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TRACEABILITY SYSTEMS IN THE AGRI-FOOD SECTOR: A FUNCTIONAL ANALYSIS

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ABSTRACT
Since January 1st 2005, traceability has become mandatory to food operators especially within the European Union. In this context, agrifood companies are obliged to be equipped with systems able to reconstruct the history of the products they handle. A large state-of-the-art has then been achieved on traceability systems which revealed that few attempts tried to characterize a complete set of functional expectations and quality indicators. Our present contribution consists in applying some principles of the functional analysis method in order to provide an evaluation framework under the form of functions and measurable indicators so as to assess, monitor and improve food traceability systems.

Keywords: Functional analysis, traceability, agrifood sector, service design, performance system design

1 INTRODUCTION AND CONTEXT
January 1st 2005 is a memorable date in the food sector history. Through the regulation (EC) 178/2002 [1], traceability has become mandatory to food companies within the European Union. This law aims at protecting public health by retrieving unsafe food on the market and defining accountability in such situations. In this context, food operators need necessarily to be provided with methodological approaches to design and deploy appropriate traceability systems (noted herein TS). However, after a deep state-of-the-art analysis on the design of a TS and its inherent performance system, it turns out that the few scientific works analysing deeply this issue still remain incomplete and unsatisfactory. As stated by Toyryla [2], much of the existing literature is anecdotal and written by practitioners. Some of the crucial issues to be worked out are the following: Who are the beneficiaries of a TS along a food chain, and what are their expectations in terms of traceability? Which functions a (good) TS must perform? How these functions can be assessed in a convenient and economical way?
Our contribution is an attempt to answer those questions by applying some functional analysis' principles to a food TS. As mentioned above, the number of references analysing deeply the issue of food traceability are scarce. According to Viruega [3], this statement can be explained by the fact that, unlike most disciplines, the traceability issue has been first carried by practitioners before scientists start to be interested in it. As a result, there are still many aspects that should be studied and analysed especially with regards to food traceability benefits and assessment. For example, the majority of references dealing with traceability's benefits mention the concerned company as the sole beneficiary. In this paper we stress that many other stakeholders may be interested by the impact and the quality of the TS of a given agrifood business. Another lack of the scientific literature is about evaluation of a TS. Despite, some performance criteria are often mentioned such as *breadth* [4], *effectiveness* [5] and *timeliness* [2], the authors do not explain in details the protocols for quantifying them. Scientifically and practically, these expected performance criteria remain to be refined so as to be able to speak about repeatable situations, measurement protocols and metrics. On this basis, the major result of the present work is a board of performance criteria for evaluating, in a practical way, the service functions supposed to be achieved by a TS.
In this paper we begin by defining the main concepts used in our approach (Section 2). Next, the system under study will be circumscribed and its surrounding environments identified (Section 3). Then, we define the expected service functions performed by the TS (Section 4). In section 5 we

describe and characterise each function by discussing its context and defining the corresponding assessment criteria. For each criterion, a quantification framework is proposed.

2 MAIN CONCEPTS DEFINITIONS

In order to provide a better understanding of our approach, the main concepts used in this paper are defined in Table 1. They relate to both functional analysis as well as food traceability.

Table 1. Some definitions of the main concepts

Concept	Definition
Function	Action of a product (here the TS), or one of its constituent parts, expressed only in terms of finality (NF X50–150)
Service function	An external function (i.e. expected action) of the product (here the TS) involving one or two (at most) surrounding environments
Surrounding environment	An external system the product (here the TS) is in relation with during a stage of its lifecycle.
Primary function	A service function aimed at satisfying the user's needs. By extension user must not be considered as the sole end-user but must be understood as any beneficiary during the product lifecycle.
Adaptation (or secondary) function	After Prudhomme et al [6]: "*A service function which reflects reactions, resistance or adaptations to elements found in the outside environment*"
Assessment criterion	A characteristic used to evaluate the way a function is fulfilled or a constraint is respected (NF X50–150)
Traceability	The "*ability to trace the history, application or location of that which is under consideration*" (ISO 9001:2000)
Upstream Traceability	According to a given entity (link) in a supply chain, upstream traceability consists in identifying the origin of input products
Internal Traceability	It consists in reconstructing the history of a given product within a company or location which is under consideration
Downstream Traceability	According to a given entity (link) in a supply chain, downstream traceability consists in identifying the destination(s) of output products

3 CIRCUMSCRIBING THE SYSTEM AND ITS ENVIRONMENTS

In food sector, all the definitions related to traceability systems present them as means that aim at finding a set of information which describe origin, location, destination, attributes or operations undergone by a given product (lot) during its lifecycle. In order to comply with functional analysis philosophy, we have made the choice not to adopt one of the definitions quoted in literature because most of them prefigure solutions. We have preferred to define a TS as *a system structured in such a way that it allows to reconstruct totally or partially the lifecycle of a given set of physical products*.

Trough the method of *surrounding environments* [7, 8] and taking the contexts of food companies (regulation, quality standards, customers' demands, etc) into account, we have identified eight **surrounding environments** that interact with the TS as shown in Figure 1. We have gathered them into 8 categories, namely: *Customers*, *Government Bodies*, *Internal beneficiaries*, *Suppliers*, *Final consumers*, *Regulations*, *Standards prescribers* and the *Products* themselves.

