Modeling Method of Traceability System based on Information Flow in Meat Food Supply Chain

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Abstract: Over the last decades, the food safety issues become more and more important, such as BSE crisis, genetically modified organism (GMO) illegal spreading and melamine-contamination event. The food industry established a traceability system to reduce the impact of food safety issues, and the system became an effective method of guaranteeing the food safety. The purpose of this paper is not only does the traceability system traces the process information but also reduce the batches of recall. We study the traceable information flow and risk transmission throughout food supply which contains raw material, process and distribution. A mathematic model based on dynamic programming was proposed to solve the risk transmission problem in a China dumpling factory, and Radio Frequency Identification (RFID) is used to identify and transfer traceable information in this study. The results show that factory can plan the produce s schedule effectively according the mathematic model to decrease redundancy of information, and the information flow model is the fundament of traceability system. Applying of RFID system can enhance the ability about information gathering and transmitting.

Keywords: traceability; information flow; mathematical model; dynamic planning; food safety

1 Introduction

Over the last decades, the food safety issues became more and more important, such as BSE crisis, genetically modified organism (GMO) illegal spreading and melamine-contamination event. So, establish a traceability system becomes an effective method of guaranteeing food supply security and providing safer food to consumers.

A good traceability involves precise information management, which means trace the location exactly and track the history of products truly throughout the entire supply chain. However, the food process is too complicated to locate the source and the terminal of a food safety crisis, because different batches of raw materials are change into different production batches and finally are distributed to different pos point of sales. Now, many papers in literature research the traceability system from an information management point of view. Those studies can't solve the defective products recalled issue. We propose a new method based on dynamic programming and integer programming to improve the traceability system.

The research points in this paper are how to locate the food hazard transmission and how to control the risk expansion during a food supply chain, which includes different batches of raw materials, products and pos point of sales. Thus, in a food safety crisis, a factory can minimize the batches of the food recalled and reduce the impacts to the consumers from defective products.

During the past food safety crisis like BSE crisis, factories are forced to establish a traceability system to decrease the quantity of the recalled products and reduce the impacts to the consumers. Such risk transmission problem can also be found in the

Chinese dumplings industry, we take this industry as an example to illustrate my model which can improve the traceability system and minimize the quantity of the recalled products.

Background and literature of traceability in food industry are described in section 1 and we provide the material and methods in the 2nd part. In section 3, we propose a mathematical model based on integer programming and dynamic programming. The formulation is to minimize the tracing risk transmission sum of all raw material batches, product batches and distribution batches. Finally, we discuss the application of the model in the food traceability system.

1.1 The traceability in food industry

The establishment of a traceability system in the food industry has received broad attention. Food safety, food quality, and consumer transparency are some driving forces of the tracking and tracing system.

The Codex Alimentarius Commission (CAC, 1999) defined traceability as the “ability to trace the history, application or location of an entity by means of recorded identifications” [1]. Regulation (EC) No.178/2002 and ISO 8402:1994, define traceability as the ability to trace and follow a food, feed, food producing animal or substance intended to be, or expected to be incorporated in to a food or feed, through all stages of production, processing and distribution[2-3].

Traceability can be divided into two key functions, tracking and tracing. Tracking can be defined as the ability to follow the path of an item as it moves downstream through the supply chain from the beginning to the end. Tracing is the ability to identify the origin of an item or group of items, through records, upstream in the supply chain [4].

The two aspects of traceability should be distinguished before starting our study, many traceability systems can only satisfy the tracing needs, but useless for the tracking needs. The mathematical model in this paper can meet the tracking demands of the traceability system.

Many countries required establish traceability system in food industry through legislation. In the European Union, traceability system is required in all stages of the food supply chain, such as beef, fish, GMOs (genetically modified organisms), etc. A food factory must register and keep process information, such as supplier, producer, dates of transaction/delivery, volume or quantity, batch number and a more detailed description of the product. This requirement is applicable since 1st January 2005[2].

