International Journal of Business, Human and Social Sciences
ISSN: 2517-9411
Vol:9, No:3, 2015

RFID Logistic Management with Cold Chain Monitoring – Cold Store Case Study

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***Abstract*—**Logistics processes of perishable food in the supply chain include the distribution activities and the real time temperature monitoring to fulfil the cold chain requirements. The paper presents the use of RFID (Radio Frequency Identification) technology as an identification tool of receiving and shipping activities in the cold store. At the same time, the use of RFID data loggers with temperature sensors is presented to observe and store the temperatures for the purpose of analyzing the processes and having the history data available for traceability purposes and efficient recall management.

***Keywords*—**Logistics, warehouse, RFID device, cold chain.

I. Introduction

RFID (Radio Frequency Identification) is one of the most promising technologies in the field of supply chain to automatically identify objects without a human interaction. It is deployed in the agro-food sector which realizes an operational efficiency, benefits and valuable improvements of the traceability processes [1]-[4]. RFID implementations are increasing due to many positive effects on information accuracy at each stage of the production and distribution for stakeholders, government organizations and consumers. It provides the origin and quality control of food products by tracking the product in the supply chain forward and tracing it backward for the purpose of quick recalls.

The use of RFID technology in the supply chain management (SCM) is an automatic identification and data capture technology that offers many advantages over wide adopted barcodes [5]. The adoption was investigated to present the benefits and drawbacks in the warehousing operations which can serve as good guidance for business cases where all partners in SCM should use the same technologies or at least the same traceability and labeling standards according to regulations. The detailed specifications and guidelines are well known as EPCglobal network [6].

The cold chain in the supply chain of fresh and perishable food is very important to ensure the safety and the quality of products specified by the expiry date. Mainly, the implementation of temperature monitoring is based on wireless sensor networks [7]. The deployment of RFID systems offers the use of RFID readers and so called "smart devices" with temperature sensors [8], [9]. They are used in the distribution and warehousing to inspect the real-time conditions to control and adjust temperatures.

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In the past few years, the European Union was supporting the development of pilot solutions to build RFID systems that will track and trace food products in the whole supply chain [10]. Two solutions were deployed in farmed fish sector in Slovenia and Spain under the project "RFID - from Farm to Fork" [11]. RFID solutions were extended for the use of RFID data loggers with temperature sensors to analyze the cold chain monitoring of products from the processing phase to the delivery [12].

II. Logistics and Cold Chain

The information flow within the logistics segment of the supply chain includes recording and exchange of the data related to the transportation and warehousing of all products. Many SMEs perform most of the supply chain phases by producing and delivering the ordered products to retailers. Very often the traceability and quality information actions are done via visual identification and/or inspection of temperatures and writing data on a paper document. By introducing RFID traceability systems it is possible for them to improve the automation and integrate all the information to be accessible over the internet by web services on all kind of devices, including smart phones [11]. Fig. 1 shows the RFID portal placed at the warehouse door where the processes of receiving or shipping pallets of boxes are performed.

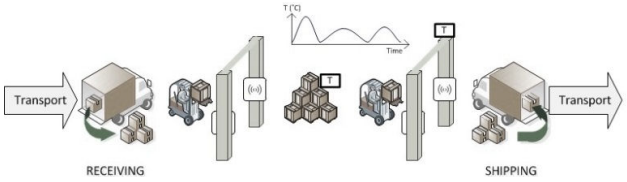

Fig. 1 RFID portal in warehouse management

According to business processes, the information related to logistics is split into transport and warehousing. It consists of the following required data: Location, ID of delivery document, Date and time of shipping and receiving, ID of boxes and/or pallets, ID of RFID data loggers with temperature sensors. The cold chain monitoring of products in logistics process starts in the processing phase. It is also specified with RFID data logger placed in the warehouse where temperatures are recorded. They are available for the inspection and stored in the database for further analysis in supply chain. The information which plays a major role to assure that product is not spoiled through the growth of bacteria during the logistics is temperature. The temperature inside the van, warehouse, and the cold store or inside the

shipping boxes containing the perishable food products directly affects the shelf life and the quality of products.

