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A Methodological Framework to Design and Assess Food Traceability Systems

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Abstract

A methodological framework to design, assess and manage food traceability systems (TS) is proposed. The services delivered for the multiple beneficiaries of the TS are listed and featured by a series of high-level performance criteria. We also propose a library of modular technical solutions to guide designers in choosing appropriate traceability solutions. Again, at this technical level, practical performance criteria are provided for daily traceability control. This performance system may be used in a design methodology as well as for auditing a TS. Based on this model, we develop an Information System that we apply to a poultry processing company.

Keywords: traceability, food tracing, food safety, performance system, information system

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Introduction

Various food security crises, like *mad cow disease*, have shaken the agri-food sector during recent years have resulted in tightened regulations and standards on food safety. For instance, according to the EC Regulation 178/2002, food companies must set up means enabling them to trace and track their products. A traceability system (noted herein TS) can be defined as a *system structured in such a way that it allows to totally or partially reconstruct the lifecycle of a given set of physical products* (Bendaoud et al. 2007). In practical terms, it provides users with a set of relevant information related to origin, composition, location and other characteristics of the product under consideration. This information can be used for different purposes. That which is most often highlighted is the ability to locate a non-conforming foodstuff and retrieve it from the market in order to protect public health. A more comprehensive view of the added value of a TS is provided in literature, especially in (Bendaoud 2008) and (Töyrylä 1999). In addition to regulation texts, food operators must comply with other requirements, particularly food safety standards such as ISO 22000, IFS (International Food Standard), BRC (British Retail Consortium) and SQF (Safe Quality Food). As many authors point out (Moe 1998; Töyrylä 1999; Viruega 2005) we noticed that the few references scrupulously dealing with the issue of food traceability still remain incomplete and unsatisfactory. In fact, most of the existing literature is written by practitioners and is not based on more systematic industrial engineering approaches.

So, on the one side there are food operators who need to be provided with methodological tools to comply with traceability requirements and, on the other, we notice the incomplete and unsatisfactory character of existing references and traceability frameworks. Starting from this situation, we have been conducting an action-research project since 2005. This project aims at proposing a set of conceptual and methodological tools to design, assess and manage a food traceability system (Bendaoud 2008). The present paper's purpose is to show some findings of this project. More precisely, it is about a functional analysis through which we define and characterize a certain number of technical functions to be fulfilled by a food TS in order to satisfy the needs of its beneficiaries.

Our research project can be understood as the study of food TS from three complementary points of view. The first one is **functional** since it focuses only on what TS are expected to do, this is also the domain of expected performances. The way they do it must not be dealt with here. This stage has resulted in three deliverables: identifying the beneficiaries of a food TS, defining the services provided by this system and building quantifiable criteria to assess these services (Bendaoud et al. 2007). The second point of view, which constitutes the subject of the present paper, is **technical** in the sense that it is dealing with lower-level functions and with processes which constitute the structural solution of a TS. As can be seen hereafter, most of these (technical) functions apply to the information used to *totally or partially reconstruct the lifecycle of* traced products. In order to have a precise idea of this information, the third perspective of our research, described as **informational**, aims at building a generic traceability data model. Its purpose is to accurately define and characterize the different data to be taken into account within the framework of a food TS. A computer platform based on this model has been developed and implemented within a French food processing company.

The research issue and the followed approach are further detailed in Section 2 and the results are presented in Section 3. We illustrate our findings in Section 4 through a practical case study within a poultry processing company. Finally, the last section (5) is devoted to a conclusion of our proposals.

Research Issue and Approach

Like other European food companies, our industrial partner (Arrivé S.A., one of France's leading poultry processing companies) has been confronted with recent traceability demands (Bendaoud et al. 2007) and had no choice but to improve its TS in order to fulfill them. In this context, we were firstly asked to carry out an audit aimed at highlighting how well the firm traces its products. Despite an in depth analysis of the literature, we failed to find rigorous and quantifiable criteria to be used to assess the strengths and weaknesses of the system. In fact, certain performance criteria are sometimes mentioned such as *breadth* (Golan et al. 2004), *effectiveness* (Bertolini et al. 2006) and *timeliness* (Töyrylä 1999), but their authors do not explain the protocols for quantifying these in detail. Our approach thus starts with a *need functional analysis* that consists of circumscribing the TS in its environment and studying various interactions that it may have with other surrounding systems. These interactions are expressed in terms of *primary functions* and *adaptation* (or *secondary*) functions. The first aims at satisfying the user's needs while the second *reflects reactions, resistance or adaptations to elements found in the outside environment* (Prudhomme et al. 2003). As represented schematically in Figure 1, eight *surrounding environments* are identified. Five of them (underlined) constitute the *beneficiaries* whose needs are satisfied through the primary functions of the TS.

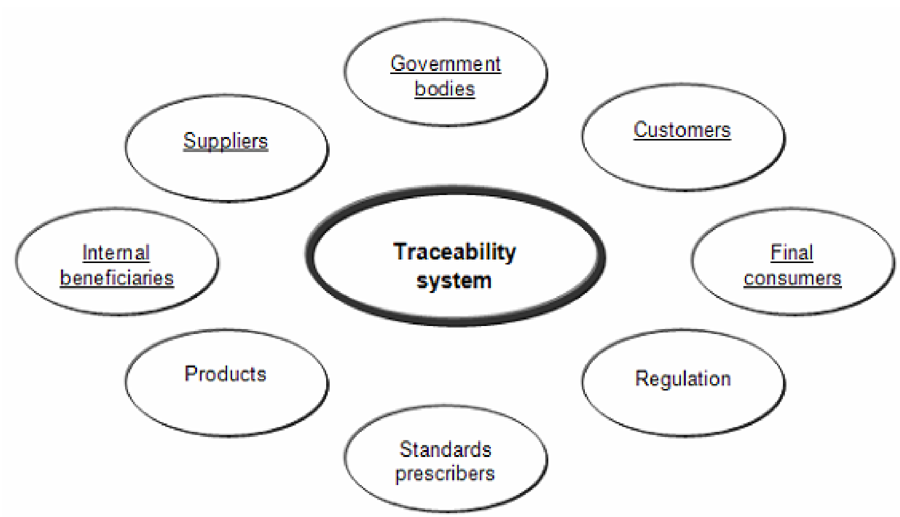

Figure 1. The TS and its Surrounding Environments

- Government bodies: Public institutions which play a role in terms of protecting consumers' health and ensuring fair competition (*e.g.* FDA in the USA and DGAL in France).
- Customers: The parties to which the products are supplied, such as supermarkets or other manufacturers.

- Final consumers: Physical persons who receive and use the product (food or feed) for non-professional purposes.
- Regulation: Laws or administrative rules that deal with food traceability (*e.g.* the *EC Regulation 178/2002* in Europe and *Bioterrorism Preparedness and Response Act* in the USA).
- Standards prescribers: Organizations which define the standards totally or partially dealing with food traceability (*e.g.* IFS and BRC).
- Products: The substances that can be used to prepare or package the foodstuff.
- Internal beneficiaries: Physical or moral entities inside the company which own the traceability system (*e.g.* quality department, supply chain department).
- Suppliers: Organizations which supply the substances used to prepare or package the foodstuff.

This approach made it possible to define a dozen of primary functions and characterize them with a set of assessment criteria (Bendaoud 2008; Bendaoud et al. 2007). These functions can be summarized in what we call a *generic primary function* (GPF):

$$\text{GPF: To provide} \left\{\begin{array}{l}\text{Government Bodies}\\ \text{Customers}\\ \text{Final consumers}\\ \text{Internal beneficiaries}\\ \text{Suppliers}\end{array}\right\} \text{with data on} \left\{\begin{array}{l}\text{upstream}\\ \text{internal}\\ \text{downstream}\end{array}\right\} \begin{array}{c}\text{Traceability of}\\ \text{products}\end{array}$$

The three dimensions of traceability mentioned above correspond to different categories of information that a TS is expected to provide in different contexts and for different purposes. According to a given entity (link) in a supply chain:

- upstream traceability consists of identifying the origin of input products,
- internal traceability consists of reconstructing the history of a given product within a company or location which is under consideration and
- downstream traceability consists of identifying the destination(s) of output products.