After the events of September 11, 2001, the USA Congress passed a law which is the Public Health Security and Bioterrorism Preparedness and Response Act. Under that law, the FDA has authority to order the detention of any food, if as determined during an inspection, examination or investigation, there exists ‘‘credible evidence or information’’ indicating that the article ‘‘presents a threat of serious adverse health consequences or death to humans or animals’’ [5], and the law calls for one-up/one-down traceability for each link in the supply chain. This regulation requires that each company in the supply chain keeps information about the company that they received the products from, the company who delivered the product to them, the company who took it away, and the company they gave the products to [6].

In Canada, Australia and New Zealand a trace back system based on tagging was established in 2001, in Japan as well strict rules have been established in the same year, and in Brazil and Argentina traceability systems are in use [7].

1.2 review of the literature

Kim, H.M., Fox, M.S. Gruninger, M(1995) defined that traceability is the ability to track a product batch and its history through the whole, or part, of a production chain from harvest through transport, storage, processing, distribution and sales. They proposed the concepts of Traceable Resource Unit (TRU) and primitive activity. A TRU is a homogeneous collection of one resource that is used/consumed/produced/released by a primitive activity in a finite, non-zero quantity. The TRU is a unique unit (batch), and there exist a primitive trace between a TRU and a primitive activity [8].

Moe(1998) have defined for each core entity a set of essential descriptors that must be included in order to secure ideal traceability of products and activities. Each of the essential descriptors is then qualified using sub-descriptors taken from purchase, production, measurements etc. He introduced the concept of chain and internal traceability, and presented many advantages from establishing traceability system [9].

L. Ruiz-Garcia, G. Steinberger, M. Rothmund (2008) presented an architectural proposal and used a web-based systems for data processing, storage and transfer along the food supply chain. The proposed solution is tested by the implementation of a prototype. So this traceability system could trace batches and processes information according to two different services, one for horizontal trace batches information and one for vertical process information [6].

C. Dupuy, V. Botta-Genoulaz, A. Guinet(2002, 2005) tried to control the mixing of production bathes in order to limit the size, and consequently the cost and the media impact of batches recalled in case of problem. In order to evaluate the accuracy of the traceability in the production process, they define the batch dispersion problem. And such a “dispersion problem”, encountered in the sausage industry has been modeled, solved and experimented. Finally, a mathematical MILP model is proposed [10-11].

A. Regattieri, M. Gamberi, R. Manzini (2007) analyzed legal and regulatory aspects of food traceability, and provided a general framework for the identification of fundamental mainstays and functionalities in an effective traceability system. The result of a project based on RFID technology were presented, which focused on the traceability system develop for the famous “Parmigiano Reggiano” cheese. Based on an integration of alphanumerical codes and RFID technology, the system is working well [12].

A.F. Bollena, C.P. Ridena, N.R. Coxb(2007) developed a mixing model to assign the probabilities of bin origin to individual fruit at the point they are packed into their final packs, the model can significantly reduce fruit mixing and improve traceability. They introduced the concepts to quantify aspects of processing transformations, Implementation of a model to enable simulations that examine the effect of splitting throughput into multiple output lines. The research suggests there is a potential to implement high-precision and fine granularity traceability in the agricultural supply system [13].

C. J. Garrido, M. R. Marin, L. J. Saez est. (2007) proposed a traceability information model for spread e-manufacturing environments to address common traceability data management problems in spread supply chain networks. The model is defined as an explicit link between the traceability data and the standardized product data structure [14].

In order to increase the traceability system usability, also minimise the risk during production and maintenance of software projects. Kernahan Michael, Capretz Miriam A.M., Capretz Luiz F (2005) proposed a system outlined to extracts traceability information directly from the source code of C# projects, and presents it in such a way that it can be easily used to understand the logic and validate changes to the system[15].

Radio Frequency Identification (RFID) system is also used in manufacture. In order to improve product quality and store a product history, starting from development and manufacturing phase until it reaches the end of its lifecycle. Based on possibility of a smart tag attachment to a product and going along with the idea of decentralizing an assembly line, Vlad Mdlin Stefan, Sgârciu Valentin (2007) propose a system which can be implemented at every operational point within an assembly line [16].

