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Development and evaluation on a RFID-based traceability system for cattle/beef quality safety in China

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ABSTRACT

Beef has become a kind of important food in China because of its nutritional value perceived by consumers. With increasing consumers' awareness and governments' regulations on beef quality and safety, traceability is becoming a mandatory requirement in cattle/beef industry. This paper developed and evaluated a cattle/beef traceability system that integrated RFID technology with PDA and barcode printer. The system requirements, the business flow of the cattle/beef chain, and the key traceability information for the system were identified through a survey. Then a conceptual model was proposed to describe the process of traceability information acquisition, transformation and transmission along the supply chain. Finally, the system was evaluated and optimized in the sampled supply chain.

The results show that the major benefits gained from the RFID-enabled traceability system are the real-time and accurate data acquisition and transmission, and the high efficiency of information tracking and tracing across the cattle/beef supply chain; the main barriers for implementing the system are the inapplicable method of inputting information, the inefficient sequence of data input and communication mechanism associated with RFID reader, and the high implementation cost.

1. Introduction

Beef has become a kind of important food in Chinese consumers' diet structure due to the recognition of beef nutritional value, the increased availability of beef supply and the affordability of Chinese consumers. According to the data from National Bureau of Statistics of China (NBSC, 2011), in 2010, the total beef production was about 6.53 million tons in China, which increased by 27.3% over 2000; the average amount of annual beef consumption in Chinese urban households was 1.98 kg per capita in 2000, but in 2010 the consumption amount increased to 2.53 kg per capita.

The concern about beef quality and safety in China has raised greatly during the past decades due to the outbreak of bovine spongiform encephalopathy (BSE) and other food safety incidents and scandals, which stir public attention and governmental fervor for quality control and safety management in food industry (Berg, 2004; Golan et al., 2004; Hillerton, 1998; Van Wezemael, Verbeke, Kügler, de Barcellos, & Grunert, 2010; Verbeke et al., 2010). As a result, a number of effective and practical interventions is implemented to the food industry (including cattle/beef industry) in order to improve food safety and strengthen consumers' confidence (Van Wezemael, Verbeke, Kügler, & Scholderer, 2011).

Traceability refers to "the ability to trace and follow a food, feed, food producing animal or ingredients, through all stages of production and distribution" (European Commission, 2000). A traceability system is considered as an indispensable instrument to improve consumer confidence in food consumption and to reduce the asymmetry of information across food supply chains. Traceability systems have been implemented in many countries and regions. EU firstly launched the traceability system in 1997 for the purpose of dealing with BSE, and the regulation of mandatory enforcement of traceability was issued in 2005, which required all food and feed in EU market should be traceable (Schwägele, 2005). The similar strict rule became effective in Japan in 2005 (Dalvit, De Marchi, & Cassandro, 2007). In US, the National Animal Identification System was developed in 2004 to trace livestock and poultry chain and considered as a kind of early traceability system implemented in practice. But unfortunately it was abandoned in 2010 due to the resistance from industrial stakeholders and policy makers. The current running system is a mandatory animal identification system, which is designed for the management of animal

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disease. In order to foster the implementation of traceability systems in food supply chain, USDA Agricultural Marketing Service also established a set of voluntary certification of animal traceability for beef export (Golan et al., 2004; Schroeder & Tonsor, 2012; Smith et al., 2005; Zhao, Chen, & Qiao, 2012). Traceability systems based on tagging technology were also applied in Canada, Australia, Brazil and New Zealand (Smith et al., 2005).

The global trend of adoption and application of traceability system is mirrored in China. In order to satisfy the international and domestic requirements for food safety and quality, at national level, the General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China (AQSIQ) applied the compulsory requirement of traceability systems to all of meat and aquatic products export companies. Other food companies were encouraged to adopt and implement traceability system by various preferential policy supports from national, regional and local governments, e.g. interest-free or low interest loan for IT infrastructure and system development. At regional level, many provincial governments also developed policies to promote traceability system application. For example, Guangdong provincial government issued the regulation on food identification code in 2009, which required all food should have the identification label.

Research into traceability systems covers a number of topics: traceability system development (Maldini, Nonnis Marzano, Fortes, Papa, & Gandolfi, 2006; Qi et al., 2010; Shanahan et al., 2009; Thakur & Hurburgh, 2009); traceability modeling (Thakur & Donnelly, 2010; Zhang, Feng, Xu, & Hu, 2011); operating mechanism and consumers perceptions of traceability system (Chrysochou, Chryssochoidis, & Kehagia, 2009; Hobbs, Von Bailey, Dickinson, & Haghiri, 2005; Van Wezemael et al., 2010; Zhang, Zhang, Liu, Fu, & Mu, 2010). Specific research on cattle/beef traceability has also been reported (Bowling et al., 2008; Kang, Zhang, Fu, & Mu, 2010; Lu, Zhang, Mu, Fu, & Zhang, 2009, 2010; Shanahan et al., 2009; Shen, Zan, Duan, Wang, & Zheng, 2007; Shi, Fu, & Zhang, 2010; Yang, 2005; Zan, Zheng, Shen, Wang, & Zeng, 2006). The focuses of these studies tend to be on information identification using RFID (radio-frequency identification) and system architecture design; there is lacking in modeling the traceability data acquisition and transmission process for developing RFID-based cattle/beef traceability system.

This paper aims to develop and evaluate a RFID-based cattle/beef traceability system (RCBTS) that incorporates PDA and barcode printer which can perform traceability throughout cattle's life cycle and provide accurate traceability information. Furthermore, a model about data acquisition and transmission of traceability information exchange is conceptualized according to the survey of the cattle/beef supply chain.

2. System analysis of the RCBTS

2.1. The survey procedure

A survey was carried out to understand the business flow of the cattle/beef chain and identify users' requirements for the RCBTS. The following survey methods were adopted:

- *Document collection*: This included collection of the logs and records about cattle/beef quality standards and Hazard Analysis Critical Control Point information in cattle/beef production process, the purpose was to determine the key parameters for developing the RCBTS.
- *Field observation*: This referred to investigating the routine flow and management issues in cattle/beef production, including the time and frequency of feeding, the diseases and treatments, the process of slaughter. The observations were conducted in the sampled enterprises in Tianjin city, Shandong province and Hebei province.
- *Interview*: This aimed to capture users' requirements for the RCBTS. The interviews were carried out in Tianjin city, Shandong province and Hebei province. A list of interviewees including 15 managers, 56 workers and herd keepers was selected from the sampled enterprises; then the interviewees were asked to answer questions about the workflow, tasks and traceability issues.

2.2. Business flow analysis on cattle/beef chain

Fig. 1 illustrates the business flow of cattle/beef chain based on the acquired information from document collection, field observation and the interview.