This generic function may, then, be simply expressed as follows:

GPF: To provide the beneficiaries of the TS with data on product traceability.

Therefore, to the question "***WHAT*** *is expected from a (good) traceability system?"* we have tried to answer by defining and characterizing the service functions (*i.e.* primary and adaptation functions) carried out by this system. In this functional perspective, the TS is viewed as a *black box* since its internal behavior is completely omitted. The subsequent question, resulting from the first, is about the how a TS works internally in order to provide what is expected from it. This is precisely the subject of the present paper in which we deal with the following research questions:

*Technically, **HOW** should a traceability system work? Which are the technical functions to do so? And, according to which criteria can the pertinence of the chosen solutions be assessed?*

These questions denote a twofold ambition. The first consists of proposing a *modular design* method that provides guidelines to choose the appropriate solution for accomplishing each functionality of the TS. The second is to define a set of quantifiable performance criteria to assess the various solutions.

A literature review reveals few attempts to define how a TS should work by identifying various “technical” functions. However, these proposals are incomplete and seem intuitive since their authors do not explain the approaches they followed (Regattieri et al. 2007; Steele 1995; Verdenius 2006). For instance, Steele identifies four elements which ‘*define the full scope of lot traceability*’: ensuring physical lot integrity (*e.g.* to prevent losing traces of a part of a lot), collecting data, maintaining links between a lot and its manufacturing process and retrieving data from the system. In the same perspective, Verdenius describes a TS as a combination of three functions: product identification, data recording and data processing. As it can be noticed, this representation is too general for practical purposes. As a last example, Regattieri defines four elements that constitute the backbone of a TS. These relate to identifying the product, tracing its characteristics, tracing its manufacturing process and choosing appropriate tools (*e.g.* and identification system that is compatible with the nature of the product).

In an attempt to answer the previous research questions, we have adopted a *conceptual design* approach that aims, according to Pahl and Beitz, to identify principles of solutions. In subsequent steps of the process, these principles can be translated into physical solutions and implementable tools. So the purpose here is to define and characterize the *technical functions* and their relationships (simultaneity, exclusion, precedence…) that fulfill the service functions of a food traceability system. According to Prudhomme, a technical function refers to *the action of a constituent part or an action between the constituent parts of the product designed to provide the service functions required*.

Starting from the *generic primary function* defined above, we opted for the FAST (*Function Analysis System Technique*) method to identify the appropriate technical functions. Developed in 1963 by Charles W. Bytheway, (see Bytheway 2005; Kaufman 2003; Wixon 1999; Yannou 1998), FAST allows a designer progressively and explicitly to visualize links between goal-functions (*i.e.* a primary function) and means-functions (*i.e.* a technical function) (Yannou 1998). In the next section, further details will be provided about the FAST method.

A Framework to Design and Assess a Food Traceability System

Defining Technical Functions of the Traceability System

As shown in Figure 2, the generic primary function (GPF) constitutes the starting point of our approach. According to the FAST method, it is considered as an upper-level function. The principle consists, very briefly, of starting with this function and asking HOW it is performed. Each answer to this question allows us to define a lower-level function that is submitted, in turn, to another question HOW, etc. The process is stopped each time the HOW- question leads directly to a technical elementary solution (i.e. an equipment or a basic organizational process).

The diagram must also be read and covered from right to left by asking WHY a given function is performed. This way of scanning the FAST diagram is useful for validating the pertinence of lower-level functions. As for the vertical dimension (WHEN), it describes temporal and causal constraints between functions. For example, a given function A cannot be accomplished prior to another function B. This process of scanning from left to right and from right to left must be performed until no new technical function can be envisaged and no other cause-mean relation can be set. We have applied this process exhaustively to a traceability system. In the following, we detail the progressive building of the FAST model leading to the set of technical functions of the TS. It partly serves as a proof of exhaustiveness and relevance of the result.

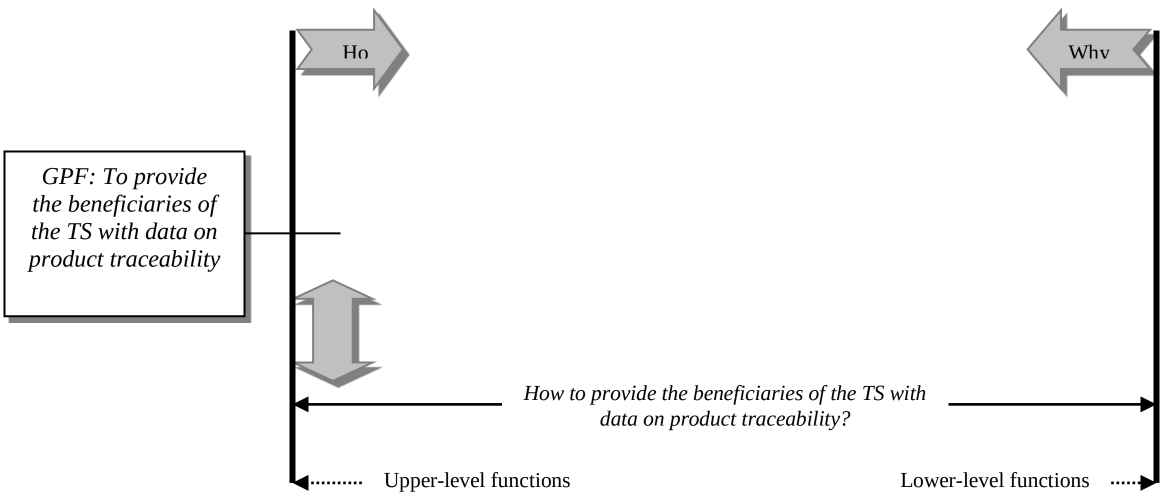

Figure 2. The Structure of FAST Diagram

Traceability data are supposed to pre-exist on a given support (paper, database, etc). So, logically, the first step consists of **restoring** them from the corresponding support. This action can be expressed through our first technical function as shown in Figure 3.

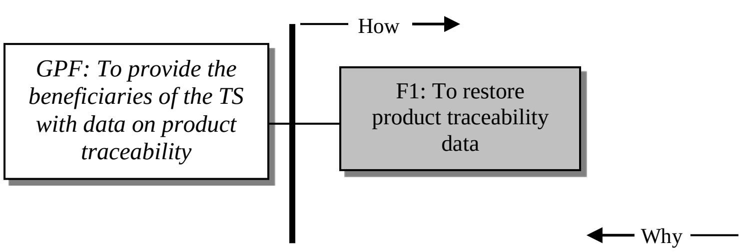

Figure 3. Identification of Function F1: *To restore product traceability data*

An internal beneficiary (a quality manager for example) who needs traceability information can ask the system directly and get what he or she wants via function F1. However in case of an external beneficiary (a customer for example), there is generally no direct access to traceability data. That is why an additional function is required to **communicate** these data to concerned beneficiaries. In Figure 4, function F2 is linked to the generic primary function (GPF) by a dotted line to emphasize its optional character.

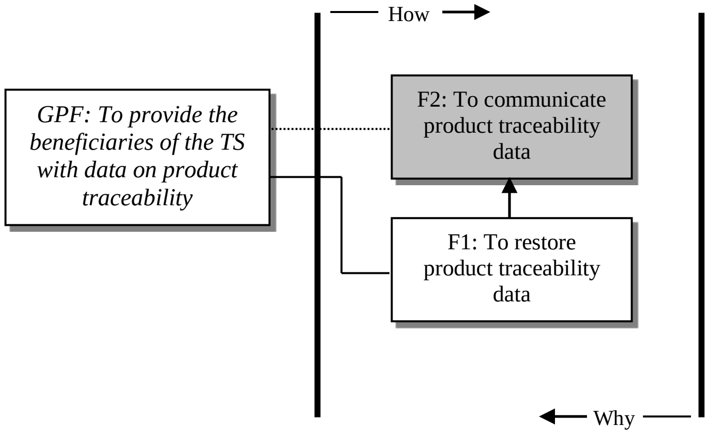

Figure 4. Identification of Function F2: *To communicate product traceability data*

This portion of the FAST diagram is read as follows: Providing the beneficiaries with traceability data can be achieved either by direct consultation of the TS (F1), which supposes that the beneficiary is a direct user, or by using communication channels (F2). In the first case, the given user is referred to as an *internal beneficiary* (See Figure 1).

