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Applying evolutionary prototyping model for eliciting system requirement of meat traceability at agribusiness level

Xiaoshuan Zhang [a,b], Shunyi Lv [a,b], Mark Xu [c], Weisong Mu [a,b,*]

[a] College of Information and Electrical Engineering, China Agricultural University, Beijing 100083, PR China
[b] Key Laboratory for Modern Precision Agriculture Integration, Ministry of Education, China Agricultural University, Beijing 100083, PR China
[c] Portsmouth Business School, University of Portsmouth, Portsmouth, Hampshire PO1 3DE, UK

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ABSTRACT

Traceability has become an effective method of ensuring food safety and connecting stakeholders in the food chain. There is an increasing growth trend in developing IT-based traceability system in recent years. But implementing hastily traceability system is likely to fail to achieve its goal if the system requirement has not been well-defined according to the changing business environment. This paper adopted an evolutionary prototyping model and used longitudinal case study to elicit the traceability system requirement at the level of agribusiness. The results show that a traceability system can support not only information tracking at operational level, but also diagnostic analysis and strategic decision making at managerial level, Hence, system requirements can be categorized as fundamental, decisive and strategic levels. The evolutionary prototyping model can improve the effectiveness of requirement elicitation.

1. Introduction

The increasing demand for healthy and safe food from the final consumer requires well structured traceability systems to be developed (Regattieri, Gamberi, & Manzini, 2007). This phenomenon is compounded by a growing body of relevant law and regulations issued in US, EU and some other countries, which require that agricultural products must be traceable. Repeated violation of the aforementioned regulations has lead to a ban on those products originated from that country. As a result, many national governments are actively encouraging the development of IT-based traceability systems for verifying and monitoring food safety in order to satisfy domestic and foreign needs (Becker, 2000; Wall, 1994). This leads to IT-based traceability systems are widely adopted in food supply chain.

A traceability system enables the identification of the parties involved in food production and transportation. The information generated from the traceability system can be made available to the consumers. The significant improvements derived from a traceability system are in three folds: (1) capturing efficiency gains through improved supply-side management. (2) Achieving marketing/competitive advantage by differentiating foods with credence attributes. (3) Improving food safety and quality control by facilitating firms in identifying and resolving food safety or quality problems (Becker, 2000; Paarlberg, 2002; Peri, 2002).

With the trend and the potential benefits envisaged, many agribusinesses are rushing to implement hastily IT-based traceability systems, the attitude tends to be "build it and they will come". However, the rate of successful implementation is less than expected. Furthermore traceability systems in some cases become a useless and costly ornament, even embarrassing failures. IT-based traceability system, like any other information systems, has to adapt to the changing business environment (Chen & Tian, 2009; Qian, Wang, Gao, & Wang, 2009; Wang, 2009). This implies that traceability system requirements are not static, but dynamic. Literatures support that the traceability systems need to respond to food security threats, documenting chain of custody and production practices, complying with regulatory requirements, etc. It is revealed that the failure of traceability systems and barriers for successful implementation are not only on information system technology aspect, but also on business flow aspect for food quality control (Alfaro & Rá bade, 2009; Setboonsarng, Sakai, & Vancura, 2009; Szulecka, 2006; Thakur & Hurburgh, 2009; Wang, 2009; Yokoyama, 2007). The challenge of developing a successful traceability system is to handle the frequently changing needs.

Software requirement engineering is concerned with understanding the needs of the current and new system and finding mechanisms to illustrate these needs (Serrano, 2003). Eliciting and verifying the well-defined software requirements is the first and fundamental step of IT-based traceability system development

* Corresponding author at: College of Information and Electrical Engineering, China Agricultural University, Beijing 100083, PR China. Tel.: +86 010 62736717.
E-mail address: wsmu@cau.edu.cn (W. Mu).

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process. Regattieri et al. (2007) proposed a framework that comprises of four pillars-product identification, data to trace, product routing, and tools, which can guide systematic organic design of a traceability system. Thakur and Hurburgh (2009) developed a model for implementing internal traceability system for a grain elevator that handles special grain. The study however did not indicate how to implement the framework and the model.