2.2.1. Link 1: Cattle breeding process

This link is the first part of the chain, from purchasing calves to the cattle are ready for slaughter. This process comprises of six key business nodes that deal with critical information acquisition and transmission: individual marking, feeding, immunization, disinfection, cowshed transfer and treatment.

Business node 1: In individual marking node, a unique ID number is assigned to each calf. Then, the individual calf's information that provided by the seller when the producer purchases the cattle is recorded and identified by the unique ID number.
Business node 2: Feeding, this is an important node for quality control. Most information is acquired and recorded in cattle feeding process, including the name of feeds, the amount of feeds, the feeding time, the workers feed the cattle, etc.
Business node 3: Regular immunization, this is necessary to prevent the cattle from infectious diseases. The traceable immunization information includes immune method, medicine, operation, etc.
Business node 4: Disinfection, which keeps the cowshed, feeding devices and cattle free from bacteria, virus and parasitic ova. The cowshed needs regular disinfection once a month. In addition, the cowsheds and tools should be thoroughly disinfected when cattle are transferred to other cowsheds in spring and autumn.
Business node 5: Cattle are transferred to other cowsheds when they are sick or at different stage of growth. Cowsheds for the sick cattle need to be treated separately to avoid cross-infection.
Business node 6: Treatments need to be applied to cure sick cattle, such as foot-and-mouth disease, infectious pleura pneumonia, influenza, etc. The active therapeutic actions should be taken in the process of breeding, and every treatment should be recorded.

2.2.2. Link 2: Beef slaughter and processing process

There are five key nodes in the business process of beef slaughter and processing that involve in traceability information transformation and transmission, including ante-mortem inspection, cattle slaughter, acid decomposition treatment, segmentation and packing.

Business node 7: Ante-mortem inspections aim to examine if the cattle are healthy. Cattle cannot be sent to the next node until the inspection results satisfy the relevant regulation requirements. The whole slaughter process is under the supervision of the inspector.
Business node 8: Cattle slaughter process, which consists of bloodletting, peeling, disembowelment, etc., during the process, the head, skin and viscera are removed from the cattle carcass.

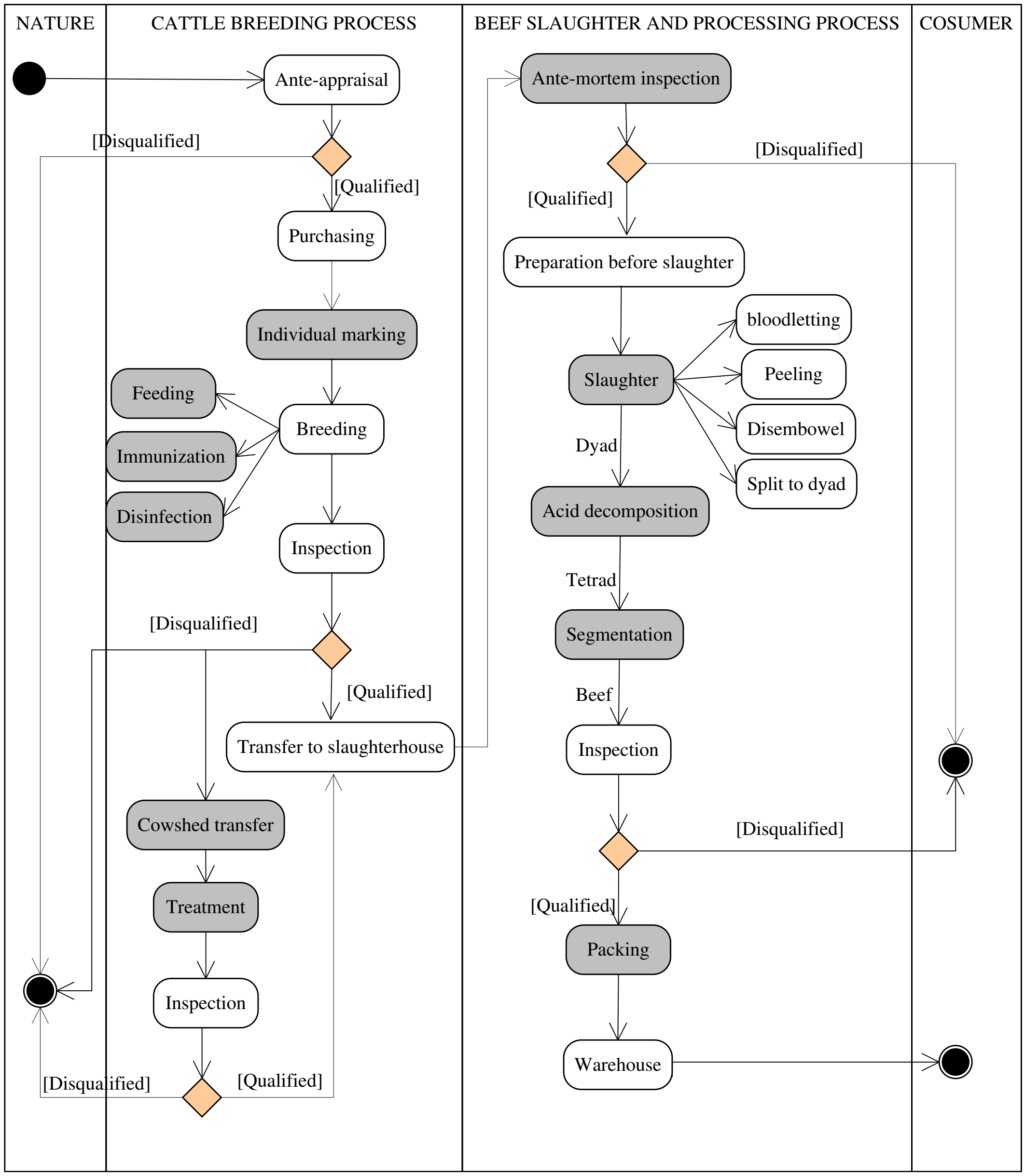

Fig. 1. The cattle/beef production business flow.

At the end of slaughter process, the cattle carcass is segmented into two halves, each of which is called the dyad.

Business node 9: Acid decomposition treatment, it is the technique that resolves the lactic acid produced in cattle carcass under rapid chilling condition, so as to reduce the content of harmful substances in beef and improve beef quality and flavor. The acid decomposition treatment should be conducted in the cooler at 0–4 °C within 60–72 h. After the process of acid decomposition treatment, the cattle carcass is divided into four quarters of cattle carcass, each of which is called the tetrad.

Business node 10: During segmentation process, the tetrad is further divided into different parts as beef products according to commercialization requirements, such as tenderloin, striploin, chuck roll, ribeye, chuck steak, knuckle, topside, rump, brisket, shin, etc.

