for all their raw materials and ingredients (including the packaging materials), but may be one third of the companies did this for their main raw material (the meat, the chicken, the fish, etc.). In integrated supply chains where the same company owns all the links we found central databases and at least some re-use of identifiers. In supply chains consisting of more than one company we found no companies that actively used the locally generated ID of the previous link of the chain to document their own transformations. Even when a unique ID was present on the TU or LU received, the companies who wanted to document transformations chose to assign their own ID upon reception.

In general, for chain traceability to be in place and for data to be retained it is necessary to record data, to send it to the next link in the chain in some understandable form, and for them in turn to receive and assimilate the data. The overall conclusions is that the companies investigated so far are very good at data recording, they range from fairly bad to quite good on data sending, but there is a lot of room for improvement when it comes to data receiving.

Conclusions

The reference process mapping method is a good tool for a first company visit. It ensures that relevant questions are not forgotten, and it significantly helps in standardizing reporting from companies and supply chains. The method enables comparison of results and benchmarking. The grouping of questions into those relating to durations and those relating to transformations has proven fruitful and helps simplify the process mapping exercise.

The method is descriptive in nature. The goal is for the method to give more or less the same results regardless of interviewer(s). To some degree this has been achieved, but since real life and real people are involved, in a field that is interdisciplinary in nature, there is a limit to how much can be formalized and standardized. Therefore, attention has to be paid to the role and background of the interviewer(s), and it is unavoidable that these factors to some degree will influence the results (see Luning & Marcelis, 2009).

The method is constructed to be generic, flexible and extensible, and should be easy to apply in any supply chain. With the number of traceability implementation projects increasing, the need and applicability of the method and the number of potential users has also increased. Although developed and tested for food products, the underlying principles and questions are similar in all production chains, and the method can be used practically without modification also for non-food products.

The focus of the investigation is on the identifiers and the transformations, not the parameters connected to the identifiers, so additional questions are needed if one wants to investigate something related to the value of the parameters (hygiene, recall readiness, sustainability, resource use, etc.). Additional questions may be added to the forms to ensure the mapping of specific information.

In many pilot projects installation of new or improved traceability software follows after the process mapping. One limitation of the method is that although the results uncovered are relevant in case of process re-engineering, deeper investigation and more questions are needed before software installation can be attempted. This is particularly related to availability of data in electronic form, software already in use, status of hardware, networks and personnel, etc.

A natural extension of the method is to describe in detail the connection from the results to one of the many data visualization methods that exist so that the process of drawing material flow diagrams and data flow diagrams is to some degree standardized. This extension was deemed beyond the scope of this paper.

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9.4 Full text version of Paper IV

Paper IV

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Granularity and its role in implementation of seafood traceability

Kine Mari Karlsen [a,*], Bent Dreyer [a], Petter Olsen [a], Edel O. Elvevoll [b]

[a] Nofima – Norwegian Institute of Food, Fisheries and Aquaculture Research, P.O. Box 6122, NO-9291 Tromsø, Norway
[b] Faculty of Biosciences, Fisheries and Economics, University of Tromsø, Breivika, N-9037 Tromsø, Norway

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ABSTRACT

In this study, granularity and its importance for traceability in seafood supply chains is studied. Granularity describes different levels of traceable units. The findings from this study show that granularity plays a key role in the implementation of seafood traceability. Implementation of a coarse granularity level is easier and cheaper than a fine granularity level, but the benefits are also lower. Fine granularity level will increase the complexity of the traceability system, and will give higher costs. A complex traceability system can affect the practical solutions and specification of the information technology systems when implementing traceability. The key is to find the preferable granularity level where the benefits exceed the costs. Consequently, the costs and potential benefits associated with implementing traceability at different granularity levels should be identified.

1. Introduction

The requirements for documenting food products are ever increasing. Extensive national and international legislation has been passed to ensure food safety, and both the industry and the consumers are also becoming more interested in additional knowledge about origin, processes, and other properties concerning the product.

The food scandals of the 1990s put traceability of food on the agenda because of an increased concern regarding food safety and quality (McKean, 2001; McGrann and Wisemann, 2001). Traceability is defined as the '...*ability to trace the history, application or location of an entity by means of recorded identifications*' (ISO, 1994). The outcome of the food scandals was that traceability was included in the European food law regulation EC-178/2002 (2002).

Lately, increased emphasis has been placed on other applications of food traceability. Traceability can be useful to optimize production planning and scheduling, e.g. minimize waste and ensure optimal use of raw materials (Wang and Li, 2006; Moe, 1998). Traceability can also be used as a part of a competitive strategy (Canavari et al., 2010) and to increase company coordination in supply chains (Engelseth, 2009; Banterle and Stranieri, 2008).

Opara and Mazaud (2001) raised a central question with regard to traceability; what unit to trace? The traceable size of the unit, so-called granularity, affects the precision of product traceability (Riden and Bollen, 2007). Finer granularity levels will yield increased precision of traceability. The size of the traceable unit will be different depending on the application of traceable information (Moe, 1998). Application of information for quality and process optimization purposes may demand smaller units. Bigger units can be used when the risk of contamination is low, or when the requirements for controlling production processes are less stringent. Thus, the levels of the traceable units are depended on a company's internal and external need for traceable information. Traceable units are raw materials and products that are uniquely identified and traceable (TraceFood, 2011).

According to Riden and Bollen (2007), there is a need to study different granularity levels to identify the potential of increased precision in traceability. They assumed that this has not been studied in detail due to lack of framework, concept, and terminology.

No published scientific papers have been found discussing different levels of traceable units in seafood supply chains, thus the aim of this study was to investigate granularity and its importance for traceability in seafood supply chains.

First, a review of granularity in traceability studies is presented. Then, the design of this study is described, including the choices of the studied seafood supply chains and the methods used to collect the empirical data. Thereafter, the main findings are presented, and finally, granularity and its importance in seafood supply chains is discussed.

2. Granularity

Granularity is used in different areas and ways to study software systems and material flow in food production. Table 1 shows

* Corresponding author. Tel.: +47 77 62 91 41; fax: +47 77 62 91 00.
E-mail address: kine.karlsen@nofima.no (K.M. Karlsen).

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some of the identified descriptions of granularity in traceability studies.

The description of granularity used in software engineering (Items 6 in Table 1) is less relevant for industrial implementation of traceability for seafood, because this description focus exclusively on using traceability in the software development process, the practical solutions to achieve traceability are not included. It is clear that this view of granularity is different compared with the other descriptions of granularity.

The most relevant description of granularity to carry out an industrial implementation of traceability for seafood is Item 5: '*...reflects the levels and size of IUs...*' by Bollen et al. (2007). One inherent weakness in this definition is that the granularity is only defined by the size of the units. Consequently, the definition of granularity applied in this paper is as follows: Granularity describes different levels of traceable units, and is determined by the size of a traceable unit and the number of the smallest traceable units necessary to make up the traceable unit at a specific granularity level. Fine granularity means smaller unit sizes, and coarse granularity means larger unit sizes. Since the total amount we want to trace is given at a specific granularity level, there is an increase relationship between the size of each unit we trace, and the number of units we need to trace. This is illustrated in Fig. 1.

3. Methodology

Fig. 2 describes the design of this study. First, Critical Traceability Points (CTPs) identification was carried out in three seafood supply chains (case studies I–III). A CTP is a place where information loss occurs (Karlsen et al., 2010). Such points occur when information about a product or process is not linked to a traceable unit and recorded systematically. CTP identification is necessary for traceability implementation, because certain recordings are necessary to prevent information loss. Then, critical points during a traceability implementation at a defined granularity level of the traceable units were identified in one of these supply chains (case study III). Thereafter, the identification of different granularity levels of traceable units were examined (case study IV).

In this study, the Norwegian fishery industry was chosen because of increased demands for seafood product documentation.

3.1. Case study I

The first step in this study was to identify CTPs in a feed supply chain for salmon (*Salmon salar*) farming. A fish feed factory (FeedCo), three suppliers of ingredients for fish feed (IngredCo), and a sea-based salmon farm (SalmCo) were included in case study I. Farmed salmon was chosen as a case, because this seafood product is an important product in Norwegian aquaculture.

A well-proven method to identify CTPs did not exist when case study I was carried out. Consequently, methods to identify CTPs were developed. Several studies on materials management have used quantitative research methods (Ellram, 1996), however these methods are not suited for obtaining in-depth data about a research question. Ellram (1996) recommends using qualitative methods to gain more knowledge about a phenomenon. The qualitative methods direct observation, structured interview, and document analysis were used in case study I, because it was assumed to yield in-depth data, fit to study information lost in the studied feed supply chain for salmon farming. For more details of this case study, see Karlsen and Olsen (2011). Another supply chain was studied in case study II to investigate whether similar findings occur in another seafood supply chain.