Evolutionary Prototyping is a popular system development technique and can enable users to develop a concrete sense about software systems that have not yet been implemented. Through using the prototype, users can identify the true requirements that may otherwise be impossible by visualizing the software systems to be built (Fu, Bastani, & Yen, 2008). In this way, the prototype model can help elicit the requirement from the changing environment. System developers advocate that requirement validation shall be compared against organizational needs, but not against the system functionality (Rolland & Prakash, 2000).

As discussed above, this paper adopts an evolutionary prototyping model to elicit and validate the traceability system requirements at the agribusiness level. Meat supply chain is selected as the objective for the implementation of a traceability system due to the following consideration: meat food is an important source of protein and necessity for human life. It has always been regarded as the improvement of the living standard of the Chinese people, particularly those in the rural areas. With the increased consumer's perception for food safety, meat quality is considered the most important factor affecting meat consumption.

2. Materials and methods

2.1. Evolutionary prototyping model and application

Evolutionary prototyping model (EPM) is a software development lifecycle model by which a software prototype is created for demonstration and requirements elaboration (Chen & Huang, 2002; Laudon & Laudon, 1999). The sequence of the steps applying EPM to develop the traceability system is depicted in Fig. 1 and described as below:

- Firstly, define the basic requirements. This is the very first, and the most important initial stage. In this stage, the system requirement may be recognized in a very broad and general form by the designer and the manager who works together with the designer.
- Secondly, create and use the working prototype. The designer develops a workable prototype system (first version) that is provided to the potential user to identify and understand the problem domain. Then, the user is encouraged to work on the prototype to test how well it meets their needs and make suggestions and requirement statement for improving the prototype.
- The system developers follow an incremental development approach to improve the second prototype on the basis of users' needs and feedback.
- Finally test the prototype and describe the system requirement. After the revising and/or improvement, the prototype will be available to the user. The process will be iterated until the users satisfied with the system and the system is suitable for the agribusiness external environment. When no more improvement is required, the tested system becomes mature and operational version.

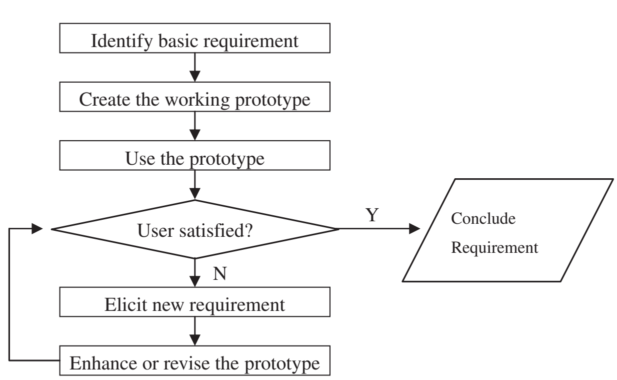


Fig. 1. The four-step process for the EPM.

2.2. Longitudinal case study

For eliciting system requirement of IT-based traceability system at meat agribusiness level, it is not appropriate to carry out large-scale survey. Survey method can provide a wide and representative, yet static snapshot of traceability system requirements at particular points, but cannot capture the dynamic changing requirements. In contrast, case study focuses on depth rather than breath in the sense that it can obtain a rich, detailed insight into the 'life' of that case and complex relationships and processes.

Case studies include various types: historical study, contemporary study and longitudinal study. A longitudinal study involves the researcher investigating the case over a period of time, e.g. from 1 month to several years, allows analyzing the processes and relationships that are continuous and changing.

As mentioned above, longitudinal case study is adopted in this study, since the prototype has been developed and tested within a case company over 4 years. The researcher obtains as much detail as possible about the requirements under investigation and observes changes more accurately. A longitudinal study method devotes itself to make possible the gathering of data over a period of time and serve to increase the internal validity of the investigation.

2.3. Sampling

Purposive sampling is used in this study. Firm A[1] in Shandong province is selected based on the following criteria:

- Firstly, the firm has experience of long-term S&T (Science & Technology) cooperation with an Agricultural University in China. And the firm is willing to cooperate with the researchers from the university on the research work – developing a traceability system for the firm.
- Secondly, the top manager of the firm had committed strongly to food quality/safety control and traceability in order to bid for meat food provider of 2008 Olympus Games at year 2005.
- Thirdly, the firm's primary business covers a vertical chain including farming, processing and marketing (Fig. 2). Its mission is to provide high-quality, fresh and safe beef and mutton products for domestic and international market. It has established a rigorous quality control system.
- Finally, the firm has the human capabilities and financial resources required by traceability system development and implementation.

