Proceeding of the IEEE
International Conference on Automation and Logistics
Chongqing, China, August 2011

Data Analysis and Simulation of Auto-ID enabled Food Supply Chains based on EPCIS Standard

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Abstract – The development of Auto-ID technologies has brought new opportunities to improve tracking and tracing process and thus enhance safety and traceability in the food supply chain. EPCIS (EPC Information Service) is a crucial specification for enabling EPC-related data sharing within and across enterprises in standardized way. Due to the limitations of real case implementations, we exploit a simulation method to replicate key identification processes and to generate EPCIS-Events which are captured by such processes in Auto-ID enabled food supply chain. For illustrating this in details, key identification processes and their mapping to related EPCIS-events are illustrated by using a case study in frozen food chain. Suggestions for EPCIS-extensions are also discussed by considering the specific characteristics of frozen food chains. In our work, the generated EPCIS-Events are sent to EPCIS-based repository in real time which better reflects the real world applications. We believe our simulation method could provide a proof-of-concept way in EPCIS-enabled tracking and tracing in food supply chain. Furthermore, the real-time transmission of EPCIS-Events provides a good basis for developing or testing high-level applications.

Index Terms – EPCIS, Simulation, Auto-ID, Supply Chain, Tracking and Tracing

I. INTRODUCTION

In recent years, food safety and quality issues have drawn more and more public attention worldwide. Food crisis und product recalls in the last decade have not only caused severe image damage and sales drop but also shaken the consumer confidence dramatically. In this context, food safety and traceability legislations and regulations are becoming more stringent [1]. The European Union (EU) Regulation 178/2002 came into effect in January 2005, while the US Bioterrorism act has been in effect from December 2003 [2].

However, the regulations have not involved the implementation details of a tracking and tracing system. According to [3], a large amount of traceability systems are still paper-based and not adequately equipped for timely and accurate tracing of products. Furthermore, the diversity of the systems also makes the integration difficult.

Nowadays, the development of Auto-ID technologies especially the RFID and 2D-Barcode technology brings new opportunities for improving tracking and tracing process and thus increases the supply chain transparency and performances [4].Since the successful adoption of Auto-ID technologies in supply chains requires not only proper hardware implementation but also efficient data management and data sharing, EPCglobal, a non-profit subsidiary of GS1 for promoting world-wide adoption of Electronic Product Code (EPC) technology, has published the EPCIS (EPC Information Service) Standard in 2007 [5]. The standard is designed to enable EPC-related data sharing within and across enterprises. It is the crucial component of the EPCglobal-network (a global approach for internet of the things) and enables a useful semantic interpretation of Auto-ID data to improve supply chain visibility. Recently, some pilot projects have started to test and adapt EPCIS standard for tracking and tracing in various branches of industry, such as pharmaceutical industry [6], automobile industry [7], textile industry [8] and so on. It is also reported that some countries have recently launched pilot projects using EPCIS in the food sector such as the fish industry [9]. As a standard of EPCglobal, EPCIS is becoming the de facto standard for exchange of RFID/EPC events in the future [10].

Despite the worldwide attention, the adoption level of EPCIS is still in its infancy [11]. The implementation of EPCIS should be investigated and adapted for various application scenarios. Furthermore, it is also important to analyze and interpret captured EPCIS-events to support high-level business applications such as a traceability system. For this purpose, we have used the simulation tool PLANT SIMULATION for simulating an Auto-ID enabled food supply chain to provide EPCIS-based reading events. The generated test data are sent to EPCIS-based repository in real time which better reflects the real world scenarios and provides a good basis for developing or testing high-level applications.

This paper is organized as follows. In section 2, related work will be described. After that we describe the typical material flow and key identification processes of an Auto-ID enabled food supply chain in section 3. Then the mapping between key identification processes and EPCIS-Events is illustrated in section 4. In section 5 the implementation details of our simulation model are introduced. Our paper closes with a conclusion and future work in Section 6.

II. RELATED WORK

As the adoption process of Auto-ID and especially of the RFID technology accelerates, how to manage and interpret captured data to improve supply chain visibility becomes a challenging research issue. The EPCIS specification defines four standard event types which cover general logistics and

978-1-4577-0302-07/11/$26.00 ©2011 IEEE

supply chain control processes. Furthermore, extensions are also allowed so that the specification can be adapted for more complicated or specific scenarios.