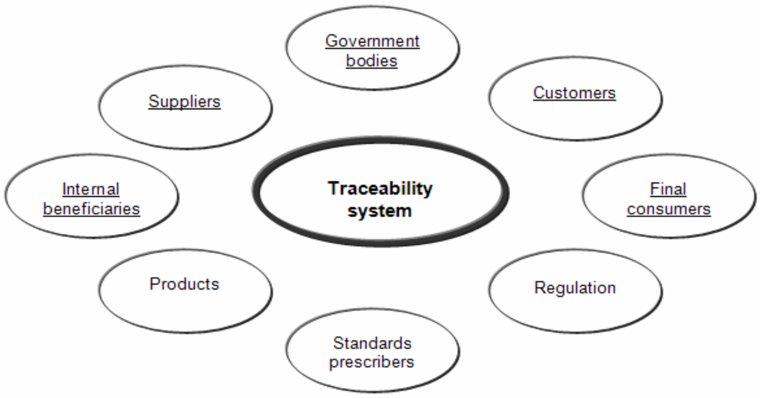

Figure 1.The TS and its 8 surrounding environments

The first 5 out of 8 may be considered as beneficiaries of the traceability system. In Table 2 we present the objectives that justify the needs of each beneficiary in terms of traceability.

Table 2. Expression of TS beneficiaries' needs

Beneficiaries	**Objectives justifying their needs in term of traceability**
Customers	To be able to identify non-conform products in order to stop their marketing or processing
Government Bodies	To protect public health by identifying and withdrawing harmful products from the market
Internal beneficiaries	• To comply with regulations and standards in terms of traceability, • To optimise recalls or withdrawals' costs by identifying and targeting the sole concerned products, • To have a better visibility on product flows.
Suppliers	To locate, within downstream steps of a chain, non-conform products which they marketed
Final consumers	To be informed on the origin, quality attributes, composition or processing steps of the products they buy

3 IDENTIFICATION OF THE FUNCTIONS PERFORMED BY TS

Based on the definitions presented above, a TS aims at providing three types of information (and then data) corresponding to the three dimensions of traceability presented in Figure 2 and suggested by EAN International[1] [9]: *upstream*, *internal* and *downstream*. These data can describe a part or the entire **lifecycle** of a given product batch (or lot). In the following, we implicitly consider that we deal with the batch-production which is very widespread within agrifood sector.

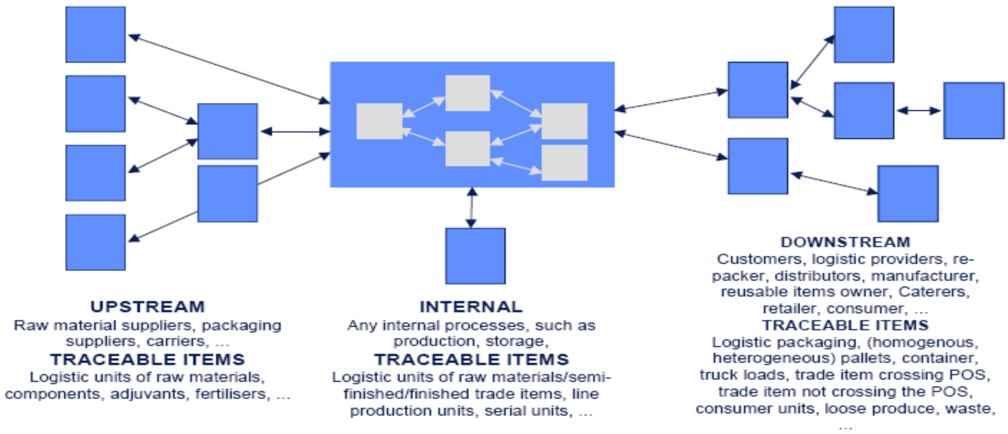

Figure 2. The three dimensions of traceability (excerpt of [9])

After analysing the interactions between TS and its environment, and taking the beneficiaries' needs into account, twelve **primary functions** (PF) were identified. They are structured according to the three dimensions of traceability:

- PF 1: To provide government bodies with data on upstream traceability of products,
- PF 2: To provide government bodies with data on internal traceability of products,
- PF 3: To provide government bodies with data on downstream traceability of products,
- PF 4: To provide customers with data on upstream traceability of products,
- PF 5: To provide customers with data on internal traceability of products,
- PF 6: To provide customers with data on downstream traceability of products,
- PF 7: To provide suppliers with data on downstream traceability of products,
- PF 8: To provide internal beneficiaries with data on upstream traceability of products,
- PF 9: To provide internal beneficiaries with data on internal traceability of products,
- PF 10: To provide internal beneficiaries with data on downstream traceability of products,
- PF 11: To provide final consumers with data on upstream traceability of products,

[1] EAN International association (becomes GS1 in 2005) is a global organisation dedicated to the design and implementation of standards and solutions to improve traceability and visibility within supply chains

- PF 12: To provide final consumers with data on internal traceability of products.

These primary functions can be presented trough a matrix form as shown in Table 3.