III. RFID Implementation in Cold Store

The warehouse hardware consists of fixed RFID reader and 2 antennas (RFID manufacturer is Impinj [13], product name Speedway Revolution Reader, product model Speedway R420, and product category, UHF Reader). To perform a control of one RFID portal in two possible actions (receiving, shipping) an external button and three light indicators (a semaphore) are added to determine the present function of portal: white – portal is on and ready for selected action; green – receiving, red – shipping (Fig. 2). RFID reader is connected to the internet via fixed cable and maintained by personal computer on the internet, running the application with GUI available to the management and to provide the traceability data to the EPCIS (Electronic Product Code Information Services) repository on the server.

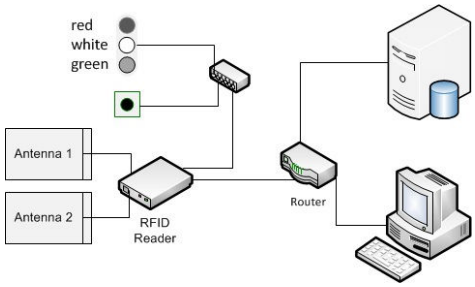

Fig. 2 RFID portal

The temperature monitoring is performed with the prototype UHF RFID data logger which is a semi-passive RFID tag. The SL900A chip is an EPCglobal Class 3 Gen2 tag which is battery-powered smart label with cool-Log™ data logging commands and temperature sensor [14]. The tag is able to automatically track, monitor, time-stamp, and record temperatures in the supply chain. The other key features are the data protection, the anti-collision algorithm, a smart power supply system, automatic sensors signal acquisition, and programmable modes of data logging. The memory stores operation unique identification number (UID) and data using the innovative analogue nanotechnology architectures. Chip supports logging data from an integrated temperature sensor with a typical nonlinearity of ±0.5ºC defined over the specified temperature range.

The process of receiving and shipping products is implemented as a portal application which makes an inventory of RFID tags passing the entrance of the warehouse. There is a need to detect passive RFID labels attached to boxes or pallets and semi-passive RFID data loggers. This is important to have the information about their presence in the cold store. For the pilot in logistic segment of cold store the following business events were defined and stored to EPCIS repository that will be used to track the required information: i) Receiving to cold store is performed for all the boxes by reading EPC code detailed information about the order, product details, receiving time, and other data; and ii) Shipping to retailers, restaurants or private customers takes place when the boxes are grouped on pallets to fulfil selling orders. The shipping time is recorded and added to the list of EPC codes as the traceability information stored in EPCIS repository.

The identification process at the entrance door consists of three states: i) ready; ii) receiving; and iii) shipping. Fig. 3 shows that the portal should be in a ready state (switch=0) and prepared for the operator to select one of the actions when the pallet of labelled boxes is arriving in the vicinity of RFID antennas. The combination of lights specifies the action: i) switch=0, white light is on; ii) switch=1, white and green lights are on; and iii) switch=2, white and red lights are on.

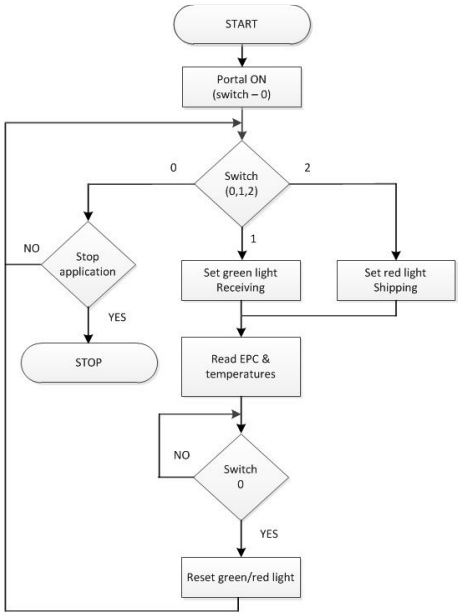

Fig. 3 RFID portal application

The movement speed of pallet must be adapted to the use of RFID data loggers in cold chain which require some additional time to read temperatures from the memory. When one of the actions is finished the operator returns the portal into ready state by switching it back to 0 (white light is on).