Business node 11: The segmented and qualified chilled beef is wrapped by vacuum packaging with the label, which contains sufficient traceability information visible on the outside of package, and then beef product is ready for sale.

2.3. The key actors in cattle/beef chain

The key actors in the supply chain need to be uniquely identified in order to develop an integrated system (Shackell, 2008). The key actors in cattle/beef chain are presented in Fig. 2.

Herd keeper: The herd keeper takes charge of cattle's breeding and management, and keeps close cooperation with the veterinary to control quality safety.

Veterinary: The veterinary plays different roles to make sure the cattle are disease free and assure the cattle meet sanitation requirement. Their responsibilities are 1) to treat the sick cattle; 2) to immunize cattle against contagion, 3) to disinfect the cowshed; 4) to implement inspection in the slaughter process.

Slaughterer: The slaughterer is responsible for beef slaughter, acid decomposition treatment and beef segmentation process.

Packing worker: The packing worker takes charge of the packaging and label sticking for the final products. The worker also sends the packaged beef products into the warehouse.

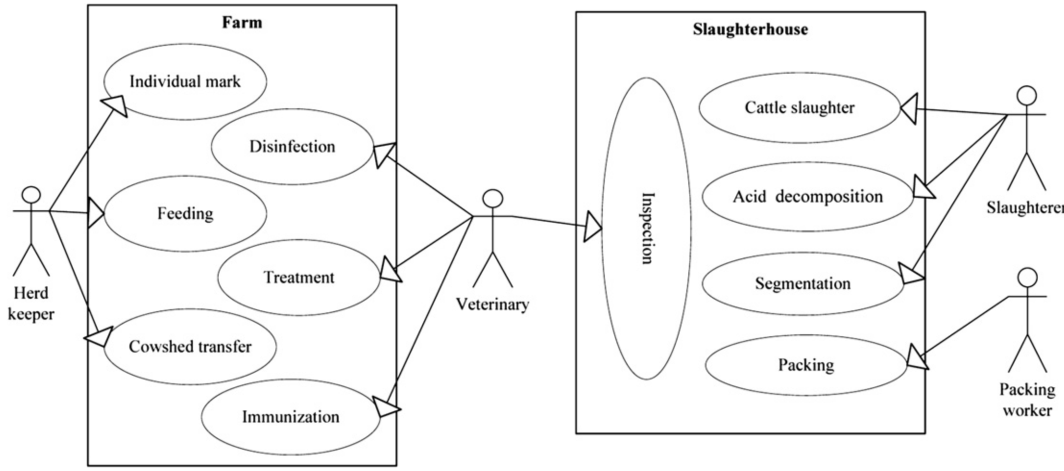

Fig. 2. The key actors in the cattle/beef production chain.

2.4. The user requirements of the RCBTS

Tables 1 and 2 illustrate user's function requirements and performance requirements for the RCBTS. The requirements are generated from the document collection, field observation and interviews.

2.5. The critical traceability information of the RCBTS

According to the Decree No.67 issued by the Ministry of Agriculture of the People's Republic of China (MOA, 2006) in 2006 and the requirements of cattle/beef quality management, the following information are identified as the critical traceability information for the RCBTS, and should be acquired, tracked and traced in cattle/beef production chain.

2.5.1. Cattle breeding information

Fig. 3 depicts an E-R (entity-relation) diagram in cattle breeding process. 15 tables were designed to store the information acquired in this process, which included cattle, feeding, cowshed transfer, disinfection, treatment, etc. Each table showed the detailed description about the required traceable information. Taking the table of "tb_Feeds" as an example, it contained the following traceable data of feedstuff: feedID, feed name, production date, product code, period of validity, the producer, producer's address, the operator, operating date and the record.

2.5.2. Beef slaughter and processing information

The traceability data in beef slaughter and processing process included the slaughterhouse (enterprise's name, business license and code, contact information, etc.); the time of the acid decomposition treatment, quarantine status and the qualified No. of the slaughter; the name of the beef products, the date of producing, the operator, etc.

Table 1
The function requirements for RCBTS.

Function module	Function description
Cattle's identification	Record the individual information and assign the unique ID number to each calf.
Information acquisition and transmission	Acquire all the data accurately and timely, and transmit the data that are generated in the process.
Information tracking and tracing	Track the information about breeding, feeds, medical treatment, etc. The system should have the ability to control the safety and quality in breeding, slaughter and processing process.
Routine management and decision support	Manage the daily operation of the farm and slaughterhouse, and improve management efficiency. Producer can quickly detect the origin of the problem when beef quality problem occurs and then can take necessary measures to solve the problem.

3. Modeling for traceability information acquisition and transmission

3.1. Traceability unit transformation along the cattle/beef chain

Traceability unit is the object of tracking and tracing across food supply chain. Based on the analysis of business flow about the cattle/beef chain and the method proposed by Li, Jin, and Chen (2010), a model was put forward for describing the traceability units transforming process, which was formulized as:

$$P_t(S) = \{ID(S), Loc(S), Matt(S), Infor(S), Oper(S), Date(S)\};$$
$$(S = \{S_1, S_2, \ldots\ldots S_n\})$$

where S is an aggregation of traceable units, S_i ($i = 0, \ldots, n$) is the traceability unit identified in the business flow. $ID(S)$ is the unique identification number of the unit, which is generated in the first link of business chain and will be transferred unchangeably to every node of the entire chain. The location information is

Table 2
The performance requirements for RCBTS.

Performance requirement	
Automation in data acquisition	The system can automatically monitor and transmit information. The data processing should be completed automatically by the system.
Reliability of the system	The system can function steady in any environment. No faults in data input and database connection.
User-friendliness	The GUI must be friendly. The software and equipment should be easy to learn and use for users.

