

A Wireless Sensor Network Based Grain Inventory Management System for Zambia's Food Reserve Agency

Cynthia Lubasi Muyunda¹, Jackson Phiri²P.G Student, Department of Electronics and Electrical Engineering, University of Zambia, Lusaka, Zambia¹Head of Department, Department of Computer Science, University of Zambia, Lusaka, Zambia²

ABSTRACT: Food security is one of the main global challenges today. Despite the fact that the number of food insecure populations remains unacceptably high worldwide, each year, enormous quantities of food are lost due to many factors such as spoilage, infestations, theft and spillage during transporting. These losses are called Postharvest Losses (PHLs). Zambia's Food Reserve Agency (FRA) currently faces PHL grain inventory losses, the current grain inventory management system is manual and paper based, and the cost of implementing a commercial automated inventory management system such as one that utilizes RFID technology is high. Hence, we proposed a sensor network that uses Radio Frequency Identification (RFID), ZigBee Wireless Sensor Network (WSN), and Cloud technologies in the development of a grain inventory management system for the FRA. An extensive literature review was conducted to find existing RFID applications in object tracking, monitoring and inventory management. A baseline study was conducted to determine the challenges faced by FRA regarding grain inventory management. The results of the baseline study were analysed and it was found that inventory is counted manually, records are mostly kept on paper and thefts are experienced. Interviews with warehouse supervisors were also conducted to get details FRA's current business transactions. These findings were used to design automated RFID Grain Inventory Management System (RFID-GIMS) models with the goal of eliminating manual and paper based systems, and eliminating theft altogether.

KEYWORDS: PHLs, FRA, RFID, ZigBee, WSN, Cloud, food security, RFID-GIMS.

I. INTRODUCTION

One of the main global challenges today, is how to ensure food security for an increasing world population whilst ensuring long-term sustainable development. Despite the fact that the number of food insecure populations remains unacceptably high worldwide, each year enormous quantities of food are lost due to many factors such as spoilage, infestations, theft and spillage during transporting [1][2]. These losses are called Postharvest Losses. Kiaya [2] defines PHL as *the degradation in both quantity and quality of a food production from harvest to consumption*. The problem of food lost to processing, spoilage, insects and rodents, or to other factors after harvest, takes on greater importance as world food demand grows. Reducing postharvest losses could, likely, add a substantial quantity to the global food supply, thus reducing the need to intensify production in the future.

The agriculture industry in Zambia remains the key sector in promoting economic growth and reducing poverty. The UN reports that about 80% of Zambia's population depend on agriculture-related activities for livelihood [3]. Zambia's FRA is responsible for managing storage facilities that house food reserves in form of grains including white maize and rice [4]. The FRA currently faces challenges in efficient management of inventory, this is according to the audit [4] that was carried out between 2006 and 2009 by the Auditor General to review the performance of FRA. According to the audit report, during the period of 2006-2009 the Agency experienced maize shortages of 115, 516 × 50kg bags valued at ZMK4, 274, 092, 000 (old currency) at various depots. These PHLs are due to theft and grain spoilage at the warehouse depots [4]. Most of these challenges are due to poor monitoring and a poor inventory management which is largely manual and paper based. Commercial off-the-shelf (COTS) systems that use RFID inventory systems are readily available but come with enormous costs for most developing countries such as Zambia.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

Owing to the challenges identified in the audit report, better management of the inventory through automation is necessary. It therefore becomes essential to have an accurate, convenient, and rapid method of identifying and managing storage of bags. This is in order to reduce error caused by visual identification, manual counting, maintenance and monitoring to ensure that the collected records are credible and accurate.

Hence, we are proposing a sensor network that will use RFID, ZigBee WSN, and Cloud technologies in the development of a grain inventory management system for the FRA. This study is part of the South Africa and Zambia Research collaboration. The research is funded by National Science and Technological Council in Zambia and National Research Foundation in South Africa.

