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Towards a Traceability Solution on the Food Supply Chain

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Abstract ***– In accordance with European and national regulations all the actors involved in the food industry must implement information systems that prove the quality of their food products and offer the means to trace products along the whole production chain, from the primary producer until the final consumer. This paper presents the results of a national research project (FoodTrace) that set as its goal development and implementation of a food quality assurance and traceability framework. The proposed multi-layered system model combines data acquisition and monitoring at production floor level with business-to-business data exchange functionalities.***

Keywords: ***traceability, food safety, food supply chain, HACCP, web services, service-oriented architecture.***

I. INTRODUCTION

Nowadays when food production, trade and consumption are following the general trend towards globalization, people are more and more concerned about the risks involved in food consumption. During recent years a number of events (e.g. avian flu, mad cow disease, genetically modified vegetables) increased public concerns about the potential human infections with animal-borne pathogens or the effect of genetically modified products on human health. The need for food traceability and quality assurance has arisen from consumers as well as government concerns over food authenticity, hygiene and safety.

The European Union lately addressed these concerns by issuing a set of documents, recommendations, guidelines, and directives. Mainly the EU Council Directive no. 178/2002 ("General Food Law") establishes definitions and guiding principles in order to provide a framework for the development of food laws in EU countries. Among the key definitions is the concept of traceability, seen as the "ability to trace and follow a food, feed, food-producing animal or substance intended to be, or expected to be incorporated into a food or feed, through all stages of production, processing and distribution". A previous, more general definition was provided by International Standards Organization (ISO) 8402-1994 that saw traceability as the "ability to trace the history, application or location of an entity by means of *recorded* information" and emphasized a key requirement for any traceability system.

International regulations concerning traceability were enforced at national level through the adoption of food quality, safety and traceability laws. Romania as member of the EU must comply with the Directive no.178/2002 which stipulates that starting with the 1st of January 2005 all food operators in EU must implement food quality control and traceability systems.

The guidelines for traceability systems were established through a number of research projects. For instance the TRACE project in which more than 50 European institutions and organizations are involved [9], defined best practices toward food safety and traceability assurance. But still, more efforts are needed in order to establish a common framework for traceability information exchange between actors of food chains: primary producers, food manufacturers, distributors, retailers and end-consumers. The challenge is to use the latest information and communication technologies (e.g. SOA, XML, SOAP) for a flexible and interoperable traceability solution.

FoodTrace is an interdisciplinary applicative project funded by Romanian National Research Authority whose main goal is the design of an integrated quality control and traceability framework for a generic production unit, component of a food supply chain [8].

This paper presents the FoodTrace project's main achievements, current status and future development goals. The next section is a short review of the requirements for a quality control and traceability system. Section 3 presents the proposed multi-layered traceability solution for a food processing unit. Implementation details are discussed in the 4-th section. Section 5 gives an overview of the designing principles and implementation scenarios for a global food chain traceability system. The last section summarize the conclusions and the lessons learned through the present project.

II. FOOD TRACEABILITY SYSTEM REQUIREMENTS

For companies, compliance to legislation is recognized as the major driving force towards introducing a quality supervision and traceability system. Value added to products through increased consumer confidence may be another important reason.

A food supply chain can be seen as a network of autonomous, inter-related and cooperating nodes [1]. A node in the supply chain is a distinguished unit where an item is produced, processed or handled in some way several actors are involved in this chain. Raw material producers, ingredients/packaging suppliers, distributors, storage operators, retailers, points of sale, shops, and transporters are all business partners on the food supply chain. Then there are regulatory authorities monitoring activities in veterinary safety, healthcare and consumer protection domains. The consumers are at the end of the supply chain.

The benefits of introducing a food quality control and traceability system are:

- Improvement of hygiene in food processing, handling and distribution processes through continuous sampling, testing and monitoring of food quality along the whole supply chain
- Prevention of food wastage
- Access provision to information concerning food and ingredients
- Enforcement of labeling and product identification (food authenticity)
- Identification and quick response to food safety incidents

The major three functional requirements for a traceability system are:

- Entity identification - unique, unambiguous identification of all food components and products, along the whole supply chain.
- Data capture and recording – processing parameters monitoring and their association with products' identity; records should be kept according to legislation and good business practice requirements.
- Data retrieval services – for rapid product tracking and recall/withdrawal operations (in case of risk events)

III. FOOD TRACEABILITY SOLUTION DESIGN

A. Project Design Goals

In order to assure interoperability with other applications the FoodTrace project proposes a specialized framework for food traceability solutions, in compliance with the Service Oriented Architecture (SOA) design concepts [10].