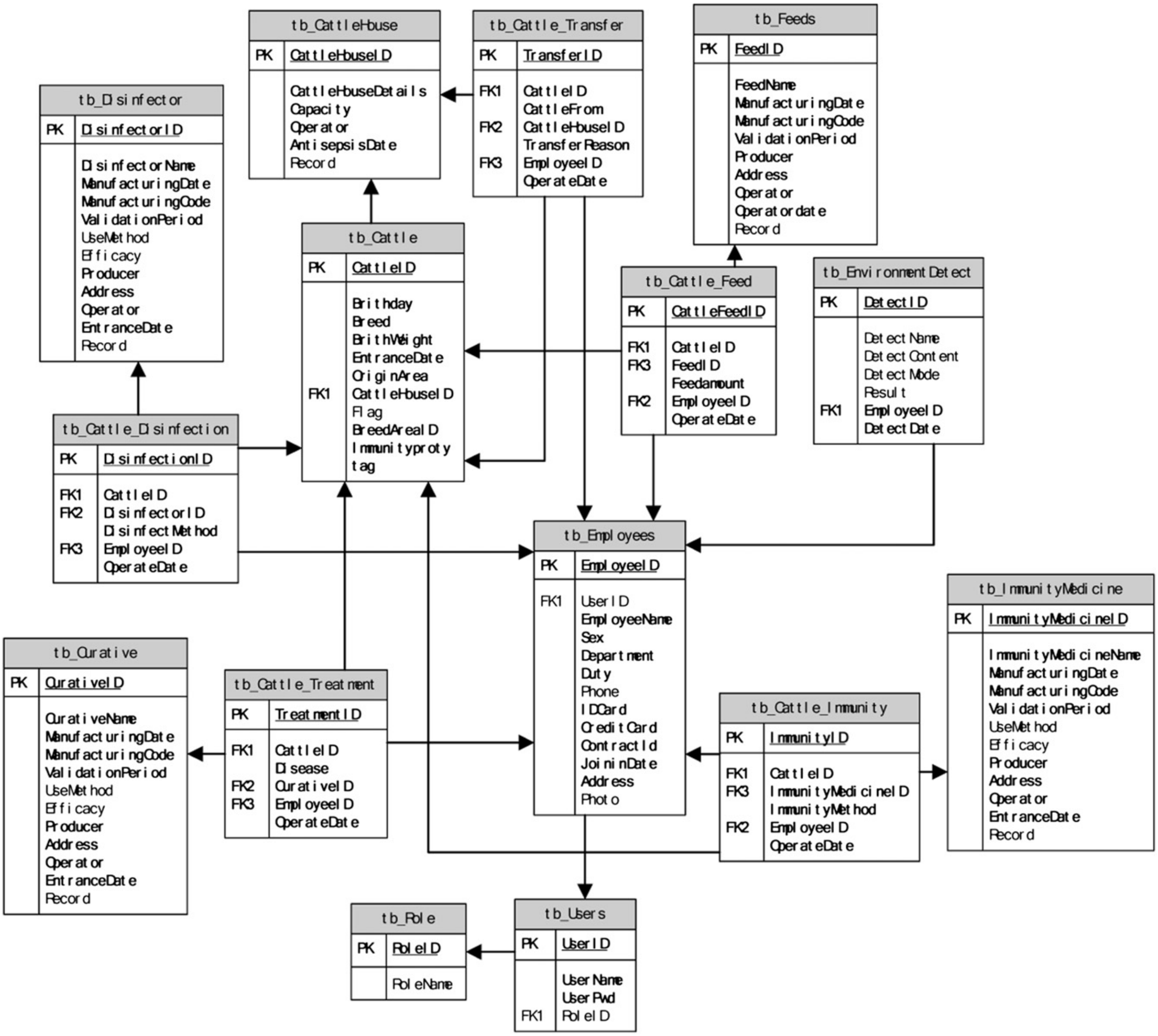

Fig. 3. The database E-R (entity-relation) diagram of cattle breeding process in RCBTS.

described by *Loc*(*S*); *Matt*(*S*) denotes the attributes of the unit; *Infor*(*S*) refers to the key information in quality tracing and tracking; *Oper*(*S*) denotes the operator; and *Date*(*S*) refers to the time when the unit exchanges information.

In breeding process, the traceable unit is an ox or a cow that passes the sanction inspection and quarantine, which is described as S_1 and the corresponding traceability formula is $P_t(S_1)$. When the ox or cow is moved into the slaughterhouse, the traceable unit is still the ox or cow and the formulary description is $P_t(S_2)$. Traceability unit transforms into a half of the cattle carcass after the carcass is divided into the dyads and the formula is $P_t(S_3)$. Then, traceability unit transforms into a quarter of cattle carcass after it is segmented into the tetrads and the formulary description is $P_t(S_4)$. In segmentation process, the traceability unit changes into 1/8 or 1/10 of the cattle carcass which is described as S_5. After segmentation, the traceability unit is the beef product which is defined as S_6 and the formula is described as $P_t(S_6)$.

Fig. 4 illustrates the transformation process of traceable units during the business flow in the cattle/beef chain. Table 3 details an instance of the traceability units transformation based on the formulary descriptions given that the initial value of *ID*(*S*) is 237052300000001.

3.2. Identification method for traceability units

There are three types of identification technologies available:

- Alphanumerical code, alphanumerical code-based management requires significant human resources because writing and reading the code are not automatic (Regattieri, Gamberi, & Manzini, 2007).
- Barcode technology has the limited capacity of processing powerful data because it relies on the laser-scanning device to read and process data in a close distance (Xiao et al., 2007).
- RFID technology, which applies radio frequency to identify objects and provides reliable and efficient tracking for the RFID tag, can store/retrieve data wirelessly and electronically (Voulodimos, Patrikakis, Sideridis, Ntafis, & Xylouri, 2010), so it works as a "mobile database" because of its high storage capacity.

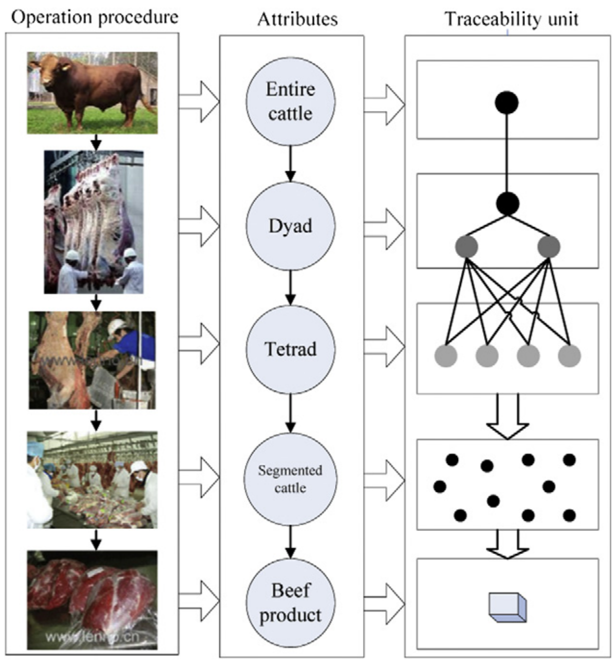

Fig. 4. The transformation of traceable units during cattle/beef production business flow.

Table 4 illustrates the comparison of different RFID technologies (Lu et al., 2009).

Following the comparison of these different identification technologies, RFID technology was adopted as the identification method and the carrier for traceability information in the RCBTS.