Restoring traceability data (F3) assumes that these have previously been stored or memorized, which is the role of our next function (F3) (See Figure 5). Here one can clearly see that the vertical oriented arrow means as well a task correlation (meanwhile another required task is…) as a task precedence.

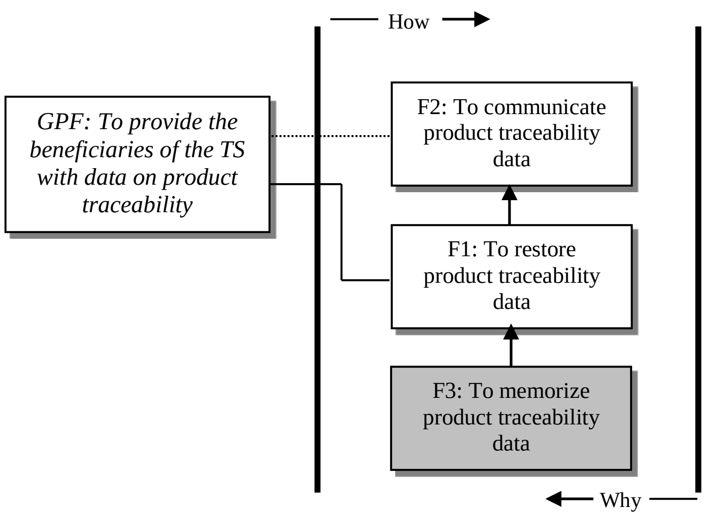

Figure 5. Identification of Function F3: *To memorize product traceability fata*

To memorize product's traceability data in a food production environment, two methods can be used (See Figure 6). The first consists of associating them directly to the product or its packaging (*e.g.* through the labels used to product identification). The other is to record these data in an external support (*e.g.* paper-based records, IT, etc).

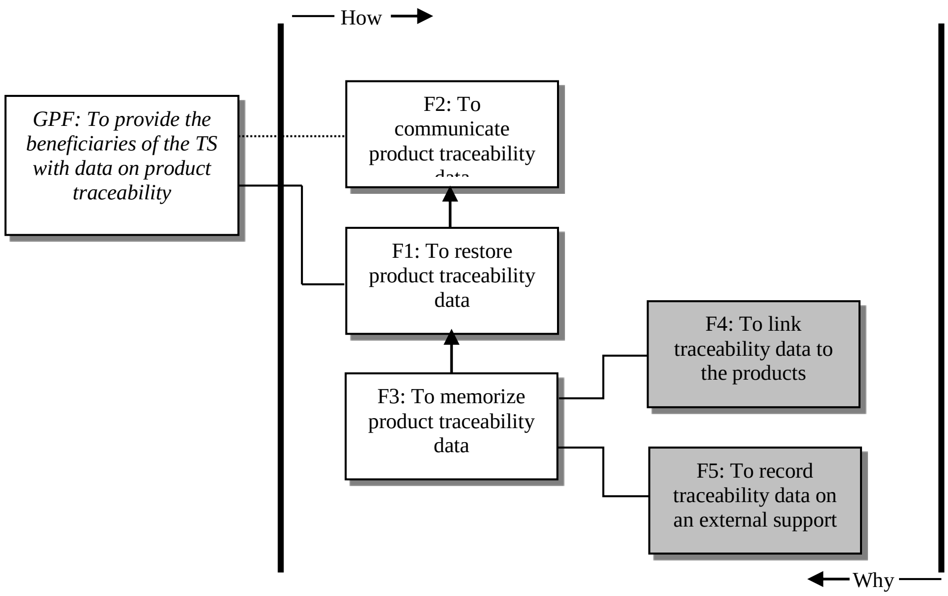

Figure 6. Identification of Function F4 and Function F5

This new part of our FAST diagram is read as follows: to memorize them, products traceability data can be either linked to the product itself **or** recorded on an external support. The disjunction "OR" is here an inclusive one since F4 and F5 can be used simultaneously.

Prior accomplishing F4 or F5, memorized traceability data must be available and known. That means the data must be acquired or obtained from a given source as represented in Figure 7 through function F6.

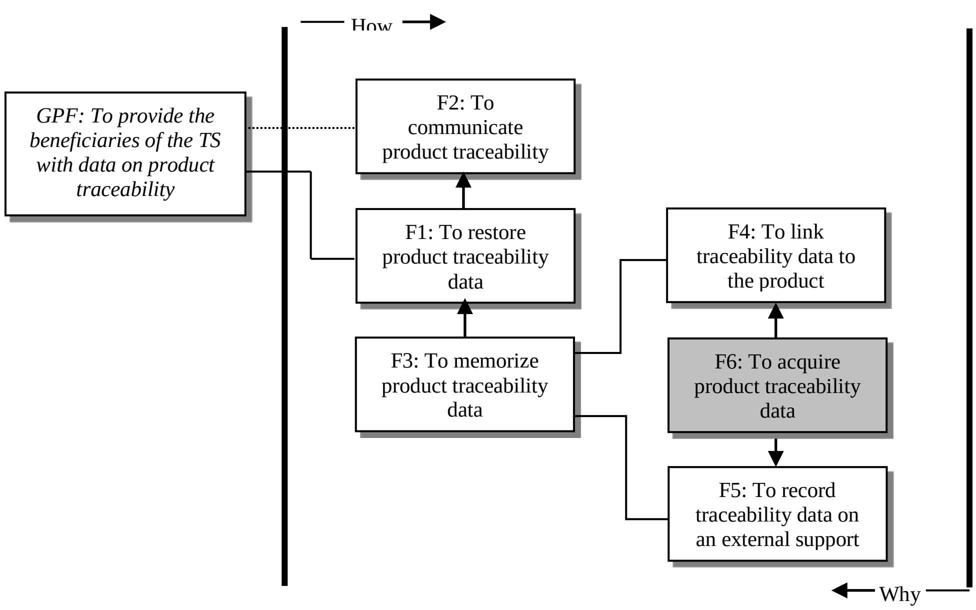

Figure 7. Identification of Function F6: *To acquire product traceability data*

Function F6 is considered as a necessary condition for accomplishing functions F4 and F5 but it does not constitute a means to carry out these functions. In other words, F6 does not provide an answer to the *HOW-question* associated either to F4 or F5.

Now, let us continue our FAST process by asking how to collect product traceability data. Two answers can be found depending on whether these data already exist or not. The first case reflects situations where traceability data are available somewhere and only need to be collected. For example, when certain raw materials are delivered to a plant, some traceability data can be collected from invoices or from delivery slips. In the second case, traceability data must be generated since they do not yet have any physical existence. For instance, in a dairy product plant, pasteurization temperature is crucial information that is first generated (created) using a thermometer and then acquired (recorded) as traceability data (F6). So, as indicated in Figure 8 two new functions are added to the FAST diagram to collect and to generate traceability data.