2 Materials and methods

2.1 A case of Chinese dumpling factory in Beijing

The case studied in this paper comes from a Chinese dumpling factory in Beijing. The company produces a variety of Chinese dumplings using different fillings. The fillings are mixed together by various ingredients, such as pork meat, beef, chicken meat and vegetables. Then, the filling ingredients are enclosed in flour and water dough. The processing flowchart of making Chinese dumpling is showed as Fig. 1.

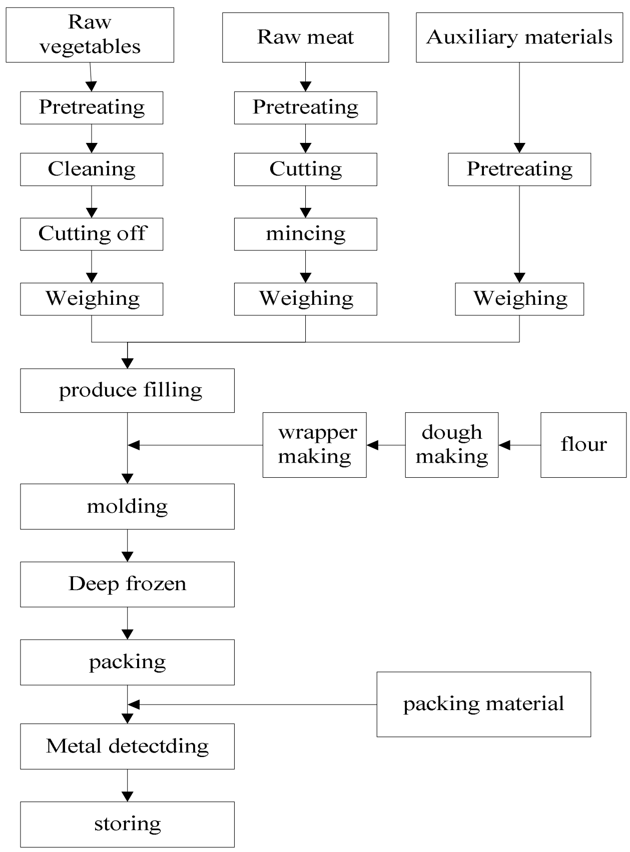

Fig. 1 processing flowchart of china dumpling

2.2 Survey in the factory

We have surveyed the factory for weeks. Firstly, we surveyed the production technology, equipment and process of Chinese dumpling. Those survey results contributed to analysis of the risk transmission problem under study. In the Chinese dumpling process, the ingredients of filings come from variety batches, and the flour batches are different. The raw materials with variety batches create products with variety batches. The finished products are distributed to variety pos points of sales with different batches. Next, we interviewed the quality control (QC) manager about the hazard and risk management of Chinese dumpling. The main food safety problems of Chinese dumpling come from the fillings which contained meat. And the factory is interested in establishing a traceability system to control the food hazard. The object of establishing the traceability system is to reduce the quantity of recalled products. Those views can be obtained from the survey.

- The main purpose of establishing a traceability system is to improve the process control of food and to reduce the recalled quantities.
- The main difficult of improving accuracy of traceability is analysis of the information flow of material along the food process, and identify traceability information at every stage.
- In the food process, the batches information transfer disorderly along the food supply chain. This problem can be solved through planning and optimizing the schedule of manufacture process.
- Establishment of traceability system in food industry could enhance products brand awareness and enhance consumer's confidence in food safety.
- The factory is willing to establish traceability system in order to increase the sales of products and meet regulation requirements.

2.3 Dynamic programming

Dynamic programming is a branch of operations research, a mathematical optimization method for solving the decision-making process. The dynamic programming theory was advanced by R.E.Bellman in the 1950s to study the multi-stage optimization problem in the decision-making process. It is an important means of programming widespread applied in many industries. Since dynamic programming theory has advanced, it has been widely used in the economic management, production scheduling, engineering and optimal control.

In the traceability information flow process, any given problem is subdivided into smaller sub problems, which are sequentially solved until the initial problem is solved by the aggregation of the sub problem solutions. Dynamic Programming approaches can be seen as transformations of the original problem to the one associated to the exploration of a multistage graph G(S, T), where the vertices S are associated to the state space and the arcs T to the set of transitions, where an optimal policy is sought. The optimality principle states that an optimal policy should be constituted by optimal policies from every state of the decision chain to the final state [17].

