Automated Tracking System Using RFID for Sustainable Management of Material Handling in an Automobile Parts Manufacturer

Z. Jamaludin[1], C.Y. Huong[1], L. Abdullah[1], M.H. Nordin[1], M.F. Abdullah[2], R. Haron[2], and K.B.A. Jalal[2]

[1]*Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka*

[2]*PHN Industry Sdn. Bhd, Alor Gajah, Melaka.*

zamberi@utem.edu.my

***Abstract*— Sustainability is a major issue facing the manufacturing industries. To remain competitive, manufacturers need to ensure that all manufacturing activities carried out at all levels of the organization are efficient, innovative, prudent, and most importantly, sustainable. Implementation of green related technologies in work process supports sustainability with positive impacts on the society and the environment. Radio Frequency Identification Device (RFID) belongs to a class of electronic device that promotes sustainability to the environment, economy and social well-being of the people. This paper presents outcomes of a work performed in collaboration with an automotive parts manufacturer on design and implementation of UHF RFID-based trolleys tracking system focusing on gains in efficiency related to speed of handling the receiving and dispatching of metal assets items between the parts manufacturer and its vendors. The system consists of tag, reader, antenna, and a host computer with SQL database server, reader connectivity program, and asset monitoring program. Results showed that the efficiency on speed of handling the receiving items and efficiency in dispatching the assets were increased by 9.4% and 34.8% respectively. In addition, the data handling efficiency were improved by 91.5% and 99.5% during loading and unloading processes respectively. Further enhancement of the system hardware is desired to improve system accuracy and performances.**

***Index Terms*— On-Metal Application; Receiving Dock; Returnable Transportation Item; RFID.**

I. INTRODUCTION

Environmental awareness on the part of industrial practitioners has seen steady growth in recent times. Numerous initiatives have been introduced and applied as part of the day-to-day operations at all levels of manufacturing activities in support of greener environment while aiming for a sustainable economy. In logistic management, closed loop model was introduced to enforce reuse of sources, instead of using or producing disposable or single-use items [1]. Three types of reuse practices in logistic management include Returnable Transportation Items (RTI), Returnable Packaging Materials (RPM) and Reusable Products (RP).

During production, items or articles are continuously moved from original point to the next point, and eventually returned to the original point at the end of each cycle. In automotive industry, metal-based RTIs, such as pallets, containers and trolleys are widely used to minimize asset cost. These types of assets are responsible to deliver materials mostly in the form of metal-based transport items between suppliers to the manufacturer, and also within different production lines and processes. In most cases, these metal-based transport items are specifically designed to transfer automobile parts of specific height, weight and shapes. A need arisen for a system that is capable of continuous tracking of the metal-based RTIs to avoid asset loss during the logistic flow. In the absent of proper tracking system, transferal loss of metal-based transport items becomes frequent scenario within the automotive industry. Manual tracking system has higher occurrence of human error in recording the logistics operation of the transport items. Common human errors in tracking system include inaccurate quantity of transport items being dispatched or received, lack of alert in transport item maintenance schedule, and loss track on location of transport items. These errors have negative affect on the production and logistics cycle time, increase the amount of transport items required (more than the required volume), result in poor scheduling of material replenishment and could cause safety issues due to poor maintenance of the transport items.

This ineffective method of tracking system is mainly due to inconsistency of worker performance in asset tracking. Inconsistent worker performance may be due to fatigue of long time working hours at repetitive routine, high workload in recording large amount of asset at one instant time (such as several delivery vehicles reached at one particular time), and large amount of asset information that need to be managed. This has given rise to the need of designing and developing an automatic tracking system that could overcome inconsistent worker performance and has the ability to identify location of the transport items resulting in less labour force and improved efficiency and productivity.

Radio Frequency Identification (RFID) and barcode technology offer efficient logistic management by automating the information identification, verification, and documentation process in near real-time [2]. RFID technology allows information collection in open space and is more robust under hazard environment, without line-of-sight requirement. The unique performance of RFID technology has added sustainability value to logistic process. It was reported in [3] that RFID technology can reduce industrial related waste in terms of time, costs, and transparency.

