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ScienceDirect

Information and Software Technology 50 (2008) 342–359

INFORMATION AND SOFTWARE TECHNOLOGY

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Patterns and technologies for enabling supply chain traceability through collaborative e-business

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Received 1 August 2006; received in revised form 8 February 2007; accepted 18 February 2007

Abstract

Industrial traceability systems are designed to operate over complex supply chains, with a large and dynamic group of participants. These systems need to agree on processing and marketing of goods, information management, responsibility, and identification. In addition, they should guarantee context independence, scalability, and interoperability. In this paper, we first discuss the main issues emerging at different abstraction levels in developing traceability systems. Second, we introduce a data model for traceability and a set of suitable patterns to encode generic traceability semantics. Then, we discuss suitable technological standards to define, register, and enable business collaborations. Finally, we show a practical implementation of a traceability system through a real world experience on food supply chains.

Keywords: Traceability; Inter-organizational systems; e-business; Information systems; Service oriented architecture; ebXML; Web Services

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1. Introduction

According to the ISO 9001:2000 standard, *chain traceability* is the ability to trace the history, application or location of an entity by means of recorded identifications throughout the entire supply chain. In practice, chain traceability is achieved if businesses keep records of suppliers and customers and exchange this information along the entire supply chain. In particular, each unit/batch (called *lot* in the following) of a component or a product must be both *traceable* and *trackable*. To trace an entity means to identify its origin by tracing back in the supply chain, whereas to track an entity means to follow the path of the entity through the supply chain from supplier(s) to consumers [1]. Traceability is a needed strategic service in any production context. It can be used to improve security, control quality, combat fraud or manage complex chains [2]. In particular, traceability in food supply chain has attracted considerable attention in the last few years for a variety of reasons [3]. First of all, it has become a legal obligation within the EU since 1st January 2005 [4]; similar requirements for traceability systems are present in the United States [5] and Japan too [6]. Then, food companies tend to consider the significant expenditure required to build a traceability system as a long-term strategic investment to create consumer confidence both in the company image and in the specific product. Consequently, other requirements for traceability exist besides the legal ones. In fact, in addition to systematically storing information that must be made available to inspection authorities on demand, a traceability system should also take food safety and quality improvement into account [7]. This means, for example, enabling the system to trace back so as to discover the cause of a problem and to prevent it from happening again, or to trigger a proper recall of potentially unsafe products, thus protecting public health. Of course, the implementation of a complete and efficient traceability system has to cope with several problems, such as the lack of alignment of the possibly different systems adopted in

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doi:10.1016/j.infsof.2007.02.017

the various segments of the supply chain, or the non-homogeneous information kept at the various supply chain units [8,9].

Building a traceability system is therefore a complex task that involves all stages of production, processing, and distribution: traceability records should be kept for both products and processes (such as movement, transformation or combination) that operate on products. To this aim, traceability needs to be supported by appropriate architectural and technical implementation solutions, as well as suitable operational services, in order to provide its expected value for business partners. These solutions have been studied in the framework of virtual organization (VO) models [10,11], where independent organizations share resources and skills to achieve a specific goal. In this context, Choudhury [12] has analyzed problems from the standpoint of a firm making strategic decisions about inter-organizational systems (IOSs), addressing the questions of what types of IOSs might be useful, and how these IOSs might be developed. By extending the typology based on the transaction cost economics proposed by Malone et al. [13], Choudhury describes three types of IOSs architectures: electronic monopolies, multilateral IOSs, and electronic dyads. The increasing feasibility of adopting a peer-to-peer (P2P) approach for business-to-business (B2B) collaborations decreases the need for centralized exchanges, making electronic dyads more and more attractive. B2B based on P2P allows implementing dynamic electronic dyads from the IOS perspective [12]. Indeed, Silva et al. [14] pinpoint that, in any implementation of a VO model, dynamic reconfigurability, and business alignment with the market requirements can be considered as the most important interrelated aspects. After a broad review of the offerings of key e-marketplace makers, they observe that the compliance towards Electronic Data Interchange (EDI) [15] is often guaranteed; despite of this, they also recognize Web Services (WS) [16] and electronic business using eXtensible Markup Language (ebXML) [17] as the most promising technologies for the creation of dynamic collaborative environments and business process integration. In Gunasekaran et al. [18], VO models are based on the outsourcing concept to take advantage of the core competencies with the objective of being flexible and responsive to changing market requirements. Thus, companies integrate various links of the supply chain and their supporting information systems: such integration is driven by the need to streamline operations. Types of architectures, dynamic reconfigurability, business alignment, dynamic collaboration, business process integration, flexibility, and responsiveness are therefore some of the main aspects that have to be considered when developing IOSs.

This paper proposes an organic approach to manage the aforementioned aspects inherent in inter-organizational information systems and relevant technical aspects specific to traceability (such as traceability semantics, scalability, information management, and lot identification) in the development of a traceability system. These aspects have been widely discussed in the literature, but often they have been tackled separately, proposing generic patterns independent of the specific application domain. In this context, our approach aims to enable existing models and technologies, and to create new domain-specific patterns in order to develop an effective traceability system. The paper is structured as follows. In Section 2, we introduce a data model for describing assets and actors. Then, in Section 3, we show a formal description of the lot behavior throughout the supply chain. In data exchange, a crucial role is played by lot identification. Section 4 introduces some of the most important techniques, such as barcodes and Radio Frequency Identification (RFID), and standards, such as GS1 and Electronic Product Code (EPC), for automatic lot identification, focusing on their potential contributions in reducing the cost of procedures for tracking goods. The structure of a traceability system depends on how data are managed by the involved actors: the possible choices are described in Section 5. Independently of the type of structure, traceability relies on an integrated environment. Section 6 discusses how this integration can be achieved by exploiting recently proposed middleware solutions, like Enterprise Service Bus (ESB). Furthermore, as the system reliability heavily depends on agreed business interfaces among the supply chain partners, Section 7 is devoted to the discussion of business process interoperability, through enabling technologies, like WS, and standards for inter-enterprise business collaboration, like ebXML. In this context, the Service Oriented Architecture (SOA) model is presented as a key paradigm. Finally, we describe a real world experience with food and beverage companies in Section 8, where the most important XML artifacts and the system architecture are presented.

2. Static structure of a traceability system

As previously stated, a traceability system must be able to trace both lots and activities [19]. This means that each data model related to traceability must include lot and activity as key entities, and allow lot tracking and tracing [1]. *Tracking* refers to the ability to follow the downstream path of a product along the supply chain, possibly according to some specific criteria. This is a crucial factor, e.g., for an efficient recall of faulty products. *Tracing*, on the other hand, refers to the ability to determine the origin and characteristics of a particular product. This is obtained by referencing to records held upstream in the supply chain. Tracing can help detect the cause of quality problems. Fig. 1 shows a typical scenario of a product recall due, e.g., to a contamination event in a simplified supply chain consisting of only four segments. In the figure, a box denotes a *traceability lot* (*lot*, for short), that is a product unit processed or packaged under the same conditions, or a batch of products that share such characteristics as type, category, size, package and place of origin. A gear represents an *activity*, such as production, packaging, distribution, and sale, which may receive *N* lots as input and