In this paper, we define a set of states to describe the TRU (trace resource unit) in Chinese dumpling supply chain. The states of stage k can be transformed to the states of the stage $k+1$ by using a transition. A transition indicates the process adopted in a stage, such as reception of raw material, process and distribution.

2.4 RFID

Radio Frequency Identification (RFID) in general means technology that uses radio frequency to identify product or object. RFID is combined with tags, readers, middleware, and application system. Through tags and readers establish communication, information system can control readers by middleware or ask readers read and write data to tags directly [18]. The transponder consists of a microchip storing the serial number that is attached to an antenna for object tracking purposes. This transponder is called RFID tag. An active tag that has high computational task requires a battery to power up the connection, for the purpose of data transmissions to the reader. Passive tags require no battery and no on-tag transmitter. Passive tags draw power from the reader that send out electromagnetic waves using a specific radio frequency emitting power to the antenna of the tags thus enabling the data to be transmitted between RFID tags and the reader [19].

RFID is a non-contact automatic identification technology, it has unique advantages, such as a large amount of data storage, can read and write, farther messaging distance, stronger air-penetration, read faster, long service life, better adaptability of environment. It also is the only multi-target recognition automatic identification technology.

RFID is used to identify and transfer traceable information in this study. The accuracy of traceability information is the key point to trace product history or track product information. Using of RFID can improve the speed and accuracy in information collection process.

3 Results

3.1 Risk transmission problem of batches

Through the research in the factory, company wants to recall defective products immediately when raw materials were contaminated and threatened consumer's health. A model (Fig. 2) describing the general procedure of defective products recall has been proposed during the survey in the factory. The model contains three stages of tracing and two stage of identification. Along the physical flow chain, the risk transmits from raw material to pos point of sales. In order to recall defective products quickly and precisely, factory should record raw material information and process information correctly; also, the factory should identify the relationship among the batches of raw materials, products and distribution.