3.2. Case study II

The second step in this study was to identify CTPs in a dried salted cod (*Gadus morhua*) supply chain. A wet salted fish producer (WetProd) and a dried, salted fish producer (DriedProd) were included in case study II. Dried, salted cod was chosen as a case in case study II, because this seafood product is an important product in the Norwegian capture-based industry, and this industry meets increased demands of documentation of this product, especially as required by law. European Union (EU) illegal, unregulated, and uncontrolled (IUU) regulations demand documentation of the origin of all wild-caught fish exported from third countries, included Norway, to the EU by way of a document called a catch certificate (EC-1005/2008, 2008). Information contained in this document includes catch information, production, transportation, and importer declarations. This requirement is an attempt to prevent IUU-fishing.

The methods used for identifying CTPs in case study I turned out to be quite time-consuming to carry out, and these methods are not easily transferable to another case study, because they were designed to study a specific case. A general method of analyzing the flow of material and information, as well as information loss in food supply chains, was developed by Olsen and Aschan (2010). This method was used in case study II, as well as in the study of several other food supply chains. It is thus assumed to be a legitimate method for identifying information lost within and between companies. For more details of case study II, see Donnelly and Karlsen (2010).

The results from case studies I and II showed that information was lost in the two seafood supply chains studied. To be able to trace a seafood product, it is necessary to carry out recordings of the relationships between the traceable units and unique identification of the traceable units at CTPs to prevent information loss. The experiences gained from case studies I and II were used to design a method for implementing seafood traceability, which led us to case study III.

3.3. Case study III

The third step in this study was to implement electronic chain traceability in a fresh saithe (*Pollachius virens*) supply chain. Fishing

Table 1
Identified description of granularity in traceability studies.

Term	Description
(1) Granularity	'*The size of unique identified TUs defines the operational visibility or granularity in a traceability information system*' Senneset et al. (2010)
(2) Granularity	'*. . .level of ambition and degree of accuracy and granularity they want for the data in their traceability system*' Arason et al. (2010)
(3) Granularity	'...different levels of detail (granularity) through the supply chain' Bollen (2004)
(4) Granularity	'*Granularity can go down to a very refined level (e.g. a package belonging to a lot). Sometimes, it may even be necessary to trace a milk package from its lot to a barrel of milk*' Kondo et al. (2007)
(5) Granularity	'...reflects the levels and size of IUs[a] that are handled by the particular system' Bollen et al. (2007)
(6) Granularity in software engineering	'*. . .the traceability granularity is reduced allowing a better matching between related artifacts*' Noll and Ribeiro (2007)

[a] Identifiable unit.

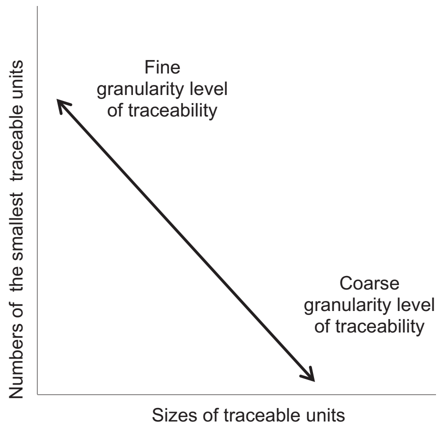

Fig. 1. Different granularity levels of traceable units.

vessels (FishVes), a landing and filleting company (LandCo), a packing and distributing company (DistriCo), and a supermarket (SuperMa) with a manned fish and meat counter were included in case study III. In addition, a sales organization (SalOrg) was involved. SalOrg was responsible for organizing the trade between the fisherman and LandCo, which was documented by a document called landing note.

The fresh saithe supply chain was chosen as a case, because SuperMa wanted more information about the fish, and to the implementation of traceability for this seafood product was presumed to be relatively easy, due to limited mixing and splitting of fish during the production process in comparison to other seafood products (e.g. dried salted cod).

A scientific method for the implementation of electronic chain traceability of seafood has not been identified. Consequently, a method for the implementation of traceability based on the TraceFish standard for captured fish distribution chains (CEN, 2003b) and the TraceFood Framework (2011) was developed. This implementation process had four different phases: (1) mapping phase, (2) planning phase, (3) implementation phase, and (4) analysis phase.

CTP identification in this supply chain was carried out in the mapping phase, where a combination of the two methods described in case study I and by Olsen and Aschan (2010) was used. Case study I describes the use of interviews, observation, and document analysis in a specific case study. Olsen and Aschan (2010) designed a general method to analyze the flow of materials and information in food supply chains with a special focus on the structured interview. In addition, the software systems used by LandCo, DistriCo and SuperMa were identified in collaboration with the companies involved.

The findings from the mapping phase were used in the planning phase, which included a plan for unique identification of traceable units and companies, adjustments to production practices and procedures, and re-engineering of the information technology (IT) systems. The identification of CTPs was used to implement traceability, with the aim to carry out certain recordings at these CTPs to prevent information loss. A net-centric service was chosen as the architecture, because this architecture made it possible to exchange information between the companies in the studied supply chain by linking their software systems, while each company

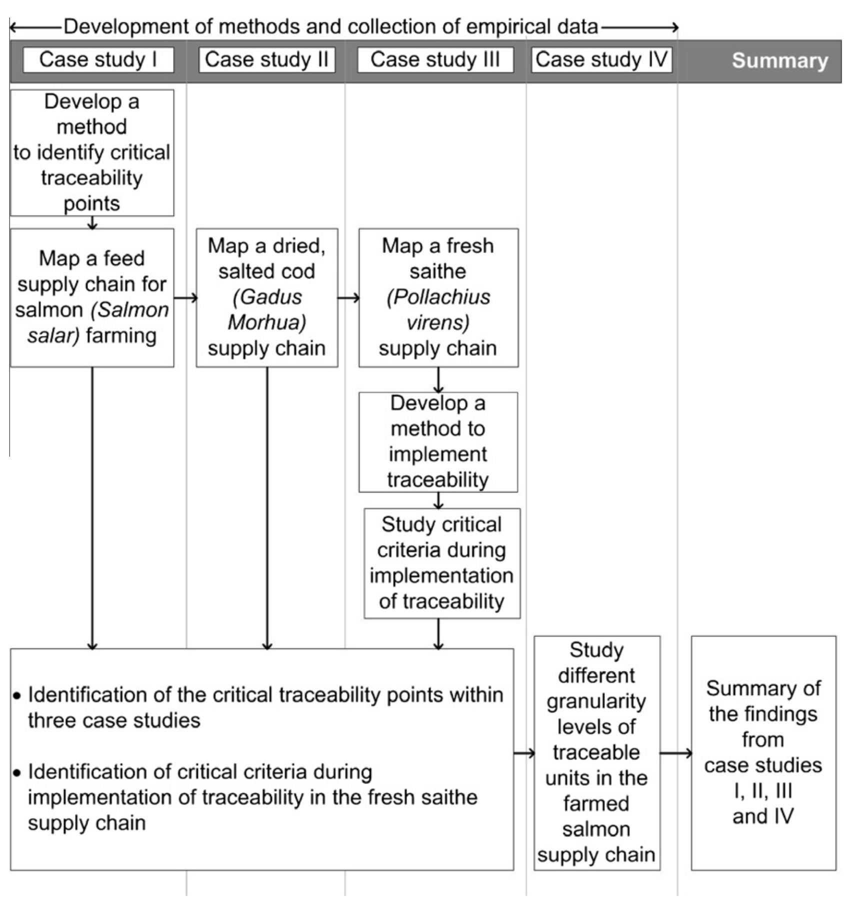

Fig. 2. The design of the study.

still retained full control of their own information. Consequently, this architecture was assumed to be the best choice when implementing electronic chain traceability in a whole supply chain.

The implementation plan was used in the implementation phase. Several parallel activities were carried out during this phase, which can be divided into two categories: (1) implementing chain traceability: installing traceability databases for uploading, handling, requesting, and illustrating information at SalOrg, LandCo, DistriCo, and SuperMa, and applying the net-centric solution; and (2) implementing internal traceability: developing and testing practical solutions to prevent information lost at LandCo, DistriCo and SuperMa. In addition, the companies involved and their IT-suppliers discussed different solutions for exchanging information between the software systems within the companies.

Critical criteria for implementing traceability were identified during this implementation. A critical criterion was identified if there was a mismatch between the implementation plan and real implementation activities, and a willingness to find an optimal solution to trace the fish was not present. A critical criterion could be a barrier to success for the implementation of traceability in the whole supply chain or it could slow down the implementation process. For more details of the implementation process, see Karlsen et al. (2011a).

Based on the experiences gained from case study III, it was clear that knowledge of costs and benefits associated with traceability must be increased, as this can help companies determine preferable granularity levels for the traceable units before the implementation process begins: what can the traceable information at different granularity levels be used for, and what information is relevant for whom? No published scientific papers have been found discussing different granularity levels of traceable units in seafood supply chains. This is thus studied in case study IV.

3.4. Case study IV

In case study IV, different granularity levels of fish feed and farmed salmon were studied using empirical data from case study I. This supply chain was chosen, because relevant data to calculate the different sizes of traceable units at FeedCo and SalmCo had already been collected (such as production capacity at FeedCo and the total number of received juveniles at SalmCo).