Table 3. The primary functions of TS

Dimensions / Beneficiaries	Upstream	Internal	Downstream
Government bodies	PF 1	PF 2	PF 3
Customers	PF 4	PF 5	PF 6
Suppliers			PF 7
Internal beneficiaries	PF 8	PF 9	PF 10
Final consumers	PF 11	PF 12	

In addition to fulfil its beneficiaries' needs, the TS must also comply with demands emanating from some elements of its environment; especially regulations and standard prescribers. This compliance is achieved thanks to the following **adaptation functions**: AF 1: *To comply with regulations' demands in terms of traceability*, and AF 2: *To comply with normative demands in terms of traceability*.
In the next section more details are given to explain more deeply each function before defining the *assessment criteria* used to characterise it.

4 CHARACTERISING TRACEABILITY SYSTEM'S FUNCTIONS

4.1 PF 1: To provide government bodies with data on upstream traceability of products

According to regulation (EC) 178 / 2002, food operators *"shall be able to identify any person from whom they have been supplied with a food* (…) and *shall have in place systems and procedures which allow for this information to be made available to the competent Authorities* (..)". The primary function PF1, which allows government bodies to be provided with data on food products' origin, can be carried out in three different contexts:

- Case of a food crisis where the company must inform competent Authorities of the supplier whose products are potentially harmful to consumer,
- Products' origin verification: in some situations, with the help of TS, a food company can prove to Authorities that a given product batch comes (or does not) from a specific origin. It is, for example, the case of COOL products (Country Of Origin Labelling) such as some wines,
- Traceability audits: in order to ensure the application of regulations in force, government bodies can undertake traceability audits within food companies.

To evaluate how well the function PF1 is performed, we use the four assessment criteria which are defined below.

4.1.1 C1: Upstream traceability exhaustiveness

This assessment criterion is defined as *the ability of TS to provide its beneficiaries with all the needed information in terms of upstream traceability of the products*. For a given product, Regulation (EC) No 178/2002 does not specify what type of information should be kept. But according to the *Traceability Guidance* (see [10]), these information can be divided in two groups: 1) the *first category* of information which shall be made available to the competent Authorities in all cases; and 2) the *second category* which includes additional information which is highly recommended to be kept. With regards to upstream traceability, the first category refers to name, address of supplier, nature of products which were supplied by it and date of transaction (receipt date). In the second category we find: volume or quantity, batch number (if any) and more detailed description of the product. According to the EC guidance on regulation No 178/2002 [10], the information to be registered has to be chosen in light of the food business activity and the characteristics of the traceability system. So, it is possible to distinguish different levels of the upstream traceability's exhaustiveness according to the number and types of the elements restored. As shown in Figure 3, the evaluation of criterion C1 can be done trough a multi-level scale: the level 1 is reached when all the information of the first category can be restored by the TS. And, if the TS can restore *n* additional elements of the second category, then the level of upstream traceability exhaustiveness is equal to "*n+1*".

The scale opposite highlights that the elements belonging to the first category is considered as an undividable minimum since they are mandatory by regulations. If one of them is absent, then the level of upstream traceability exhaustiveness is equal to zero. In order to be as generic as possible, we did not specify neither the nature nor the number of additional elements to be restored by the TS. So, each food business can adopt the scale to its own context.

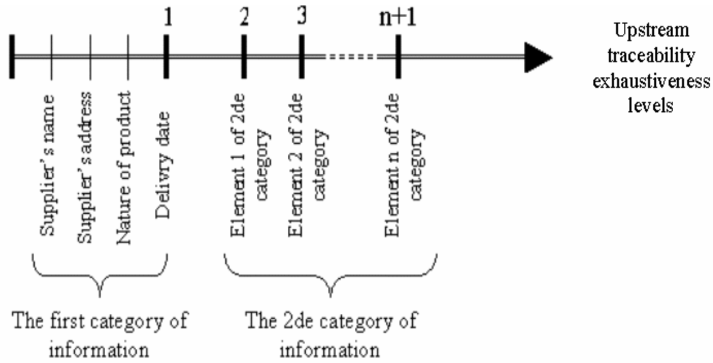

Figure 3. Upstream traceability exhaustiveness levels

For a given input product, it is very easy to estimate the corresponding *upstream traceability exhaustiveness* by simply identifying data restored on it by TS. Those data can be found easily by interviewing Quality managers or by directly consulting the TS. For example, if the TS can provide the four elements of the 1st category and two other data (e.g. lot number and quantity), the level of upstream traceability exhaustiveness for this product will have a value of 3.

The value of assessment criterion C1 is then obtained by calculating the average level of all the input products. In the case of a high number of input products, the estimation can be done on the basis of a representative sample. Of course the minimum level of upstream traceability exhaustiveness is 1 and the objective level can be determined according to the context of each company.

4.1.2 C2: Upstream traceability authenticity

This assessment criterion is defined as *the ability of TS to restore faithfully (i.e. without error) the data related to upstream traceability of the products.* To quantify C2, we propose the following approach:

- Compose a list of a representative sample of input products such as raw materials or ingredients,
- During receipt operations, choose a batch for each product of the sample and note down its real data related to upstream traceability (e.g. supplier's name, lot number, etc). As mentioned previously, the nature of data to be registered can vary from a food business to another. Persons conducting this exercise have to beware to influence the usual procedure of receipt operations because their presence may have an impact on traceability data recording strictness (Hawthorne effect); which can bias the evaluation results,
- For each element of the sample, query the TS and note down the data it restored,
- Compare the "real" values (noted during receipt operations) with the ones restored by the TS. Let X be the total number of data compared and Y the number of data for which both values are identical. A quantification of criterion C2 can be expressed as a percentage of Y/ X. In Table 4 we propose a model that can be used to quantify the upstream traceability authenticity.