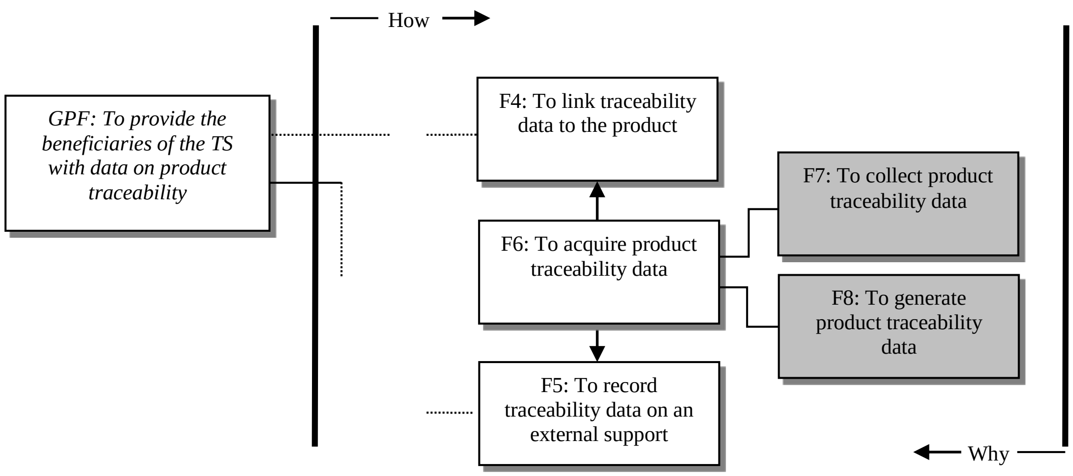

Figure 8. Identification of Functions F7 and F8: *To collect and to generate product traceability data*

In the food industry, products are often managed through the notion of lot (or batch). According to European Council Directive 91/238, a lot can be defined as "*a batch of sales units of foodstuff produced, manufactured or packaged under the same conditions*". In the traceability field this is a key concept. For example, in case of a food crisis affecting a given product, instead of recalling all the instances of that product, a traceability system makes it possible to target only the batch that is actually concerned. To achieve this, each lot must be given a unique identity. This task is assigned to function F9 that must be completed prior to F7 and F8 (See Figure 9) since collecting or generating traceability data necessarily refers to a given lot of products.

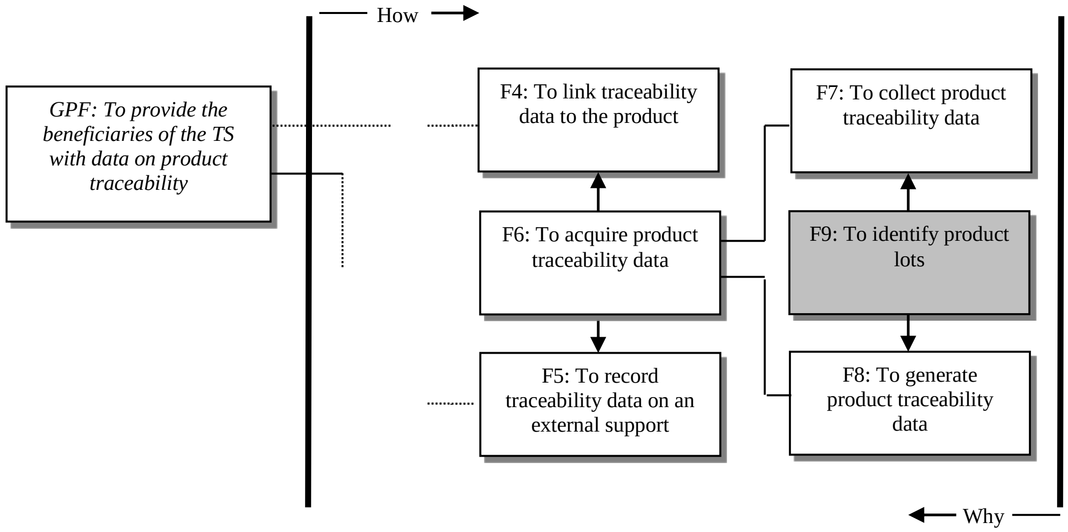

Figure 9. Identification of function F9: *To identify product lots*

Identification aims at distinguishing between different instances (lots) of the same product. In practical terms, it consists of firstly creating the identifier (F10), and then associating it to the appropriate lot (F11). These new functions are added to our FAST diagram as shown in Figure 10.

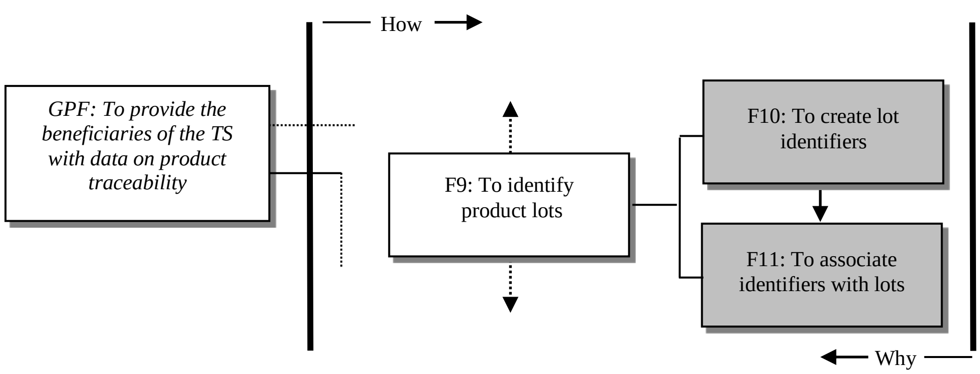

Figure 10. Identification of functions F10 and F11: *To create and to associate lot identifiers*

On the basis of our industrial experience and several literature references (Garrido Campos and Hardwick 2006;Jansen-Vullers et al. 2003;Pinto et al. 2006; and Rönkkö et al. 2007) the lot number is the identifier most used. Generally, a lot number takes a form of alphabetic, digital or alphanumeric code and can be either automatically (by IT) or manually generated. There are different ways to associate an identifier with the corresponding lot depending on the kind of considered product and on the technology adopted. For example, we can print (mark) the identifier directly onto the product (e.g. eggs, canned foods, cow tattoo, etc.), use barcodes or RFID tags. Finally, to physically associate an identifier with a lot, we can use direct marking (F12) or indirect marking (F13) as shown in Figure 11.

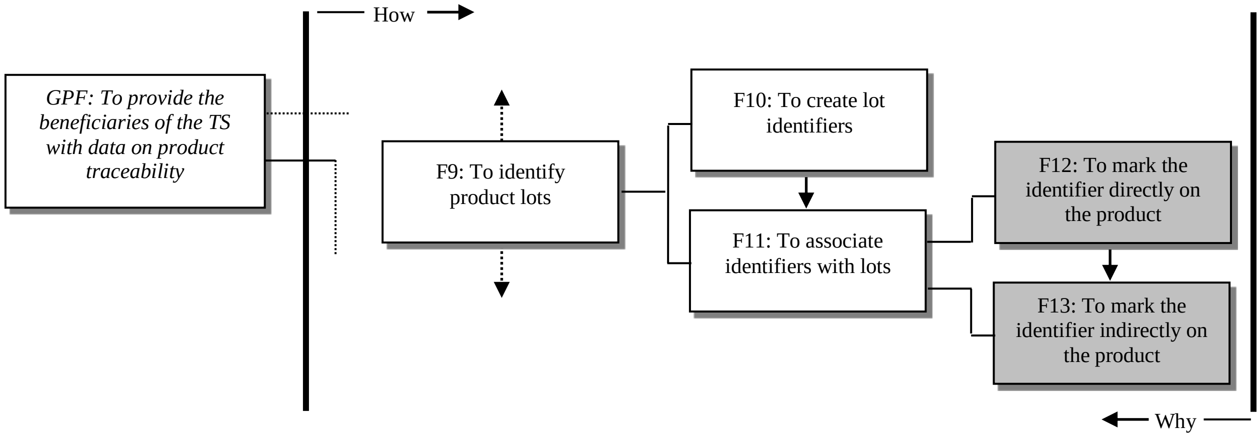

Figure 11. Identification of functions F12 and F13: *To mark the identifier directly/indirectly on the product*

As we can see in Figure 11, functions F12 and F13 can be used simultaneously to ensure a link between a product and its identifier. For example, for a lot of canned fish, the lot number can be printed on each can (F12) and also marked on a barcode stamped on a trade unit (box or pallet). Such a redundancy may guarantee a better reliability for a low extra cost. In both scientific and technical literature, all solutions that can be used to perform function F13 are grouped under the generic expression *identification carriers.* Hence, to the question *"how can we mark the identifier indirectly on the product?"* we can answer *"by using identification carriers".*

In practice, an identification carrier is generally used both to identify the product and to carry a set of (traceability) data describing this product (See F4). An RFID tag, for instance, contains the lot number of the product and other data such as manufacturing date, manufacturer's address, etc. Therefore, we can enhance the FAST diagram with a new function (F14: To use identification carriers).