The high frequency (HF) RFID tag with 1 Kbit capacity was selected and redeveloped as the cattle identification tag (usually the tag was stuck into cattle's ear and named as "ear label"). The storage area was divided into 32 blocks (each block was 4 bytes). The first two blocks stored 64 bits UID defined by ISO/IEC15693-3, the next two blocks stored the command statements, and cattle's individual information was written in the rest of the 28 blocks. The information included cattle's identification number, the breed, date of birth, place of birth, weight of birth, the farm code, immune state, quarantine status and treatment records (see Fig.5). The information was written into the ear label by a 13.56 MHz RFID Reader/Writer device which connected with the PC platform.

The data transformation and transmission in beef segmentation link were more complex. In order to achieve the fast speed of data transmission during traceable units' transformation, it was necessary to choose a kind of higher efficient device that could read/write data at one time when there were more RFID tags. Considering that UHF RFID had the capacity of reading a large number of tags simultaneously ranged in 3–9 m at high read speed, UHF RFID tag was adopted as the data exchange carrier in beef segmentation and processing process.

The identification code was encoded according to the Decree No. 67 issued by the Ministry of Agriculture of the People's Republic of China (MOA, 2006). The code consisted of 15 digits: the first digit represented the type of livestock; the next six digits referred to the administrative region code of the county (city) in terms of GB T2260_1999 (NBSC, 2006); and the final eight digits were the sequence order numbers (MOA, 2006; Xiong et al., 2010).

3.3. Implementation of traceability information acquisition and transmission

3.3.1. The implementation of traceability unit S_1

PDA (personal digital assistant) P130, embedded with a RFID reader module, was adopted in the RCBTS as the HF RFID reader, which had 16 M bits flash for program space and 16 M bits flash for user data space. The PDA was redesigned and developed as the data acquisition and storage device to record information in cattle breeding process. The traceability information for traceability unit S_1 was stored in the user data space. The memory usage was shown in Fig. 6.

When the herd keeper records the new traceability information into RCBTS, he/she firstly reads cattle's identification number from RFID tag via the PDA, and then inputs the new relevant daily breeding information into the PDA, such as the name of feed, amount of feed, feed code, etc. The new records are temporarily stored in the PDA memory until the herd keeper collects all of routine management data and transfers all records into PC through a serial port line.

3.3.2. The tracking and transmission of traceability unit S_2–S_6

When an ox or a cow is moved into slaughter line of the slaughterhouse, the operator reads the data stored in the ear label by the PDA, and then copies the data into another two RFID tags; when the ox or cow is slaughtered and divided into dyads, the two RFID tags are respectively adhered on the hind hoof of the two dyads, and the information in the tag is transferred with the dyad to the next processing node. When the dyad is segmented into the tetrad, the operator needs to set four copies of the RFID tags, each tag is attached on each of the tetrad. In segmentation node, the traceable units change from four to eight or ten units, and the operator acquires the information in HF RFID tags by UHF reader and copies these data to eight or ten new UHF RFID tags. In packing workshop, the operator adds new information about beef products into each UHF RFID tag by the UHF reader devices; at this point, all the traceability information has been obtained and stored, and the end-products with complete traceable information are ready for sale in the market. Finally, the operator prints a 2D barcode label by code printer placed at the packing workshop and attaches the label at the package of final beef product.

The process of traceability units' transformation and information transmission is summarized as below:

$P_t(S_1)$: S_1 is the first traceability unit in the business flow. At this point, HF RFID ear label is applied to record cattle's individual

Table 3
An instance of the traceability units transformation in cattle/beef production business flow.

	ID(*S*)	*Loc*(*S*)	*Matt*(*S*)	*Infor*(*S*)	*Oper*(*S*)	*Date*(*S*)
$P_t(S_1)$	237052300000001	Breeding farm	Entire cattle	Feeding, medical treatment, etc.	Herd keeper	T1
$P_t(S_2)$	237052300000001	Holding pen	Entire cattle	Ante-mortem inspection status.	Veterinary	T2
$P_t(S_3)$	237052300000001	Slaughterhouse	Dyad	The information about the two halves of cattle carcass.	Slaughterer	T3
$P_t(S_4)$	237052300000001	Slaughterhouse	Tetrad	The information about the four quarters of cattle carcass.	Slaughterer	T4
$P_t(S_5)$	2370523000000010x	Segmentation workshop	Segmented cattle	The information of the segmented beef.	Slaughterer	T5
$P_t(S_6)$	2370523000000010x	Cold storage	Beef product	The weight and name of the beef product.	Packing worker	T6

Table 4
The comparison of different kinds of FID technologies.

	Frequency range	Read range	Cost	Security
Low frequency (LF)	125–134 kHz	<0.5 m	Low	Not good
High frequency (HF)	13.56 MHz	1–3 m	Lower	Good
Ultra High frequency (UHF)	400–1000 MHz	3–9 m	High	Normal
Microwave	2.45 GHz	~10 m	Highest	Normal

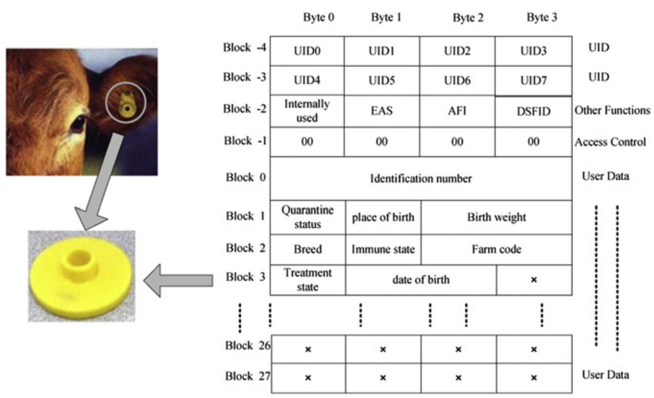

Fig. 5. The data stored in RFID ear tag in RCBTS.

information and store the information in cattle breeding process.

$P_t(S_1) \rightarrow P_t(S_2)$: The operator reads the information stored in RFID ear label by the PDA, and then writes the ante-mortem inspection information into the RFID tag.

$P_t(S_2) \rightarrow P_t(S_3)$: The operator applies PDA reader to acquire the information in RFID ear label of S_2 and transfers the information into another two RFID tags; each of the two tags is adhered to the hind hoof of the cattle dyad.

$P_t(S_3) \rightarrow P_t(S_4)$: The operator repeats the procedure in the previous step and transfers the information from S_3 to the new four RFID tags, each of which is attached to the cattle tetrad and used for identifying traceability unit S_4.

$P_t(S_4) \rightarrow P_t(S_5)$: The operator acquires the identification information in traceability unit S_4 by UHF reader and writes the data into eight or ten new UHF RFID tags.

$P_t(S_5) \rightarrow P_t(S_6)$: The operator updates the information about beef products into UHF RFID tags and adopts the barcode printer to switch the carrier of identification information from RFID tags to the 2D barcode labels. Finally, all data about the cattle/beef are attained and stored in the 2D barcode label that pasted on the package of the beef product.