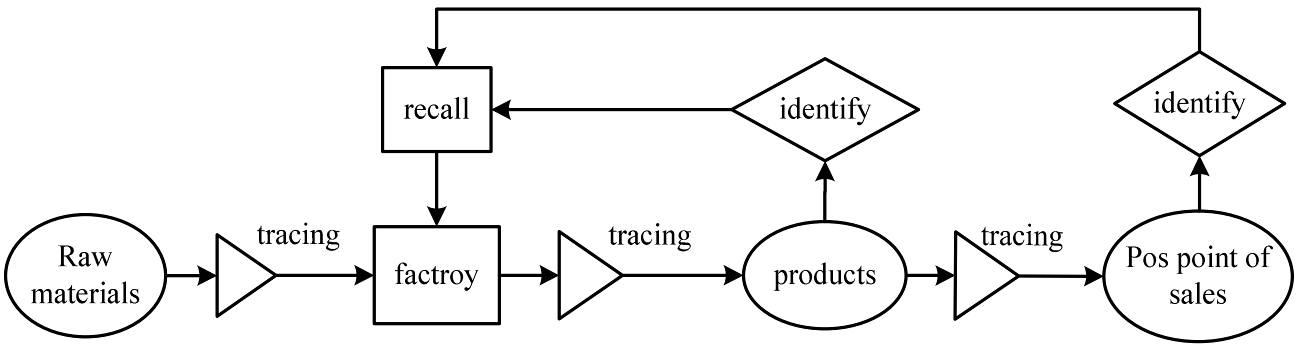

Fig. 2 the product recall model when raw material contaminated

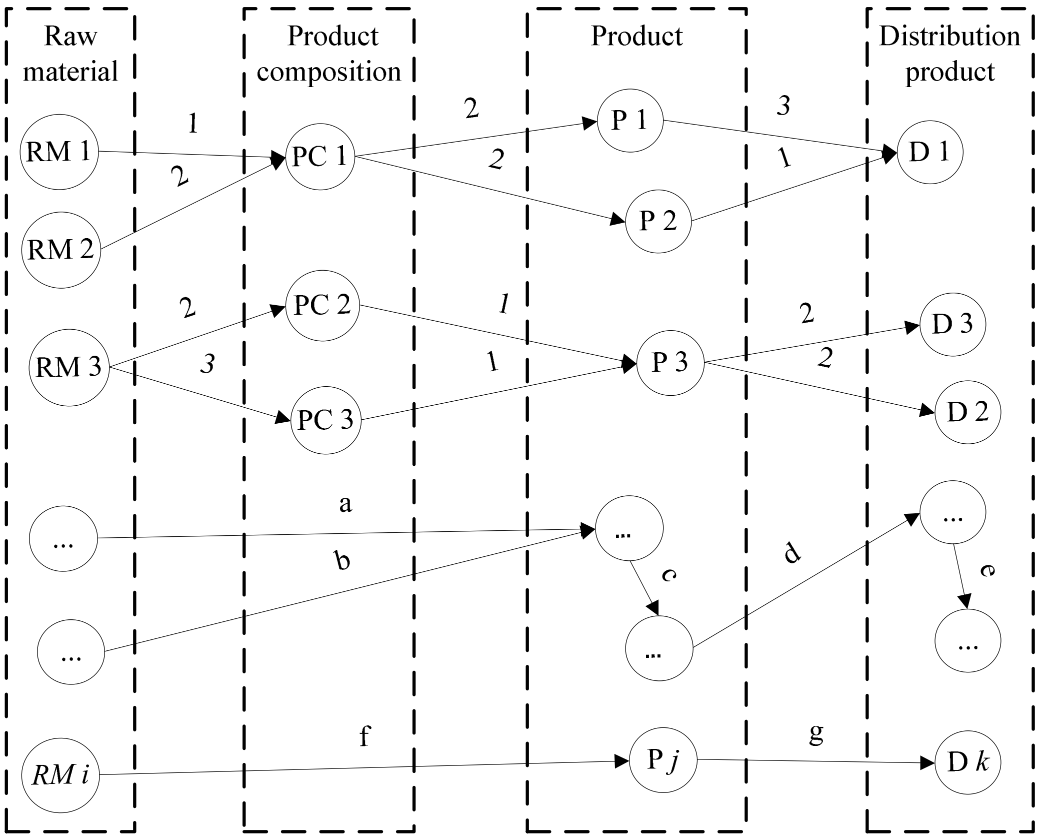

Fig.3 Gozinto graph model of dumpling batches transfer

The purpose of the study in the factory is to minimize the cost due to a food safety crisis. If a food safety problem comes from a raw material batch, the factory will trace and identify all products which contain the raw material, and recall those products from marketing quickly.

In order to evaluate the accuracy of the traceability in the production process, Dupuy(2002) introduced a new measures: downward dispersion, upward dispersion and batch dispersion.

In this process, the factory mixes all raw material batches i and produces products batches j . Further in the distribution process, production of batches j is delivered into different pos point of sales with distribution batches m . We propose a graphical model (Fig 3) to describe the risk transference problem, according to Gozinto graphs which proposed by C. A van Dorp[20]. In Fig 3, each node represents a batch and each edge represents a link between two batches.

This model can clearly describe the food material risk transmission problem. All types of raw materials in the Chinese dumplings are in a fixed proportion. Each kind of Chinese dumplings have its bill of material (BOM), which means all products are composed of given raw materials with a fixed proportion according to BOM. In the distribution chain, the products are delivered to different pos point of sales; this is bill of distribution (BOD). The BOM represents the Gozinto graph's information structure. The weight represents each relation between a sub-ordinate and super-ordinate process.

The result is, the factory receives several batches of raw materials, then, those batches of raw materials are processed into different batches of production which created many product batches, finally, different batches of products are delivered to many pos point of sales. This shows the supply chain is a complex process.