2.4. Data collection and analysis

Data collection were carried out in January 2006 and continued to the end of December 2008. Ten interviews were conducted

[1] Firm A is not the true name. The company has asked us to remain anonymous.

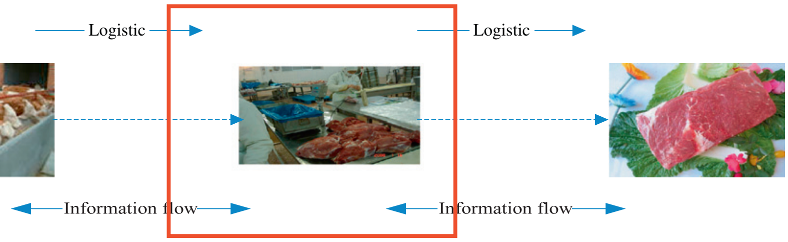


Fig. 2. The schematic representation of the meat chain at Firm A.

during the period, employees from different management levels of the firm were interviewed using a semi-structured questionnaire. All the conversations were recorded with the consent of the interviewees. Each interview lasted about an hour.

Following the method proposed by Alfaro and Rá bade (2009), the following techniques were adopted for data analysis and in order to enhance the internal validity and reliability of the case study:

- Interviewing different levels of informants about traceability system function and interface, etc., as the traceability system will serve each level and function of the organization
- Categorizing systems requirements into two major groups: functional requirements and non-functional requirements (NFR). The former was used to describe the functionality of the system. The latter was concerned with describing how well the system delivered the functional requirements.
- Taking the tentative analysis back to the interviewees to verify if the results were accurate and plausible, and requested other experts and colleagues to comment on the findings.
- Presenting the final findings to the top managers of the firm and external experts to seek the consensus or clarification.

3. Results and discussion

3.1. System development and evolution

Firm A began the implementation of its traceability system in January 2006 with the help of a knowledge transfer partner – an Agricultural University in China (AUC). A research group was formulated consisting of: AUC served as system developer and knowledge engineer and the staff from the firm served as the domain experts and end users. After almost 4 year's cooperation, the traceability system is evolved from an early prototype to a mature system.

The following section describes the evolution of the development process and summarizes the prototype model in three stages.

3.1.1. Version 0.0: system implementation and feedback

Since the very beginning, the system designer from AUC worked with the staff from the firm to capture the basic needs of the traceability system via interviews. Firm A expected the traceability system to be an intra-firm level intranet to constantly monitor the whole production processes and to assure food safety. The aim was to make customers perceive that its food would be healthy and safe. In case anything goes wrong, the firm could determine exactly at what stage and time the error had occurred.

The system (Version 0.0) was based on B/S (Browser/Server) mode using ASP.NET and SQL Server, which consisted of three main modules: information input, information transfer and bar code printing (one dimension barcode label). The traceability information covered the entire supply chain – from the arrival of raw materials at the processing plants to the delivery of final products to the end customers. The traceability data was manually entered into the system.

After completing the design of the Version 0.0 prototype, four external experts, some workers and managers from the firm were invited to a workshop. They were provided with an intensive introduction and demonstration to the system, some useful feedback was obtained from the workshop. The Version 0.0 prototype also was set up in the plant and run on-line. Operational staffs of the firm tested and evaluated the system in the actual business process. Although many questions and advises arose from the staffs and experts, the result was encouraging and staff were excited about traceability system implementation.

The drawbacks and new requirements derived from evaluation of the Version 0.0 were summarized as follows:

(1) Traceability information update and accuracy. The information flow in Version 0.0 was: firstly, the data was recorded on paper by farmers and workers in the workshop. Secondly, the data was verified by the intermediate manager. Thirdly, the recorded data was entered into a database manually via keyboard by data workers. Fourthly, another manager verified and confirmed the data again. Finally, the traceability information was authorized to be issued by top managers. The process also involved many other staffs. One problem observed was that it was difficult to ensure the correctness and accuracy of the original data due to that data was not collected and recorded at real-time.