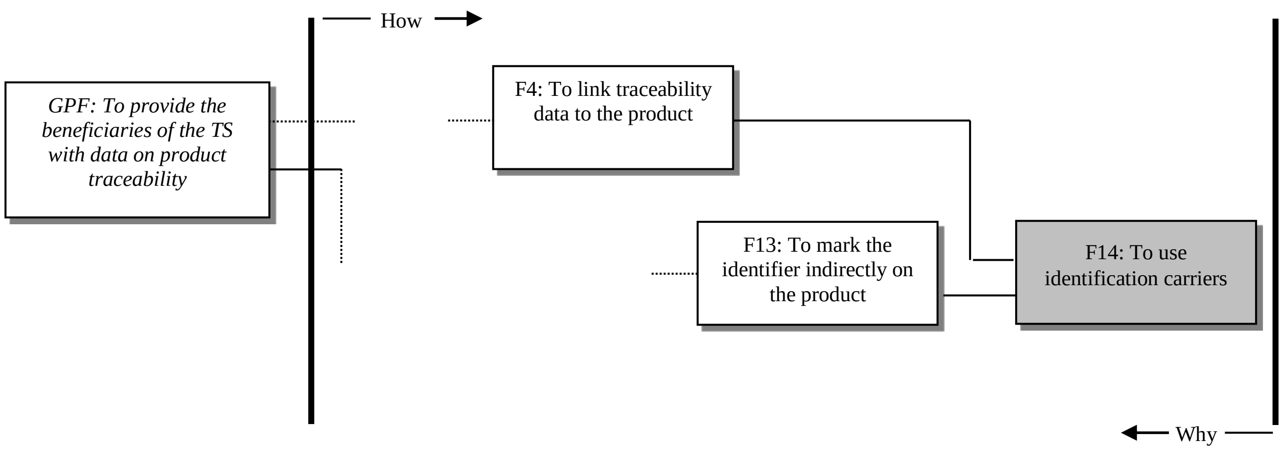

Figure 12. Identification of function F14: *To use identification carriers*

Through the previous paragraphs, we have presented the typical functions that must be performed by a food traceability system in order to satisfy its beneficiaries. But, as some of these functions relate to product lots, it would be interesting to define a last function (F15) that deals with creating lots (See Figure 13). In a production or manufacturing process, a lot is created when a homogeneous group of products is considered and identified as a unique entity. For example, all the chickens bred in the same conditions (place, feed, etc.) can be considered as a unique lot. As can be noticed in Figure 13, function F15 necessarily takes place before function F11. However, it is quite possible to create a lot identifier prior to creating the given lot and *vice versa*.

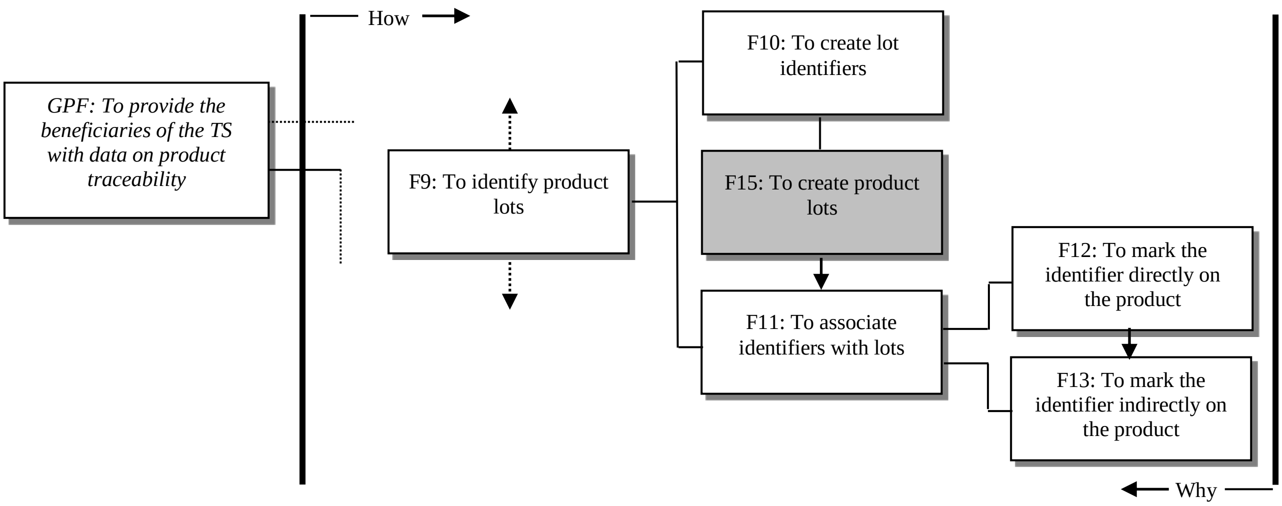

Figure 13. Identification of function F15: *To create product lots*

After identifying the fifteen technical functions of a traceability system and explaining their logical links, let us put them together to construct our complete FAST diagram (See Figure 14 in Appendix A).

Synthesis of the Technical Functions

Our ultimate objective is to propose a library of technological solutions associated to the technical functions in order to be used during the design of traceability systems. In practice, the design process of a TS now amounts to a two-step process: a first composition of technical functions respecting the logic of the FAST (successive choices with inclusive disjunctions), and a second choice of technological solutions (physical or IT equipment, organizational principles or working principles, processes) for each of the existing technical functions. In our case, the first design process leads at best to the nine functions located at the right hand side of the FAST diagram. These functions are henceforth called the **technical functions** (TF) of the traceability system. They are listed in Table 1 in chronological order.

The intermediate functions presented in the FAST diagram (such as F6, F9 and F13) are considered as the goals to be achieved through the nine technical functions listed above. Therefore, they do not appear in Table 1.

Table 1. The Nine Technical Functions of a Traceability System

Carrying out order	Function code	Designation
1	TF1	To create product lots
1	TF2	To create lot identifiers
2	TF 3	To mark the identifier directly on the product
2	TF 4	To use identification carriers
3	TF 5	To collect product traceability data
3	TF 6	To generate product traceability data
4	TF 7	To record traceability data in an external support
5	TF 8	To restore product traceability data
6	TF 9	To communicate product traceability data

Note. If function TF4 is used exclusively to carry traceability data (F4), it is achieved in the forth position, between TF6 and TF8. In practice, this case is quite rare since an identification carrier serves mainly to physically associate an identifier with the corresponding product.

To summarize this section, we started by identifying the highest finality (series of service functions) expected from a traceability system which consists in providing the system's beneficiaries with different kinds of data. Using the FAST method, this finality is logically broken down into a series of nine technical functions that a traceability system must partly or totally comply with. Practically speaking, this model has been set up as a two-step design process of a TS and a library of TS technological solutions that a designer may use to automate and document the detailed design of a TS. The choice of a technological solution depends essentially on the expected performance level of a given function. In the next section, we propose a set of criteria that can be used to assess the (internal) performance of a traceability system.

Performance Assessment of Traceability Systems

In this section we propose a series of 20 performance criteria that can be used to characterize and assess the completion of the nine technical functions previously identified. We call them ***technical criteria*** (TC). In Bendaoud (2008) we have provided a detailed description of each criterion in describing its quantification procedure and measurement protocol. Some of the criteria presented in Table 2 (found in Appendix B) are illustrated in the next section through a case study.

As can be noticed, none of the criteria listed above refers to the cost of data storage. In fact, due to the continuous decrease in cost of storage materials (Morris and Truskowski 2003) this criterion seems less crucial. However, data acquisition cost is frequently mentioned in literature. Unfortunately, we did not find any reference explaining how to assess this criterion in a concrete way. In an attempt to fill in this gap, we propose (Bendaoud 2008) a calculation method to estimate unit cost of traceability data acquisition.

In this section we have briefly presented a set of 20 criteria to use for assessing the technical functions of a traceability system. Further details about their quantification procedure and measurement protocol are provided in Bendaoud (2008). These criteria can serve either to evaluate the performance of an existing system or to choose appropriate solutions for a future one. In the next section, we present a case study through which some of the performance criteria described above will be illustrated.