The configurable components of the proposed framework must allow simple implementation and deployment of traceability solutions, adapted to the specific needs of different kind of food production units. The framework will facilitate compliance with international standards and regulations concerning food safety and traceability.

Main design goals and important issues that must be taken into consideration are:

- Automated real-time monitoring – for improvement of hygiene in food processing, handling and distribution processes and prevention of food wastage
- Compliancy with international food processing and handling standards and regulations: ISO, HACCP and TQM
- un-ambiguous and unique identification of products during their lifetime – with the use of GS1 bar coding and business entity identification, RFID, EPC, UPC, etc.
- Interoperability – using new ITC standards and technologies (XML, Web Services, WSDL, SOAP, UDDI, BPEL, WSRP)
- Availability and reliability – providing necessary data redundancy at all application layers
- Security – applying the latest security patterns to protect data and applications from attacks and intruders.

B. Implementation issues

When analyzing the food supply chain two distinct information streams are obvious and have to be taken into account. First is the intra-business stream, also called the internal or horizontal stream, which provides internal food traceability for the product, items and lots. The second is the inter-business partners’ stream also called the vertical stream, which supports food supply chain traceability for product items, lots and other logistic units.

To achieve the project goals a schedule with two stages was proposed for the implementation. The first stage provides components of a flexible, configurable framework for the internal traceability solutions in production units. Then the framework's functionality is extended in order to allow information exchange and retrieval between business and non-business partners on the supply chain, leading to a global supply chain traceability solution.

C. Architectural Solutions

Two possible architectures are emerging from the food supply chain analysis [11]. The first is a distributed architecture where traceability information is stored at each business partner site, and the interested parties have to query the business partner site in order to retrieve it (internal traceability) or to repeat the query process up-/down-stream on the food supply chain to obtain full traceability.

A second architecture is a mixed one, with traceability information collected and stored at each trade partner’s site and published with various levels of granularity in traceability information repositories (local, regional or national). The interested parties have to subscribe and then query the corresponding repository(ies) in order to access and retrieve necessary information.

IV. FOOD INTERNAL TRACEABILITY IMPLEMENTATION DETAILS

The proposed internal traceability infrastructure for a node of the supply chain (Fig.1) was structured as a multi-layered architecture, with three main layers (Fig.2), each with a number of sub-layers:

1. Data Acquisition and Storage Layer
2. Quality Control and Internal Traceability Layer
3. Access, Communication and Presentation Layer