Despite various evidences on applications highlighting capabilities of RFID in improving transparency and visibility of RTI in logistics process, there exists very limited study on RFID technology being applied for on-metal application and real implementation of passive tag on-metal RFID application. This research intends to further the study on RFID system development for improved accuracy in on-metal application, with focus on material handling process in automotive industry. The study on RFID system development includes the system design and validation phase to improvise feasibility analysis for on-metal RFID technology application.

This paper presents design, development, and implementation of an automated tracking system for metal-based trolley using RFID technology. The system was designed and validated at an automotive manufacturing plant in Alor Gajah, Melaka. The aim of this paper is to measure the sustainability of the RFID technology in terms of time reduction and process transparency in actual manufacturing environment. The automated RFID-based tracking system was applied on metal-based kitting trolleys that are regularly used to transfer automobile parts between the manufacturing plant and its suppliers.

This paper is organized as follows: Section 2 presents a review on RFID technology and its sustainability performance in several applications; Section 3 describes the data collection procedure, RFID system setup, and system validation at the manufacturing plant; Section 4 shows the results of the preliminary study and RFID system accuracy; Section 5 relates the results of the RFID system performance to sustainability value, and presents a new process flow model for material handling process at the manufacturing plant and lastly; Section 6 concludes the findings and listed recommendations for future works.

II. RFID Technology

RFID technology is an automatic identification technology that performs flow of unique information of an object or a person through the electromagnetic signal waves [2]. RFID technology consists of an interrogator, a transponder, and a host computer. The interrogator transmits radio wave signal to detect tags within the interrogating field. For the case of passive tag that is presence within the interrogating field, the incident wave energy received is then applied to energize the tag circuitry. The powered tag then responded with unique information specific to the tag back to the interrogator. The downlink and uplink communication between the interrogator and the tag is necessary for the RFID system detection, else tag within the interrogating field is failed to be detected.

RFID technology is known to improve information flow efficiency in residential, industrial, and commercial communities [4]. The high information flow efficiency of RFID technology has led to traceability and visibility of tagged item at near real-time value. RFID technology with item traceability and visibility features are environmental friendly and promote waste reduction in material and financial resources. The sustainability value of RFID technology has been recognized in both public and private sectors [5]. These are categorized into environmental, economic, and societal as listed below:

a. *Environmental sustainability:* RFID technology can be reviewed in term of energy efficiency. In material transfer process, energy efficiency is related to optimization of lorry deployment [6] based on product level visibility of the RFID-based inventory management system. The optimized lorry deployment frequency will eventually reduce the number of travel trip, and subsequently reduced the fuel consumption and carbon dioxide emissions. Energy efficiency is related to reuse and repair of materials or parts for prolong materials or parts life cycle. Based on findings in [7], RFID-based reverse logistic improves information flow and decision making on handling returned products, in results on better management on material reuse.
b. *Economic sustainability:* RFID technology has been emphasized in term of profit return and cost reduction. For example, an RFID-based warehouse monitoring system can reduce the inventory cost by constant monitoring of the inventory level [8]. By monitoring inventory level on shelf, order replenishment is performed to achieve economic order quantity that meet demands in the production line and thus minimizing holding costs, order costs, and shortage costs. In case of RFID-based environment monitoring system, wine quality is maintained by controlling the temperature and humility of the wine cellar [9]. The ability to preserve high quality product with continuous environment monitoring in turns improve the profits margin and safe-guard the high reputation of the process manufacturers.

Societal sustainability: RFID technology also gives positive outlooks to the welfare of public community. Reference [6] has shown success in a project that applied RFID technology to measure amount of recycled item collected where financial rewards are provided in return. This project has contributed welfare care to the community by providing cleaner environment and economy supports. Also, [3] has convinced that information transparency in food supply chain contributes to societal sustainability to customers and stakeholders. Information transparency is referred to as accurate, reliable, timely, and available data that identified the specific object. Information of food product is visible throughout food supply chain by using RFID technology. Food product visibility eventually gain customer confidence on food consumption and provides safety and health information of food product to the population.