The traceable units at FeedCo and SalmCo were determined by applying the definitions of traceable units from the TraceFood framework (2011). Different batch levels were identified at FeedCo and SalmCo. The coarsest granularity level of fish feed batches studied was 'one year', because it was assumed that a coarser granularity level would not be relevant for FeedCo with respect to traceability. For more details of case study IV, see Karlsen et al. (2011b).

4. Results and discussion

In this chapter, the main findings of this study are presented and discussed.

4.1. Critical traceability points

Twenty-one CTPs were identified in the studied feed supply chain for salmon farming (Fig. 3). The most important findings with regards to traceability were insufficient recordings of the relationships between the traceable units (CTPs 1–18) and the lack of unique identifiers for the traceable units (CTPs 19–21). These identifiers are vital for achieving traceability (CEN, 2003a; Denton, 2003; Kim et al., 1995; Moe, 1998). The identified CTPs can be divided into two types: (1) recordings of the relationships between traceable units (hereafter called CTP-relation), and (2) unique identification of the traceable units (hereafter called CTP-ID).

Fifteen CTPs were identified in the studied dried salted cod supply chain (Fig. 4). The findings with regards to traceability were insufficient recordings of the relationships between the traceable units (CTP-relations 1–10) and lack of unique identifiers for the traceable units (CTP-IDs 11–15).

Twenty CTPs were identified in the studied fresh saithe supply chain (Fig. 5). The findings with regards to traceability were insufficient recordings of the relationships between the traceable units (CTP-relations 1–13) and the lack of unique identifiers for the traceable units (CTP-IDs 14–20).

The findings from the case studies I–III show that the number of CTP-relations is higher than that of CTP-IDs (Fig. 6). The fish feed factory had the highest number of CTPs (18 CTPs in total). This is a result of their use of eight different raw materials to produce fish feed, and not recorded the mixing and splitting of these input factors. Wet salted fish producer also had a high number of CTPs (10 CTPs in total). This company had few input factors (wild-caught fish and salt); the high number of CTPs was caused by a production process where the wild-caught fish was split and mixed several times. The fish farm had the lowest numbers of CTPs.

Identifying CTP-relations and CTP-IDs is essential when implementing traceability in a seafood supply chain. This leads us to case study III, where the aim was to carry out necessary recordings at the CTPs to prevent information loss by completing an industrial implementation of traceability in a seafood supply chain.

4.2. Critical criteria in traceability implementation

Case study III presents an implementation of electronic chain traceability in a fresh fish supply chain. Experience gained from this study showed that implementation is complex and involves many different aspects that affect each other (Karlsen et al., 2011a).

A number of critical success criteria were identified as a result of this implementation. The ability to identify benefits to be gained from implementation of electronic chain traceability was identified as one of these. Communicating and understanding the benefits of a traceability system is important for successful implementation of traceability (Sohal, 1997).

Many authors have identified several benefits of using traceability for the food industry (Frederiksen, 2002; Opara and Mazaud, 2001; Wang and Li, 2006; Chryssochoidis et al., 2009; Töyrylä, 1999; Mai et al., 2010; Hobbs, 2004). Still, there are companies that have not yet recognized the benefits of using traceability (Wang and Li, 2006).

If a company cannot identify any benefits in carrying out an implementation, the motivation will soon wane. This will affect the willingness to invest in any technology needed to achieve better documentation of produced products.

Implementing an efficient traceability solution may require big investments (Sohal, 1997). There are different types of costs associated with traceability implementation (e.g. administrative, material, operational, equipment/technology, initial and ongoing costs) and these investments are highly variable (Can-Trace, 2007). One finding in case study III was that the investments necessary for successful traceability are dependent on several factors. These investments were affected by which software solutions and electronic recording equipment were available in the company. Other factors affecting investments were the degree of integration required in the software systems for successful internal traceability (simple or full integration), investments in new IT-solutions, and necessary re-engineering of current IT-systems. In case study III, the costs of increased traceability seemed to be higher at the landing and filleting company than at the supermarket and packing and

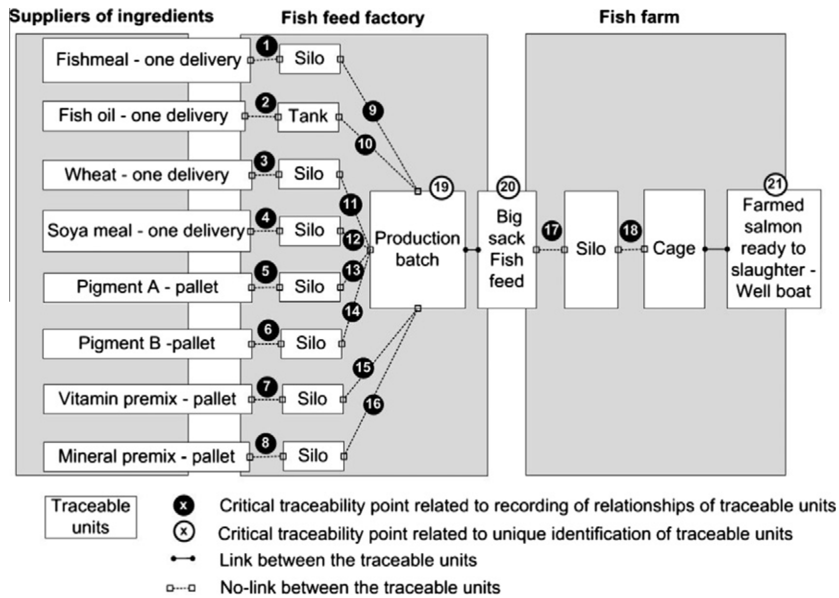

Fig. 3. Critical traceability points in the feed supply chain for salmon (*Salmon salar*) farming (Karlsen and Olsen, 2011).

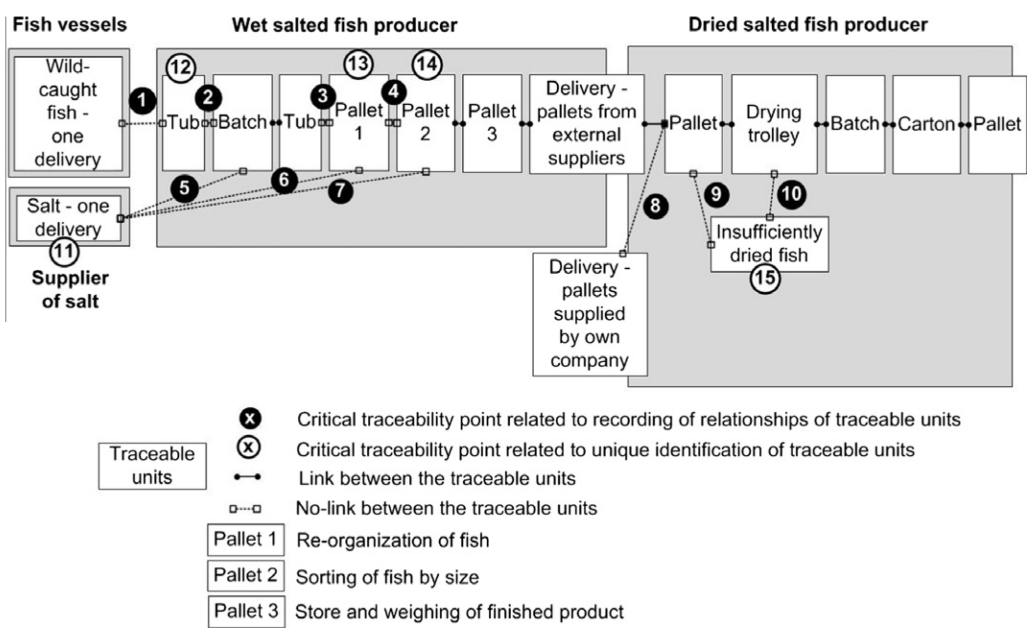

Fig. 4. Critical traceability points in the dried salted cod (*Gadus morhua*) supply chain studied.

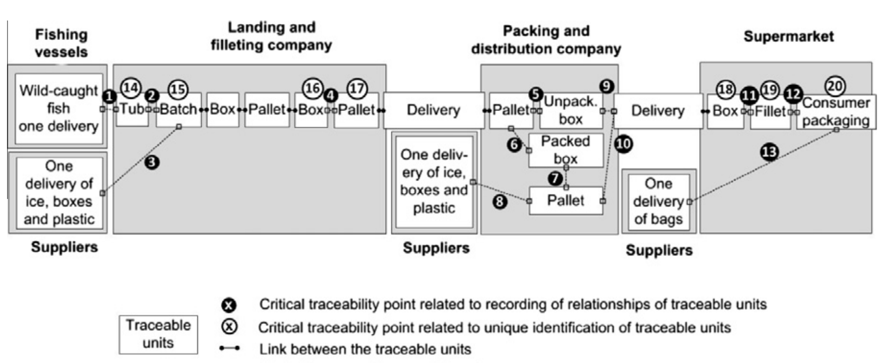

Fig. 5. Critical traceability points in the fresh saithe (*Pollachius virens*) supply chain studied.