After ratification of this specification, the implementation and adoption of EPCIS are discussed in several papers. In [12] the author introduces how to use EPCIS-Events for the facilitation of tracking and tracing throughout the lifecycle of electronic products. In VDI 4472 the adoption guidelines of EPCIS in the automobile industry are discussed [13]. A new event type namely the assembly event is suggested as an extension of the standard, because according to the Guideline the existent four standard event types cannot cover the assembly process in the automobile supply chain. There is also related research in the area of food supply chain. Myhre [10] has proposed a traceability solution based on EPCIS. Thakur [14] introduces a methodology for modeling traceability information using EPCIS framework and UML state charts by providing illustrations from two food supply chain scenarios. However, these papers above have mainly discussed the concept of the EPCIS-based framework. No corresponding data were generated or tested for further analysis.

Since the EPCIS adoption is still in a pilot phase, only few real-world examples of RFID enabled supply chain exist that can be directly examined [15]. Therefore, simulation is an important and useful methodology to provide a proof-of-concept of the EPCIS adoption. Jakkhupan [16] has proposed a procedure to simulate RFID system based on EPCglobal Network Standard. In his work, a significant simulation tool is proposed by deploying selected EPCglobal Network components which spans from RFID Hardware emulator to EPC Discovery Service. In this simulation model, only a simple supply chain with one manufacture, one distributor and one retailer is simulated. Supply Chains with specific application scenarios have not been considered. Since the simulation tool needs to be installed in a separated working station for each supply chain partner, simulation expense could increase when the number of supply chain partners arises.

Data generator is also a common tool for providing test data in computer science. However, it cannot represent the strict temporal interdependencies in supply chains [17].

In our work, we use discrete event simulation for supply chain to generate EPCIS-Events, which has the following advantages. First, it enables simulation of the real-world material and information flows, while fulfilling the strict temporal interdependencies as mentioned above. Moreover, with a proper configuration, the simulation model could be easily extended for different application scenarios.

The similar research work can be found in the following papers. Bottani [15] has presented a discrete event simulation model for logistics processes of a RFID-enabled Warehouse for Fast Moving Goods. The flow of EPC data is generated by such processes for supporting high-level analysis tools. Müller [17] has introduced a simulation model for generating realistic test data in pharmaceutical supply chains. Different from these studies, our work focuses on the analysis and simulation of EPCIS-Events in the area of food supply chain. Furthermore, the generated data in our simulation will be transmitted to the EPCIS-based repository in real time, which better reflects the real world scenarios and could therefore enable more capable and meaningful high level applications such as Supply Chain Event Management (SCEM) [18].

III. CONCEPT OF AUTO-ID ENABLED FOOD SUPPLY CHAIN

In this section, we propose a typical process of an Auto-ID enabled food supply chain using a case study of frozen food chain, e.g. Pizza distribution process. The study presented in this paper stems from a research project in the Technical University of Munich. One of the key application scenarios in this project is the frozen food chain, on which our simulation model has been grounded. For other application scenarios the concept could be adapted or extended in similar ways.

In order to reduce costs and improve distribution efficiency, customer orders in the frozen food chain are usually picked at central cold food distribution centers and then the picked products are sent to retailers via cross docks of local distribution centers. Therefore, one specific package of frozen food will usually go through three to four tiers in the supply chain. These consist of one manufacturer who produces the food, one central distribution center where the products are stored and picked, one local distribution center where the products are cross docked and one retailer which in general is a supermarket. The retailers, which are located in the vicinity of central distribution centers, receive their orders usually directly from these centers.

The tracking and tracing accuracy is determined by the level of identification [19].The highest possible resolution level that one can have is the item-level identification, which means to attach a unique code for each product going through the chain. However, since most of today's food supply chains are based on a product-type level identification, switching it to an item-level identification system would lead to immense costs for information management and system replacement. Therefore, in our study, we suggest a case level and pallet/container level identification using EPC encoding system.

Fig. 1 illustrates the suggested identification points for tracking and tracing in frozen food chain. In our study, each case is packed with products and tagged with a 2D-barcode label. For achieving a higher accuracy of traceability, this 2D-barcode label contains not only the unique identification number of the case, but also the EAN code, the lot number as well as the expiry date of the products it contains. In our case study, the frozen products are picked using pallets and then the pallets are transported per refrigerated trucks from manufacturer to central distribution centers. In the following distribution process, the frozen products are picked using returnable thermal containers, which are equipped with insulating material and sometimes also with dry ice.