III. System Design And Development

Based on the review performed, RFID technology suits well in the case study where an automated tracking of material handling operation using kitting trolley at a receiving dock of an automotive manufacturing plant is desired. Prior to the on-field implementation of the RFID-based system, a preliminary study was carried out for ten working days period. The objective was to understand current performance of the material handling process at the receiving dock. In this study, main activities involved in logistics process were recorded. Figure 1 illustrates the time taken in main processes activities of logistics included delivery order confirmation time (T_C), transfer process time (T_T), loading process time (T_L) and unloading process time (T_{UL}).

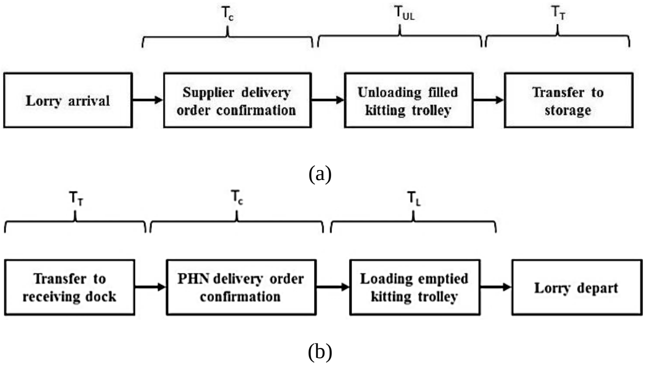


Figure 1: Process flow for (a) receiving fully loaded kitting trolley (unloading process), (b) dispatching emptied kitting trolley to supplier (loading process)

The automated tracking system consisted of both software and hardware components. The hardware components include a Dell Vostro 3400 laptop (as host computer), eco-UHF RFID reader, reader antenna and Xerafy Mercury Metal Skin UHF tag. On the other hand, the software development contributes as tool for management of data flow, such as data collection, data storage, and data presentation.

Figure 2 shows the schematic diagram of the system hardware. A detailed description of the software used for data collection and representation are summarized in [10]. The software becomes the medium that send interrogating command to the reader and update the database of the tag response results at the host computer. The software allows system user to view current status of all kitting trolley. Technical details of the software are described [11].

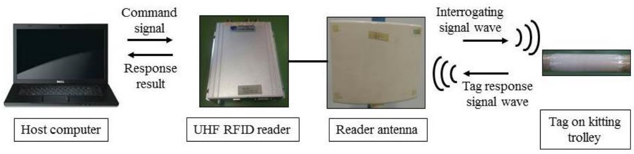


Figure 2: Schematic diagram of an RFID-based automatic tracking system

Figure 3 shows an overview of system architecture for the RFID-based RTI tracking system. The system architecture consists of three tiers relating to monitoring activity of the kitting trolleys. The first tier, that is data collection, is responsible to deliver command of captured RFID tag information and reply command of RFID response. This tier is connected with the next tier through transmission control protocol/ internet protocol (TCP/IP) connection point. The second tier; named data storage tier, is responsible to store any received information and response to any query on specific information. The query is requested by system user through data management tier, which is the third tier. Data management tier consisted of model identification of the kitting trolley locations and providing reports on RTI activity in real time.

Initially, series of RFID technology verification tests were performed with selected specifications. A methodological approach was proposed in [12] to measure the performance of RFID technology. Approach applied in this research is known as standard tests to measure performance of the RFID technology [13].