A Case Study from a Poultry Processing Company

This case study aims at illustrating some concepts and propositions presented in the previous sections. It is carried out within a poultry processing company equipped with a traceability system in order to comply both with regulations and its customers' demands. This company slaughter several tens of thousands head per day on more or less automated lines. Nevertheless, as mentioned in Section 5, our model is generic enough to be applied regardless of the size and equipments of the company. To describe its traceability system, we focus on a single product: Roasted Chicken Thighs. The process starts with marinating the thighs in a sauce prepared with water, salt, paprika and other ingredients. After this step, the marinated thighs are roasted using an oven. The output is a set of products that are prepared in the same conditions and share the same characteristics. In other words, they belong to the same lot. So a new lot of products is created (See function TF1). The amount of products belonging to the same lot represents the size of the given lot. In our case study, an average lot weighs about 256 Kg. Given that a single trade unit (i.e. a box) used by the company weighs about 4 Kg., we obtain a lot size ratio of 64 (See TC1). This means that in case of a non-conformity affecting the process described above, the company must recall 64 boxes even if the entire lot is not actually affected.

So as to identify the given lot uniquely (See TF2), the company traceability system automatically generates the lot number 904422048886 which comprises 12 characters (See TC4) and can be considered as a meaningful identifier (See TC2). In fact, its first character refers to the year of production (9: 2009) and the following four (0442) identify the workshop where the lot is produced. The rest is made up of a sequential number. Thanks to its length and its meaningfulness, this identifier is unique forever (See TC3).

In order to physically associate the lot number to the products, the company uses barcodes as identification carriers (See TF4). According to manufacturing managers, they are robust enough (See TC6) and the marking indelibleness (See TC5) is satisfactory. However, humidity, combined with ventilation of cold rooms can weaken the link between products and their identification carriers (See TC7). The capacity of these barcodes (See TC8) is sufficient to carry some other data, especially manufacturing date and manufacturer's identity. Regarding the benefits of these identification carriers, the company does not consider their cost (a few euro cents) to be a problem (See TC9).

In addition to using a unique identifier, the traceability of our lot is ensured thanks to the acquisition of various data during its lifecycle. For example, the identifiers of its ingredients are collected (See TF5) automatically by scanning the barcode of each component. Information about quantities and cooking temperature is generated (See TF6) using weights and thermometers. Data acquisition speed (See CT10) is estimated by comparing the average duration of the process to the average time spent in acquiring traceability data. In this case, we found that about 9% of the process time is dedicated to traceability data acquisition (scanning barcodes, entering the quantities handled, etc.). The intervention of users is limited since the majority of these data is automatically acquired (e.g. barcode scanning, date recording…). This way of operating improves data acquisition reliability (See TC11). According to regulation, standards and costumers demands, we have listed a set of traceability data that must be managed by the company. The comparison of this list to the list of data that are actually acquired reveals a good data acquisition completeness (See TC12). The total cost of acquiring each single piece of data is about 0.036 € (See TC 13).

Every night, the traceability data that are acquired in workshops are sent to an Oracle database where they are recorded (See TF7) for a period of five years, which is satisfactory according to regulations in force (See TC14). Thanks to daily backups and strict management of access rights, the security of traceability data is ensured (See TC15).

In order to restore traceability data (See TF8), the company uses a web-based software that allows users to question the database through various criteria (See Bendaoud 2008). In Bendaoud et al. 2007, we provide a detailed evaluation of the criteria associated to function TF8. In terms of exhaustiveness (See TC16), we explained that the amount of data provided is beyond what regulations demand. Between their acquisition (See TF5 and TF6) and their consultation by the user, traceability data are simply memorized in a database without any alteration so they remain authentic (See TC17). In general, a few seconds are enough to answer a given traceability request (See TC18). The precision of traceability data (See TC19) is satisfactory. For example, in case of a recall, the company is able to target the sole incriminated lot.

Traceability data are often used inside the company. However, in some cases, external actors (especially customers and Government Bodies) ask for certain information describing the origin and/or the characteristics of a given lot. The required data are generally sent (See TF9) by quality managers using email or fax so the transmission is fast enough (See TC20). In about 30% of cases, we observed that receivers are not satisfied with the content or the format of the data they receive (See TC19).

In the following table we present a summary describing the solutions adopted for each technical function in our case study.

Table 3. A Brief Summary of the Case Study

TS technical functions	The solutions adopted
TF1: To create product lots	A new lot is created after each activity resulting in a homogenous set of product (e.g. raw materials receipt, chicken roasting).
TF2: To create lot identifiers	Lots are identified with lot numbers that are automatically generated by the Computer-Aided Manufacturing System.
TF3: To mark the identifier directly on the product	Due to the nature of its products, the identifiers are not marked directly on them.
TF4: To use identification carriers	The main identification carriers used are barcodes.
TF5: To collect product traceability data	Some data are collected manually from different documents such as delivery slips. Some others are collected automatically using, for example, barcode readers.
TF6: To generate product traceability data	That concerns essentially the data describing product quantities that are generated with scales.
TF:7 To record traceability data in an external support	Traceability data are recoded inside an Oracle™ database.
TF:8 To restore product traceability data	A web-based software allows users to restore traceability data through multi-criteria requests.
TF:9 To communicate product traceability data	Traceability data are regularly communicated to third parties (customers, health authorities, etc.) using usual communication tools especially email and fax.

Today, the company is entirely satisfied with the capacity of its traceability system to fulfill regulations and customers demands. To ensure a consistent performance level, some of the criteria presented in this paper are used during traceability audits carried out internally.

Conclusion

In response to the food crisis of recent years, traceability has become an incontrovertible means of protecting consumers by locating harmful products and retrieving them from the market place. In this context, food operators have no choice but to comply with the various regulations and standards in force. In this paper, we present some findings of a broader research project in which we proposed methodological tools intended to design, assess and manage food traceability systems so as to fulfill these demands.

Using the FAST method, we have proposed a model describing the internal behavior of a traceability system. This behavior refers to the functions (or the processes) performed by the system in order to provide a good service to its beneficiaries. This model constitutes a framework for designing or setting up a food traceability system. In fact designing or setting up such systems consists of selecting appropriate solutions (i.e. tools and organizations) to perform each function. For example, to identify product lots many options are available such as using barcodes or RFID tags. The choice depends on the performance level expected for this function. We have defined a set of quantifiable criteria that can be used either to choose between possible solutions for a given function, or to assess the whole performance of the system. To illustrate our proposals, a case study is presented in the last section of the paper. It shows how the different functions are accomplished within a poultry processing company and gives an idea about the related performance criteria.

Presently, several commercial solutions propose traceability solutions (i.e. software, hardware, identification tools, etc.). However, for confidentiality reasons, it has not been possible to get the founding principles and data models used by these providers to build their traceability systems. However, no one proposes a modular functional approach like we do. In Section 2 we present four alternative approaches that are mentioned in literature Regattieri et al. 2007; Steele 1995; Verdenius 2006. In Bendaoud, (2008) we explain how existing proposals are unsatisfactory since they lack exhaustiveness and are not based on known systematic frameworks. For example, despite certain attempts to analyze and comprehend the performance of such systems, the criteria that have been previously proposed lack exhaustiveness and clear measurement protocols. In comparison with most existing approaches, our proposal aims to be more comprehensive, more rigorous and more practical. Thanks to FAST method (that is acknowledged by design communities), we progressively define technical functions of a TS and systematically link them to the ultimate finality of this system. Strictness and exhaustiveness are among FAST method strengths. As such, it allows to systematically establish all the causal connections between the service (finality) provided by the system and its components (technical functions). In terms of design, this approach guarantees a continuous causal flow between the ends and the means. It minimizes, accordingly, the risk of design errors (e.g. to forget an intermediate step in traceability process). Another practical aspect of our proposal mainly lies in providing concrete examples and in defining quantifiable assessment criteria. Furthermore, the originality of our work lies in applying a conventional method used in design to a specific food processing issue, and in particular to an immaterial system of "traceability" which is composed of procedures, computers, personnel and organizational components. The present TS model is also applicable to other contexts where traceability is crucial (e.g. pharmaceutical, aerospace, etc.) provided that the traced elements are identifiable. These elements can be either individual entities or groups (i.e. lots) of entities. Actually, we can consider an individual entity as a lot composed of one instance.