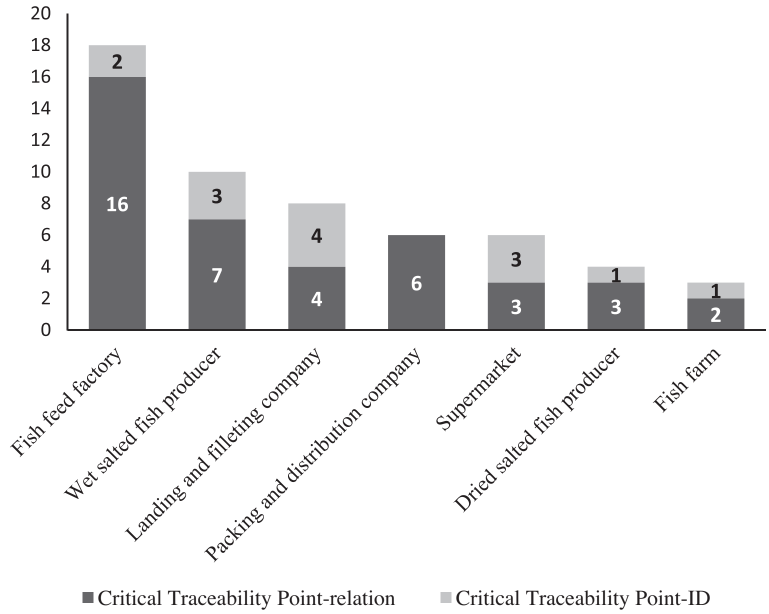

Fig. 6. Numbers of identified critical traceability points in the studied seafood supply chains.

distribution company. Another finding in case study III was that the companies would not make the investments necessary for better product documentation if they could not identify the benefits they stood to gain by making these investments.

In case study III, it became clear that the motivations behind implementing a traceability solution may vary, and identifying the costs and benefits of traceability is critical for the implementation. Consequently, more studies including cost-benefit analyses are needed to help companies determine the preferable granularity levels of traceable units, which leads us to case study IV. The key is to find the preferable granularity level where the benefits exceed the costs.

4.3. Granularity level of traceable units

Case study IV showed that granularity can have different levels in the studied feed supply chain for salmon farming, the granularity level will increase (finer granularity) with decreased batch sizes and increased number of the smallest batches necessary to make up the batch at a specific granularity level (Karlsen et al., 2011b). An important factor that must be considered in this discussion is how granularity levels will affect production practices and IT-systems in a company. One should determine whether it is going to be problematic to develop practical solutions for achieving traceability. A fine granularity level will have greater impact on practices and IT-systems than a coarse granularity level. A finer granularity level will increase the chance of reaping the benefits of using traceability. In other words, implementation of a coarse granularity level is easier and cheaper than a fine granularity level, but the benefits are also lower. Consequently, the costs and potential benefits associated with implementing traceability at different granularity levels should be identified.

Which granularity level to use, is depended on the stakeholderś need for traceable information. There are different applications of traceability. Traceability can be used to fulfil legislation, and to document food safety issues, quality, sustainability, and welfare. In addition, traceability can be useful to meet requirements in certification schemes, to gain competitive advantages, to improve chain communication, used as a respond to the threat of bioterrorism, and to optimize production.

In the next sections, the affect different granularity levels has on the ability to trace seafood will be discussed, illustrated by examples from the studied seafood supply chains.

4.4. Different granularity levels

The European Food Law is an example of a coarse granularity level of the units. This legislation requires one-up-one-down traceability (EC-178/02, 2002). The companies in the Norwegian seafood industry fulfil this granularity level already, because all companies have control over the deliveries from/to their suppliers and customers for economic transactions. Thus, there are no new investments for the companies using this granularity level.

The IUU-regulation is an example of legislation that requires a finer granularity level of the traceable units than does the Food Law (EC-1005/2008, 2008). This regulation affects all Norwegian seafood producers and exporters exporting wild-caught fish to the EU. The catch certificate from Norway is based on the Norwegian system of landing notes (CatchCertificate, 2011). A central element in this regulation is that a catch certificate must be issued for each consignment of wild-caught fish to the EU where the catch information of this fish is included. If one consignment consists of several catches of wild-caught fish, the producer has to stay on top of the production process in order to be able to issue a catch certificate. The question here is which granularity level of the traceable units to use in order to satisfy the requirements of this legislation? The answer to this question is not straightforward, due to various production concepts and production practices in the Norwegian capture-based industry (e.g. fresh fish, wet salted fish, dried salted fish, and stock fish).

The dried salted fish production at the dried salted fish producer in case study II is an example of a fine granularity level for traceable units. They achieved internal traceability by documenting the splitting and mixing of fish during production by assigning internal numbers to the units (Donnelly and Karlsen, 2010). They believe that their ability to keep track of production routines has become an invaluable management tool. For example, they explained that the improved traceability system had enabled them to track the quality of a supplier’s fish and allowed them to take immediate action when problems with quality were reported. They also reported that implementing internal traceability has led to greater efficiency in production.

Another example of fine granularity level is the approach used in case study III, where the goal was to trace the traceable units step by step through a whole supply chain. The application of information in one company can affect the granularity level in another company. This can be illustrated by two scenarios: Scenario (1) The supermarket wanted information about the catch area (e.g. the North-East Atlantic Ocean). The landing and filleting company did not need to carry out detailed recordings during production, because all the landed fish at this company was caught in this catch area. If the packing and distribution company received fish from another catch area, they would have to keep this fish separate during packing. Scenario (2) The supermarket wanted information about the gear type (e.g. long-line); all fish caught with the same gear type must be kept separate during the production and packing processes at the landing and filleting company and packing and distribution company.

It is clear that how users apply the traceable information affects the granularity level needed. The companies can choose to use traceability to gain other benefits then only fulfilling legal requirements by implementing finer granularity levels for their traceable units, such as increased internal control or supply chain communication. The chosen granularity level will determine the complexity of the traceability system, and can affect the practical solutions and specification of the IT-systems in the implementation of traceability.

It is clear that the implementation of seafood traceability is affected by the chosen granularity level of the traceable units, but how will the randomness of the fish supply affect the ability to trace seafood at a fine granularity level? In the next sections, this will be discussed by comparing implementation of traceability at a fine granularity level for wild-caught fish and farmed fish.

4.5. Fine granularity level and its affect on traceability

The implementation of traceability at a fine level of granularity for wild-caught fish is probably more challenging than for farmed fish because of the differences between these two production concepts. In aquaculture, producers have much more control of the raw materials they receive; the fish size and quality of the farmed fish is quite stable, and different species are not mixed together. This makes it easier to coordinate and plan the time of production of farmed fish. The slaughter plant can coordinate with the fish farms when they have capacity to receive and produce the farmed fish.

The capture-based concept has much less control over the quantity of wild-caught fish delivered, and the variation in fish size, quality, and number of species is great, especially in the Norwegian conventional fisheries.[1] In these fisheries the sizes of fishing vessels and gear types vary greatly, and the volume of wild-caught fish delivered from e.g. a vessel using Danish seine can be very big compared to a delivery from a small vessel using jig. If a company wants to trace deliveries back to each fishing vessel, the volume is important, because separating smaller landings of wild-caught fish will affect the efficiency of production and practices. This illustrates how the context can impact implementation of traceability in seafood supply chains at different granularity levels.

For the capture-based supply chains, the number of batches within a year of the granularity levels varies from year to year due to the randomness of wild-caught fish deliveries. Mixing several catches together is a practical adjustment for achieving an efficient production, because separating all the small catches would be very time-consuming (Donnelly and Karlsen, 2010). A fine granularity level can present big challenges due to the randomness of landing rates for wild-caught fish. This will also affect the other companies in the specific supply chains. Consequently, an important factor to include in a discussion of preferable granularity level of batches in capture-based industry is finding practical solutions for traceability.

[1] Fishing with the following gear types: gill-net, long-line, Danish seine, jig, fish traps, and pots.

5. Conclusions

Granularity and its importance for traceability in seafood supply chains is examined in this study. It is clear that a traceability system can be simple (one-up-one-down traceability); costs would be low and implementation would be easy. Traceability can also be complex. Fine granularity levels will increase the complexity of the traceability system, and will entail higher costs, because there is more information to record, a higher number of transactions, and new systems and procedures would possibly have to be introduced (Golan et al., 2004).

There are different costs and benefits to using traceability, and companies apply traceable information differently. Any implementation of traceability in seafood supply chains should thus include an open discussion of the distribution of costs and benefits between companies in the chain (Mai et al., 2010). An evaluation of costs and benefits using traceability will determine the complexity of the traceability system and can affect practical solutions and IT-system specifications in the implementation process. Granularity thus plays a key role in the implementation of seafood traceability. Another important factor to consider when discussing granularity level is optimization of the practical solutions used to trace the seafood products.