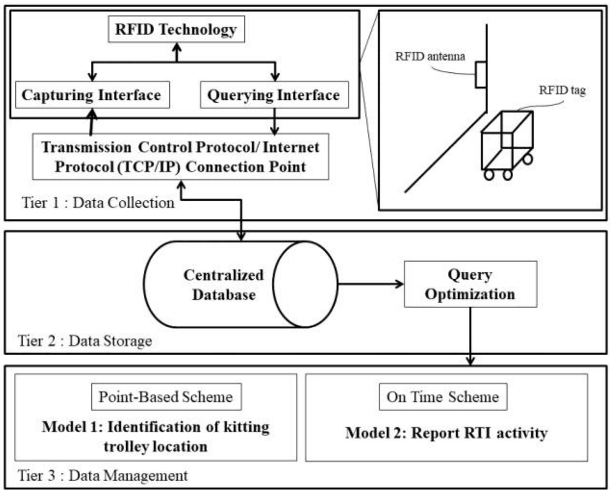


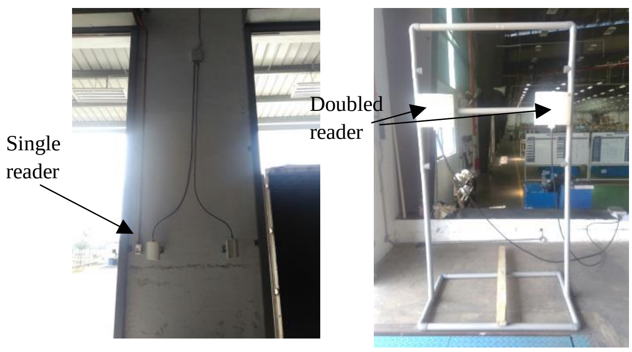
Figure 3: System architecture of RFID-based RTI tracking system

Standard tests refer to assessment of RFID technology performance under optimal conditions in closed environment with no drastic environmental change. Standard tests which covered elements such as FRID tag orientation, range, non-metal detection, and multi-antenna tests were conducted at the Control and Instrumentation Laboratory of the Faculty of Manufacturing Engineering (FKP), Universiti Teknikal Malaysia Melaka (UTeM). Table 1 lists the specifications applied during the system industrial validation process.

Table 1
System Configuration for Industrial Application

Specifications	Values
Horizontal distance between reader antenna and tag	1m - 3m
Height of reader antenna from ground	1.5m, 2m
Height difference between reader antenna and tag	0.3m ~ 0.8m
Tag orientation to reader antenna	Horizontal-perpendicular Horizontal-parallel

Figure 4 shows the graphical overview of the system using one and two reader antennas placed along the entrance of the receiving dock at a height of 1.5m. The reading interval of the eco-UHF RFID reader was set at 60ms and 20ms in order to study the capability of the system in tracking fast moving trolley. The system was validated for a period of 15 days. The actual number of detected trolleys was then compared with the number of tagged trolleys. This determines the system accuracy.



(a) (b)

Figure 4: On-site system setup configurations using (a) single antenna, (b) doubled antenna.

IV. RESULTS

Prior to the implementation, material handling process at the receiving dock is performed manually. Preliminary results in Table 2 showed that the average total time taken in unloading fully loaded kitting trolley and loading of emptied kitting trolley are 104.6min and 33.6min respectively. The different in average total time of the two material handling processes is due to quality and quantity of inspection on automobile parts that are required before transfer to storage is performed. Besides the huge different in kitting trolley transfer time, delivery order confirmation time and loading/ unloading time required about 9 to 10 minutes to complete respectively.

Table 2
Results of Preliminary Study

Time of Main Process Activity	Average Time Taken (minutes)	
	Fully Loaded Kitting Trolley	Emptied Kitting Trolley
Delivery order confirmation time, T_c	9.0	8.7
Loading / Unloading time, T_L/T_{UL}	9.9	8.8
Kitting trolley transfer time, T_T	85.7	16.0

Table 3 lists results of the system validation tests performed at the manufacturing plant. The two reader antennas setup produced the highest reading accuracy. This is expected as two reader antennas generate larger interrogating range and longer interrogating time, thus improving tag detection accuracy. Low reading interval of eco-UHF RFID reader is able to overcome the high speed of kitting trolley movements (maximum detectable speed was 0.8m/s).