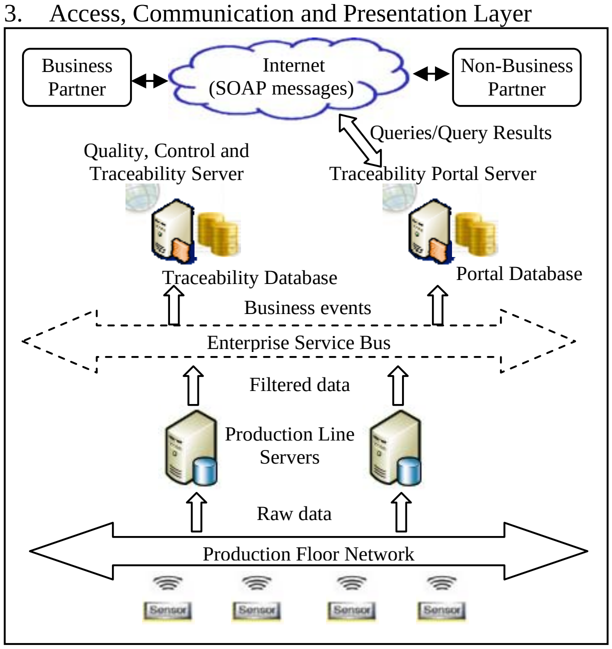

Fig. 1. Logical Infrastructure of a Food-chain Node

A. *Data Acquisition and Storage Layer*

The data acquisition and storage layer (Fig.2) is responsible for production line monitoring and supervision. Production processes are continuously monitored with sensors and transducers (temperature, humidity, pH...), bar-code and RFID readers, LCD displays, and alarm units [3]. Hand-held I/O devices (e.g. PDAs) are used by process-operators in order to visualize data and dynamically configure the system. These devices are linked through industrial networks (e.g. ModeBus), serial channels (RS485) and wireless connections. Data carriers (RFID tags and bare-code labels) are used to associate identification information of raw materials, ingredients, product items and logistic units with production parameter values, as they advance through production line. Wireless and Ethernet networks are used to channel this information from data capture devices to the production line servers where raw data is logged.

B. *Quality Control and Internal Traceability Layer*

The quality control and internal traceability layer (Fig.2) is responsible for managing all the business entities involved in the production process: organization, subsidiaries, production lines, equipment, recipes, product items, product batches/lots, logistical units, Hazard Analysis and Critical Control Point (HACCP) plan [5], critical control points (CCP), hazards, actions, documents, and operators. It provides interfaces for various categories of users and for different operations:

- Configuration and deployment of various business objects and database tables.
- Assignment of unique identification codes for entities, using GS1 coding standards as follows:
  - Global Location Number (GLN) - identification of physical, functional and legal entities.
  - Global Trade Item Number (GTIN) – identification of products, ingredients and services.
  - Serial Shipping Container Code (SSCC) - identification of logistic units.
- Documents' generation and association with products in accordance with HACCP plan.
- Print-out and attachment of appropriate identification tags and labels to different traceability units.
- Storage of all correlated business information in an internal database.
- Triggering corrective actions when hazards were detected.
- Notification of upper layer when a business event occurred (for example start/end of a product batch/lot, hazard detected at a certain CCP, shipping of a logistic unit).

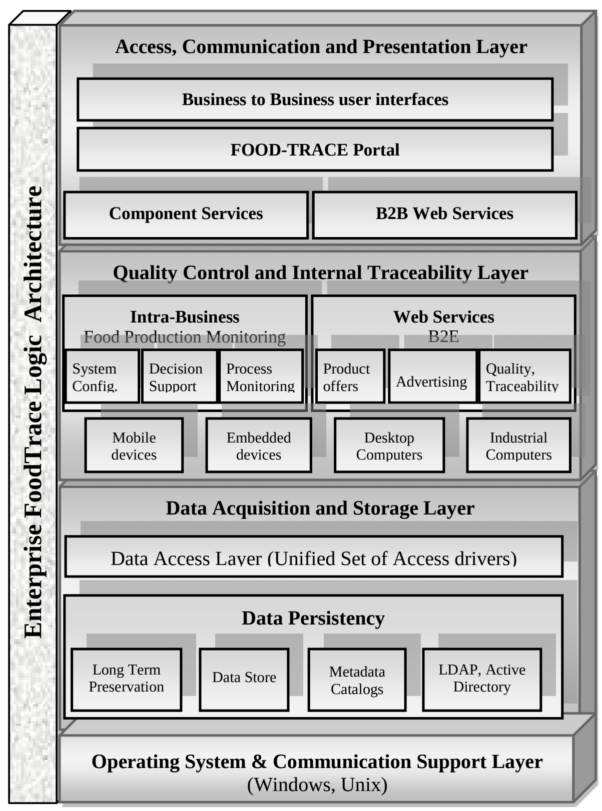

Figure 2. The FoodTrace Quality and Traceability System

This layer is implemented as a set of cooperating business objects, web services, business processes and an internal traceability database and it is located in the processing lines server.