Table 4. A model card for upstream traceability authenticity evaluation

Input products	Source / Data types	Values registered during the exercise	Values restored by TS	Comparison
Product 1	Supplier's name	*Company A*	*Company A*	*1*
	Lot number	*L25000*	*L26000*	*0*
	Quantity	*200 Kg*	*200 Kg*	*1*
	Temperature	*7°C*	*4°C*	*0*
Product 2	Supplier's name	*Company B*	*Company F*	*0*
	BBD (Best Before Date)	*21 July 2008*	*21 July 2008*	*1*
	Lot number	*L27500*	*L27500*	*1*
	Quantity	*1500 Kg*	*1500 Kg*	*1*

For pedagogical reasons, we have chosen a very simple example with only two products and five types of traceability data. We can easily use a tool like MS Excel to evaluate assessment criterion C2 by writing a "1" in *comparison* cells each time the values of the same row are equal. Then, with a simple formula we calculate the sum of these cells and divide it by the number of products. For the example above, the assessment criterion C2 has a value of 63% (i.e.5 divided by 8). Upstream traceability authenticity is a crucial criterion which should be at its maximum (i.e. 100%). A value under this target means that some of the data restored by the TS are incorrect; which can mislead decisions makers inside or outside the company. A lack of data is preferable to a wrong data.

4.1.3 C3: Upstream traceability speed
This assessment criterion is in inverse proportion to the time spent to answer a given request about upstream traceability. To evaluate it, we propose to adopt the following procedure:
- Compose a list of a representative sample of input products such as raw materials or ingredients,
- For each element of the sample, choose a lot number (or any other unique identifier) and consult TS in order to find the data related to its upstream traceability,
- Calculate, in minutes, the average time needed to restore upstream traceability data of a given lot. The shorter this value, the better the Upstream traceability speed of TS.

At the beginning of this section we mentioned that the primary function PF1 can be carried out in three different contexts. For each context, a target speed can be defined by the considered agrifood business.

4.1.4 C4: Upstream traceability precision
Precision is a criterion frequently quoted in traceability literature [4, 11, 12]. However the existing references do not provide a clear and structured approach to quantify it. In this paper we define upstream traceability precision as *the ability of a TS to identify, among several possibilities, the exact origin of a product batch*. In this context, the typical question to be answered is: *Where does the batch B of input product P stem from?* If the TS directly pinpoints a unique origin (supplier), we have a precise upstream traceability. In other cases, it can pinpoint several **potential** origins. We have then an *approximate* traceability which consists in finding approximately a batch's origin according to the receipt date and hour, or to the duration of a given operation [13]. In contrast with *approximate* traceability, we propose the concept of *strict traceability* to describe situations where TS provides direct and non-ambiguous answers to beneficiaries' requests. To distinguish these types of traceability, we use a parameter called *TS strictness* which is proportional to data recording frequency at different operations. Depending on the dimension of traceability under consideration, we use respectively upstream, internal, or downstream traceability strictness. In practice, a strict traceability depends on how systematic is data recording at different steps of the process. So, to evaluate the criterion C3, we simply propose to estimate the percentage of input products for which origin's data are **systematically** recorded. For example, if a company records systematically the origins of 20 out of 100 input products, the upstream traceability precision will be 20%.

4.2 PF 2: To provide government bodies with data on internal traceability of products
According to European Regulations, internal traceability is not mandatory, but it is strongly recommended (see [10]). However, one can find some situations in which a food company may be required to provide competent Authorities with internal traceability. For example TS can be used to prove that the company is in conformity with regulation's demands related to products processing. In practice, internal traceability data describe input lots and output lots of a given operation, products' quality attributes and process parameters such as cooking temperature. The assessment criteria characterising the primary function PF2, will be defined again through the concepts of exhaustiveness, authenticity, speed and precision.

4.2.1 C5: Internal traceability exhaustiveness
This assessment criterion is defined as *the ability of TS to provide its beneficiaries with all the needed information in terms of internal traceability of products.* Today there are no Regulations defining precisely the internal traceability data that should be accessible by government bodies. Hence, it is difficult to elaborate a generic framework that can be used to evaluate internal traceability exhaustiveness of a given TS. So, we recommend that each enterprise should consider the demands related to its own context so as to identify internal traceability data to be managed. For instance, in the case of a poultry processing company in which we conduct our action-research, there are generally 11 types of data related to internal traceability. Those data are structured around the notion of *manufacturing operation*; i.e. a given step of the process undergone by products. Those data are: manufacturing order (MO) number, date & hour of the MO, manufacturing workshop where the MO

occurred, manufacturing line, input[2] products' names, input products' lot numbers, input products' quantities, input products' BBD (best before date), output products' names, output products' lot numbers and output products' quantities. So, restoring internal traceability for a given batch consists in retrieving data cited above for each operation that it underwent. On this basis, an estimation of the internal traceability exhaustiveness can be obtained following this evaluation framework:

- Compose a list of a representative sample of **finished** products batches,
- With the help of TS, trace back each element of the sample to the beginning of its process inside the plant or the food business in question. During this tracing action, one or more manufacturing operations will be scanned,
- For each one of those operations, check whether the TS is able to restore all the required data of internal traceability. Let X be the total number of data to be restored. If, among those X data, Y is the number of data actually restored by TS. An estimation of C5 is obtained by dividing Y by X.