Paper is organized as follows. Section II covers the literature review, which describes the workings and characteristics of RFID systems, the integration of RFID, WSNs and Cloud technology. In Section III the related works concerning RFID applications in object tracking, monitoring and inventory management are presented. Section IV presents the methodology. Section V presents the results and discussion of the baseline study conducted to determine the challenges faced by FRA regarding grain inventory management. Finally, Section V presents conclusion.

II. LITERATURE REVIEW

Radio Frequency Identification (RFID) is an automated system that utilizes wireless technology to uniquely identify and track tagged objects in the form of a unique serial number [5]. RFID technology gathers data about an object without the need to touch or see the data carrier. Weis[6], suggests that the earliest application of RFID systems was in 'Identify Friend or Foe (IFF)' systems in British Royal Air Force during World War II. A typical RFID system is composed of four basic components including RFID tags, readers, antennas and a central node computer system which may house the database server and management software (middleware) [5][7][8].

The RFID tag or transponder is the data carrier that transmits information to the RFID reader (transceiver) within a given range through a microchip and antenna embedded in it [9][10][11][12]. The antenna which is attached to the microchip in the tag transmits information from the chip to the reader [10][11][12]. The tag is attached to or embedded in an object to be identified such as a product, box, or pallet [12]. The RFID tag forwards the information to a host computer which houses the database through the RFID reader [10][11][12]. RFID tags have three classifications, these include, active, passive and semi passive [13][10]. Active tags comprise a battery that makes available power so the tag can transmit a signal to a reader [13]. Passive tags do not contain a battery and are powered solely by the magnetic field emanated from the reader, and, hence, have an unlimited lifetime [13][8]. Semi-passive tags are powered by both an internal battery and electromagnetic waves sent out by the reader [13]. Semi-passive tags are similar to active tags as they have their own power source, but the battery is only used to power the microchip [5].

The second component in an RFID system is the reader. It consists of an antenna, a decoder and a transceiver. The readers' role is to query a tag and receive data from it [14]. Readers convert radio waves from tags into a form that can be passed to middleware [14]. A reader can be fixed in a suitable place or hand-held [15][16].

The antenna generates radio signals to activate the tag and read/write data to it [5]. An antenna amplifies the signal which is emitted by the reader to the tag. It likewise is used to amplify the signal which is returned to the reader by the tag; this increases the tag reading range [17].

Middleware and the database server are at the heart of a comprehensive RFID system [5][14]. Middleware at the central node manages incorporation of data received from the reader [18]. Middleware manages the information exchange between the readers and the backend database server [14]. Furthermore, by monitoring multiple readers, middleware can detect the movement of tags as they pass from the read range of one reader to another [19].

In addition to middleware, servers housing the databases are critical components of a complete RFID system. Computer database servers mainly complete the data storage, management and read-write control of the radio frequency tags. They provide the data obtained from the reader to the software application [7].

WSNs and RFID can be integrated to extend the read range of RFID system applications and also offer added value to existing applications [20]. There are a few possible wireless technologies that can be used such as Wi-Fi, Bluetooth and ZigBee to extend the range of an RFID reader. The Wi-Fi and Bluetooth wireless standards, unlike ZigBee, consume more power and offer more features than needed and are therefore more expensive [18][21].

ZigBee is a technology based on the IEEE 802.15.4 wireless standard [18][21][22]. ZigBee belongs to a family of Low-Rate Wireless Personal Area Networks (LR-WPANs) [22]. ZigBee uses a customized wireless transmission

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

protocol, that is, the ZigBee protocol, which is designed based on simplicity and reliability. ZigBee offers better features that meet the needs of WSNs in terms of energy saving [18][21].

Data collected from the RFID readers can both be processed and stored either on local servers or on servers that are housed in the cloud. Cloud computing is a computing paradigm in which real-time scalable resources such as files, data, programs, hardware, and third party services can be accessible from a Web browser via the Internet to users. Clouds are classified according to their deployment models as private, community, public and hybrid Clouds [23][24]. Clouds also offer different service models, the service models include; software, platform and infrastructure as service [23].