3.2 The TRU of batch

The process of Chinese dumpling involving different raw materials and several processing stages is so complex that the information identification is difficult. So the TUR which we select is the critical point of the traceability system. We define the TRU as each batch of food or material along the food supply chain. That means the minimum unit is a single batch in the traceability system. Fig. 4 shows that the TRU determines the tracking and tracing units and their transformation during processing and trading activities in the supply chain. In this graphical model, the batches transmission link to information transmission. The TRU is identified by batch information (BID).The TRU is transferred along the food supply, a TRU represents a bathe of material, product or distribution and it is identified by raw material batch ID(RMBID),product batch ID(PBID) or distribution batch ID(DBID) correspondingly.

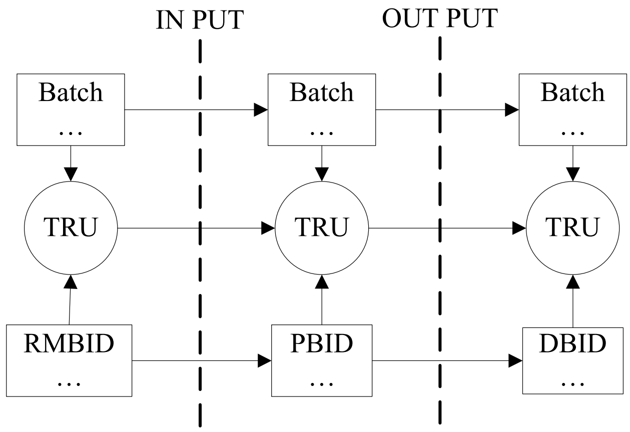

Fig. 4 the traceable resource unit (TRU) of batch along food supplies

The challenge of tracking based on batch is variable of the TRU (batch mixing). For instance, two different batches are combined into one batch during the process; one batch is divided into two batches during the distribution.

3.3 Mathematical model

A mathematical model is proposed to solve the information flow optimization and risk transfer problem. The variables are offered in the Talbe 1.

Dynamic programming is used to propose the mathematical model; the model can describe the batch risk transfer problem and optimize the TRU transfer.

A dynamic programming model contains the following basics:

Stage: Stage is divided along the whole food supply naturally according the order of logistics and time. This used to resolve the optimization problems in accordance with the stage order. The stage variable is represented by k .

State: State means the beginning of each stage of the process in which natural conditions. It should be able to describe the characteristics of the process along the food supply chain, also requires the state is directly or indirectly, can be observed. The state variable is represented by x_k.

Decision: When a stage with the state which has identified can make the various options to access to the next stage of a state, such an option as a means of decision-making. The decision variable is represented by u_k.

Strategy: Strategy is assembled by variable decision. The strategy is represented by d_k.

In order to design of a dynamic programming algorithm, we use the following steps to establish mathematical model:

Step 1: The stage is divided as TRU which has adequately described in 3.2.

Step 2: The objective situation of stages is expressed by state.

Step 3: Establishing the transformation equation from state k to state $k+1$

$$x_{k+1} = T_k(x_k, u_k) \quad (1)$$

Step 4: Making the decision of the traceability information flow and risk transfer.

$$u(i,j) = \begin{cases} 1 & \text{if batch of raw material } i \\ & \text{is the component which} \\ & \text{used in batch of product } j \\ 0 & \text{if batch of raw material } i \\ & \text{is not the component which} \\ & \text{used in batch of product } j \end{cases} \quad (2)$$

$$u(j,k) = \begin{cases} 1 & \text{if batch of product } j \text{ is} \\ & \text{transported to pos point of sales} \\ & \text{with batch of distrubution } m \\ 0 & \text{if batch of product } j \text{ is not} \\ & \text{transported to pos point of} \\ & \text{sales with batch of distrubution } m \end{cases} \quad (3)$$

Step 5: Establishing the function about hase benefit of strategy.

$$d_k(x_k, u_k) = \sum u_k \quad (4)$$

Step 6: Establishing the dynamic programming mathematical model.