(2) The label printing and reading. Dot-Net technology has the limitation in accessing the industrial printer to label printing. An error for printing traceability label encountered during the system test. System managers need to spend long time on printing the traceability label. In addition, label reading errors occurred frequently when reading and recording information from ear tag or one dimension barcode labels in order, due to the high-temperature and humid ambient environment during the process of slaughtering. Some labels even became unreadable or carried fault information. This would affect the next step – information transfer.

3.1.2. Version 1.0: System improvement and feedback

The evaluation and feedback of Version 0.0 leaded to further improvement of the system. System designers and developers summarized the feedback and identified the new requirements with a focus on traceability information update and accuracy, communication of hardware and software. The system was improved as follows:

- Dual computing model (C/S integrated with B/S) was adopted as the foundational computing framework, which took into account of equipment stability, design simplicity and information security. In the dual computing model, the label printing system was developed as a separated module based on the C/S computing model, because it had the advantage to access the hardware and reduce the probability of label printing error. (see Fig. 3a). The other subsystems remained were based on B/S computing model and served as traceability information collection, processing and publishing (see Fig. 3b).

- PDA (Personal Digital Assistant) and RFID (radio frequency identification) were introduced as additional information collecting and transferring device. The emerging wireless technology creates the reality that an employee can be in the field with a cell phone, and PDA (or lap-top), wireless access to company system real-time is possible. Supported by the wireless devices, the traceability information of ear tag from farming chain could be correctly read and transferred into RFID tags attached to the carcass. Moreover, the PDA could collect real-time data on the spot and transfer the processing data into RFID tags. Fig. 4 illustrates the information collection and transmission flow based on PDA and RFID.

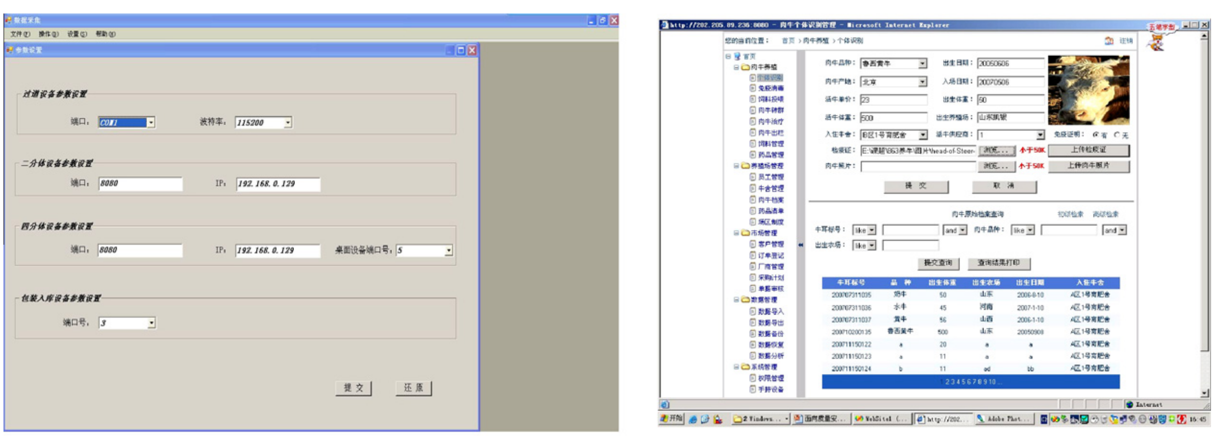
After the improvement finished, the system was upgraded to Version 1.0. After several months' system test and evaluation, the results showed that most of the users were satisfied with the system function: the system could perform and record daily and routine traceability information into the system; it was useful to know where a product was in the supply chain and tracked the product by traceable unit in the supply chain. Intermediate managers felt that they could control traceability information effectively with the new system, so they had more room for making quality control decisions. They hope that the system could provide further decision support function. Overall the Version 1.0 had less influence on decisions making. Drawbacks and new requirements from evaluation of the Version 1.0 were summarized as follows:

(1) Lack of traceability information processing. In case of a product recall, the system can provided accurate information on the availability of the product at the point of sale via the traceability lot/batch. But the system did not decrease the amount of products recalled in case of production batch mixing. Larger batch mix, more cost would arise during a possible recall. Optimized batch sizes would reduce the recall cost. On the other hand, the system would identify where the problem was, but it could not identify the reason for the problematic products. Identifying the reason, location and person who was responsible for the problematic products would be useful to evaluate the supply chain safety, eliminate and control the quality risk and prevent the fault event, so as to improve meat quality and safety.