III. RELATED WORKS

RFID technology is widely being used today in many applications. Application areas include security and access control, transportation, food traceability, livestock tracking, inventory tracking, library resource tracking and supply chain tracking to name a few [25][13].

Under vehicle tracking, Esker [26] suggests that RFID technology can be used for everything from renting out cars and bicycles to tracking vehicles. Esker [26] proposes a method to make self-service car rentals possible. In his method, an RFID chip implanted card is given to customers of the car service. The customer waves the card in front of an RFID sensor, unlocking the car. The keys are placed in the car and can only be accessed once the RFID chip is recognized. The RFID chip enables monitoring by the rental company, deterring theft.

In the field of automatic tool identification and monitoring, Sui et al. [27] identified the problem of low efficiency and low degree of tool management information around tools and information relating to the tool. They suggested that the tool was the most important resource in modern manufacturing industries. Hence, they developed a model and a software system that utilized RFID to solve the problem of tool identification and management.

In libraries, RFID is primarily used to automate the book handling process including check-out, inventory control, check-in and anti-theft [5][14].

In health care, Khursheed et al. [28] and Prasad and Rajesh [29] suggest that the health care system has a great opportunity for increasing RFID use to improve patient care and efficiency of the hospital. RFID wireless technology provides great potential for services such as medical device alarm notifications, surgical instrument and hospital equipment tracking, and e-prescription writing [29][28].

In agriculture, Hornbaker et al. [30][31] developed a conceptual design for tracking grain using GPS and RFID grain chip technology. They propose development of RFID grain chips that use existing passive microchip technology and encased in a durable container with the size, weight and texture characteristics of the grain being tracked, such as corn, soybeans, or wheat. At any tracking stage, they propose the ability to write and read data from the grain chip, insert new grain chips, and extract grain chips.

IV. METHODOLOGY

A. BASELINE STUDY

The purpose of the baseline study was to establish the challenges faced by the FRA regarding grain inventory management. A Mixed Methods Research Methodology was used in this study.

For the quantitative data, a structured questionnaire was administered to a sample size of 42 respondents. The questionnaire was used to collect data from the FRA members of staff that work under warehouse management in the grain marketing department at 3 warehouse depot locations in Lusaka and Central Provinces. For the qualitative data, interviews with the warehouse supervisors were conducted. The depot locations were purposively sampled.

B. SOFTWARE DESIGN METHODOLOGY

The system requirements specification and model design phase of the research study employed the use of qualitative data which was supplied through interviews that were supplied by the FRA. The interviews with the warehouse supervisors provided the qualitative data needed to design the automated RFID business processes and the system architecture.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

C. BUSINESS PROCESS MAPPING

The proposed FRA process flow from source to destination is shown in Fig. 1. It is derived from the FRA's current transaction process methodologies as described by the warehouse supervisors. Automating paper and manual based phases in the processes is the change that is proposed here.

The source of the maize is at the villages in the districts. Small scale farmers bring maize that they have harvested from their fields to a central place in the village. The maize is initially brought in their own maize bags, they then purchase the FRA bags at a small fee and transfer the grain to the FRA bags. They then tag each grain filled bag with an RFID tag and then seal the bag. The tagged grain bags are then passed through an RFID antenna/reader placed at the central loading place in the village. Tag data from the RFID chips in the grain bags is read by the RFID readers and transmitted through the ZigBee WSN to the middleware which is housed in servers in the cloud. At the middleware, the tags in each grain bag are programmed with information relating to that bag. Stock is then transported to the central district warehouse depots for temporary storage.

At the district depots, RFID readers/antennas are installed at the warehouse doors to enable reading of the tagged bags and inventory tracking. From the district depots, stock is transported to the provincial warehouse depots for permanent storage.