C. Access, Communication and Presentation Layer

The access, communication and presentation layer (Fig.2) is responsible for all interactions with the end-users: registration, authentication, information access authorization, query and query results handling. It was implemented as a portal application designed to allow user access to internal traceability information and also to provide other features and interesting food protection and safety information. Its main functions are:

- Information publishing capabilities
- Traceability queries and result reports
- Administration tool
- Security management
- On-line help and detailed documentation

Access to the internal traceability information is done through a set of specific, predefined, immediate query operations applied to the internal traceability database. These queries allow tracing reports on items, batch/lots, logistic unit codes, and associated documents. Queries were implemented as web services and they include the following reports: business partner details, available products and stock lists, business events history (for example shipping of products), history of batch/lot production.

Figure 3 presents the query section of the traceability portal. The query results are displayed with ASP.NET 2.0 DataGrid, GridView and/or DetailView controls combinations, which allow master/detail relationships representation. It is also possible to save the results in an XML file (including the generated corresponding XML schema).

The traceability portal application provides an administration tool, which allows the portal administrator to establish the layout and content of the portal and to manage portal security. User authentication (form- or Windows/NTLM-based) validates user credentials. The former is the most appropriate for Internet based applications and is enabled by default. Access to resources (sections, modules, queries and data) is controlled through the role-based authorization process.

The traceability portal application was implemented in C# language using Microsoft Visual Studio .NET 2005 and ASP.NET 2.0 [6][7]. It is hosted under Internet Information Services v5.1, and it uses SQL SERVER 2005 as database management system. During application tests, traceability data was accessed using the following Internet browsers: Microsoft Internet Explorer, Mozilla Firefox, Opera and Netscape Navigator.

V. FOOD SUPPLY CHAIN TRACEABILITY

Two groups of activities can be identified with regard to food supply chain traceability:

- Activities carried out between business partners (inter-business)
- Activities carried out between business partners and non-business partners (non-inter-business)

In order to apply traceability to the food supply chain it will be necessary to have a set of interoperable, cooperating traceability applications at business and non-business partner sites. This can be achieved by encouraging and promoting an open, cooperating approach between

