Food Control 74 (2017) 98–106

Contents lists available at ScienceDirect

Food Control

journal homepage: www.elsevier.com/locate/foodcont

Comprehensive and quantifiable granularity: A novel model to measure agro-food traceability

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ARTICLE INFO

Article history:
Received 21 September 2016
Received in revised form
24 November 2016
Accepted 25 November 2016
Available online 26 November 2016

Keywords:
Traceability
Food traceability
Granularity
Model
Index system

ABSTRACT

Recent developments in the legal establishment and the market have motivated more agro-food companies to implement traceability systems (TS). TS play an important role not only for planning system implementation before development, but also for analyzing system performance after using the system. A novel agro-food TS model is presented here, based on comprehensive and quantifiable granularity concepts. A 2-layer index system was established; the first layer was mainly factors such as precision, breadth, and depth, and the second layer included seven indicator sub-factors: external trace units, internal flow units, IU conversion, information collection content, information update frequency, forward tracking distance, and backward tracing distance. An indicator's overall score was scaled with five contributing scores that graded the assignment method. Indicator weight was confirmed with the AHP method. The weight values of the seven indicators were 0.1985, 0.1141, 0.0872, 0.1870, 0.1248, 0.1442, and 0.1442, respectively. A weighted sum model was adopted to calculate the evaluation value. A high evaluation value indicated high granularity. The granularity model was applied in two enterprises, here identified as WPF and WFPE, which were located at different stages in wheat-flour supply chain. The survey results showed that WFPE should invest more in tracing equivalent granularity than WPF should because it involves multi-stage processing, a complicated supply chain structure, it is a large enterprise, and operates in a strict regulatory environment. Furthermore, WFPE was motivated to implement a high granularity level because of benefits in supply chain management, market and customer response, and recall and risk management. In the future, an updated granularity evaluation model that could combine enterprise characteristics and uncover hidden costs and benefits will be studied further.
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1. Introduction

Some astounding events, such as the BSE case in the early to mid-1990s (Wales, Harvey, & Warde, 2006), and the 1999 dioxin contamination of chicken feed in Belgium (Bernard et al., 2002), have focused attention on the topic of food safety (Bertolini, Bevilacqua, & Massini, 2006). Traceability is an effective method to ensure food safety and quality and to reduce the costs associated with recalls (Regattieri, Gamberi, & Manzini, 2007). Traceability is defined in international standards, in legislation, and in some dictionaries; the most cited standalone definition was formulated in a scientific article (Badia-Melis, Mishra, & Ruiz-García, 2015). By combining parts of existing definitions, Olsen and Borit (2013) offered a new definition: the ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, by means of recorded identifications.

In recent years, traceability systems research has been carried out on various topics, such as traceable technology (Li, Qian, Yang, Sun, & Ji, 2010; Pierini, Fernandes, Diniz, de Araújo, Di Nezio & Centurión, 2016), system development (Feng, Fu, Wang, Xu, & Zhang, 2013; Thakur & Hurburgh, 2009), traceability modeling (Comba, Belforte, Dabbene, & Gay, 2013; Van der Spiegel, Sterrenburg, Haasnoot, & van der Fels-Klerx, 2013), operating mechanisms, and consumers' perceptions (Dabbene & Gay, 2011; Kim & Woo, 2016). Rapid development of information and

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http://dx.doi.org/10.1016/j.foodcont.2016.11.034
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Nomenclature

BSE	bovine spongiform encephalopathy
RFID	radio frequency identification
WSN	wireless sensor network
DSS	decision support system
TS	traceability system
SCM	supply chain management
FSC	food supply chain
TRU	traceable resource unit
IU	identifiable unit
AHP	analytic hierarchy process
CR	consistency ratio
BDC	batch dispersion cost
FIFO	first in, first out
RMB	renminbi
WPF	wheat planting firm
WFPE	wheat-flour processing enterprise

communication technologies provides an effective way to improve traceability. Identification technologies such as barcodes and RFID can be integrated into a traceability system to identify products or batches quickly (Luvisi et al., 2012; Yang et al., 2016). WSN and portable devices with real-time and on-scene features have become impactful means for collecting environmental monitoring and farming operations information (Qian et al., 2015; Steinberger, Rothmund, & Auernhammer, 2009). A DSS fitted to the FSC requirement can help with compiling useful information from a combination of raw data, documents, personal knowledge, and/or models to identify food safety problems, making decisions to accept or reject food products, and conducting interventions (Van der Spiegel et al., 2013).