At the provincial warehouse depots, readers are installed at the warehouse doors and at the main gates. As the transporter passes through the gate with stock, the reader automatically performs a count and checks it against the records in the database that is housed in the cloud. The stock is stacked in the warehouse and is stored there until need arises to perform selling transactions or to transfer stock to another warehouse in the same depot or to another FRA depot.

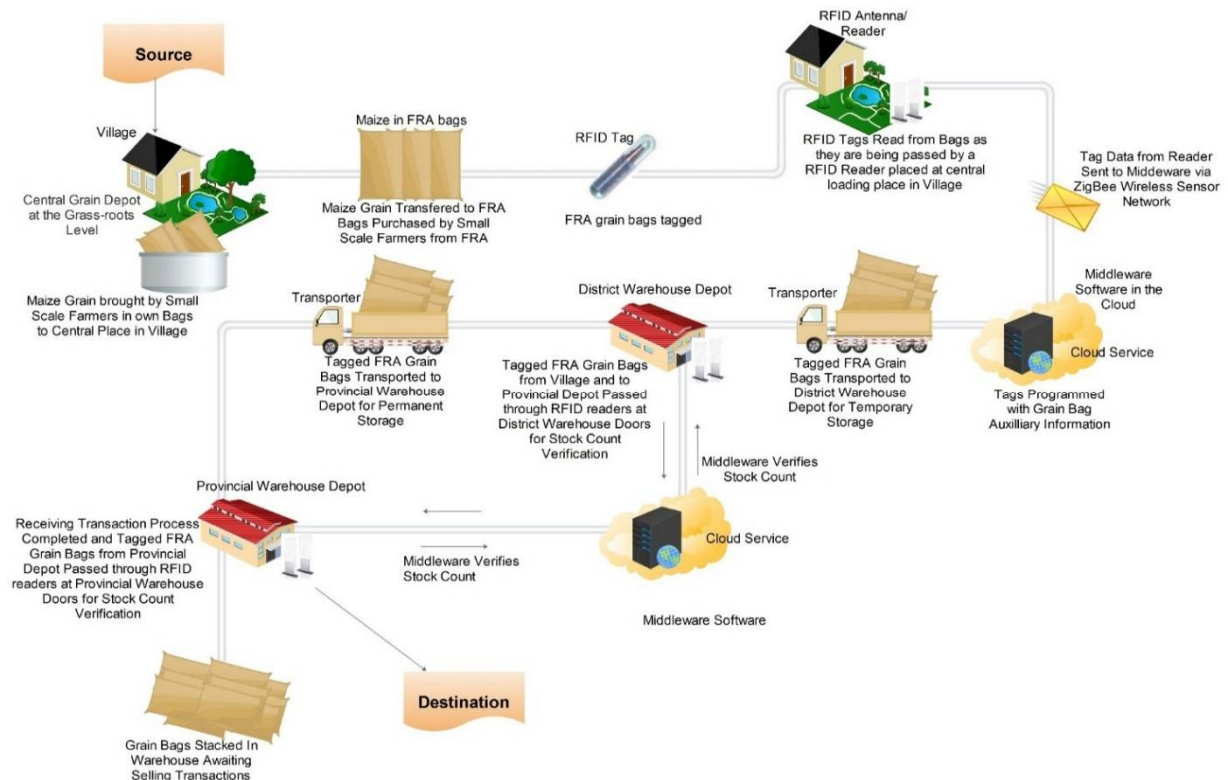


Fig. 1 Overall Process Flow from Source to Destination

D. SYSTEM ARCHITECTURE

In Fig. 2, an architecture of the RFID-GIMS system is shown. The RFID middleware constitutes application interface, event control, data processing, and device management modules. The ZigBee WSN transmits the tag data

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

through the ZigBee middleware, the RFID middleware then receives the data for event control such as filtering, notifications, and aggregation. The device management module manages the different types of hardware communicating with the middleware. The application interface provides an interface for the middleware and the database storage to communicate. The user applications access data stored in the database in the cloud for inventory management operations.