All traceability systems should be designed based on the needs of its users. It is pointless to build a great palace for a single family, where only 10% of the area is used daily; a better solution would be to build a house suited to the needs of the family, where the whole house is used every day. The key is to identify the preferable granularity level for the traceable units. Preferable granularity offers sufficiently detailed information in a traceability system at acceptable costs.

6. Further work

Identifying applications for traceability and benefits of traceable information in seafood supply chains is a clear area for further studies. There is also a need to increase knowledge of preferable granularity levels for traceable units by carrying out real industry studies. A central issue raised by Souza-Monteiro and Caswell (2004) is '*who bears the cost and who reaps the benefits of traceability*'? Further theoretical developments on how granularity impacts costs and benefits in the implementation of traceability are needed. Other interesting questions are: Are the benefits and investments different depending on the companies' position in a supply chain? Are there more advantages to internal traceability compared to chain traceability? Are there different benefits and investments of traceability for different foodstuffs ('high'-value products vs. 'low'-value products)? What is the preferable granularity level for different seafood companies? How will the production concept and use of technology affect the preferable granularity level?

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9.5 Full text version of Paper V

Paper V

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The TraceFood Framework – Principles and guidelines for implementing traceability in food value chains

Jostein Storøy [a], Maitri Thakur [a,*], Petter Olsen [b]

[a] SINTEF Fisheries and Aquaculture, SINTEF Sealab, Brattørkaia 17C, 7010 Trondheim, Norway
[b] Norwegian Institute of Food, Fisheries and Aquaculture Research (Nofima), Muninbakken 9-13, Breivika, 9291 Tromsø, Norway

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ABSTRACT

Requirements related to food safety and associated legislation and certification have increased a lot in recent years. Among these are the requirements for systematic recordings to be made throughout the supply chain so that in case of a food crisis it is possible to trace back to source of contamination, and to perform a targeted recall of potentially affected food items. These systematic recordings must be connected to the food items through unique identifiers, and the recordings, the identifiers and the documentation of how ingredients and food items join or split up as they move through the supply chain is what constitutes a traceability system. For the food industry, the traceability system is also an important tool for controlling and optimizing production, for getting better industrial statistics and better decisions, and for profiling desirable product characteristics. Current status is that many food producers have good, often electronic traceability systems internally, but exchange (especially electronic exchange) of information between the links in the supply chain is very time-consuming or difficult due to the diversity and proprietary nature of the respective internal systems. To facilitate electronic interchange of this type of data, an international, non-proprietary standard is needed; one that describes how messages can be constructed, sent and received and also how the data elements in the messages should be identified, measured and interpreted. The TraceFood Framework was designed for this purpose, and it contains recommendations for "Good Traceability Practice", common principles for unique identification of food items, a common generic standard for electronic exchange of traceability information (TraceCore XML), and sector-specific ontologies where the meaning and the inter-relationship of the data elements is defined. The TraceFood Framework is a joint collaboration of many EU-funded projects dealing with traceability of food products; especially the integrated project TRACE where most of the work related to specification, design and testing of the framework has taken place.

1. Introduction

Food trade is one of the largest global businesses today and traceability throughout the food supply chains has gained considerable importance over the last few years (Carriquiry and Babcock, 2007; Jansen-Vullers et al., 2003; Madec et al., 2001; McKean, 2001; Thakur and Hurburgh, 2009). Consumers all over the world have experienced various food safety and health issues. In addition to this, the consumer demand for high quality food and feed products, non-GMO (genetically modified organisms) foods and other specialty products such as organic food has grown in the past years. These factors have led to a growing interest in developing systems for food supply chain traceability. A number of food safety and traceability laws exist in different countries. The European Union law describes "Traceability" as an ability to track any food, feed, food-producing animal or substance that will be used for consumption, through all stages of production, processing and distribution (Official Journal of the European Unions, 2002). Traceability is important for many reasons like responding to the food security threats, documenting chain of custody, documenting production practices, meeting regulatory compliance or analyzing logistics and production costs. USDA Economic Research Service states that besides ensuring a safe food supply, use of a traceability system results in lower cost distribution systems, reduced recall expenses, and expanded sales of products with attributes that are difficult to discern (Golan et al., 2004). In every case, the benefits of traceability translate into larger net revenues for the firm. Thus, food traceability has become important for reasons other than just the legal obligations in several countries.

The ISO 22005 Food Safety Standard requires that each company know their immediate suppliers and customers based on the principle of one-up and one-down (International Organization for Standardization, 2007). It also states that one weak link in the

* Corresponding author. Tel.: +47 457 92 572.
E-mail address: maitri.thakur@sintef.no (M. Thakur).

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supply chain can result in unsafe food, which can present a serious danger to consumers and have costly repercussions for the suppliers. Food safety is therefore the joint responsibility of all the actors involved. The Bioterrorism Preparedness and response Act of 2002 (the Bioterrorism Act) requires all food and feed companies to self-register with the Food and Drug Administration and maintain records and information for food traceability purposes (US Food and Drug Administration, 2002). Therefore, all the actors involved in the food supply chain are required to store necessary information related to the food product that link inputs with outputs, so that when demanded, the information can be provided to the food inspection authorities on a timely basis. Previous research has emphasized the importance of internal traceability systems (Moe, 1998). In order to achieve a fully traceable supply chain, it is important to develop systems for chain traceability as well as internal traceability. This includes linking, to the best extent possible, units of output with specific units of input. Each supply chain actor should have an internal record-keeping system that would enable them to trace back the ingredients and track forward the products in order to determine the cause of the problem or to efficiently recall the associated (or contaminated) food products. Each actor must be able to trace back and track forward the product information by one-up and one-down basis which implies that each actor in the supply chain must not only know their immediate suppliers and customers but also maintain accurate records of their internal processes.

The terms "tracking" and "tracing" are commonly used to describe traceability. Tracking (forward) is the ability to follow the downstream path of a particular trade unit in the supply chain, while, tracing (backward) is the ability to identify the origin of the products used in a particular trade unit. Thus, tracking is a top-down approach and tracing is a bottom-up approach. Both, tracking and tracing play a very important role in the overall supply chain traceability. According to Van Dorp (2002), tracking and tracing provides the visibility to the supply chain as a tracking function creates a historical record by means of recorded identifications. A good traceability system should have the capability of performing both functions efficiently.

Previous studies have identified some of the biggest challenges in implementing traceability systems in food supply chains. These include the lack of proper identification of the products, inability to keep track of product transformation and lack of standardization of data exchange with other actors in the chain. In the next sections, we describe the work done under the TRACE project on developing the guidelines and the TraceFood Framework for implementation of a traceability system in food supply chains.

2. Generic principles for a food traceability system

There are some well established methods and principles that underlie efficient implementation of traceability in the food industry; many of them described in previous papers and in various guidelines. The most important methods and principles, and the ones incorporated into the TraceFood Framework are:

2.1. Unique identification of traceable units

Regattieri et al. (2007) suggests that the step of product identification is fundamental to a traceability system. Moe (1998) suggests that unique identification and traceability in any system hinges on the definition of a Traceable Resource Unit (TRU) which is a unique unit. According to Article 3 of EC/1760/2000, one of the most important elements for the system for identification and registration of bovine animals is unique identification of individual animals.

2.2. Documentation of transformations

Several product transformations such as mixing, splitting, discarding of TRUs occur in the food supply chains. In order to be able to track and trace products throughout the chain, food business operators must keep track of all products and their transformation through all stages of production (Donnelly et al., 2009; Schwägele, 2005; Thakur and Hurburgh, 2009). Transformations are points within a supply chain where the resources are merged, transferred, added or split. (Derrick and Dillon, 2004) or mixing zones (Skoglund and Dejmek, 2007). Documentation of transformations in a traceability system is very important. Transformations are an important factor that affects the potential precision of a traceability system (Bollen et al., 2007, Bollen et al., 2006; Riden and Bollen, 2007). Transformations in a food supply chain include joining or aggregation of resources, splitting or segregation, as well as transfer, storage or destruction of resources (Thakur and Hurburgh, 2009).

2.3. Standardization of information exchange

Another challenge with implementation of supply chain traceability is the exchange of information in a standardized format between various links in the chain. Globalization combined with the ever-increasing complexity of food supply chain networks has led to an increase in the significance of efficient systems for information exchange between food businesses. However, due to lack of standardization, data handling practice is both time-consuming and costly. This includes wide use of manual information recording and traditional means for data exchange like; telephone, fax and email. Such practices are very inefficient and the data is not reusable which leads to recording of the same data numerous times throughout the whole supply chain, thus increasing the risk of errors. This information needs to be exchanged in a precise, effective and electronic manner (FSA, 2002; Moe, 1998). To facilitate electronic interchange of such product information, international, non-proprietary standards are required such as the ones highlighted by Jansen-Vullers et al. (2003). Standards must describe how information can be constructed, sent and received and also how the data elements in the information should be identified, measured, interpreted and stored (Folinas et al., 2006).