Table 3
Results of System Validation for Loaded and Emptied Kitting Trolleys

Kitting Trolley	Testing setup	Actual number of tagged trolley	Number of RFID Reading Response	Reading Accuracy (%)
Received (Loaded trolley with automobile parts)	Single antenna	88	26	29.5
	Two antennas	44	17	38.6
Dispatched (Empty trolley)	Single antenna	98	41	41.8
	Two antennas	31	19	61.3

V. DISCUSSION

UHF RFID system is a technology to automate the data collection process without the line-of-sight detection and allows multiple tag reading in wide range area. Compared to process flow in Figure 1, the UHF RFID system produces shorter process flow by combining two main process activities, as shown in Figure 5.

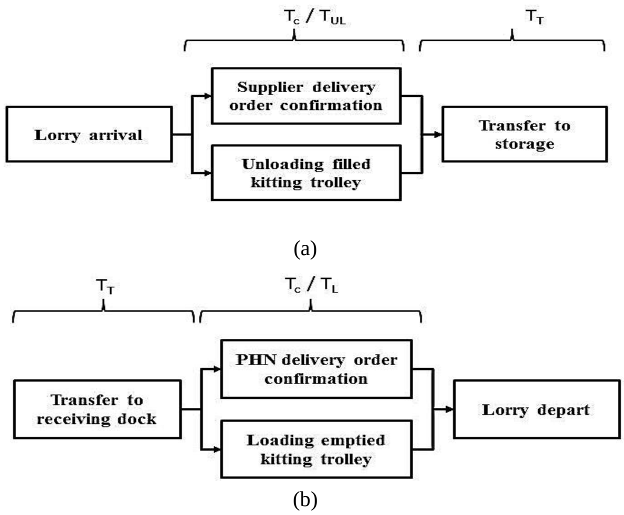


Figure 5: RFID-based process model of (a) receiving fully loaded kitting trolley (unloading process), (b) dispatching emptied kitting trolley (loading process) in PHN Pegoh plant

The parallel process on delivery order confirmation process and loading/ unloading process reduces the total time of material handling process. This shorten process flow has provide sustainability value of reducing waste of time in logistics activity.

Results shown in Table 3 indicate poor tracking ability of the system. At current status and configuration, the RFID tracking system does not have sufficient capability for 100% tag detection accuracy. Incrementing the number of antenna did increase the reading range (about 4% increments in reading accuracy) but it was not sufficient to cover the large total area of the receiving dock. Also, metal in vicinity also caused poor RFID system performance. This was validated in results shown in Table 3. Effect of metal in vicinity was apparent as comparison was made in reading accuracy between loaded trolleys (high volume of metals) and dispatched trolleys (scarce volume of metals). Results showed that the system accuracy for single and double antenna system dropped from 41.8% to 29.5% for the case of single antenna, and 61.3% to 38.6% for the case of two antenna system setup. Based on [14], metal is able to reflect electromagnetic wave and reduce its power. The weakened signal wave caused receiving passive tag antenna not able to fully power tag circuitry to send tag response signal back to the UHF RFID reader.

According to [15] reflection of right hand circular polarized wave on metal surface produces reflected wave in left hand circular polarized. Figure 6 shows the pattern of propagating wave in right hand and left hand circular polarized. This condition, however, can only be achieved if the metal surface is flat and is normal to incident wave. Therefore, in the absence of this condition, there existed in the open space environment of the test setup, mixture of right hand and left hand circular polarized wave. This mixture reduced the aligning process of linear polarized wave to the strongest linear field component of the circular polarized wave. This difficulty has led to larger polarization loss in transmission wave.