Fig. 7 illustrates the whole process of data transformation and transmission between traceable units in RCBTS, which integrated PDA, HF RFID reader, UHF RFID reader with barcode printer.

4. System design and implementation of the RCBTS

4.1. System development environment and system architecture

The RCBTS provides an integrated framework for the cattle/beef identification and traceability function from cattle breeding to end-product. The types of hardware and software used for developing the system and the operational environment are listed in Tables 5 and 6.

The RCBTS consists of three subsystems: the breeding management system, the slaughter management system and the retrieve system (see Fig. 8).

4.2. The breeding management system

Fig. 9 illustrates the framework of the cattle breeding management system, which consists of two modules:

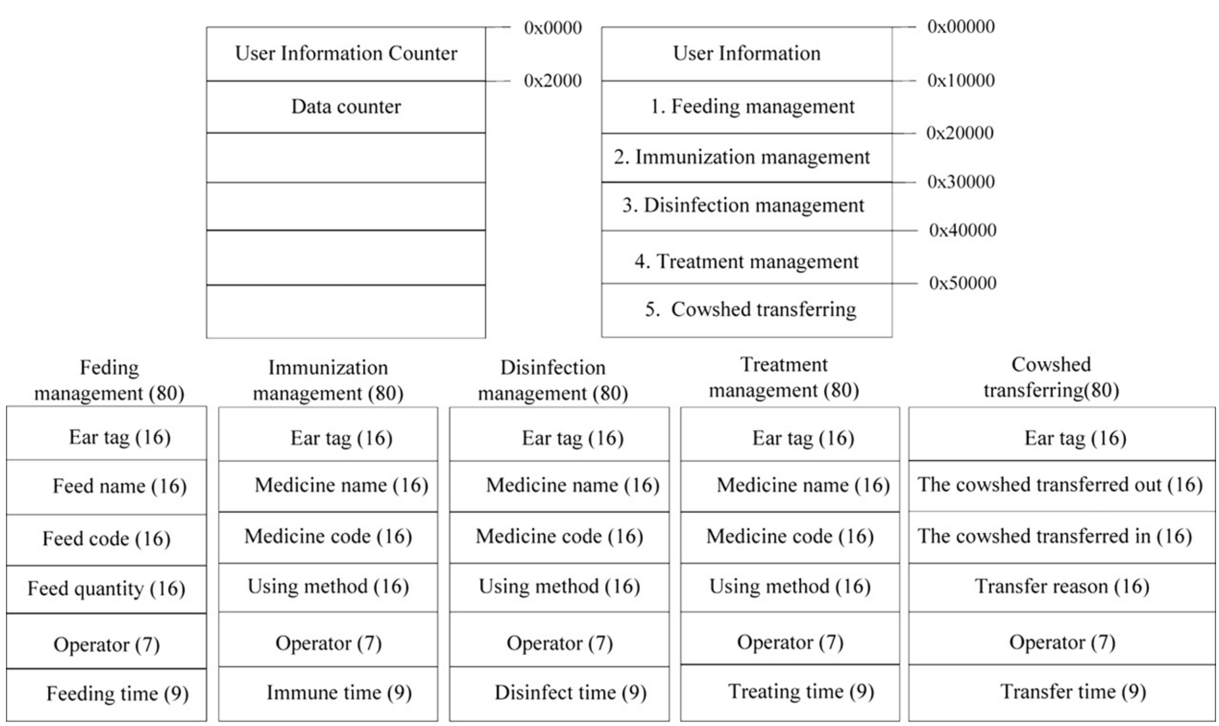

Fig. 6. The memory usage of redesigned RFID label for RCBTS.

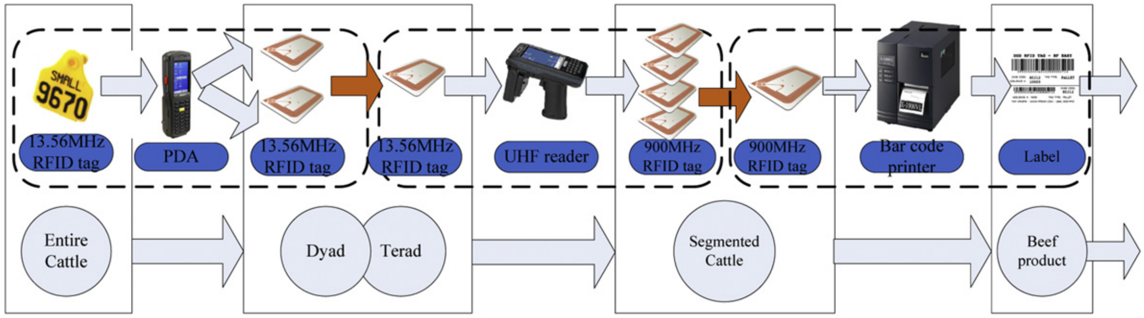

Fig. 7. The process of the data transformation and transmission between traceable units in RCBTS.

- The PDA-based module is designed for data acquisition during the cattle breeding process. The herd keeper reads the identification code in cattle's ear label and inputs the breeding information by the PDA combined with RFID reader. The information is then stored in the PDA and transmitted to the database in PC platform through USB interface.
- The PC-based management module is designed for cattle identification and the daily management. It can provide the functions of managing farm information, receiving data from the PDA, and writing cattle's identification information in RFID tag (Voulodimos et al., 2010) (see Fig. 10).

4.3. The slaughter and processing management system

Integrated with fixed UHF reader, PDA and barcode printer, the slaughter and processing management system performs the functions of data exchange and transfer in the slaughter and processing process. Supported by this subsystem, a worker reads the information from the PDA, then transmits the data to UHF tags, and finally transforms the carrier of traceability information from RFID tags to 2D barcode labels. Fig. 11 shows the terminal print interfaces of the slaughter and processing management system, which represents the information of traceability code, name of product, weight of product, the producer, production date, production place and the website of the producer.

4.4. The traceability information retrieval system

The retrieval system provides an interface for consumers to retrieve the traceability information of the end-products. Consumers can input the traceability code via three types of inputting devices, i.e. keyboard, touch screen and barcode scanner, and then the system retrieves the details of the traceability information. Fig. 12 shows the retrieved information by consumers at the terminal, which displays all the traceable information at each stage of the business flow, i.e. the information of the beef product (product name, weight and production place), the information of the producer (enterprise's name, address, contact number and website), the breeding information (date of birth, place of birth, weight of birth, immunization records, treatment records, feeding records, disinfection records and the cowshed transfer records), and the processing information (quarantine status, the slaughter approval number, date of slaughter, the time of acid decomposition treatment and the certification information), etc.