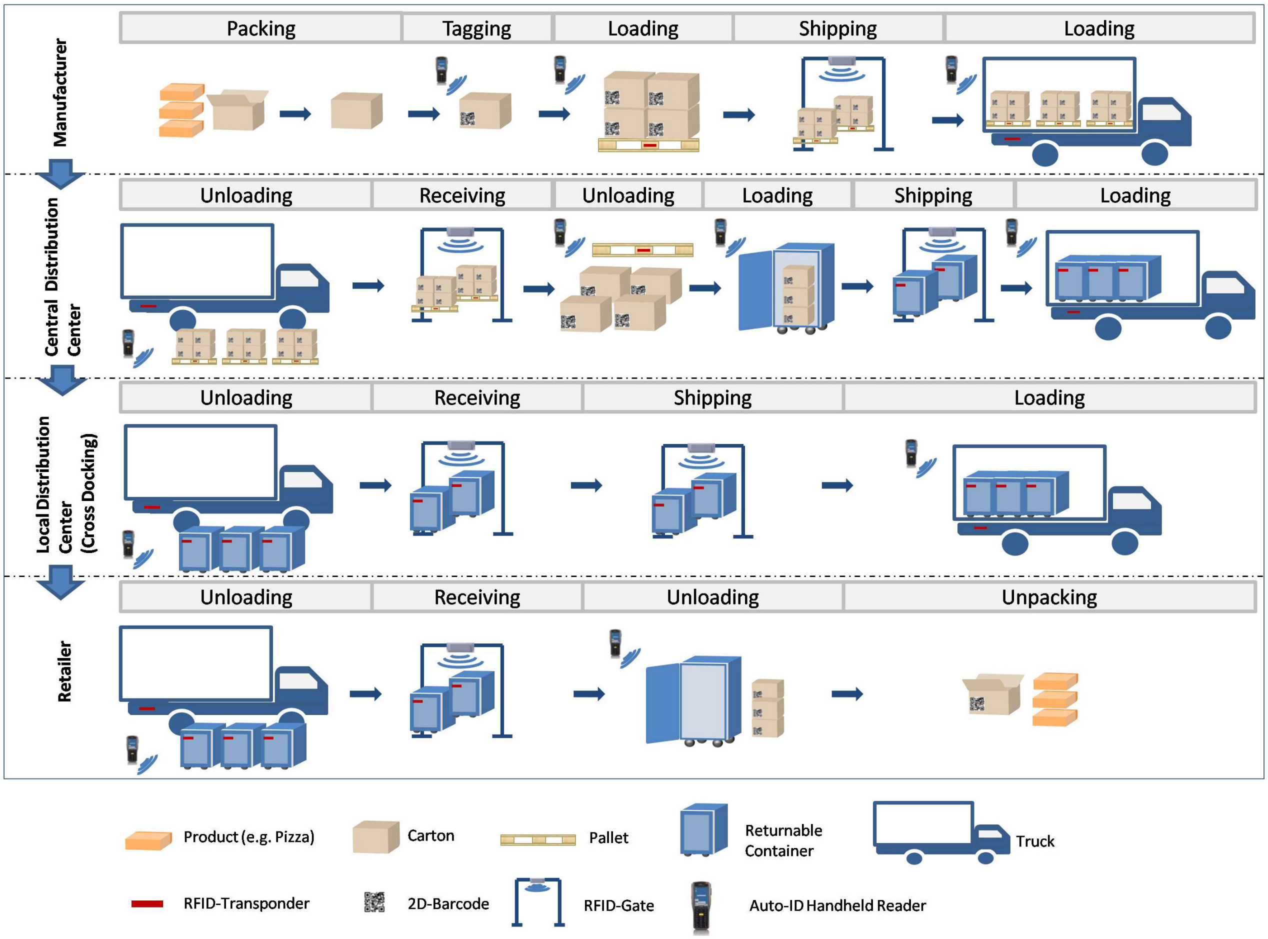

Fig. 1. Key identification processes for tracking and tracing in Auto-ID enabled frozen food chain

Therefore, they could be transported with dry products together using normal trucks without cooling system. Since temperature control plays a very important role in the frozen food chain, each container is assumed to be equipped with a RFID temperature logger, which combines a RFID tag with temperature sensors and is aimed to monitor temperature fluctuations during shipment and storage of temperature sensitive goods [20][21].

The identification points are implemented using Auto-ID handheld readers and RFID-Gates. The Auto-ID handheld readers are mainly implemented for scanning labels on cases and containers/pallets for generating aggregation events while RFID-Gates are mainly deployed at receiving and shipping areas, as illustrated in Fig.1. These identification points are the key positions for an effective and accurate tracking and tracing process. In the real-world application, they could also be implemented using alternative Auto-ID solutions. For instance, we can also attach RFID-transponders on the cases and automate the scanning process using conveyer with fixed RFID-Readers instead of handheld readers. However, despite of implementation difference, the captured EPCIS-events will be the same.