4.2.2 C6: Internal traceability authenticity

This assessment criterion is defined as *the ability of TS to restore faithfully (without error) data on internal traceability of products*. To quantify it, we propose to adopt the procedure summarised below:

- Compose a list of a representative sample of manufacturing operations made inside the plant or the business food under consideration,
- Attend each operation and note down the values of all data related to internal traceability (e.g. date, inputs' lot numbers, outputs' quantities, etc). As mentioned previously, this kind of procedure must be undertaken without influencing the usual functioning of data recording process. Otherwise, the evaluation would be biased,
- After this ground stage, query the TS and note down the values it restored about the same operations,
- Compare the "real" values (collected during the fieldwork) with the ones restored by the TS. Let X be the total number of data to be compared and Y the number of cases with identical values. A quantification of criterion C6 can be expressed as a percentage of Y/ X. In Table 6, we present an illustration with a case of a chicken thighs' traceability that we have evaluated.

Table 6 Example of internal traceability authenticity evaluation

Operations	Traceability data	Values collected	Values restored by TS	Comparison
Poultry Slaughtering	Manufacturing Order	61250524	61250524	1
	Date & hour	20/04/2006 10h	20/04/2006 10h	1
	Lot Number	017520	017520	1
	Quantity	2270	2270	1
Poultry Cut- up	Manufacturing Order	61350246	61350246	1
	Date & hour	21/04/2006 10h	21/04/2006 10h	1
	Input chickens lot numbers	017520 017522	017520	0
	Output thighs lot number	61350246	61350246	1
	Input chickens weight	1800	1800	1
	Output thighs weight	1520	1600	0
Thighs conditioning	Manufacturing Order	61557219	61557219	1
	Date & hour	21/04/2006 15h	21/04/2006 15h	1
	Input lot number	61350246	61350246 and 50247	0
	Output lot number	61557219	61557219	1
	Input weight	700	740	0
	Output weight	685	785	1

Table 6 shows that 12 out of 16 data provided by TS are correct. According to the framework explained above, we obtain an *internal traceability authenticity* of 75 % for chicken thighs. Of course

[2] In the context of internal traceability the terms *input* and *output* refer to a given operation; not to the entire company.

this table contains only a part of traced data so as to provide just a synthetic view of our evaluation approach.

4.2.3 C7: Internal traceability speed

This assessment criterion is in inverse proportion to the time spent to answer a given request about internal traceability. To evaluate it, we propose to adopt the following procedure:

- Compose a list of a representative sample of finished products handled by the company in question,
- For each element of the sample, choose a lot number (or any other unique identifier) and consult TS in order to restore its data related to its internal traceability,
- Calculate, in minutes, the average time needed to restore all the internal traceability data of a given lot. The shorter this value, the better the internal traceability speed of TS.

As mentioned before, a target speed can be defined according to the characteristics of the TS under consideration and to the context that prevails (food crisis, audit, etc).

In our case study of poultry processing, the time needed to restore the main element related to internal traceability of a given lot depends on its size. The average time is about 25 minutes.

4.3.4 C8: Internal traceability precision

Internal traceability precision of TS refers to its *ability to identify, without shortage or excess, the products that share one or more given characteristics*. For example, if we were alerted by a supplier that a raw materials' lot is non-conform and that we would like to destroy all finished products integrating it, a precise TS must pinpoint <u>exactly</u> the items that are <u>actually</u> concerned. In addition to ***internal traceability strictness*** mentioned previously (§4.1.4) and that can be estimated by the percentage of process' steps in which internal traceability data are systematically recorded, there are two other parameters to be considered while evaluating the internal traceability precision. The first one is the ***lot size*** which refers to the "*amount of products that is identified under the same identifier"*(see [14]). The other is ***batch*** (or lot) ***dispersion*** proposed by Dupuy *et al* [15] to assess the mixing of production batches.

Many authors [4, 11, 12] state that traceability precision is inversely proportional to lot sizes. As a reference we choose *trade units* (bins, boxes, etc) which is a quantity of products "*upon 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 [9]). So, to give an idea about the contribution of lot sizes to internal traceability precision, we propose to divide the average trade unit by the average lot size. The result is called ***lot size ratio***. The bigger this ratio, the better the traceability precision. However, adopting small lot sizes is not enough if products' lots are frequently mixed. According to Dupuy *et al* [15, 16], there are two dimensions of lot dispersion: 1) *downward dispersion* of a raw material batch which is the number of finished product batches which contain parts of this raw material batch; and 2) *upward dispersion* of a finished product batch which refers to the number of different raw material batches used to produce this batch. By summing all raw material downward dispersion and all finished products upward dispersion we obtain the *batch dispersion* of the TS under study. However, instead of raw materials and finished products we generalise those concepts to the entire products handled within a process. Thus, for a given operation, we speak about downward dispersion of an input lot and upward dispersion of an output lot. On this basis, we propose to estimate the ***global lot dispersion*** of a process as the following:

For each operation, for each input product and for each output product,

- Calculate the average downward dispersion for input lots. That is, the average number of input lots used to produce one lot of output products (1),
- Calculate the average upward dispersion for output lots. That is, the average number of output lots produced from one lot of input products (2),
- The average of (1) and (2) corresponds to global dispersion of the process in question.