IV. Results and Discussion

A. Fish Pilot

The proposed RFID system was placed at the entrance door of the Fonda cold store premises [15]. All further descriptions are related to the logistics of fresh fish in boxes covered with wet ice. RFID data loggers with temperature sensors were placed inside and on top of Styrofoam boxes to perform the cold chain control (Fig. 4). The logistic traceability process started at the end of the processing phase where the fish was packed for the known customer, labeled with RFID tag (Fig. 5) and ended at the delivery to retail and/or private customers. Following information was identified to be included in the processing and placed on the RFID label: customer name, fish size defined by weight categories, preparation type (un-

cleaned, cleaned, filleted, …), quantity of ordered fish (number of boxes, weight quantity, number of fish), LOT or Batch number (Date, Cage, Generation), weight is written on the box during order preparation, processing date (catch date), and product expiry date (defined by processing date + 10 days). Quick Response code (QR) is printed on the label and presents the web link that can be scanned by smart phone to get the traceability information.

Fig. 4 RFID data logger (SL900A) on a box

Fig. 5 RFID label

RFID portal was set up with two antennas on each side of the door or with one antenna on the top (Fig. 6). EPC codes were read from RFID labels and RFID data loggers to identify products and assets. Two applications were developed, one to perform receiving/shipping activities that were uploaded as the traceability data to EPCIS repository on the server. The other one was used to read data from RFID data loggers at any time and to show the temperature graph.

Fig. 6 Boxes with RFID labels and RFID data logger pass the portal

B. Cold Store Tests

Many tests were made during the period of deployment in the evaluation of the supply chain with different number and placements of boxes on pallets oriented towards the antennas. Positions of antennas, their power setting and placements of RFID temperature data loggers inside a box were analyzed. Optimal position of the attached RFID labels was defined. When they were directly faced towards antennas from any side of the pallet the reading rate was 100%, otherwise if they were in the middle of the boxes on the pallet there can happened that some of them were not identified.

Fig. 7 shows RFID portal application with EPC codes of boxes and RFID data loggers passing the entrance door. It offers the following information: i) RFID reader status (read EPC) and process (receiving); ii) displays the list and the number (34) of identified EPC codes on boxes and RFID data loggers (3); iii) button to check the details of boxes with orders (customer name, box weight and other data).

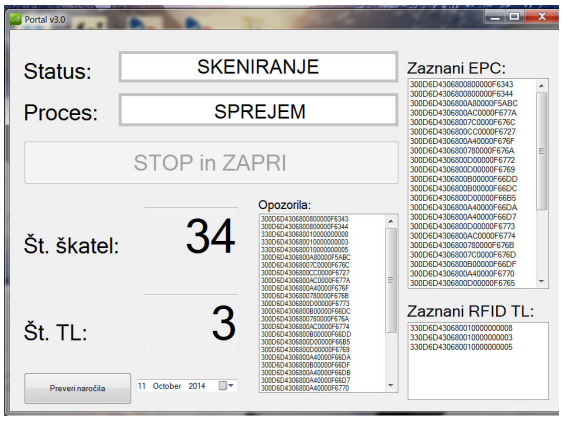

Fig. 7 RFID portal application (receiving/shipping)

RFID data loggers that were placed inside and on the boxes in the processing phase were inspected for the temperatures when they entered the cold store (receiving) and when they left the cold store (shipping). Fig. 8 shows the results of the desktop application that performs the temperature inspection of RFID data loggers in the blue Styrofoam box on top of white boxes.