IV. MAPPING BETWEEN KEY PROCESSES AND EPCIS-EVENTS

The EPCIS specification defines four different event types:

1) **ObjectEvent**, which describes events pertaining to one or more objects identified by EPCs;

2) **AggregationEvent**, which is used for the aggregation or disaggregation process of parent EPC and child EPCs, such as loading the cases onto a pallet;

3) **QuantityEvent**, which takes place with respect to a specified quantity of an object class, such as reporting inventory levels of a product;

4) **TransactionEvent**, which describes the association of physical objects to business transactions.

The specification has also defined several obligatory and optional fields for each event type, including e.g. the action field for describing the event's lifecycle of the EPC(s) named in the event, the epcList field for the identified EPC codes, the bizLocation for recording the business location where the events are generated, the ParentID field for the identity of a "parent" in an aggregation process and so on.

Supply Chain Tier	Key Process	Event Type	Action	Extension Fields
Manufacturer	1. Tag cases (with packed products)	ObjectEvent	ADD	EAN_Code, Lot_Number, Expiry_Date
	2. Load cases onto pallet	AggregationEvent	ADD	
	3. Bring pallets to shipping area	ObjectEvent	OBSERVE	
	4. Load pallets onto truck	AggregationEvent	ADD	
Central Distribution Center	5. Unload pallets from truck	AggregationEvent	DELETE	
	6. Bring pallets to receving area	ObjectEvent	OBSERVE	
	7. Unload cases from pallet	AggregationEvent	DELETE	
	8. Load cases into container	AggregationEvent	ADD	
	9. Bring containers to shipping area	ObjectEvent	OBSERVE	Over_Thres_Temp, Temp_TimeStamp
	10. Load containers onto truck	AggregationEvent	ADD	
Local Distribution Center	11. Unload containers from truck	AggregationEvent	DELETE	
(Cross Docking)	12. Bring containers to receiving area	ObjectEvent	OBSERVE	Over_Thres_Temp, Temp_TimeStamp
	13. Bring containers to shipping area	ObjectEvent	OBSERVE	Over_Thres_Temp, Temp_TimeStamp
	14. Load containers onto truck	AggregationEvent	ADD	
Retailer	15. Unload containers from truck	AggregationEvent	DELETE	Over_Thres_Temp, Temp_TimeStamp
	16. Bring containers to receving area	ObjectEvent	OBSERVE	
	17. Unload cases from container	AggregationEvent	DELETE	
	18. Unpack products from case	ObjectEvent	DELETE	

Table 1. Mapping between key processes and EPCIS-Events

In our study, the EPCIS-Events are mainly used for tracking and tracing purpose. Therefore, we merely analyze and generate the ObjectEvents and the AggregationEvents in the simulation. The QuantityEvent and the TransactionEvent are excluded. We illustrate the mapping of key process for tracking and tracing into EPCIS-Events in Table 1. Besides process description and event type names, value of the action field for each event is also shown, which is relevant for the context of an EPCIS-Event.

Furthermore, since extensions are allowed in the EPCIS specification, we suggested several extension fields into some EPCIS-events at specific identification points. As mentioned before, the EAN code, lot number and expiry date of the contained products are generated as extension fields in the ObjectEvent when a case is tagged. Moreover, fields related to recorded temperature values are also added in order to record and analyze temperature information in the frozen food chain. As mentioned before, the returnable thermal containers are equipped with a RFID temperature logger. Since RFID temperature loggers usually have only limited memory capacity, one application possibility is to use it in over-threshold logging mode, i.e. only the over-threshold temperatures will be recorded and saved in the memory. The saved temperature values as well as the time stamp are read by RFID reader in the shipping and receiving area and are transmitted to the EPCIS-based repository in the extension fields Over_Thres_Temp and Temp_TimeStamp. Based on this information, temperature related analysis and decision could be carried out.

V. IMPLEMENTATION OF THE SIMULATION MODEL

We model the logistics process described in section 3 using the simulation tool PLANT SIMULATION. In the simulation model, we used the XML interface integrated in the software for generating EPCIS-Events with XML bindings. In order to enable an easy and flexible adaption to different application scenarios, we implemented several custom models for identification points of the key processes which are described in section 4. Furthermore, we developed standardized methods which function as middlewares and serialize the reading events into XML files. Once a physical object passes through an identification point, a method will be triggered and the corresponding EPCIS-Events will be generated. Table 2 illustrates the encoding schema we used in our simulation, which is compatible with the EPC tag standard [22].