References

Aarnisalo K., S. Heiskanen, K. Jaakkola, E. Landor, and L. Raaska. 2007. Traceability of foods and foodborne hazards. Research Notes 2395, VTT Technical Research Centre of Finland.

Bendaoud, M., C. Lecomte and B.Yannou B. 2007. Traceability systems in the agri-food sector: A functional analysis. Paper presented at the 16th International Conference on Engineering Design, Paris, August.

Bendaoud M., 2008. Methodological and conceptual contributions to the design, management and improvement of food traceability systems : Application to poultry slaughtering and processing industry. Ph.D. diss., École Centrale Paris.

Bertolini, M., M. Bevilacqua, R. Massini. 2006. FMECA approach to product traceability in the food industry. *Food Control* 17(2):137-145.

Bytheway, C.W. 2005. Genesis of FAST. *VaLue W O R L D 2*8(2):1-7.

Chew E., M. Swanson, K. Stine, N. Bartol, A. Brown, and W. Robinson. 2008. Information Security - Performance Measurement Guide for Information Security. National Institute of Standards and Technology. US Department of Commerce.

Chitode, J.S. 2008. Communication Theory - Thired Revised Edition - Technical Publications Pune, India.

Dupuy C. 2004. Analysis and design of tools for food products traceability in order to optimize manufacturing lots dispersion (title translated from French). Ph.D. diss. Institut National des Sciences Appliquées de Lyon.

Garrido Campos J., and M. Hardwick. 2006. A traceability information model for CNC manufacturing. *Computer-Aided Design* 38(5):540-551.

Golan E., B. Krissoff, F. Kuchler, L. Calvin, K. Nelson, G. Price. 2004.Traceability in the U.S. Food Supply: Economic Theory and Industry Studies. United States Department of Agriculture, March.

Green B., and M. Bide. 1997. Unique Identifiers: A Brief Introduction. Book Industry Communication, London.

GS1. 2005. GS1 Traceability Standard - Business Process and System Requirements for Full Chain Traceability. Available online: http://www.gs1.org/docs/gsmp/traceability/GS1_Global_Traceability_Standard_i1.pdf - Accessed 13th February 2010.

Hoagland J.A., R. Pandey, K. N. Levitt. 1998. Security Policy Specification Using a Graphical Approach. Department of Computer Science - University of California, Davis, July.

Jansen-Vullers, M.H., C.A.van Dorp, A.J.M.Beulens. 2003. Managing traceability information in manufacture", *International Journal of Information Management* 23(5): 395-413.

Kaufman, J.J. 2003. Building FAST Models Based on Issues of Concern, SAVE International. Available online: http://www.value-eng.org/knowledge_bank/dbsearch.php?c=view&id=116 (accessed 13th February 2010).

Lecomte C., C.-D.Ta, and M. Vergote 2006.Analysis and improvement of traceability in agri-food industries (Translated from French). 214. AFNOR, Paris.

Moe T. 1998. Perspectives on traceability in food manufacture.*Trends in Food Science & Technology* 9(5):211-214.

Morris, R.J.T. and B. J. Truskowski. 2003. The evolution of storage systems. *IBM Systems Journal* 42(2):205 - 217.

Pahl G., and W. Beitz. 1996. Engineering Design - A Systematic Approach, Second Edition ed, Springer, London.

Pinto, D.B., I.Castro, and A.A.Vicente. 2006. The use of TIC's as a managing tool for traceability in the food industry.*Food Research International*. 39:772–781.

Pipino L.L., Y.W. Lee, and R.Y.Wang. 2002. Data Quality Assessment. Communications of the ACM. 45(4): 211-218.

Töyrylä, I. 1999.Realising the Potential of Traceability - A case study research on usage and impacts of product traceability. University of Technology (Espoo, Finland),

Viruega J.-L., 2005. Traceability: Tools, methods and practices (Translated from French), 237.Editions d'organisation, Paris.

Prudhomme, G., P. Zwolinski, D. Brissaud. 2003. Integrating into the design process the needs of those involved in the product life-cycle. *Journal of Engineering Design* 14(3): 333 - 353.

Regattieri, A., M. Gamberi, R. Manzini. 2007. Traceability of food products: General framework and experimental evidence. *Journal of Food Engineering* 81(2):347-356.

Resende-Filho M., and B. Buhr. 2007. Economics of traceability for mitigation of food recall costs. (Unpublished but available on) Munich Personal RePEc Archive, http://mpra.ub.uni-muenchen.de/27677/

Rönkkö M., M. Kärkkäinen, and J. Holmström. 2007. Benefits of an item-centric enterprise-data model in logistics services: A case study. *Computers in Industry* 58(8-9): 814-822.

Sharp, K.R. 1990. Automatic Identification: Making It Pay. 276. Van Nostrand Reinhold Computer, New York.

Steele D. 1995. Structure for lot-tracing design. *Production and Inventory Management Journal* 36(1):53.

Tellkamp C. 2006. The impact of Auto-ID technology on process performance – RFID in the FMCG supply chain.Ph.D. diss. University of St. Gallen.

Verdenius F. 2006. Using traceability systems to optimise business performance, in I*mproving traceability in food processing and distribution*, edited by Smith I. and A. Furness , 26-51. Cambridge, England. Woodhead Publishing Limited.

Wang R.Y. and D. Strong. 1996. Beyond Accuracy: What Data Quality Means to Data Consumers. *Journal of Management Information Systems* 12(4):5-34.

Wixon, J.R. 1999. Function Analysis and Decomposistion using Function Analysis Systems Technique. In *IX International Council on Systems Engineering (INCOSE 99)*, Brighton, England.

Wray B. 2007. ISBT 128 An Introduction to Bar Coding Version 2 0 1. Computype, Inc., St. Paul, MN, USA.

Yannou, B. 1998. Functional Analysis and value Analysis (Translated from French). In *Conception de produits mécaniques, Méthodes, Modèles, Outils*, Editor, Tollenaere M., 77-104. Hermes, Paris.

Yialelis N. 1996. Domain-Based Security for Distributed Object Systems, Imperial College London.

Appendix A.