The objective function (5) allows to calculating the minimum batches transmission.

$$\begin{cases} f_k(x_k) = \min\{d(x_k, u_k) + f_{k+1}(x_{k+1})\} \\ f_{N+1}(x_{N+1}) = 0, \ k = N, N-1, \cdots, 1 \end{cases} \quad (5)$$

Step 7: seeking out the restraint condition

In the food process, the mass of materials must comply with conservation of mass, according this theory, we seeking out the restraint condition which expressed by equations (6), (7), (8), (9) based on C. Dupuy, (2005)

$$\sum Q_{RP}(i,j) = Q_{RM}(i) \quad (6)$$

$$\sum Q_{PD}(j,m) = Q_P(j) \quad (7)$$

$$\sum BOM_{RP}(r_i, p) \times Q_P(j) = Q_{RM}(i) \quad (8)$$

$$\sum BOD_{PD}(p,d) \times Q_{DP}(m) = Q_P(j) \quad (9)$$

Table. 1 Nomenclature of the variables

i	indexes of raw material batches information
j	indexes of product batches information
m	indexes of distribution batches information
x_k	represents state variable
u_k	represents decision variable
$d_k(x_k, u_k)$	represents benefit of phase
$BOM_{RP}(r, p)$	means all productions are composed of given raw materials and proportion, this is bill of material
$BOD_{PD}(b,c)$	means the productions are delivered to different pos point of sales; this is bill of distribution
$Q_{RM}(i)$	quantity of the raw materials batch i
$Q_P(j)$	quantity of the products batch j
$Q_{DP}(m)$	quantity of the distribute products batch m
$Q_{RP}(i,j)$	variable which is the quantity of the raw material bath i used in product batch j
$Q_{PD}(j,m)$	variable which is the quantity of the product batch j delivered in distribution on batch m

3.4 Information flow

The batch transmission under study involves the association of an information flow and physical distribution. The traceability system must keep the information forward and backward for each organization in the supply chain according to the regulation in the EU and ISO recommendation.