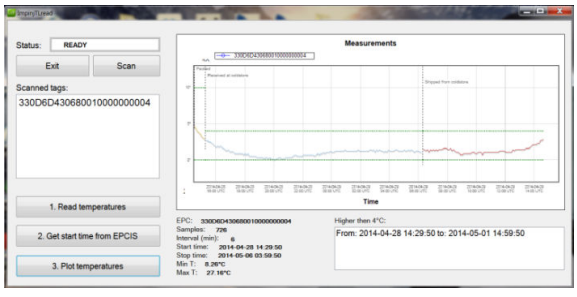

Fig. 8 Temperatures read from RFID data logger in the box

Additionally, RFID data loggers were placed in the cold store to inspect the ambient temperature. Fig. 9 shows the

graph of temperature equal to 1˚C and some high outliers of temperatures up to 10˚C. This was detected during the working hours when the employees were entering the cold store and leaving the door open when performing some tasks.

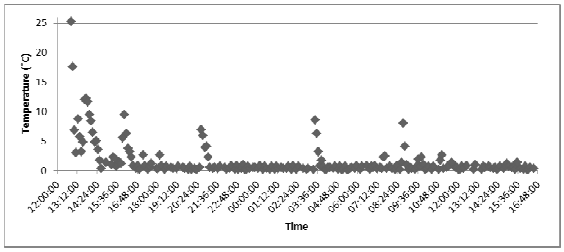

Fig. 9 Temperatures in the cold store where the boxes of fish were stored for 28 hours

C. Evaluation Results

RFID portal performed well according to the tests and presents a prototype solution in the warehouse cold store. The main conclusions and findings were: i) RFID labels must be visible on one of the outer side of pallet; ii) Receiving and shipping of items on a manually controlled forklift with different speed moving through a portal was tested. It has no influence on the number of detected items in the case of reading EPC codes; iii) The process of reading temperatures from RFID data loggers on the box required from 2-5 seconds that all the data from the memory was received and stored to the database, otherwise only the EPC code was available; iv) The change of RFID reader settings of antennas power to maximum enables the identification of RFID temperature data loggers inside the box. They could be detected in the boxes placed on the top of the pallet; v) Identification results were uploaded to the EPCIS repository in the form of events as a part of traceability implementation of the fish pilot.

The internet connection must be available but in case of any problems, the application on RFID portal generates and stores XML files of events in the cold store locally, to be automatically uploaded later when the connection problem is fixed.

V. Conclusion

Automated identification of fish products in the cold store, activities of inventory management and cold chain monitoring were performed via the deployment of RFID technology. This helps to improve the accuracy rate at the box level according to the processing results and eliminates shipping errors.

Information about the delivery and the stock is available to company manager and the complete list of the boxes in the cold store can be checked. RFID system performed well according to the evaluation tests and it was verified that RFID labels should be placed on the outer side of boxes containing fish and wet ice. In that case all the items could be detected, which is mandatory for the success of identification at the entrance door. The proposed RFID system is scalable, which means that in case of several locations or entrance doors of cold store more antennas (one RFID reader can maintain four antennas) or even more RFID portals can be used. For extending the number of antennas the application must be upgraded and for extension of number of portals, the applications can be copied to other portals with the changes that define locations of readers.

It was also proven that the cold chain monitoring is performed without any additional devices installed in cold store. Additional tests of boxes placed on pallets to analyze several other options of cold chain monitoring with the existing RFID devices are planned for the future work. The best position and power of antennas will be investigated for other placements of RFID labels on boxes and for fixing the RFID portal on the wall. The aim of the evaluation results is to use RFID portal as a demonstration tool of traceability and cold chain monitoring in the warehouse.

Acknowledgment

M. Trebar thanks her colleagues for the support, new ideas, for the work on pilot implementation and for the collaboration during the evaluation process in the cold store. Additional thanks also to the personnel of Fonda enterprise to support the implementation of traceability pilot in their business processes at the fish farm.

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