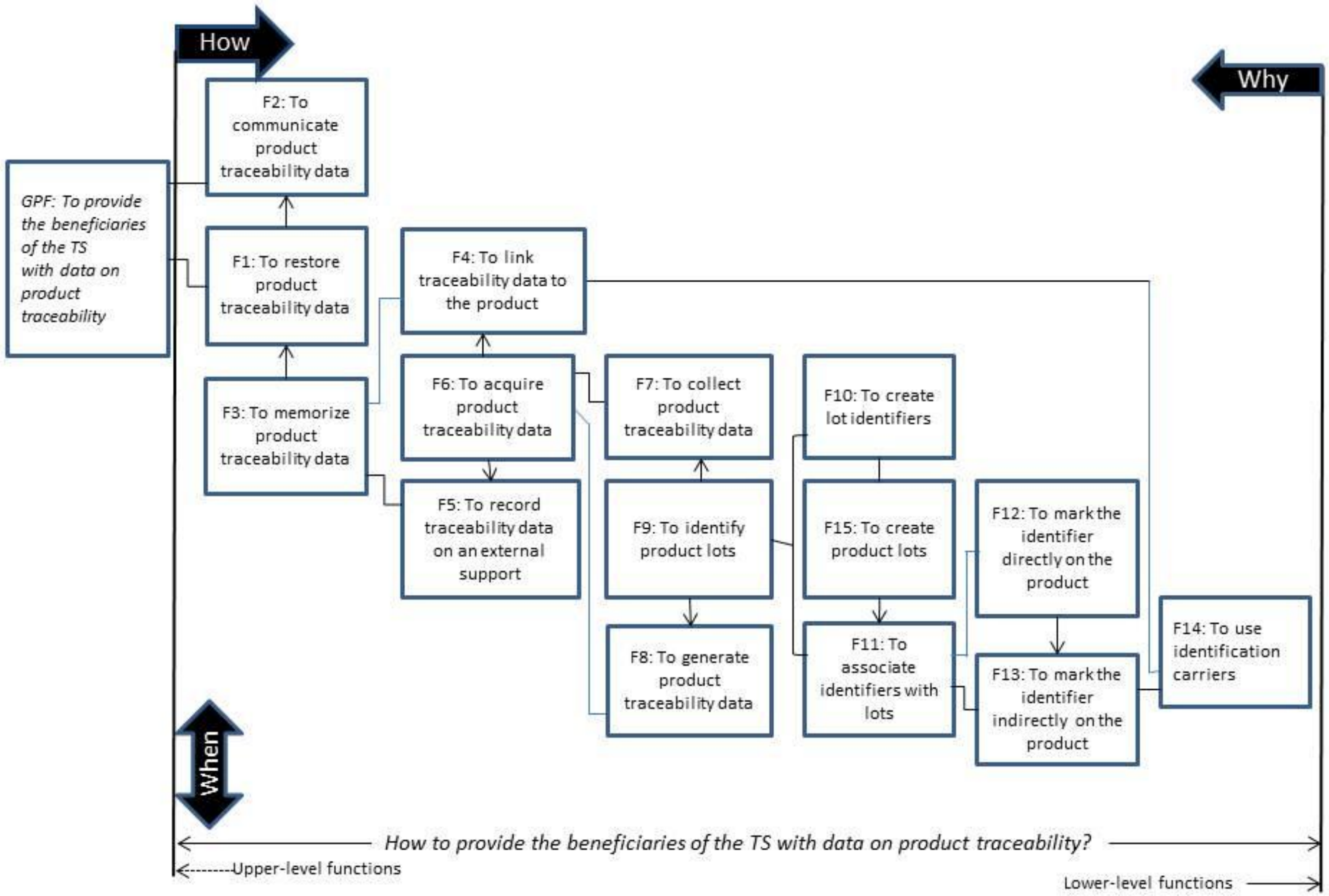

Figure 14. FAST Diagram of a Traceability System

Appendix B.

Table 2. Performance criteria of traceability systems

Technical Functions	Performance Criteria	Definitions / Comments
TF1 : To create product lots	TC1 : Lot size ratio	Many authors (Golan et al. 2004; Lecomte et al. 2006; Resende-Filho and Buhr 2007) state that traceability precision is inversely proportional to lot sizes. Our reference is trade items (bins, boxes, etc) which is a quantity of products “on which there is a need to retrieve predefined information and that may be priced or ordered or invoiced at any point in any supply chain” (after Aarnisalo et al. 2007; GS12005). Lot size ratio is obtained by dividing the average trade unit by the average lot size. The bigger this ratio, the better the traceability precision.
TF2 : To create lot identifiers	TC2 : Meaningfulness of lot identifiers	An identifier is meaningful or intelligent (according to Green 1997), if it carries a given meaning. With meaningful identifiers, some information can be obtained directly without asking the information system (e.g. a lot number made from a production date)
	TC3 : Uniqueness period of lot identifiers	The period during which a given identifier cannot be used to identify more than one lot (Dupuy 2004).
	TC4 : Lot identifiers length	The length of a lot identifier refers to the number of characters it is made up of. This criterion can have certain impacts, for example, on the size of identification carriers.
TF3: To mark the identifier directly on the product	TC5 : Marking indelibleness	The identifier marked on the product must be indelible enough to withstand its surrounding conditions (heat, dampness…). This ability depends mainly on the technology used (e.g. ink jet, laser …). To estimate this criterion, we suggest dividing marking length of life by the shelf-life of the product identified.
TF4: To use identification carriers	TC6 : Identification carrier robustness	The robustness of an identification carrier refers to its ability to withstand the surrounding conditions in which it is used. This criterion can be evaluated through the percentage of identification carriers presenting a sufficient resistance.
	TC7 : Reliability of the link between the product and its identification carrier	In addition to having robust identifications carriers, it is crucial that these remain linked to the products to ensure permanent identification. The criterion TC7 can be estimated by dividing the minimum time during which the carrier is linked to the product by product shelf-life.
	TC5 : Marking indelibleness	Criterion TC5, described above, also applies to the identifiers that are marked on the identification carriers. In the case of electronic carriers (e.g. RFID tags), marking indelibleness refers to the ability to read the content recorded inside them.
	TC8 : Identification carrier capacity	The amount of data that can that can be recorded on an identification carrier. For example, a linear barcode’s capacity varies from 1 to 40 characters. With a capacity of several Ko, RFID tags can be used not only for identification purposes, but also to carry other traceability data (Tellkamp 2006).
	TC9 : Identification carrier cost	The cost of identification carriers is an important parameter to be taken into account in a traceability project. For example, due to their cost (USD $0.3-0.5), RFID tags are more suitable for identifying high value-added products.

Table 2. Performance criteria of traceability systems-Continued

Technical Functions	Performance Criteria	Definitions / Comments
TF5 : To collect product traceability data & TF6 : To generate product traceability data	TC10 : Data acquisition speed	This performance criterion is inversely proportional to the time needed to acquire the required traceability data. In practice, data acquisition takes place each time the product undergoes a given operation (processing, packaging, etc.).
	TC11 : Data acquisition reliability	This performance criterion refers to the system's ability to collect data that are free-of-error in the sense of Pipino et al. (2002). In other words, they must be correct and reflect reality. According to Sharp (1990) and Wray (2007) , when data are recorded manually, one error is produced every 300 words. The value of TC11 can be obtained by estimating statistically the percentage of data that are considered as correct.
	TC12 : Data acquisition completeness	The completeness refers to the extent to which the amount of acquired data is sufficient. According to Wang and Strong (1196), data completeness is a contextual criterion since it is strictly related to the context where data is used. In mathematical terms, if the needed data are represented by set A and the data that are actually acquired are represented by set B, TC12 can be expressed as follows: $CT12 = \frac{card(A \cap B)}{card(A)}$ (%)
	TC13 : Data acquisition cost	According to the amount of data acquired, the frequency of their acquisition and the tools used, the cost generated can be high. This cost is related to the means used in the data acquisition process, especially workforce, equipment and consumables (e.g. paper, ink, energy…).
TF7 : To record traceability data in an external support	TC14 : Traceability data's sustainability	This performance criterion refers to the length of time during which traceability data remain accessible. This duration can be defined according to the shelf-life of the product under consideration.
	TC15 : Traceability data's security	In some cases, traceability data can be subjected to different threats. In the literature, information security is generally described in terms of confidentiality, integrity and availability (Chew et al. 2008; Hoagland et al. 1998; Yialelis 1996).
TF8 : To restore product traceability data (In Bendaoud, (2007), we have described in detail how to quantify the performance criteria related to this function in practice.)	TC16 : Traceability data's exhaustiveness	The ability of traceability system to provide its beneficiaries with all the data needed.
	TC17 : Traceability data's authenticity	The ability of traceability system to restore product traceability data faithfully (i.e. without error).
	TC18 : Traceability data's speed	This assessment criterion is in inverse proportion to the time spent in answering a given request about product traceability.
	TC19 : Traceability data's precision	Precision is a criterion that is frequently quoted in the literature (Golan et al. 2004; Lecomte et al. 2006; Resende-Filho and Buhr 2007). It can be defined as the ability of a traceability system to identify, among several possibilities, the exact answer to a given request.

Table 2. Performance criteria of traceability systems-Continued

Technical Functions	Performance Criteria	Definitions / Comments
TF9 : To communicate product traceability data	TC19 : Quality of transmitting traceability data	According to communication theory, the quality of the message exchanged between an information source and a recipient is conditioned by the noise that is prone to. In Chitode (2008), the noise is defined as any unwanted signal that tends to interfere with the required signal. TC19 can be calculated as the ratio of successful communications divided by the number of total communication made during the period under consideration
	TC20 : Speed of transmitting traceability data	This criterion is inversely proportional to the time needed to transmit the message from its sender to the recipient. It depends, mainly, on the communication channel that is used (fax, mail, phone…).