Previous studies have shown that there is currently no standardized way of formatting information for exchange in traceability systems. Research suggested that structured data lists, vocabularies and ontology will be appropriate tools in achieving effective universal data exchange (Donnelly et al., 2009; Dreyer et al., 2004; TRACE 2, 2008). Individual companies have made great progress in proprietary technologies for automated data capture and electronic data coding. However the benefit of these is lost when the data element transmission is required for use outside the originating company as it is only effective when there is an identical software system at the receiving end (Donnelly et al., 2008). In addition, the food businesses are concerned about data security due to the sensitive nature of information and do not want to share it unless this information is stored in protected repositories.

3. The TraceFood Framework

The TraceFood Framework is built upon the generic principles described above and provides a toolbox with principles and guidelines for how to implement electronic chain traceability (Fig. 1). The framework consists of the following components TraceFood Wiki, 2009. <http://www.tracefood.org>:

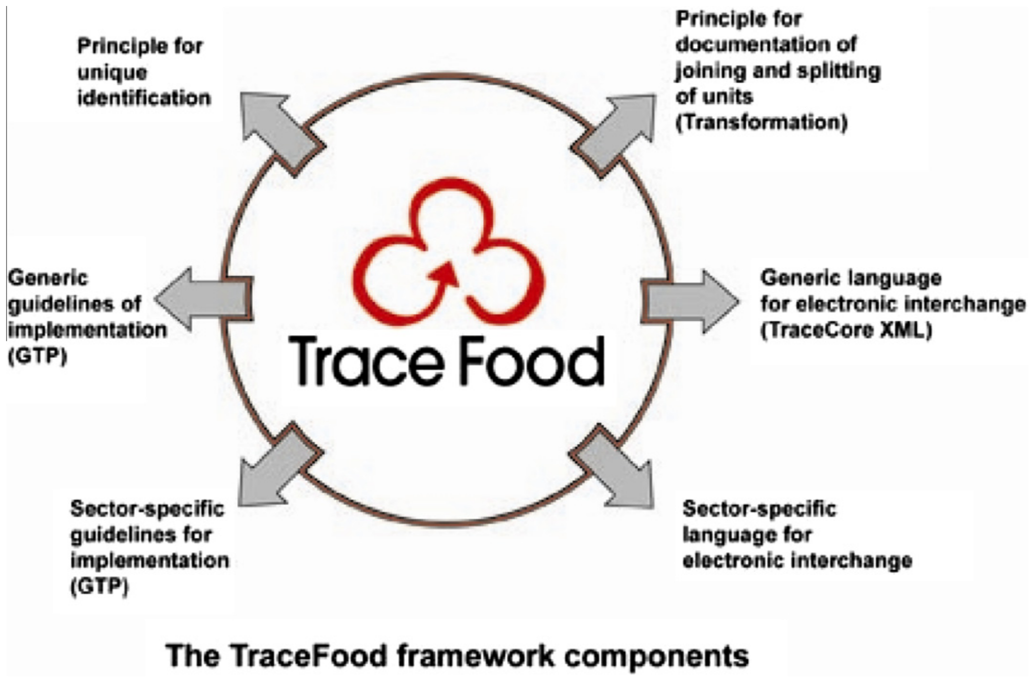

Fig. 1. TraceFood framework components.

- Principle of unique identifications
- Documentation of transformations of units
- Generic language for electronic exchange of information
- Sector-specific language for electronic information exchange
- Generic guidelines for implementation of traceability
- Sector-specific guidelines for implementation of traceability

The core components of the TraceFood Framework are described in the next sections.

3.1. Unique identification in the TraceFood Framework

In order to achieve referential integrity and true traceability, the TraceFood Framework requires that the traceable units shall be uniquely identified. Furthermore it requires that a minimum of additional information shall be linked to the traceable units throughout their lifetime. Later on this data may be accessed via the unique identification number. Common practice for creation of the smallest traceable unit varies in different industries. In the fish farming business a bucket of roe, a full containment of a well boat or a fish crate are typical TU's. In the meat sector a crate of meat is a typical TU.

3.1.1. The GS1 numbering system

GS1 administers a global number system for identification and description of items. The TraceFood Framework recommends the use of the GS1 numbers for unique identification for Traceable Units and Logistic Units (TUs and LUs). The concept of the GS1 128 Symbology is to code a set of data elements frequently used in trade and logistic (i.e. Net weight, Production date, etc.) and explain the meaning of the data elements by using a prefix called an Application Identifier (AI). The AI identifies the meaning and the format of the data that follows it (data field). In the example data (3101) 05545, 3101 is the Application Identifier telling that this data element means Net weight with an accuracy of one decimal, and 05545 specifies the Net weight to be 554,5 kg. The GS1 128 Symbology provides adequate predefined data elements to enable unique identification of both Trade Unit and Logistic Unit.

3.1.2. Unique identification of Trade Units (TUs)

The GS1 128 symbology does not have one single data element for the unique identification of a Trade Unit (i.e. a particular fish crate). However the symbology provides a trade item number, named GTIN, which identifies a variant of Trade Units (i.e. crate of 20 kg fresh Superior Atlantic salmon of 4–5 kg each fish). GTIN is an abbreviation for Global Trade Item Number. To uniquely identify the particular crate, one has to add one or more predefined data elements. In the TraceFood standard this identifier is called GTIN+, where the + indicates that additional information is needed for this purpose. To make up the GTIN+, the GTIN (AI 01) must be combined either with a Batch number (AI 10) and a Serial number (AI 21), or with only the Date and time of production (AI 8008).

GS1 defines the batch number as an internal number of a production batch. It is common practice to allocate this number to all produced units with similar properties (i.e. origin/farm area, time of arrival, supplier, etc.) and/or produced within a certain time period (i.e. one hour, a shift, one day, one week, etc.). Since most commonly many TUs are given the same batch number, unique identification of each TU demands further specification. An appropriate solution is to allocate a serial number to each produced TU (for instance, a meat crate).

Using example data, the GTIN+ applying the Batch- and Serial-number looks as follows:(01)07038010000065(10)123456(21)1234567890

The second alternative is to make up a unique identification of a Trade Unit by combining the GTIN and Date and Time of production (AI 8008).

Exemplified with real data GTIN + may be presented as follows:(01)07038010000065(8008)040915125603

The figures following AI(8008) have a structured format, meaning year/month/day/time/minute/second. In some cases a LU and a TU will be of equal size (i.e. a full containment of a cargo boat carrying grain).

3.1.3. Unique identification of Logistic Units (LUs)

GS1 provides a globally unique data element for the identification of a Logistic Unit, called SSCC (Serial Shipping Container Code).

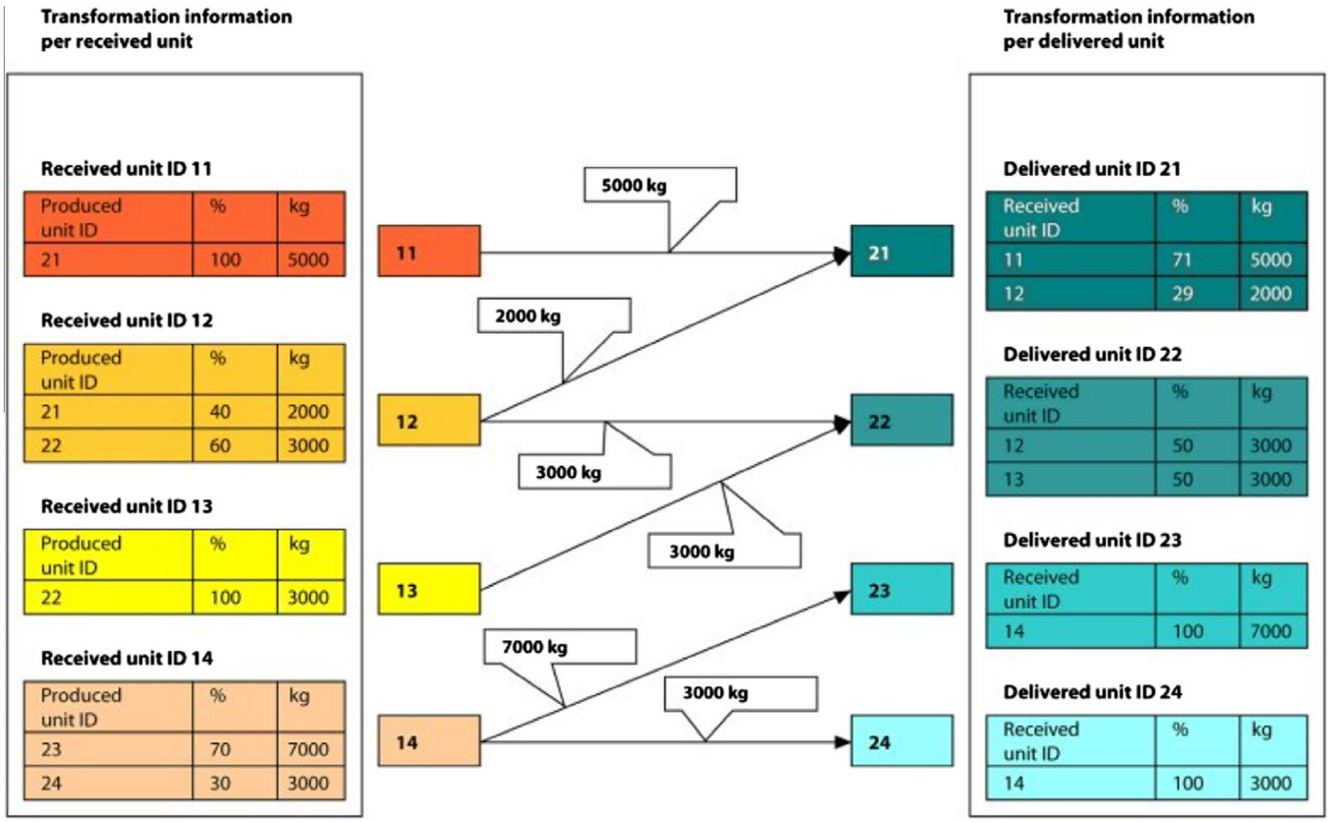

Fig. 2. Relations between received and dispatched Trade Units are indicated (Arrows indicate flow of goods).