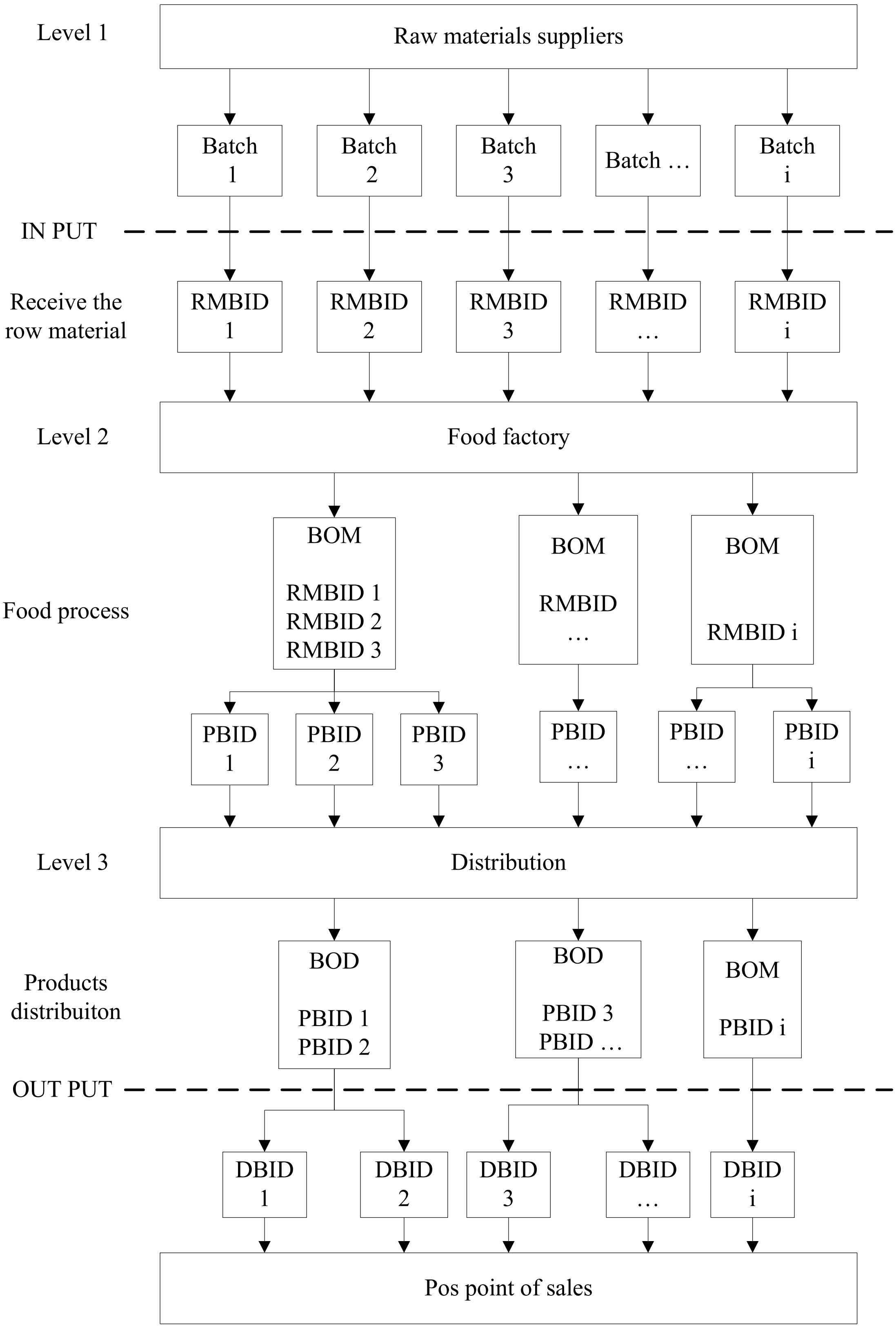

Fig.5 the information flow in food supply chain

We propose the model of batch information transmission (Fig.5) based on Ruiz-Garcia(2008). Every TRU represented by batch information (BID) through the information transmission process. Every traceability system actor is responsible for batch data acquisition, processing, storage and transmission. Along the information flow, the supplier batch information was identified by raw material batch information (RMBID), the product batch information was identified by produce batch information (PBID), and the distribution batch information was identified by DBID.

The information flow model shows that batch information is transmitted among the participants among the food supply chain. Every actor can deliver the batch information backward and forward.

3.5 Identification and transmission of information

RFID is one of the most useful tools available in the tracking technology. Its capacity in tracking involves a complicated process, the traceability system can use RFID to identify information from beginning of food supply chain to consumer due to its feasibility. RFID radio frequency signals can automatically identify targets and objectives to obtain relevant data and identify a number of labels at the same time. So it can be used to identify the tracing information along the food supply chain. For such a Chinese dumpling processing operations, the usage of RFID system to ensure traceability system of data collection and transmission is conducive to increase the accuracy and speed of information identification and transmission.

In the Chinese dumpling processing, when the beginning of the raw material is received, the RFID device obtain information about raw material batch which will be saved to the database. In the end of packing, the RFID device will detect the product labels which contain the product batch information and identify information at the same time to preserve relevant records. During the distribution process, the RFID device reads the product information, and generates retail information coding in the traceability system, and preserves relevant records at the same time.

4 Conclusions

The traceability system has been established to manage information in the food supply chain or food process, this kind of traceability system just satisfies the needs of tracing. Although it is good for companies, the capability of tracing has not been under considered. The food companies focus on tracking precisely when the raw materials contaminated in order to reduce the quantity of recall. So, improving the precise of the traceability system is a critical point under study.

Each batch of raw materials, products or distribution is the minimum TRU in the traceability system. The batches mixed along the food supply chain, so the TRU is variable, this increases the complexity of traceability. In order to improve precision of traceability system, we should optimize the produce orders.

The mathematical model can be used to minimize the recalled batches if food safety crisis bursts. Food factory can reduce the impact to consumer's confidence and cost of recall. It is a useful way of food crisis management. The mathematical model also can be used to schedule production plan. With the optional selection, the factory can decrease the mixed batches and can reduce the information redundancy of a traceability system.

The traceability information flow proposed in paper can be used in traceability system design and develop. This model clarifies the structure of traceability system and information gathered in food process.

The reliability of traceability system depends on whether the batch information is true or not. The factory should ensure the record entire and accurate, and also enhance communication among the actors in the food supply chain. RFID technology used in traceability system can improve the traceability information collected accuracy and speed.

In the further researches, we will calculate the mathematical model with a system simulation method. The result of simulation in computer using software will evaluate the mathematical model.

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