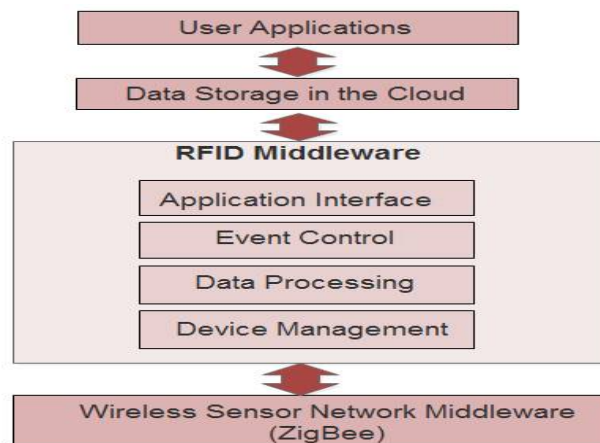


Fig 2 RFID GIMS System Architecture

E. Use Cases

The Use Cases in Fig. 3 show the interactions between the actors and the system in our system implementation. The main actors of our system were the middleware, reader and application users. The RFID reader is responsible for recording inventory stock items by detecting the tags attached to the items and sending data read from tags to the middleware. The RFID middleware sits between the RFID hardware and the backend database. It therefore is responsible for retrieving data from the reader and reader integration and control. The users at the application interface first log into the system and then they can generate reports, perform transactions and view inventory data.

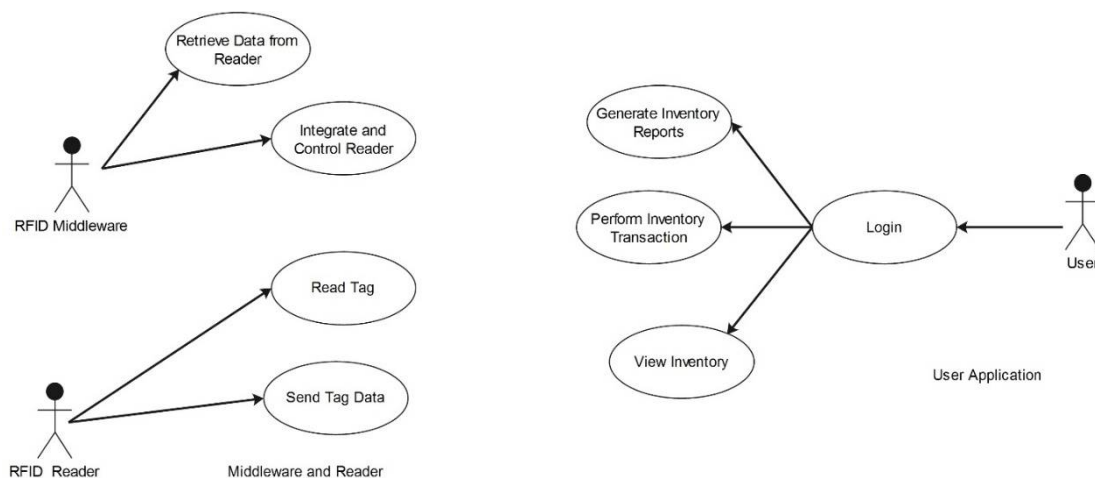


Fig. 3 RFID-GIMS Use cases

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

V. RESULTS AND DISCUSSION

In Section A, the results of the baseline study are presented and in Section B the discussion of the results is presented.

SECTION A: BASELINE STUDY

Quantitative data was collected from FRA depots located in Lusaka and Central Provinces. Fig. 4 shows that the majority 50.0% of the respondents stated that the inventory system records management maintained at FRA is one that is manual and is maintained using paper and spreadsheets. 35.7% stated that only paper was used and 14.3% said only Excel Spreadsheets were used.