A pallet of fish crates or 40 feet containers of fish are typical logistic units. TraceFood requires that the IDs of the separate TU's within the LU shall be linked to the LU identifier, in practice to the SSCC.

The SSCC number structure is (00) 235467985462312345, were 00 is the Application Identifier and the following figure is an 18 digit unique number.

3.2. Documentation of transformations

To be able to trace backwards to find origin and track forward to find all related units it is crucial to record all transformations (split and joins) a trade unit is subject to. The following steps specify how to keep track of transformations.

1. Define the TU in the business under examination.
2. Record IDs of received TUs (raw materials and/or ingredients). There are two ways to record the TUs: (i) if the received Trade Unit has a unique ID, record it and (ii) if the received Trade Unit does not have a unique ID, allocate one to it. If the second alternative is selected, TraceFood standard requires recording of some more information, specified in fig. 5.
3. Record the ID of the TUs that go in production, and give all produced TUs a unique ID. In practice, the ID of TUs that go in production would be linked to a production batch (Batch number) at that stage. Every produced TU must be allocated a unique number (GTIN+). In this way the ID of received TUs would be linked with the ID of produced TUs. This practice ensures forward traceability inside the business. Where possible and relevant, it is also recommended to record the fraction (%) and/or the Net weight of each TU that goes in production.
4. Record the ID of all TUs dispatched. Fulfilling the requirements in steps 2–4 provides both a link between received and dispatched TUs (and the other way around), via the production process (called internal traceability), and a link to previous and next food business operator (called chain traceability). In the TraceFood Framework the mapping of these relations is called transformation information. Fig. 4 shows how relations are linked both ways through a business. Entire TU 11 is input factor in TU 21, while TU 21 is also made up by TU 12. Both fractions (%) and Net weight are indicated. In this figure the production step is removed and only relations between received and dispatched TUs are shown.

If all the transformations are documented in a systematic way, it makes it easy to analyze the relationships between different trade units. Fig. 2, for instance, shows trade unit relationships within a business. For instance, trade unit 21 is composed of all of trade unit 11 and a part of trade unit 12. Both fractions (%) and Net weight are indicated.

3.3. Generic language for electronic exchange of information

Any electronic information interchange of product data is based on two types of messages:

(a) A request for data of a certain type, pertaining to a product or a group of products
(b) A response to the request, containing the data requested

This is commonly referred to as a request–response scheme. Note that the response can be send also without an explicit electronic request present; it is not uncommon for well-integrated business partners to agree that a minimum data sheet always should be sent electronically when the product is shipped. Also note that some data are sensitive and extensive classification and validation of the requester needs to be done before a

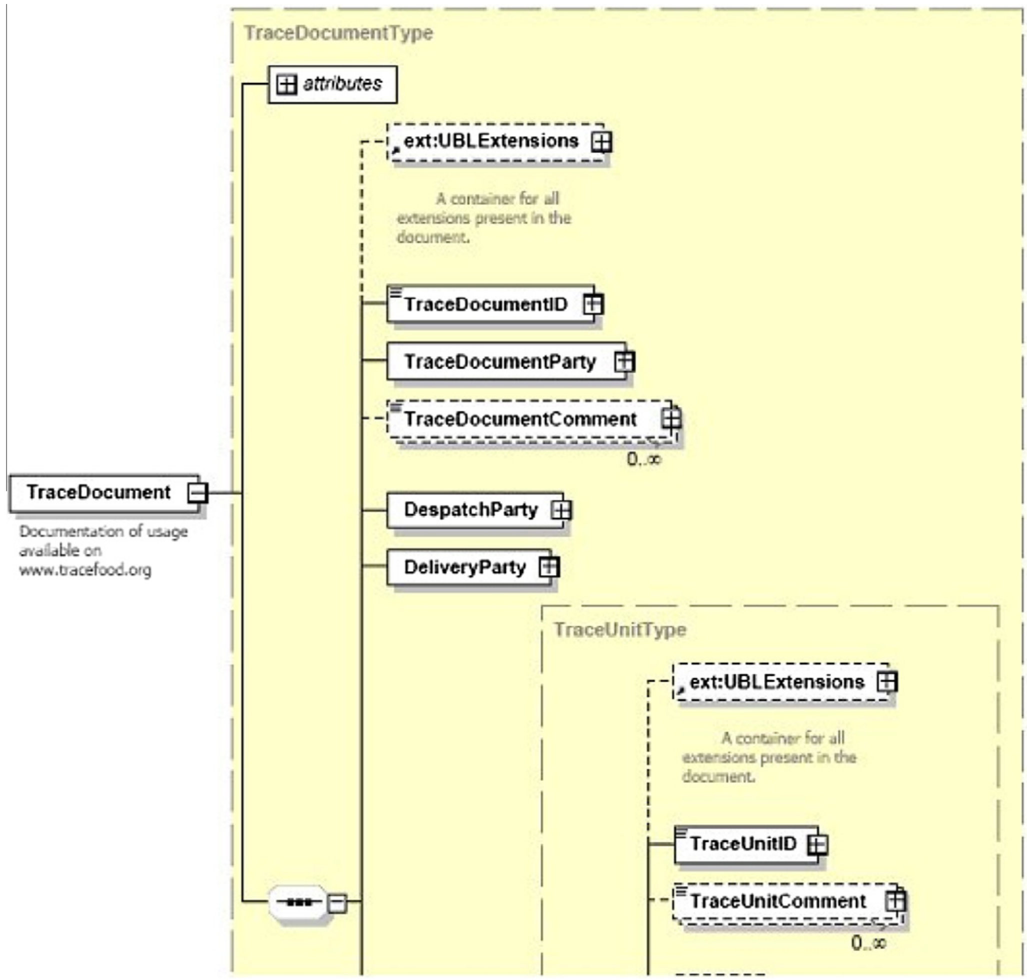

Fig. 3. TraceCore XML schema.

response is chosen. This functionality is supported by the request–response scheme in the TraceFood Framework, but further discussion on the details of it is beyond the scope of this paper.

For an electronic request–response scheme to work, the customers' and suppliers' respective software applications must exchange messages in a format recognized, so there must be a standard format for the message structure. In addition, there must be some agreement about the content of the message, and this issue is discussed further below.

TraceCore eXtensible Markup Language (TraceCore XML – TCX) developed under the TraceFood project is a standard way of exchanging traceability information electronically in the food industry. TCX makes it possible to exchange the information that is common for all food products, like the identifying number, the origin, how and when it was processed, transported and received, the joining and splitting of units, etc. (TraceFood, 2007). The purpose of TCX is to define a format where all the minimum elements needed to model traceability relations between organizations in a supply chain are included. Only some basic properties are included in the core, while extension mechanisms are meant to provide ways to include industry specific properties, properties exchanged between specific parties etc.

An example of the TraceCore XML schema is shown in Fig. 3. TraceCore XML may be used for exchange of information between different traceability databases as shown in Fig. 4.

3.4. Sector-specific language for electronic information exchange

As indicated above, it is not enough to agree on the message structure. If the producer tells the customer that the property "Fat content" has the value "14%", the customer needs additional information to understand what this means. The fat content of what? Measured how and where? If left to themselves, different producers may use different names for the same properties, and different producers may even use exactly the same name for what is in fact a completely different property. Even if the same property name is used, there may be multiple ways to specify the value of the property. If the property is "Fish species", the values "Atlantic cod", "Bacalao del Atlántico", "Gadus Morhua", "COD" and "1480400202" all mean exactly the same (the two latter are the FAO 3Alpha Code and Taxonomic Code respectively). To facilitate clear and unambiguous information interchange, a sector-specific standard for properties and values are needed, specifying exactly what the properties should be called and how they should be measured. The viability of such common standards was shown in the TraceFish project where both sector-specific standards (for captured fish and farmed fish) and generic standards (for electronic coding and request–response scheme) were developed. The TraceFish work established sector-specific data models that not only contain information about data elements (including the relationship between them) relevant for product information in one link of the supply chain, but also information for each link.