Those estimations are done through a set of data that can be obtained in different ways: from possible rules established by Quality Department, from consulting and analysing products' traceability over a significant period or by following directly the process steps of a significant sample of products. The ideal value of global dispersion is "1" which means that there is not any mixing of different lots of a same product. If we divide this "ideal" value by the real one, we obtain an interesting ratio. For example, a value of 25 % refers to a global dispersion of 4. Table 7 summarises the three contributing parameters relatively to the internal traceability precision of a ST. Taking the contribution of each parameter to internal traceability precision into account, we made a pairwise comparison [17, 18] that allows to associate the following estimations of relative weight for each one: internal traceability strictness: 27 %, lot size ratio: 9 % and global lot dispersion: 64 %. Finally, an estimation of criterion C8 is obtained by calculating the weighted arithmetic mean of the three parameters:

$$\text{Internal Traceability Precision} = \frac{(\text{Internal traceability strictness} \times 27) + (\text{Lot size ratio} \times 9) + (\frac{1}{\text{Global lot dispersion}} \times 64)}{100}$$

Table 7. Internal traceability precision parameters

	Internal traceability precision of a TS depends on		
	Internal traceability strictness	Lot size ratio	Global lot dispersion
Quantification	Percentage of process' steps in which internal traceability data are systematically recorded (in %)	Dividing the average trade unit by the average lot size (in %)	On the basis of downward and upward dispersions explained above (in %)

By applying the approach explained above to our case study, we have found the values showed in Table 8.

Table 8. Examples of Internal traceability precision quantification

Internal traceability strictness	**Lot size ratio**	**Global lot dispersion**	**Internal traceability precision**
100 %	1, 51 %	12,34	**32 %**

4.3 PF 3: To provide government bodies with data on downstream traceability of products

According to regulation (EC) 178 / 2002, food operators must have systems to identify the other businesses to which their products have been supplied. This information must be made available to the competent authorities. The primary function PF3, which allows government bodies to be provided with data on food products' destinations, can generally be carried out in two different contexts: 1) Case of food crisis where the enterprise must inform competent Authorities of the customers it provided with products that are potentially harmful to consumer. 2) Traceability audits undertaken by government bodies in order to ensure the application of regulations in force. To evaluate how well function PF3 is performed, we use four assessment criteria which will be defined below.

4.3.1 C9: Downstream traceability exhaustiveness

This assessment criterion is defined as *the ability of TS to provide its beneficiaries with all the needed information in terms of downstream traceability of the products*. By analogy with upstream traceability exhaustiveness (§ 4.1.1), we use the two categories of information defined by European regulations [10]. With regard to downstream traceability, the 1^{st} category refers to name, address of customer, nature of products that were delivered to that customer and delivery date. The 2^{de} category contains volume or quantity, batch number (if any) and more detailed description of the product. So, it is possible to distinguish different levels of downstream traceability's exhaustiveness according to the number and types of the elements restored. As shown in Figure 4, the evaluation of criterion C9 can be done through a multi-level scale: the level 1 is reached when all the information of the 1^{st} category can be restored by the TS. And, if the TS can restore n additional elements of the 2^{de} category, then the level of upstream traceability exhaustiveness is equal to "n+1". Following an approach similar to the one explained in § 4.1.1, we can

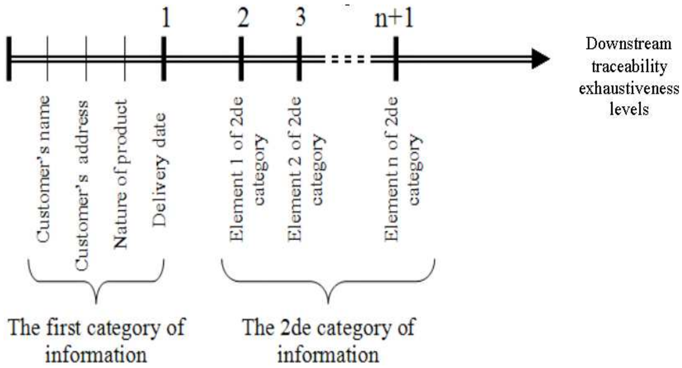

Figure 4. The downstream traceability exhaustiveness levels

evaluate C9 by calculating the average level of all the output products dispatched by the company.

4.3.2 C10: Downstream traceability authenticity

This assessment criterion is defined as *the ability of TS to restore faithfully (i.e. without error) the data related to downstream traceability of the products.* To quantify it, we adopt the procedure below:

- Compose a list of a representative sample of output products such as finished or by-products,
- During dispatching operations, choose a batch for each product of the sample and note down its real data related to downstream traceability (e.g. customer's name, date, etc). Persons conducting this exercise have to beware to influence the usual procedure of dispatching operations because their presence may have an impact on the strictness of traceability data recording (Hawthorne effect),
- For each element of the sample, query the TS and note down the data it restored,
- Compare the "real" values (noted during dispatching operations) with the ones restored by the TS. Let X be the total number of data compared and Y the number of data for which both values are identical. A quantification of the criterion C10 can be expressed as a percentage of Y/ X. A model like the one presented in Table 4 can be adapted to conduct this evaluation process.

