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Supply chain product visibility: Methods, systems and impacts

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ABSTRACT

Supply chain product visibility may be defined to mean the capacity of the supply chain to have a view of a product's lifecycle, from its conception, manufacturing, distribution, delivery to the end customer, customer's experience of the product, and the product's end-of-life activities and processes. This implies developing and keeping a record of the product's materials and components, its physical state throughout the supply chain, the product's forward movement to the user-customer, customer's experience of the product, and the reverse logistics and reuse or termination of the product. The aim of visibility is to foster planning, control and agility of operations associated with the product and to improve customer experience of the product. "Tracking" is the term often used to describe the determination of the identity and state of a product in the forward direction (from manufacturing to the end user), while "tracing" is used to infer the product's path and history from downstream to upstream of the supply chain. In recent times there has been an upsurge of academic and commercial interest in product visibility. This interest has translated into numerous architectures, technologies and software for product visibility, both at the atomic (item) and composite (or aggregate) levels. Based on an extensive content analysis of academic and trade literature, including websites and documents of vendors and users of the technologies, this paper captures, analyses, compares and contrasts the design choices, essence, results and current and potential future impacts of some of the recent developments. The study also used survey by questionnaire across industries to assess user requirements of tracking and tracing systems and structures. The paper also charts future research directions for end-to-end visibility of product classes and their instances in supply chains.

1. Introduction

End-to-end supply chain product visibility by product tracking and tracing has been exploited as a means of product security and process control and optimization in many industrial sectors, ranging from manufacturing, transportation and distribution, retailing, aviation, healthcare (including management of pharmaceuticals and patients), agriculture to food safety (Bottani & Rizzi, 2008; Hsu, Levermore, Carothers, & Babin, 2007; Hsu & Liao, 2011; Hsu & Wallace, 2007; Lee & Lee, 2010, 2012; Lee & Özer, 2007; MAFF Japan, 2003). Ongoing rapid developments in RFID, the evolution of communication and localization technologies (such as XML, ebXML, EDI, Bluetooth, WiFi, WiMax, WiBro, Zigbee, Ultra-Wide Band, RuBee, IEEE 802 family of standards, infrared, indoor messaging), MEMS-based small sensors and actuators, web services, multi-agents, together with the digitization of public infrastructures in the era of "internet of things" (IoT) have ushered in several methods, systems and architectures for achieving visibility of products classes and instances across supply chains. Product visibility is achieved by tracking and tracing the product, possibly throughout its lifecycle, using a variety of methods and technologies, like barcode, RFID, communication channels and sensor networks. Supply chain tracking is the ability to follow the design, composition, processing, application, location and forward path of a product or batch/lot downstream of the supply chain to the end customer. Tracing, on the other hand, is the ability to ascertain the origin, path, history, design, composition, etc., of the product upstream the supply chain. Tracking and tracing are complementary activities and their aims are to increase the security of the product, streamline and optimize production planning and distribution systems and processes, locate sources of quality issues (faults or contamination), manage recalls efficiently, etc.

In the food industry, visibility has witnessed considerable interest and attention in recent years (Amador & Emond, 2010; Bechini, Cimino, Marcelloni, & Tomasi, 2008; Bechini, Cimino, & Tomasi, 2005; Trienekens, Wognum, van der Beulens, & Vorst, 2012). The reasons for the interest in RFID by the food industry include the fact that food visibility has become a legal obligation in many jurisdictions and companies in the food supply chain now consider investment in visibility as a strategic move to promote public

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confidence in their products. The need for and benefits of visibility have also been suggested in the context of the virtual enterprise, supply chain risk management, agent-based control of industrial systems, and strategic and dynamic business reconfiguration and alignment. Visibility also plays an important role in closed-loop product lifecycle information management (PLIM) (Kiritsis, 2011; Ranasinghe, Harrison, Främling, & McFarlane, 2011). The airline industry is making a faster progress in the adoption of PLIM (Airlines of America, 2009, chap. 9) but there are pending challenges.

To date, there exist many RFID and sensor network-based architectures and hardware for supply chain product visibility. Some have been simply proposed and possibly prototyped in the literature while a few others have actually been deployed by the industry. They do not always satisfy the same set of requirements and their applicability is domain-specific. Therefore, it is relevant to seek to determine and characterize the application domains as well as the similarities, differences, advantages and disadvantages between the different network, hardware and middleware configurations and designs. To the knowledge of the authors, there is no up-to-date literature that comprehensively classifies and differentiates between the currently available visibility configurations and systems. This paper fills this gap. The classification and comparisons by Främling, Ala-Risku, Karkkainen, and Holstrom (2007) and Främling, Harrison, Brusey, and Petrow (2007) appears incomplete, being limited to three systems and to object identifier formats; see also Holmström, Kajosaari, Främling, and Langius (2009). Främling et al. (2007) and Främling and Harrison et al. (2007) compares only EPC network, DIALOG (ID@URI) and World-wide Article Information (WWAI) systems. The work by Ranasinghe et al. (2011) compare the same systems as in Främling et al. (2007) and Främling and Harrison et al. (2007) and examined their suitability to the specific needs of product lifecycle information management (PLIM) of three case study companies (Fiat, Caterpillar, and Indesit). The criteria used by this paper to classify and distinguish between systems for supply chain product visibility were derived from actual user requirements. The user needs were determined by conducting a survey by questionnaire.