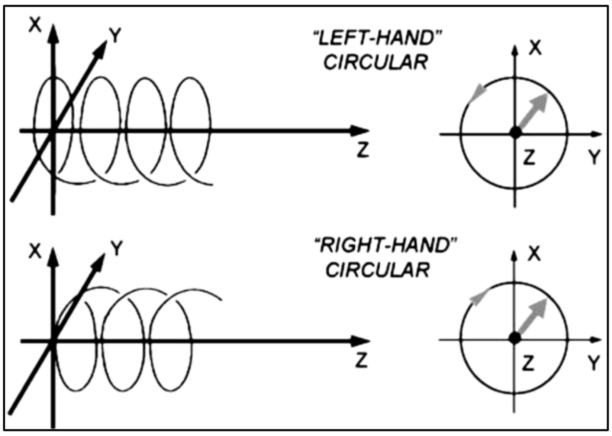
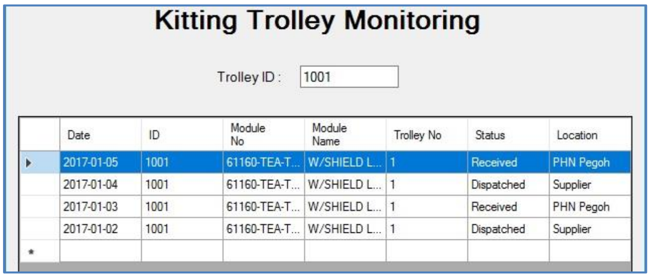


Figure 6: Schematic diagram of circular polarized wave [16]

It was suggested in [13] that increasing the number of wave reflection on metal would reduce the power of electromagnetic wave. Even though the line of sight loss is less in circular polarized wave, the reflected wave has less power to tag circuitry. This give negative impacts to passive tag since its power source is solely dependent on power of receiving wave. Passive tag in metal environment has higher risk in receiving low power incident wave if distance between reader antenna and the tag is large.

In term of system monitoring, Figure 7 shows an example of the UHF RFID system automated confirmation process. For example, kitting trolley with tag 1001 was detected automatically when it passed through the UHF RFID reader antenna and its status was then updated. The system user was able to instantly identify the exact kitting trolley that was loaded / unloaded.


Kitting Trolley Monitoring

Trolley ID : 1001

Date	ID	Module No	Module Name	Trolley No	Status	Location
2017-01-05	1001	61160-TEA-T...	W/SHIELD L...	1	Received	PHN Pegoh
2017-01-04	1001	61160-TEA-T...	W/SHIELD L...	1	Dispatched	Supplier
2017-01-03	1001	61160-TEA-T...	W/SHIELD L...	1	Received	PHN Pegoh
2017-01-02	1001	61160-TEA-T...	W/SHIELD L...	1	Dispatched	Supplier

Figure 7: RFID-based tracking system on kitting trolley

Also, the location of the kitting trolley can be correctly determined when the tag was detected at the receiving dock entrance. Traceability of the kitting trolley showed the transparency value in providing accurate and timely data to the responsible employee. Informational transparency value on tracking kitting trolley has added sustainability value into implication of UHF RFID system. Transparency value of the kitting trolley reduced the time needed in locating the kitting trolley and the transferal loss cost during material transfer process between the manufacturing plant and its supplier.

VI. CONCLUSIONS

RFID technology is an automatic identification technology that is able to perform multiple data collection in non-line-of-sight wide range area. The RFID system applied at receiving dock of the automotive manufacturing plant has showed the sustainability values of RFID technology in reducing the overall material handling time and improving visibility on-location of the kitting trolleys. The RFID-based process flow was able to reduce loading and unloading process time by approximate nine minutes. Kitting trolley traceability reduced the transferal loss cost in closed loop logistics flow. Even though the RFID system design and applied in this case study only manage a 50% tag reading accuracy, the results showed time reduction in material transfer time. It is suggested that an upgraded RFID system setup consisting two sets of antennas placed side by side at both side of dock is developed for future study. The study of RFID technology sustainability in the vicinity of heavy metal environment can be extended throughout all points in the closed loop logistics; such as in supplier receiving dock, storage and production site, for wider sustainability value on tracking the RTI's.

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