4.3.3 C11: Downstream traceability speed

This assessment criterion is in inverse proportion to the time required to answer a given request about downstream traceability. To evaluate it, we propose to adopt the following procedure:

- Compose a list of a representative sample of output products such as finished or by- products,
- For each element of the sample, choose a lot number (or any other unique identifier) and request TS about data related to its downstream traceability (e.g. customer name, date, quantity, etc),
- Calculate, in minutes, the average time needed to restore downstream traceability data of a given lot.

In order, to be reactive, this time must be as short as possible. So, food operators can define different speed targets depending on the context (food crisis, traceability auditing, etc).

4.3.4 C12: Downstream traceability precision

Downstream traceability precision can be defined as *the ability of TS to identify, among several possibilities, the exact destination(s) of a product lot.* In this context, the typical question to be answered is: *By which customer(s) the lot L of the output product P has been received?* In order to evaluate C12, we propose to adopt an approach similar to the one used to evaluate the internal traceability precision (§ 4.3.4). But instead of considering the entire process, we will be limited to dispatching operations. As a result, we obtain the following formula:

$$\text{Downstream traceability precision} = \frac{(\text{Downstream traceability strictness} \times 27) + (\text{Lot size ratio} \times 9) + (\frac{1}{\text{Global lot dispersion}} \times 64)}{100}$$

4.4 PF 4: To provide customers with data on upstream traceability of products

Through the primary function PF4, customers of a given enterprise are provided with a set of data describing products' origin. We distinguish two contexts in which this function can be carried out: 1) in case of COOL products, the company can be requested to prove the origin of its products; and 2) in case of traceability audits regularly performed by some customers in order to assess their suppliers' ability to trace their products. To evaluate this function we propose the same criteria defined for PF1. Namely, upstream traceability authenticity, upstream traceability exhaustiveness, upstream traceability speed and upstream traceability precision. Even if we assign the same assessment criteria to many functions, the objective levels of each of them may differ according to the context in which these functions are performed.

4.5 PF 5: To provide customers with data on internal traceability of products

In addition to products' origin, customers can also be interested in information about internal traceability. This can happen in three contexts: 1) to check that a given product is processed in specific conditions (e.g. Halal or Casher products) or fulfils particular standards (e.g. Bio, Label Rouge or Max Havelaar.), 2) in case of COOL products, and 3) in case of traceability audits as explained before. The primary function PF5 is assessed through the four criteria defined previously for internal traceability: internal traceability authenticity, internal traceability exhaustiveness, internal traceability speed and internal traceability precision. For each one a target level can be identified by the company.

4.6 PF 6: To provide customers with data on downstream traceability of products

Every food business can be obliged to inform its customers of the destinations to which a given product's lot is dispatched. The typical situation is a food crisis where the customers provided by a harmful product have to be informed as soon as possible so that they stop marketing it. Another case consists in traceability audits regularly carried out by some customers in order to check the efficiency of their suppliers' TS. The evaluation of the function PF6 can be done through the four criteria related to downstream traceability: downstream traceability authenticity, downstream traceability exhaustiveness, downstream traceability speed and downstream traceability precision. Traceability managers can assign a target level to each of them according to the concerned situation.

4.7 PF 7: To provide suppliers with data on downstream traceability of products

This function is activated less frequently than the others. In fact, there are few situations where a supplier makes use of its customer' ST to find downstream traceability of its own products. However, one can find cases in which the customer' ST can be for a great help to suppliers. For example, when a company is liable for marketing a harmful product's lot, it is in its best interest that TS of downstream partners be efficient. Once more, the evaluation of this function can be done through the four criteria related to downstream traceability: downstream traceability authenticity, downstream traceability exhaustiveness, downstream traceability speed and downstream traceability precision. For each of them a target level can be defined.

4.8 PF 8: To provide internal beneficiaries with data on upstream traceability of products

Beyond meeting regulations, customers and standards demands in term of traceability, a TS constitutes also an interesting tool to be used for production and quality management purposes. As shown in Table 9, its main internal beneficiaries belong to Quality, Production and Supply chain departments within a given company.

Table 9.The main internal beneficiaries of the TS

Internal beneficiaries	**Examples of services provided by TS**
Quality managers	Reconstructing the products' history to check that they fulfil the quality specifications
Production managers	Given the variability of raw materials, food processors constantly need information on origin and characteristics of their products. Also, in same processes, one needs an *active traceability* in order that some steps be validated before starting others (see [3])
Supply chain managers	Thanks to accurate data provided by TS, it is possible de track and check products flows through the chain [19]

To evaluate this function we use the same criteria defined for PF1: upstream traceability authenticity, upstream traceability exhaustiveness, upstream traceability speed and upstream traceability precision. For each one a target level can be defined.

4.9 PF 9: To provide internal beneficiaries with data on internal traceability of products

For the same reasons mentioned in Table 9, data related to internal traceability are also very useful for internal beneficiaries. The primary function PF9 can be characterised through the four criteria that we have defined previously for internal traceability: internal traceability authenticity, internal traceability exhaustiveness, internal traceability speed and internal traceability precision. A target can be defined for each of them according to the context.