(2) Lack of safety control decision support. The Version 1.0 prototype was the system that followed and tracked the movements of the foods in the supply chain, but did not directly perform food safety (hygiene) management, quality management and environmental management in the production process. In other words, Version 1.0 only tracked the problematic products and could neither actively improve safety, nor create credence attributes. Linking the prototype to an effective food safety control system could provide a solution to the problems mentioned.

3.1.3. Version 2.0: System incremental development and feedback

The feedback from Version 1.0 suggested that further system improvement should be to incorporate with intelligent decision support for quality control management. After several discussions between system developers and intermediated managers and



(a) (b)

Fig. 3. The system screenshot: (a) RFID configuration interface based on C/S and (b) system screenshot for farming chain based on B/S.

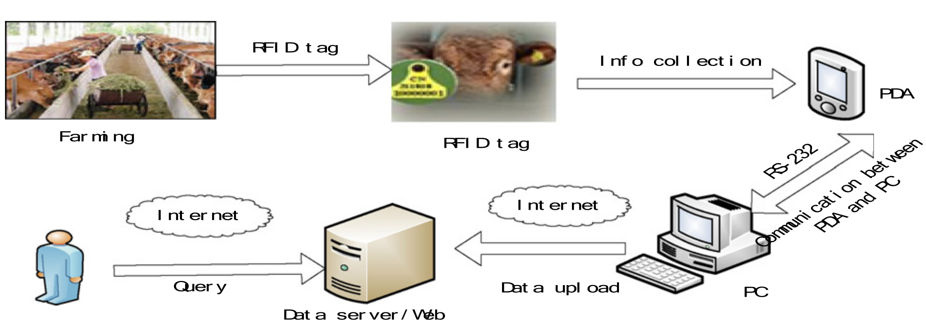


Fig. 4. Information collection and transmission flow based on PDA and RFID.