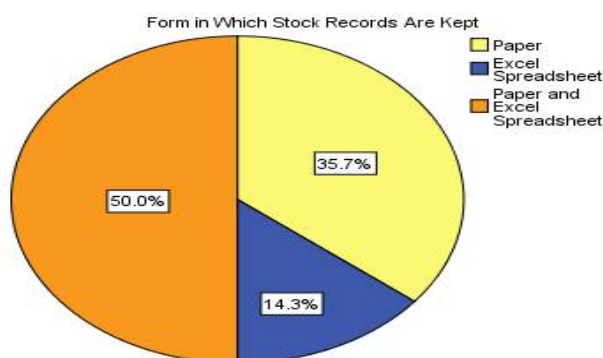


Fig. 4 Form in Which Records are Kept

Regarding the number of people counting stock per warehouse, the study results in Fig. 5 show that the majority 45.0% of respondents said that they engaged only two people to count stock per warehouse. 37.5% said they engaged three, while 12.5% said they engaged five and 4.8% said they engaged ten people.

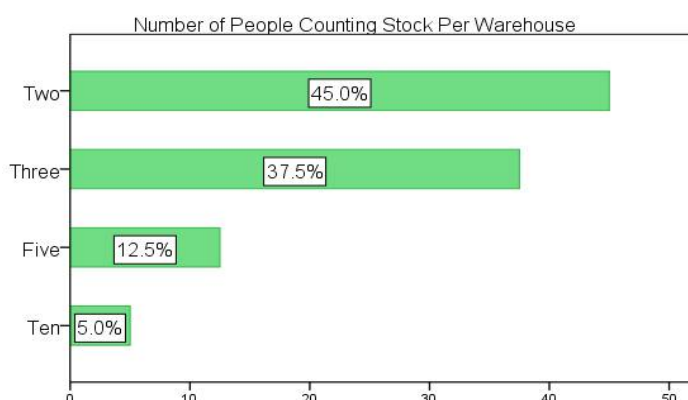


Fig. 5 Number of People Counting Stock per Warehouse

When asked when they last completed a physical stock count and produced a report, 52.4% said a day ago. The other respondents 45.2% said a week has passed since they completed a complete physical stock count and produced a report. These statistics can be seen in Fig. 6.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

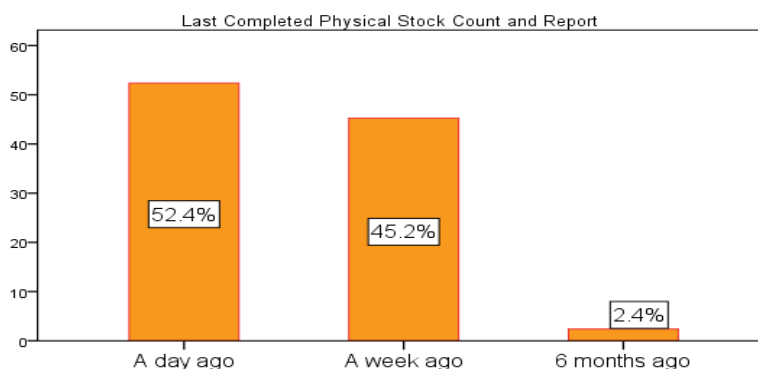


Fig. 6 Last Completed Physical Stock Count and Report

When asked about theft experience at the warehouses, the study results in Fig.7 show that 23.8% of the respondents agreed to the experience of theft at the warehouses while 76.2% disagreed to the experience of theft.

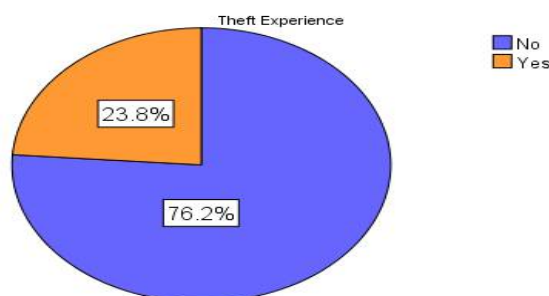


Fig. 7 Theft Experience

SECTION B: DISCUSSION

The main aims of this study were to establish challenges faced by the FRA regarding grain inventory management and to design a model for an automated RFID inventory management. From the baseline study that was conducted, the results show that the FRA warehouse employees use a physical method of counting. Two to five warehouse staff are employed to perform the counting.