Table 5
The hardware deployment of the RCBTS.

Devices	Model and parameter
PDA	Uniposs P130: Linux operating system, 32-bit ARM processor, 2 M RAM + 32MSDRAM, Built-in RS232 serial port, 15,000 mAh Rechargeable lithium batteries.
PC	Internet™Core™2 Duo CPU E7200 2.53 GHz, 2 GB memory, 250G hard disk.
The RFID reader	ThingMagic_M5, Antenna is MTI8-Thing Magic-ANT-NA-2CO Model.
Industrial printer	SATO: LM408E, Print mode: Heat transfer/thermal.

5. System evaluation of the RCBTS and results analysis

5.1. Evaluation method for the RCBTS

There are two types of evaluation methods for information system, which are formative evaluation and summative evaluation.

Table 6
The RCBTS development and operational environment.

System	Operating system	Development tools	Development language
PDA: data acquisition system	Linux	CYGwin	C
PC: management system	Windows 2003 server	Visual Studio 2005, SQL Server 2005	C#, XML

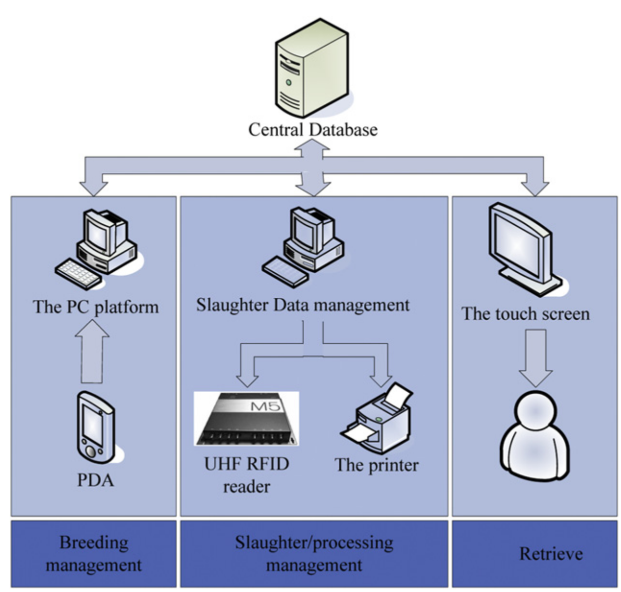

Fig. 8. The system architecture of RCBTS.

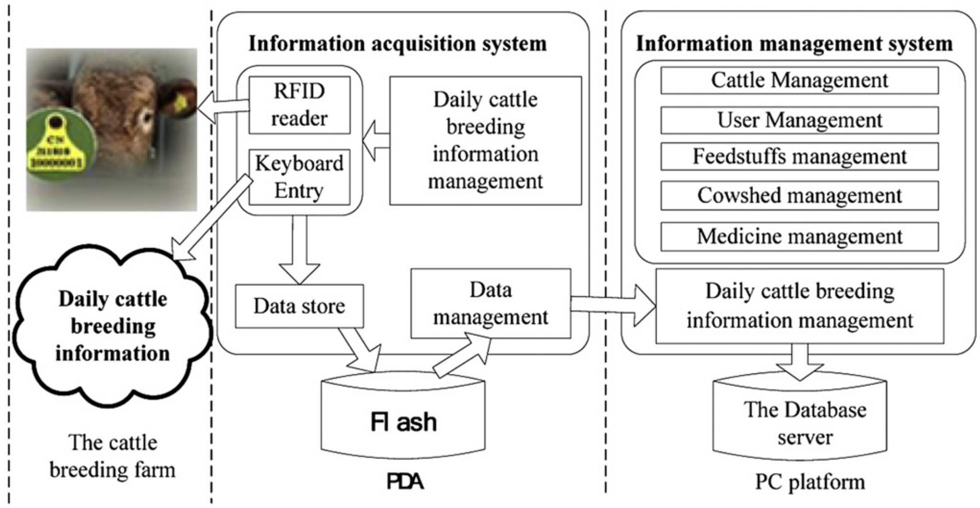

Fig. 9. The framework of the breeding management system.

Formative evaluation takes place before system implementation, and the feedback is used to influence the system design. Whereas, summative evaluation takes place after implementation and aims to test the proper functionalities of the final system (Coskun & Grabowski, 2005; Uden, 1995). In this study, the summative evaluation was adopted to test the RCBTS. The evaluation criteria for the RCBTS are listed in Table 7.

The system evaluation was carried out following several steps as outlined below:

5.1.1. Sampling

The system users were sampled from a selected cattle/beef companies in the supply chain in Tianjin. All the participants agreed to take part in the system trial and provide their feedback and comments.

5.1.2. Test preparation

The main tasks of preparation for system trial were setting up program/devices and training the participants. All devices (2 computers, 1 code printer, 13.56 MHz RFID readers and 900 MHz RFID readers) were set up in farms and the slaughterhouse, where the RCBTS and its running environment had been installed. A workshop was held in the slaughterhouse in March 2010 to train the participants about using and operating the system. Furthermore, a user guide of the RCBTS was provided to the participants for reference.

5.1.3. System evaluation and feedback collection

System trial was carried out in two phases. Ten calves were sampled by the system developers in July, 2010; the information of each calf was recorded in the RFID ear label, which was pierced in calf's ear. Herd keepers recorded the breeding information for these cattle every day by PDA and PC platform during the breeding period.

Three months later, three qualified oxen were sent to the slaughterhouse as the initial trial and the other were used for the trial of the optimized system. The information in each ear label was copied to another two RFID tags through PDA, and then each of the