The paper is organized as follows. Sections 2 and 3, respectively, present the background to the study and the research methodology. Section 4 discusses the methods for supply chain product visibility, and Section 5 presents hardware and software configurations for product visibility, the properties of visibility systems, as well as how the properties vary amongst the various systems. Section 6 presents the results of a survey by questionnaire on user requirements of visibility systems. The requirements emerged from extensive literature review and consultations with practitioners via questionnaire survey and interviews. Section 7 discusses the existing architectures and structures for supply chain visibility, and Section 8 compares four of the frameworks for visibility on the basis of a sub-list of user requirements of Section 6. Because it is not possible to describe and discuss all the structures to great length in this paper, only four of them are described in detail. Those four were selected because they are currently in deployment in the industry and are not simply proposals. Section 9 concludes the paper.

2. Background to the study

Some analytical, simulation and empirical studies have shown that racking can reduce retailer inventory costs by up to 30% (Hong, Kim, & Kim, 2010; Hong, Yoo, Ko, & Kim, 2008; Lee & Özer, 2007), while others have estimated savings of at most only 2% (Ferrer, Dew, & Apte, 2010; Sarac, Absi, & Dauzére-Pèrez, 2010; Shafiei, Sundaram, & Piramuthu, 2012; Souza et al., 2011). For a number of different motives, in the food industry, visibility has seen a significant interest in recent years (Amador & Edmond, 2010; Bechini et al., 2005, 2008). The reasons include the fact that food visibility has become a legal obligation in many jurisdictions (FDA, 2004; Food Standards Agency, 2002a, 2002b) and companies in the food supply chain now consider investment in visibility as a strategic asset to promote public confidence in their products. The need for and benefits of visibility have also been suggested in the context of the virtual enterprise (Bechini et al., 2005, 2008), the internet of things (Atzori, Iera, & Morabito, 2010), quality assurance beyond the food supply chain (Tse & Tan, 2012; Xu, 2011), supply chain risk management (Gomez, Laurent, & El Moustaine, 2012), agent-based control of industrial systems (Hsu et al., 2007; Hsu & Wallace, 2007; Vrba, Macůrek, & Mařík, 2008), and strategic and dynamic business reconfiguration and alignment with the marketplace (Chen, Cheng, & Huang, 2013; Jedermann & Lang, 2008; Véronneau & Roy, 2009; White, Daniel, & Mohdzain, 2005; Xia & Chen, 2011).

The increasing feasibility of peer-to-peer (P2P) communications, as often used in electronic data interchange (EDI), decreases the need for centralized exchanges and makes electronic dyads more attractive (Bechini et al., 2008). However, it is also argued that concepts like RFID, web services (WS), electronic business using eXtensible Markup Language (ebXML), Enterprise Service Bus (ESB), and Service-Oriented Architecture (SOA) hold better prospects for enabling product visibility and dynamic collaborative environments and business process integration (MIMOSA, 2006). In data exchange, RFID plays the essential role of automatically identifying mobile products and/or lots (Ahn, Childerhouse, Vossen, & Lee, 2012; Chappel, 2004; Chatziantoniou, Pramatari, & Sotiropoulos, 2011; Gibbs & Damodaran, 2002; Zhou, 2009).

Visibility also plays an important role in closed-loop product lifecycle information management (PLIM), a concept whose adoption and realization by the industry has been understandably slow and incomplete (Cassina, Taisch, Potter, & Parlikad, 2008; Främling, Ala-Risku, Kärkkäinen, & Holmström, 2006; Främling et al., 2007; Främling & Harrison et al., 2007; Kiritsis, 2011; Ranasinghe et al., 2011). PLIM is being pursued more vigorously by the Airline industry than other industries (Airlines of America, 2009, chap. 9) but there are still challenges outstanding. PLIM is composed of three interrelated or intertwined phases: beginning of life (BoL), middle of life (MoL), and end of life (EoL). Product conceptualization and manufacturing constitute the BoL phase, while the MoL stage begins as the product leaves the retailer or dealership. The EoL stage begins when the product reaches the end of its usage by the end user. During EoL, the product may be reprocessed for reuse or resale, recycled or disposed/discarded. Drivers like environmental regulations, cost recovery, safety and warranty management, and greenwashing (i.e., the scenario of a company cultivating a positive public perception of its green credentials while not investing enough in greening the supply chain) are increasingly motivating improved and wider application of EoL strategies. In some industries, e.g., the aircraft or heavy industry, the MoL phase may last for up to 30 years. PLIM has the following potentials: assist manufacturers in making product design improvements using data obtained from PLIM; using product lifecycle to innovate and develop new product lines; adapting production and distribution systems to improve product design, performance and efficiency; developing the capacity for predictive maintenance so as to reduce or eliminate the need for unscheduled maintenance; forecasting possible product failures; providing instant access to maintenance and usage histories of products and components; assessing the suitability of a product or component for recycling, reuse, or remanufacturing; and deciding any legal or trade regulations concerning the recycling or disposal of the product or its parts.

Visibility is a complex task. The complexity results from several factors, the main ones of which include: the fact that visibility data