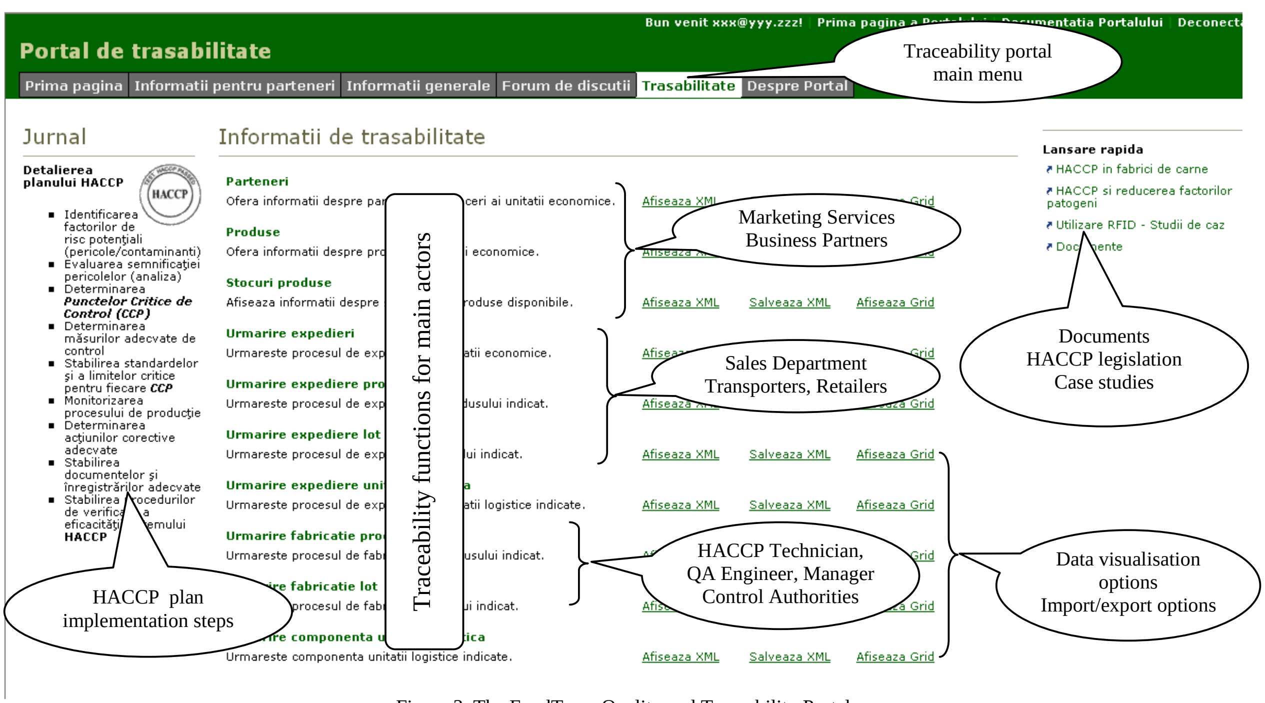

Figure 3. The FoodTrace Quality and Traceability Portal

different business and non-business organizations and by developing and using traceability applications in compliance to internationally accepted business communication standards.

The food supply chain traceability infrastructure will result in building up a network of traceability nodes running cooperating traceability services and traceability clients. The first group of nodes is conceived and appropriate for business partners (food operators of different kinds), whereas the second group is targeted for non-business partners. A food supply chain traceability solution can be implemented using the FoodTrace framework with minimal customization for each business/non-business partner member of the food chain.

A. *Components and Functional Requirements*

In order to provide food supply chain traceability at business level, the system must solve the following functional requirements:

- to provide a reliable and secure inter-partner business message exchange
- to define and correlate inter-business master data
- to exchange necessary business data in order to support traceability on the supply chain
- to accept user subscription requests, provide subscription information and cancel user subscription.
- to receive, schedule and answer to query messages
- to notify subscribed users, about the occurrence of business events
- to monitor and log network traceability traffic and provide statistics and reports
- to handle exception conditions and recover from error situations

The FoodTrace Portal allows tracing both the production processes and the transportation/delivery processes:

- *Tracing item production* - get a collection of all information regarding production of the specified item or batch/lot.
- *Tracking item, batch/lot or logistic unit movement* - get a collection of all information regarding shipment, transportation and delivery of the required item, batch/lot or logistic unit.

The FoodTrace Client framework component assures data access for non-business partner nodes. The functional requirements for this component include the following operations:

- Communicate with the FoodTrace Services through reliable and secure message exchanges
- Implement track unit (downstream) and trace unit (upstream) operations
- Download traceability documents from food operator sites
- Format, report and archive retrieved traceability information

The retrieved information is displayed with TreeView controls in an ASP.NET 2.0 environment.

B. *Inter-Partner Messaging*

Business and non-business partners have to communicate in order to allow data flow on the supply chain. This communication will be done through business messages exchanged over a network transport protocol [2]. Due to its simplicity, and its wide-acceptance the Simple Object Access Protocol (SOAP) has been chosen to implement the inter-partner messaging subsystem. SOAP with attachments (SwA) makes possible to transfer business and traceability documents (text and/or binary) over Hypertext Transfer Protocol (HTTP).

The XML structure for a traceability document as proposed in the Trace project [9] is presented below:

```
<TraceDocument>
  +<UBLExtensions>
  <TraceDocumentID>unique_document_ID</TraceDocumentID>
  +<DespatchParty>
  +<DeliveryParty>
  +<TraceUnit>
  +<TraceabiltyRelations>
  +<Aggregation Relations>
</TraceDocument>
```