Nowadays, mandatory or voluntary TS are being enforced worldwide, driven by food safety and quality, regulatory, social, economic, and technological concerns (Bosona & Gebresenbet, 2013). Some systems of government supervision have been applied, such as EU Rapid Alert System for Food and Feed (RASFF), the Food Modernization and Safety Act (USA), and the National Agriculture and Food Traceability System (Canada) (Badia-Melis et al., 2015). From the view of improving enterprise SCM, some authors state traceability system research and its application according various agro-food or food quality requirements, such as for vegetables (Mainetti, Patrono, Stefanizzi, & Vergallo, 2013; Qian et al., 2013), fruits (Porto, Arcidiacono, & Cascone, 2011; Reyes, Correa, Esquivel, & Ortega, 2012), aquaculture (Parre O-Marchante, Alvarez-Melcon, Trebar, & Filippin, 2014), and poultry (Lavelli, 2013).

Because of the benefits of increased customer satisfaction, improvement in food crises management, enhancing in SCM, developing company competence, and contributing to agricultural sustainability, agro-food companies should be motivated to implement traceability systems (Dabbene & Gay, 2011). In such a context, a system to measure traceability plays an important role not only for system implementation plans before development, but also to analyze system performance after using the system. Although some research has been performed to measure the precision, breadth, and depth (Bollen, Riden, & Cox, 2007; Golan et al., 2004a, 2004b) of traceability, three limitations are obvious: 1) single-factor measuring cannot provide a comprehensive index, 2) qualitative analysis cannot provide a quantifiable evaluation, and 3) research on traceability has not evaluated the costs and benefits of implementing TS for various enterprises. To overcome these shortcomings, the concept of granularity was used for reference and a comprehensive and quantifiable granularity model was developed in our research. Various methods to measure traceability are reviewed here in Section 2. Section 3 presents a novel method for measuring agro-food traceability based on granularity. The novel model is applied in two cases through granularity evaluation and cost and benefits comparison in Section 4.

2. Literature of traceability measurement systems

Since effective TS should address the tracing and tracking of products and the complete information associated with product history throughout the FSC, the effectiveness of TS should be assessed in view of overall FSC performance. In fact, many factors, such as conflicting goals between partners in the FSC, complicate the evaluation of TS. Table 1 shows some recent TS evaluation methods.

Defining and evaluating the performance of TS represent the first step in developing traceability-oriented management policies. Various criteria have been proposed based on the elaboration of recall costs. To formalize this problem, Moe (1998), proposed the concept of TRU for batch processes as a “unique unit, meaning that no other unit can have exactly the same, or comparable, characteristics from the point of view of traceability.” By TRU and combined the information attributes, the breadth, depth, and precision of TS was proposed. These three dimensions were widely used to discriminate among traceability objects (Banterle & Stranieri, 2008; Zhang, Bai, & Wahl, 2012). McEntire et al. (2010) added a quantity of access to form four criteria to measure traceability. Access describes the speed with which tracking and tracing information can be communicated to supply chain members and the speed with which the requested information can be disseminated to public health officials during food-related emergencies.

Bollen et al. (2007) further elaborated on TRU by introducing the notion of IU, which represents the unit of a product that must be uniquely identifiable within each system in which it is traceable. The size of an IU corresponds to the granularity of the traceability system. Many definitions and descriptions of granularity have been proposed. Granularity is determined by the size and number of batches. Finer granularity allows for adding increasingly detailed information about a product and for acting at a more detailed and range-limited level in the case of a recall (Karlsen, Dreyer, Olsen, & Elvevoll, 2012). The relationship of granularity and precision consists in that granularity could affect the precision of product traceability if a product is tracked at a fine level of granularity and IU is small. In such cases, there is always the opportunity to combine IUs to achieve the required precision (Riden & Bollen, 2007).

In addition to precision, breadth, depth, and granularity, other indicators have also been used to measure traceability. Purity was used in horticultural pack house processing transformations (Riden & Bollen, 2007), and capability, rapidity, and accuracy has been used in fish processing plants (Mgonja, Luning, & Van der Vorst, 2013).

3. Traceability measurement model on comprehensive and quantifiable granularity evaluation

3.1. Framework for comprehensive granularity

Most of the above-mentioned indicators describe traceability from a particular viewpoint, but there is some insufficient from integrated viewpoint based on IUs, information recording and supply chain coordination. Similarly for granularity; it has been defined only by the size of the units or as equivalent to precision.

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