On the issue of when the warehouse staff last completed a physical stock count and produced a report, the responses were divided between a day ago (52.4%) and a week ago (45.2%). Also, the results show that FRA experiences thefts. The FRA keeps records mostly on paper and spreadsheets. Manual systems that utilize paper tend to be time consuming, inefficient, inaccurate, and error prone. Paper records are faced with risks of getting lost or damaged. Generating reports from paper based records is equally time consuming, error prone and inefficient.

From the results, it can be seen that a sensor based RFID inventory system can provide a more accurate, convenient, and rapid method of identifying and managing storage of stock. An automated system can aid in reduction of errors caused by visual identification, manual counting, maintenance and monitoring to ensure that the collected records are credible and accurate.

VI. CONCLUSION

In this paper, we conducted a baseline study to establish the challenges faced by the FRA regarding grain inventory management. From the results, we can deduce that the FRA uses a manual paper and excel spreadsheet based inventory system. Also, thefts are experienced, though fewer and far between. Finally, stock is physically counted by two to five employees per warehouse and it takes a day to a week to complete a physical stock count and a report. Secondly,

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

models were designed that can be used to automate the FRA's business processes. These models were used to develop an automated RFID Grain Inventory Management System.

REFERENCES

- [1] FAO, "Global food losses and waste: Extent, Causes and Prevention," 2011.
- [2] V. Kiaya, "Post-harvest Losses and Strategies to Reduce Them," 2014.
- [3] The Government of the Republic of Zambia, "The United Nations Conference on Sustainable Development," Rio, 2012.
- [4] A. O. Chifungula, "FRA Audit Report," Lusaka, 2009.
- [5] U. G. M. N. Mamdapur and I. Rajgoli, "Implementing radio frequency identification technology in libraries: Advantages and disadvantages," *International Journal of Library and Information Science*, vol. 3, no. 3, pp. pp. 46-57, March 2011.
- [6] S. A. Weis, *RFID (Radio Frequency Identification): Principles and Applications*, 2006.
- [7] J. Qian, Z. Liu and X. Xie, "Design and Application of RFID Technology in Container Port," *Scientific Journal of Information Engineering*, vol. 4, no. 2, pp. 26-37, April 2014.
- [8] J. M. Sardroud, "Influence of RFID technology on automated management of construction materials and components," *ScientiaIranica*, vol. 19, no. 3, p. 381-392, February 2012.
- [9] E. Ilie-Zudor, Z. Kemeny, P. Egri and L. Monostori, "The RFID Technology and its Current Applications," in *In proceedings of the Modern Information Technology in the Innovation Processes of the Industrial Enterprises-MITIP*, 2006.
- [10] J. K. Visich, J. T. Powers and C. J. Roethlein, "Empirical applications of RFID in the manufacturing environment," *Int. J. Radio Frequency Identification Technology and Applications*, 2009.
- [11] S. Sharma, S. L. Shimi and S. Chatterji, "Radio Frequency Identification (RFID) Based Employee Monitoring System (EMS)," *International Journal of Current Engineering and Technology*, vol. 4, no. 5, pp. 1-5, October 2014.
- [12] P. Salunke, P. Malle, K. Datir and D. J., "Automated Toll Collection System Using RFID," *IOSR Journal of Computer Engineering (IOSR-JCE)*, vol. 9, no. 2, pp. 61-66, Jan-Feb 2013.