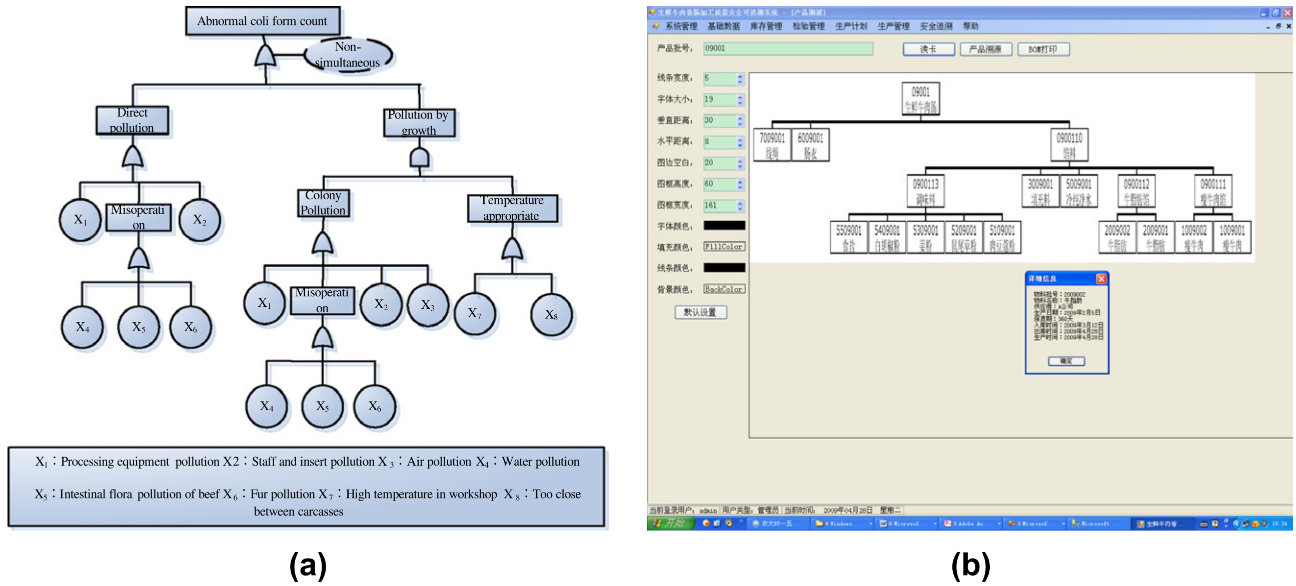


Fig. 5. The screenshot with the decision model: (a) fault diagnosis based on FMECA and (b) the traceability mode based on BOM.

workers, the system incremental development concentrated on building the following modules:

- The fault diagnosis model based on FMECA (Failure Mode, Effects, and Criticality Analysis) integrated with Petri Net was developed for identifying failure modes, and eliminating those with higher severity and/or probability (see Fig. 5a). In the model, Petri net performs the function of describing the static structure, and simulating dynamic systems, which enable retrospective analysis of meat safety completely and thoroughly. The FMECA could classify the fundamental failure modes with relatively high probability and severity of consequences, this is useful for the remedial effort to be directed where it would produce the greatest value.
- The early-warning model based on critical point control was developed for monitoring the processing environment, sending warning signal and removing hidden dangers in time. For instance, when the temperature and humidity in the processing workshop exceed a required standard, the system would send warning signal automatically.
- The batch optimization model based on linear programming (Dupuy, Botta-Genoulaz, & Guinet 2005) was developed for minimizing the quantity of recalls by categorizing the product at the BOM (bill of material) (see Fig. 5b).

With the new system, the top management team could get the accurate and unfiltered information on each aspect of the supply chain. Implementation of the traceability system had enabled the firm successful in bid for being an official meat provider to the 2008 Olympus Games. The firm's market had been extended widely and their products were easily identified by consumers. It showed that the traceability system was becoming a new method of differentiation and a means of gaining competitive advantage.

3.2. System requirement elicitation and analysis

Fig. 6 below shows the system evolution over the 4 years. The evolution is from two different directions relevant to the system requirement.

3.2.1. System function requirement elicitation and analysis

The system evolution shows that the traceability system is initialized to support quality information tracking and management. Now it has evolved toward an intelligent decision support system

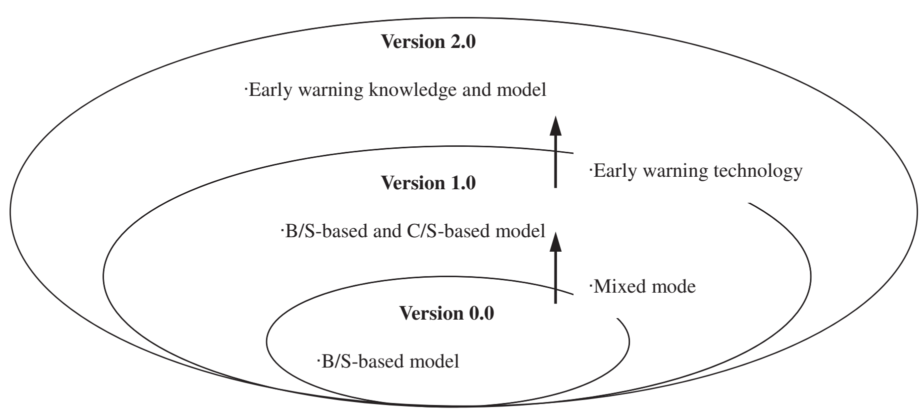


Fig. 6. The development process and evolutionary phases.

for quality control. It also suggests that the traceability system should be built to meet the requirements at three levels for agribusiness:

- The fundamental requirement at the operational level, the system serves as a *management information system*. Traceability system records the daily and routine quality safety information and keeps tracking the elementary activities and transaction. Under this context, consumers can trust the product safety through inquiring directly relevant production records across the whole product supply chain. At the same time, the firm can share the traceability information easily with other stakeholders and partners of the supply chain.
- The decisive requirement at the intermediate level, the system serves as an *intelligent decision support system*. Traceability system can not only simply trace the problematic products, but also diagnose the faults reasons. Furthermore, it monitors the quality safety via integrated intelligent computing technology, particularly provides decision aid according to predefined rules. If quality hazard rises, the firm is able to quickly determine exactly where and when the error has occurred, and who is responsible. This could be the only effective way to continuously improve product quality safety and stabilize technical performance.
- The strategic requirement at the top level, the system serves as the key component of the *executive support system*. Traceability system acts as a marketing decision aid that can differentiate the end products from other business competitors so as to improve competitiveness and to meet the internal and external environment change. This is in line with the assertion (Alfaro & Rá bade, 2009; Maurizio, Roberta, & Roberta, 2006; Wang, 2009) that traceability system can be used as a strategic tool to improve enterprise management and competition.

3.2.2. System technical requirement

As discussed above, the functional requirements for traceability system have evolved and become more complex, which requires more specific technology to support. To cope with the complexity of requirements changes, an intelligent traceability system is needed to integrate different information and communication technologies (ICT) and computing technique, to make information more easily available to consumers. The evolutionary prototyping, via iterative and incremental development, through integrated with longitudinal case study can provide deep understanding about the functional requirements of the traceability for effective management of food quality and safety. ICT that can effectively support traceability system development and implementation is suggested as follows:

- Dual computing system. Traceability system can adopt the dual system – B/S and C/S as the computing structure: B/S has advantage to transfer information for customers through websites and exchange data electronically among the supply chain stakeholders. C/S has advantage to control printing technology, affixing printed labels and communication with B/S.
- Information record-keeping, labeling and transmission technology. Auto identification technologies, such as bar codes, two-dimensional bar codes, or radio frequency identification (RFID), shall be integrated into the traceability system to improve the transparency and reliability of information. This allows transfer of information in a readable, easy, and laborsaving way.
- Intelligence processing technology. Traceability system is evolved toward a monitoring and early warning system for food safety and production. The system, coupled with intelligent technology and algorithm, can enable identifying quality hazard or risk more quickly across the supply chain, and provide appropriate actions.

4. Conclusion

In summary, the prototype evolution exhibited through firm A traceability system demonstrates that functional requirements of a traceability system can be effectively identified. Traceability systems that support three levels of business needs can win not only the confidence of consumers, address the documentation requirements, but also represents an optimal way of monitoring what is happening along the whole supply chain at all times. Furthermore, the system can support food quality control and managerial decision making. Capturing dynamic system requirement is the key to successful development of traceability systems. Firms also need to balance the costs and benefits of developing and implementing a traceability system. The following conclusions are drawn from this study:

(1) The evolution process of traceability system from Version 0.0 to Version 2.0 suggests that system is experiencing the transformation from passive information tracing to proactive food quality control. Traceability systems are becoming an important tool to help firms manage the information flow of products, improve food safety, quality, and support market differentiation. This can be achieved primarily in two ways:
   - System functional transformation: from quality tracking and tracing to quality safety control, from information management to intelligent decision.
   - Information technology integration: from B/S to B/S integrated with C/S and wireless, from simply data record to complicated systematic modeling to improve the system development speed, operating efficiency and ability of decision aid.

(2) Evolutionary prototype model, integrated with longitudinal case study, can effectively elicit the traceability requirement dynamically, – i.e. even requirements changed substantially during implementation at the firm level. The method is most useful when there is some uncertainty about requirements or design solutions, particularly for decision-oriented application where future tend is difficult to predict.

It is worthy to note the issues to be addressed in future research: due to the selected firm is a vertical supply chain, some system requirements may not be captured. This issue has been arisen when the traceability system was promoted in Tianjin City. The selected meat supply chain in Tianjin City is at horizontal level, the stakeholders in the supply chain had the different database and information system infrastructure. It is important to examine how to integrate the difference format of traceability information into the standardization database across the supply chain.

In addition, consumers also are the end users of the traceability system. The traceability requirement from consumer mostly focuses the information breadth and the channel to retrieve the information. The paper does not take into account the traceability system requirement from consumer perspective.

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