In this simulation, each case is uniquely identified with a SGTIN (Serial Global Trade Item number). Each pallet, container and truck is identified with a GRAI (Global Reusable Container Code) number. Furthermore, for every shipment a SSCC (Serial Shipping Container Code) will be assigned to the transport unit. We also generated an AggregationEvent for relating the SSCC number to the GRAI number of a transport unit at each time a shipment assigned. This assures not only an improved tracking and Tracing process but also makes the management of returnable transport items more efficient.

We applied the Fosstrak EPCIS repository for our information system. Fosstrak is an open source software platform to support Auto-ID application developers and integrators. The Fosstrak EPCIS Repository as well as the capture and query interfaces are developed according to the EPCIS specification and are certified by EPCglobal.

Objects/Architechture Components		EPC Number
Objects	Case	urn:epc:id:sgtin:Company_ID.Type_ID.Serial_ID
	Pallet	urn:epc:id:sscc:Company_ID.Serial_ID
		urn:epc:id:grai:Company_ID.AssetType_ID.Serial_ID
	Container	urn:epc:id:sscc:Company_ID.Serial_ID
		urn:epc:id:grai:Company_ID.AssetType_ID.Serial_ID
	Truck	urn:epc:id:grai:Company_ID.AssetType_ID.Serial_ID
Architechture Components	Read point	urn:epc:id:sgln:Comany_ID.Location_ID.Reader_ID
	Business location	urn:epc:id:sgln:Company_ID.Location_ID.Extension_ID

Table 2. Encoding Schema used in the simulation

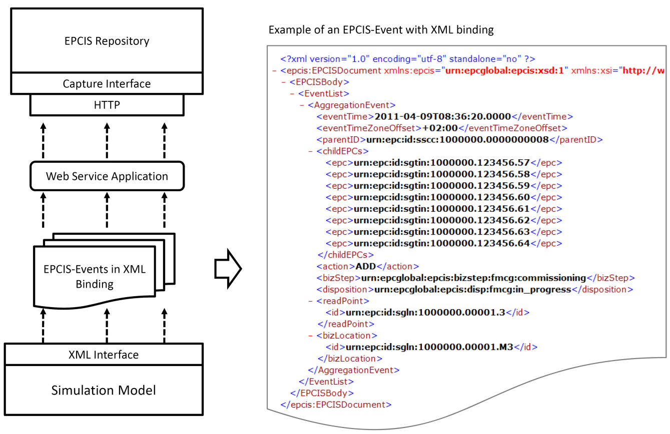

Fig. 2. System architecture for real-time transmission of EPCIS-Events from simulation model to EPCIS repository

For transmitting the generated EPCIS-Events into EPCIS repository in real time, we implemented a web service application which sends the EPCIS-Event to the EPCIS-based repository as soon as it is generated. This reflects the real world scenario better and could enable many capable high-level applications. The architecture of our information system is illustrated in Fig. 2.

VI. CONCLUSION AND FUTURE WORKS

The contributions of the paper are summarized as follows:

First, this study has presented a conceptual framework of EPCIS-based tracking and tracing in Auto-ID enabled food supply chains. By using a case study in frozen food chain, we illustrated the key processes and identification points which are relevant for an efficient tracking and tracing process.

Second, the current EPCIS specification needs to be adapted and extended for different application scenarios. In our study, we have suggested some meaningful extension fields related to product EAN code, lot number and also the temperature values for the EPCIS implementation in the frozen food chain.

As the third point, the study has presented a method for generating EPCIS-events based on supply chain simulations. Because of the lack of real world examples, we believe the simulation method can be useful for providing a proof-of-concept of the EPCIS implementation. In our simulation, EPCIS-events are transmitted to EPCIS repository in real time as soon as they are generated, which provides a very good basis for developing or testing high-level applications.

In future research, we will adapt our simulation for various application scenarios. Furthermore, we will build up high-level application for analyzing as well as visualizing the generated EPCIS-Events. Finally, Supply Chain Event Management (SCEM) plays an important role in some application scenarios, e.g. an alarm should be triggered when the over-threshold temperature is detected in the frozen food chain, or a SMS should be sent to the working staff, when a transport truck has not arrived from point A to point B on time, etc. Therefore, simulating some abnormalities in the supply chain and building up the corresponding SCEM application is an interesting future research step.

ACKNOWLEDGMENTS

This work was supported in part by the FORFood Project which is funded by the Bavarian Research Foundation and aimed to optimize the usage of resources and to increase food quality and efficiency in food manufacture and distribution.

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