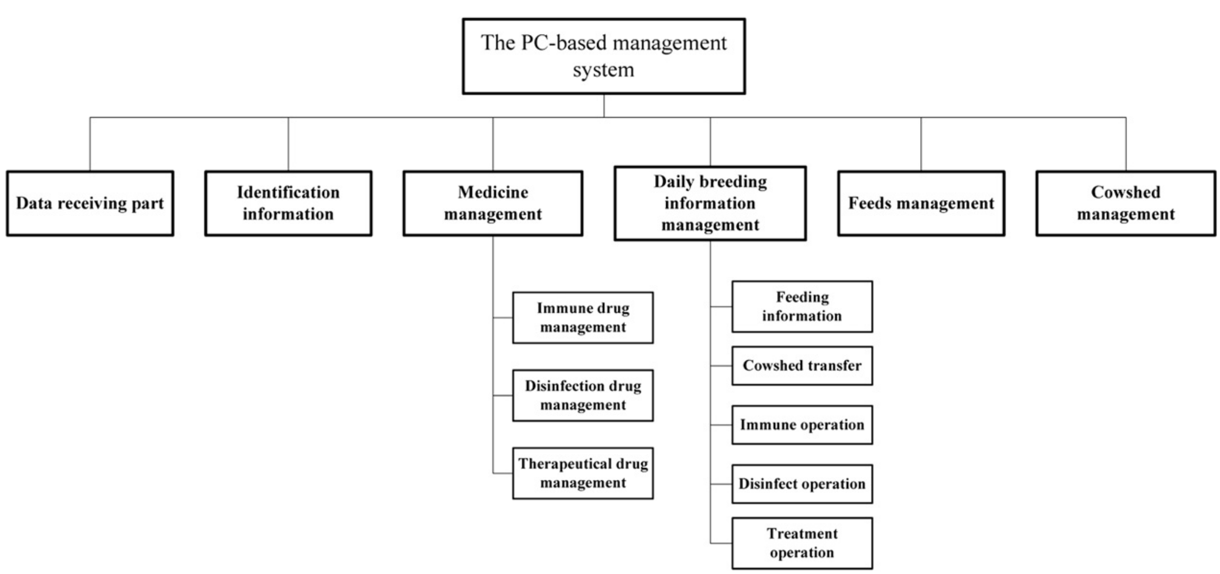

Fig. 10. The architecture of the whole PC-based subsystem of RCBTS.

Fig. 11. The interface of the slaughter management subsystem.

two tags was adhered to the hind hoof of the dyad of the cattle carcass (divided from the same cattle); when the dyad was segmented into tetrad, four RFID tags were copied and each tag was attached on each of the tetrad, and then the tetrad was transferred to the segmentation workshop after the acid decomposition treatment process. In segmentation workshop, operators applied UHF reader to copy the data into eight UHF RFID tags, each of which was to be attached to each segments. Before the end-product was packaged, the packing staff read the information in UHF RFID tag by UHF reader and printed barcode label through the barcode printer, and then attached the label on the product external wrapping.

During the trial process, system users were encouraged to explain the details of the performed tasks and encountered difficulties. The feedback and comments were recorded by a designated system designer, which would be discussed in the next section.

5.2. Evaluation results and discussion

Voulodimos et al. (2010) reported that accurate and highly sophisticated management of animal capital could be performed with the adoption of RFID technology. The evaluation results also showed that application of the RCBTS could provide real-time and

Fig. 12. The interface of the retrieve system.

Table 7
The evaluation criteria for RCBTS.

System performance	Evaluation criteria
The functional performance of the RCBTS	(a) System usability (b) System reliability (c) System flexibility
The operating performance of the RCBTS	(a) Displaying characteristics (b) Ease of learning (c) Complexity of user interface (d) Interface satisfaction (e) Operator understandability (f) Implementation cost

accurate data acquisition and transmission enabled by RFID technology, and consequently achieve information traceability across the cattle/beef supply chain. However, the system showed some insufficient. Table 8 lists the benefits and deficiencies of the system extracted from users' feedback.

Inputting traceability information was perceived to be complex and time-consuming for herd keepers. More time was needed for inputting the name of feeds (or medicines) because Chinese Pinyin input method that provided by PDA was not easy to use for them. To solve this problem, alternative input methods, i.e. menu input and code input method were provided in the new updated PDA device.

Another notable barrier was associated with data input and communication using the RFID reader. In cattle breeding process, the data input sequence was designed as "read tag → input data → read next tag → input data", the operator had to input the same feeding information every time when he/she created information for different cattle. Because the feeds for the cattle at the same growing stage remained the same and stable, duplication of the same feeding information on different cattle wasted time and caused data integrity problem. The new sequence was optimized as "input the common data → read tag → read next tag", so that the operator can input the same feed information in PDA once and then the data can be shared for different cattle. The optimized inputting mechanism proved itself to be timesaving, especially in the circumstances that a large number of cattle records needed to be processed.

Table 8
The results of the system evaluation.

Index	Result
System usability	The system can realize the function of each module. The system can automatically acquire, transmit and processing data.
System reliability	The breeding PC subsystem can operate well in the farm. The PDA subsystem has a disconnection problem with the PC part.
System flexibility	The RFID in the ear tag sometimes would be unintentionally destroyed when herd keepers attempted to attach it on cattle's ear.
Display characteristics	The responses to the color of the background, the font and the layout of the system are good.
Ease of learning user interface	Users can quickly learn how to use the PC platform in the breeding subsystem and the retrieve system based on the user's guard.
Complexity of user interface	The PDA-RFID platform is not easy to use because the inputting information and reading RFID ear tags are complex for the farmers.
Interface satisfaction	The interface of the PC platform and the slaughter system are satisfied.
Operator understandability	The interface in this system is easy to understand by the operators.
Implementation cost	The implementing cost of RFID label is out of expectation.

RFID technology adopted by the RCBTS entailed three major functions: identifying cattle, acquiring breeding data and transmitting traceability data. The evaluation results showed that the application of RFID technology can improve automation, efficiency and convenience of the traceability system. Nevertheless, at least seven 13.56 MHz RFID ear labels and eight 900 MHz RFID tags were required to track one calf from breeding to slaughtering in the sampled scenario, even had not taken into account of the possible damage of RFID tags during the system running. The price per RFID tag was around 2–4 CNY in 2010, the total cost was about 40 CNY for tracing an ox or cow. Over 95% interviewees complained the cost was too expensive. Therefore, how to reduce implementation cost was an important issue. There are two possible solutions for the cost reduction: one solution is to recycle the RFID tags from the consumers and reuse, but it would be difficult to be implemented due to the shortage of the recycle channels and costs; the other solution is to replace all the RFID tags as the kind of RFID tags with more store capacity (i.e. 900 MHz RFID tags); although there would have some storage redundancy during the breeding process, the tags could be easily recycled in the segmentation process.

6. Conclusion

This paper developed and tested a RFID-based cattle/beef traceability system for the implementation of real-time traceability management along cattle/beef production flow. The system adopted RFID technology, PDA and barcode printer to accomplish the acquisition and transmission of traceability data in cattle/beef supply chain. System trial results showed that the RFID-based traceability system could greatly improve automation, efficiency and convenience in cattle/beef enterprises management as a controlling tool for product quality and safety.

System evaluation was conducted in sampled enterprises in the cattle/beef supply chain in China. Although the interviewees perceived that traceability system can improve their management efficiency and ensure product quality, there existed some barriers for system adoption: the inapplicable method of inputting information, the inefficient sequence of data input and communication mechanism associated with RFID reader, and the high implementation cost. The first two problems arose from the operators, who expected the system to be easy to use and maintain, and the barriers were resolved and optimized by system developers. The cost issue was a concern by most managers, who anticipated the system to be cost effective and high compatible. It is suggested that the cost could be cut down through recycling RFID tags in the supply chain.

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