- [13] K. A. Singh, G. Sudipta, R. Biswajit, T. D. Kumar and R. P. S. Baghel, "Application of Radio Frequency Identification (RFID) Technology in Dairy Herd Management," *International Journal of Livestock Research*, vol. 4, no. 1, pp. 10-18, 2014.
- [14] K. N. Singh and P. Mahajan, "Application of RFID Technology in Libraries," *International Journal of Library and Information Studies*, vol. 4, no. 2, pp. 1-9, April-June 2014.
- [15] S. K. Ravi, H. G. Varun, P. Vamsi and P. Pratyusha, "RFID Based Security System," *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, vol. 2, no. 5, April 2013.
- [16] Motorola, "Motorola Fixed RFID Reader Antennas," [Online]. Available: <http://www.fieldtechnologiesonline.com/doc/motorola-fixed-rfid-reader-antennas-0001>. [Accessed 15 September 2015].
- [17] S. Vestnik, G. Ostojic, S. Stankovski, D. Vukelic, L. M., H. Hodolic, B. Tadic and S. Odri, "Implementation of Automatic Identification Technology in a Process of Fixture Assembly/Disassembly," *Journal of Mechanical Engineering*, vol. 57, no. 11, pp. 819-825, June 2011.
- [18] V. Sheridan, B. Tsegaye and M. Walter-Echols, "ZigBee-Enabled RFID Reader Network," 2005.
- [19] P. Hamilton and S. Sankaranarayanan, "Intelligent Agent Based RFID System for on Demand Bus Scheduling and Ticketing," *International Journal of Future Computer and Communication*, vol. 2, no. 5, pp. 399-406, October 2013.
- [20] S. Mejjaouli and F. R. Babiceanu, "RFID-wireless sensor networks integration: Decision models and optimization of logistics systems operations," *Journal of Manufacturing System*, vol. 35, p. 234-245, March 2015.
- [21] A. B. Hatem and H. Habib, "Bus Management System Using RFID In WSN," in *European and Mediterranean Conference on Information Systems*, Abu Dhabi, 2009.
- [22] P. Medagliani, G. Ferrari and M. Marastoni, "Hybrid ZigBee-RFID Networks with Highest Energy Efficiency," University of Parma, Italy.
- [23] A. Shawish and M. Salama, "Cloud Computing: Paradigms and Technologies," in *Inter-cooperative Collective Intelligence: Techniques and Applications*, Berlin, Springer, 2014, pp. 39-67.
- [24] D. Guinard, C. Floerkemeier and S. Sarma, "Cloud Computing, REST and Mashups to Simplify RFID Application Development and Deployment," ACM, San Francisco, 2011.
- [25] K. M. A. Muhammad, B. Faruk and M. A. A. Kalam, "Impact of Radio Frequency Identification (RFID) Technology on Supply Chain Efficiency: An Extensive Study," *Global Journal of Researches in Engineering*, vol. 13, no. 4, p. 9, 2013.
- [26] F. Esker, "RFID in Vehicles," 2015.
- [27] X. Sui, Y. Teng, Y. Chen and X. Wang, "Design of Tool Automatic Identification and Database Management System Based on RFID," *International Journal of Database Theory and Application*, vol. 7, no. 5, pp. 133-144, 2014.
- [28] F. Khursheed, H. S. Saeed, R. N. Kidwai and S. Rahman, "RFID: in the World of Health Care," *International Journal of Life Sciences and Review (IJLSR)*, vol. 1, no. 2, pp. 34-40, February 2015.
- [29] N. K. R. S. Prasad and A. Rajesh, "RFID-Based Hospital Real Time Patient Management System," *International Journal of Computer Trends and Technology*, vol. 3, no. 3, pp. 509-517, 2012.
- [30] R. Hornbaker, V. Kindratenko and D. Pointer, *An RFID Agricultural Product and Food Security Tracking System*.
- [31] R. H. Hornbaker, V. Kindratenko and D. Pointer, "Method and System for Tracking Grain". United States of America Patent US 20060004484A1, 5 January 2006.