4.10 PF 10: To provide internal beneficiaries with data on downstream traceability of products

General Food Law [1] establishes the liability principle which stipulates that food operators are responsible for the quality of foodstuffs they put in the market. Hence, they must be able to identify the destinations of their products so as to recall or withdraw them in case of food safety problems. A good TS allows the company to be reactive and efficient in such situations. The evaluation of the function PF10 is done through the four criteria related to downstream traceability: downstream traceability authenticity, downstream traceability exhaustiveness, downstream traceability speed and downstream traceability precision. For each one a target level can be defined.

4.11 PF 11: To provide final consumers with data on upstream traceability of products

Final consumers are among the beneficiaries of TS since it is a mean that can be used to inform and ensure them on quality, composition, origin or processing conditions of the products they buy. According to [20], this is especially important in cases where the consumer is willing to pay a higher price for products that are produced under certain guaranteed circumstances such as organically produced food or that coming from a desired origin. The primary function PF11 can be archived in two contexts: 1) traceability data are directly associated to the product or to its packaging; or 2) when the consumer takes contact with the company to have additional information about the product he/she bought. Like the other functions in relation with upstream traceability, PF 11 can be characterised using the following criteria: upstream traceability authenticity, upstream traceability exhaustiveness, upstream traceability speed and upstream traceability precision.

4.12 PF 12: To provide final consumers with data on internal traceability of products

As stated above, in some cases the final consumer needs to be provided with data describing the operations undergone by a given product. A survey published in June 15th 2006 by IPSOS institute shows that 54% of French consumers think that there is a lack of information about cultivation, animals farming and processing methods of food products (Source : www.tracenews.info). The primary function PF12 is assessed through the four criteria that we defined previously for internal traceability: internal traceability authenticity, internal traceability exhaustiveness, internal traceability speed and internal traceability precision.

4.13 AF 1: To comply with regulations' demands in terms of traceability

In European Union, the General Food Law [1] provides the mandatory elements in terms of traceability. According to Article 17, member States "*shall maintain a system of official controls and other activities as appropriate to the circumstances*". In France for example, this mission is conducted by organisations linked to the DGAL[3] and the DGRCCRF[4] and consists in: 1) Verifying the existence of procedures and means to manage traceability, products' recall / withdrawal and to inform competent Authorities. 2) Carrying out traceability tests to check the ability of TS to restore required information. Thus, through the adaptation function AF1, the TS must be able to demonstrate that it fulfils regulations demands. The characterisation of this function can be done through an assessment criterion (C 13) called ***regulations compliance level***. To evaluate it, we propose to simulate official controls according to the context of the enterprise and to express the results as a percentage of conformity to regulations demands. Of course, this evaluation is very approximate since official controls are still not formalised enough in view of recent coming into force of General Food law.

4.14 AF 2: To comply with normative demands in terms of traceability

In addition to official controls, food operators are also submitted to traceability audits carried out by the prescribers of standards related to quality and food safety. Among the widespread ones we cite ISO 9001, IFS, BRC, GS1 and SQF. During these audits, TS must be able to prove its compliance to standards under consideration. Given the number of existing standards and the diversity of their demands, it is difficult to elaborate a generic framework for characterising AF2. So, we propose to use an "adjustable" assessment criterion (C14) called the ***level of compliance to X standards*.** X refers to the standards in question (e.g. the level of compliance to IFS standards). Its evaluation can be achieved as follows: 1) on the basis of the referential in force, draw up a list of the demands to be satisfied, 2) check whether the TS fulfils them, 3) express the results as a percentage of compliance to this referential. The value obtained represents assessment criterion C14.

5 CONCLUSION

Through this paper we tried to provide a methodological framework to be used by food operators to design and assess their traceability systems so as to comply with the stakeholders' needs and the

[3] Direction Générale de l'Alimentation
[4] Direction Générale de la Concurrence, de la Consommation et de la Répression des Fraudes

demands imposed by their environment. In this purpose, we applied some functional analysis principles which allow us to: 1) circumscribe the system and identify its surrounding environments, 2) identify the primary functions and adaptation functions that it performs in order to satisfy its beneficiaries' needs and to fulfil regulations and standards' demands, 3) each function has been characterised through a set of assessment criteria for which we have presented an evaluation framework. Due to diversity of the contexts where TS can be implemented and the nature of related needs, the main limitation of our approach lies in the difficulty to provide detailed and generic methods to quantify the criteria defined. Another remark concerns the necessity to validate the criteria related to precision (C4, C8 and C12) through more than one case-study. The originality of our proposal consists in applying a conventional method used in design activity to a specific food processing issue, and in particular to an aquite immaterial system of "traceability" composed of procedures, computers, personnel, organisation, etc. In comparison with the existing works in this field, it has notably allowed to define a set of quantifiable criteria that are more precise and more formalised than those proposed in literature. The results can be adapted and applicable to other areas where traceability is crucial such as pharmaceutical or aerospace industry. As a logical continuation of the present work, we are currently defining and characterising a set of technical functions to be performed by TS in order to acquire, store and manage data needed the five beneficiaries (see Table 2). Through our action-research within a poultry processing company, we are also developing a reference data model describing the attributes and relationships between the informational objects handled by the TS.

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