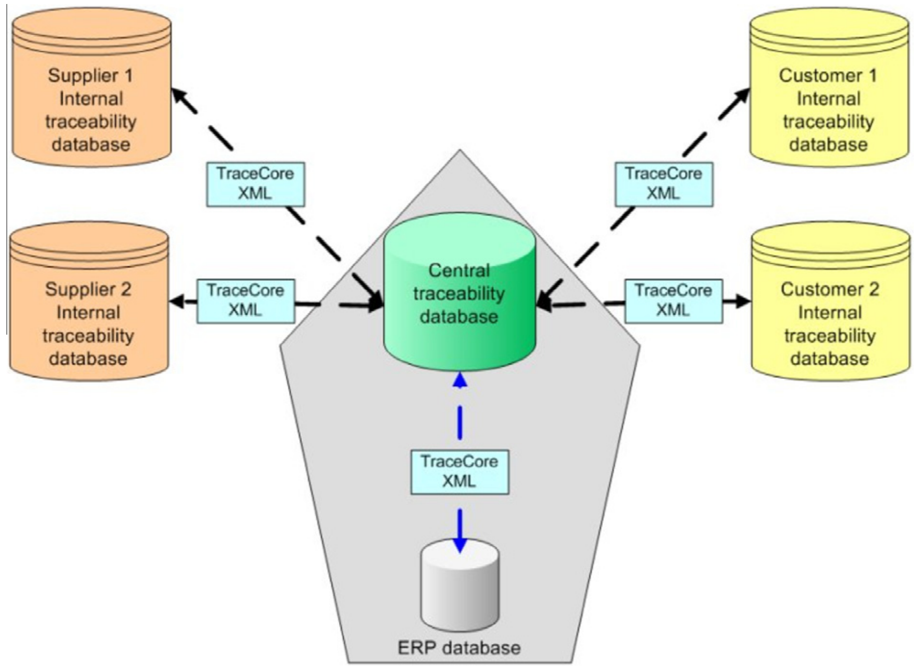

Fig. 4. Integration of TraceCore XML with external databases.

3.5. Generic and sector-specific guidelines for implementation of traceability

The final components of the TraceFood Framework are the generic and sector-specific guidelines for implementation of traceability. The generic guidelines include parameter list for the data to be recorded in for all food products (such as: producer ID, trade unit ID, etc.) In addition to the generic guidelines, sector-specific guidelines must be developed which are product specific and includes:

(1) Creating a standardized parameter list for the given product throughout the value chain.
(2) Identifying data to be recorded at each link in the value chain.
(3) Creating a data management and information exchange model for both internal and chain traceability in the value chain.

4. Pilot studies

The TraceFood Framework has been used to develop Good Traceability Practice (GTP) guidelines for seafood, mineral water, honey and chicken value chains. Standards were developed for these that consist of specifications for the information to be recorded in these value chains to achieve good traceability. Fig. 5 presents an illustration of the sector-specific standard for a fish value chain. The data elements to be recorded are shown.

4.1. Seafood sector

A standard for traceability of finfish products including the specifications on the information to be recorded in captured finfish distribution chains was developed using the TraceFood Framework which is now available as an ISO standard, ISO 12875:2011. In addition, best practice guidelines for capturing product, process and quality data in fish farming cage was also developed. The purpose of these guidelines was to harmonize all data capture including parameters, measurement points and techniques in sea-based fish farming so that the quality of the data coming into the traceability and production management systems is homogeneous. This ensures that data from different facilities is comparable. The TraceFish standard developed based on the TraceFood Framework was tested in the EU Integrated project SEAFOODplus.

4.2. Mineral water

An Ad-hoc standard based on the GTPs for implementing traceability in a mineral water value chain was developed. The standard specifies how mineral water should be identified, how the generated information should be stored by each of the involved businesses. Several relevant parameters that must be linked to a specific trade unit are specified including the parameters linked to the production history. This includes records of HACCP analysis, microbiological and chemical tests, quality control checks, etc. The full standard and descriptions are available at www.tracefood.org. Similar standards were developed for the honey and chicken sectors.

4.3. Observations from the pilot studies

The experiences from the pilot studies conducted based on the TraceFood Framework show that the food industry did not realize the true value of using an electronic traceability system as the costs of installing and operating the system exceeded the benefits. Also, for an efficient traceability system, all partners in the supply chain must have the ability to record and share the information in a standardized manner. The industry lacked this capability, making the implementation of the standards based on the TraceFood Framework more complex.

5. Discussion

TraceFood Framework presented in this paper consists of recommendations for "Good Traceability Practice", common principles for unique identification of food items, a generic standard for electronic information exchange (TraceCore XML), and

Table 3 — Detailed information requirements for fishing vessels

Data element		Description	Examples	Categorisation		
				Shall	Should	May
VESSEL						
CFV101	Food business ID	Unique national identification number for the organization plus country prefix as well as name and address of the food business that operates the vessel	Humber Trawlers, Albert Dock, Hull, HU1 7AR, England		x	
CFV102	Vessel call sign	International Telecommunication Union Radio Call Sign (IRCS) for the vessel	EA8588		x	
CFV103	Vessel ID	Flag state, name and registration number of the vessel	UK, "Phoenix", H123		x	
CFV104	GMP certification	Names of fish quality or food safety GMP schemes by which vessel is certified	Efsis			x
CFV150-	(unassigned)	Further information elements that describe the vessel, linked to Vessel ID				x

From ISO/DIS 12875 – Example of sector-specific recording standard, fishing vessel information

Data element		Description	Examples	Shall	Should	May
FOR EACH TRADE UNIT CREATED						
Identity						
CFV201	Trade unit ID	UTUI	978817525.0766.000010123	x		
Description						
CFV202	Type of unit	Description of physical type of unit (single fish, box, tank, hold, block or package of fish, etc)	Box			x
CFV203	Net weight	Recorded as a weighed or estimated quantity of fish (kg)	Estimated, 45 kg		x	
CFV204	Species	LAT - followed by latin name, or FAO - followed by FAO 3alpha code, or TSN - followed by Taxonomic Serial Number (may be repeated if several species)	LAT - *Gadus morhua* FAO-COD TSN- 164712		x	
CFV205	Area/country of origin	FAO area/RFMO area for marine fish or country of origin for fish from inland waters, or more specific location	27		x	
CFV206	Product form	Whole, gutted or headed, etc.	Gutted		x	
CFV207	Size grade	Nominal weight (kg) or length (cm) range, or ungraded	3-4 kg			x
CFV208	Product condition	Live, ambient, chilled or frozen	Chilled			x

From ISO/DIS 12875 – Example of sector-specific recording standard, trade units created by vessel

Fig. 5. Sector-specific standard for recording traceability information in a fish value chain.

sector-specific ontologies that defines the meaning and interrelationships between data elements. More general standards for electronic exchange of business information exist (UN/EDIFACT, UBL, GS1 XML, etc.), but the TraceFood Framework is unique in providing functionality for non-proprietary standard exchange of food traceability information. The TraceFood Framework and the TraceCore XML have been tested in food industry pilot chains in Norway, Spain, France and China, and the purpose of this paper is to describe the framework itself as a methodology for implementing traceability in food value chains. It seems clear that a standard such as the one described is needed, and that the options are to either use the TraceFood Framework and the TraceCore XML as it is, or to extend one of the other existing standards so that food traceability information can be exchanged as required. The sector-specific language for electronic exchange of information in the fish industry which originated in TraceFish and was incorporated into the TraceFood Framework is now ISO/DIS 12875 "Traceability of finfish products – Specification on the information to be recorded in captured finfish distribution chains" and ISO/DIS 12877 "Traceability of finfish products – Specification on the information to be recorded in captured finfish distribution chains".

In conclusion, the tools for implementation of traceability exist, and most of the technical challenges have been solved. Some parts of the TraceFood Framework can be directly applied in other food chains, and other parts can serve as a template. The many implementation projects where the TraceFood Framework was used showed that the main obstacle for successful and efficient implementation of traceability in food product chains is organizational, not technical. In general, the food businesses are not motivated to implement new standards for information exchange and traceability as they perceive this as an additional cost and are not aware of the associated benefits. Also, the companies are not willing to make changes to their current operational practices. In addition, companies are also concerned about data security and are not willing to share sensitive information unless it is protected in trusted repositories but this issue was secondary to their reluctance to change their current practices.

Further work needs to be done on quantifying the costs and benefits of a traceability system based on the TraceFood Framework. Currently the companies don't have a detailed picture of their internal processes, so cannot quantify benefits in detail. This leads in turn to skepticism about the advantages of implementation. This is an important factor with regards to implementation routes, i.e. market forces or regulatory enforcement.

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