It allows identification of the main entities involved (sending and receiving partners, traceability units), and their relationships in terms of production, packaging and delivery. The following example takes a simple business transaction case, where a supplier identified as SUP0001 sends a container BOX0001 with two packs (PAC001 and PAC002) and two tub containers (TUB001 and TUB002) to a customer identified as CUS0001. It shows how this can be encoded using the previous XML traceability document structure. The example only emphasizes the main structure of the XML traceability document, using fictive identifiers, different from the unique global identifiers used in real world cases.

```
<FoodTraceDocument>
  <FoodTraceIDDocument>DOC0001</IDDocumentFoodTrace>
  <SendingParty>
    <ID>SUP0001</ID>
  </SendingParty>
  <ReceivingParty>
    <ID>CUS0001</ID>
  </ReceivingParty>
  <TraceabilityUnit>
    <TraceabilityUnitID>BOX0001</TraceabilityUnitID>
  </TraceabilityUnit>
  <TraceabilityUnit>
    <TraceabilityUnitID>TUB0001</TraceabilityUnitID>
  </TraceabilityUnit>
  <TraceabilityUnit>
    <TraceabilityUnitID>TUB0002</TraceabilityUnitID>
  </TraceabilityUnit>
  <TraceabilityUnit>
    <TraceabilityUnitID>PAC001</TraceabilityUnitID>
  </TraceabilityUnit>
  <TraceabilityUnit>
    <TraceabilityUnitID>PAC002</TraceabilityUnitID>
  </TraceabilityUnit>
  <AggregationRelationship>
    <OuputUnitID>BOX0001</OutputUnitID>
    <InputUnitID>TUB0001</InputUnitID>
  </AggregationRelationship>
  <AggregationRelationship>
    <OuputUnitID>BOX0001</OuputUnitID>
    <InputUnitID>TUB0002</InputUnitID>
  </AggregationRelationship>
  <AggregationRelationship>
```

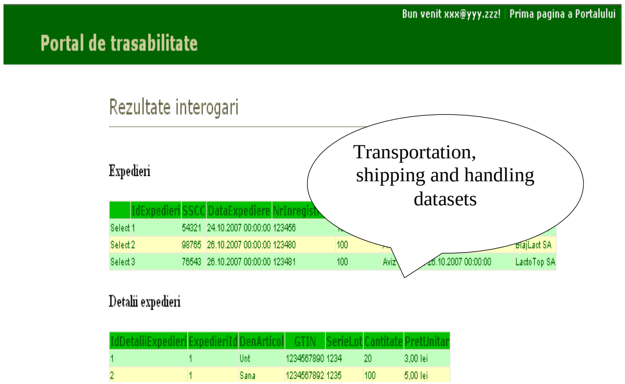

Figure 4. FoodTrace Portal Query Results Page

```
    <MasterUnitID>BOX0001</MasterUnitID>
    <SubUnitID>PAC001</SubUnitID>
  </AggregationRelationship>
  <AggregationRelationship>
    <MasterUnitID>BOX0001</MasterUnitID>
    <SubUnitID>PAC002</SubUnitID>
  </AggregationRelationship>
</FoodTraceDocument>
```

An example of the way the query results for shipping information are presented to the end user is shown in Fig.4.

C. Web Service, Messaging Service and Document Security

In order to provide the necessary level of security for the Web Services, messages and documents exchanged between the business partners the proposed solution properly addressed the three main security requirements for partner authentication, data integrity and data confidentiality at all levels of the inter-partner communications layer.

Web Services security requirements are mutual authentication (form-based authentication with user credentials and/or user/server X509 certificates), access control (role-based authorization), and secured interaction with other components during request processing (Kerberos protocol).

The messaging service use either secure communication channel established with Secure Socket Layer (SSL) or message level security based on X509 certificates. It also provides reliable message exchanges (detecting duplicate messages, implementing retry logic, handling message loss, preventing message replay attacks) and error report and recovery.

At the document level digital signature and total/partial content encryption technologies offer solutions for non-repudiation and data confidentiality.

Microsoft Web Service Extensions version 3.0 [12] was used to implement the messaging service and the security aspects related to Web Service operations and message and document exchange, because it provides for the necessary reliability, interoperability and flexibility.

VI. CONCLUSIONS

Designing and implementing a food supply chain traceability solution is a complex, interdisciplinary project of real interest and applicability for the entities involved in food production, processing and distribution. In order to assure upstream and downstream information exchange concerning food quality and traceability inter-operable, cooperating applications must be implemented in every node of a food chain. The paper presents modeling and implementation aspects of such an application for a food processing unit. The solution can be adapted also to other unit types.

The proposed traceability model is structured on 3 main layers: a data persistency layer, a quality and internal traceability layer and a communication and presentation layer. The first layer solves data acquisition and products' monitoring, the second layer is responsible for internal traceability aspects and the third one solves the data access and inter-business data exchange functionalities.

The adopted solution is based on the latest ITC technologies (SOA, SOAP, XML, web services) and offers flexibility, scalability and inter-operability with similar applications.

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