Radio Frequency Identification (RFID) Technologies for Locating Warehouse Resources: A Conceptual Framework

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Abstract

In the supply chain, a warehouse is a crucial component for linking all chain parties. It is necessary to track the real time resource location and status to support warehouse operations effectively. Therefore, RFID technology has been adopted to facilitate the collection and sharing of data in a warehouse environment. However, an essential decision should be made on the type of RFID tags the warehouse managers should adopt, because it is very important to implement RFID tags that work in warehouse environment. As a result, the warehouse resources will be easily tracked and accurately located which will improve the visibility of warehouse operations, enhance the productivity and reduce the operation costs of the warehouse. Therefore, it is crucial to evaluate the reading performance of all types of RFID tags in a warehouse environment in order to choose the most appropriate RFID tags which will enhance the operational efficiency of a warehouse. Reading performance of active and passive RFID tags have been evaluated before while, semi-passive RFID tag, which is battery-assisted with greater sensitivity than passive tags and cheaper than active tags, has not been examined yet in a warehouse environment. This research is in- progress research and it seeks to (i) provide a general overview of the existing real-time data management techniques in tracking warehouse resources location, (ii) provide an overall conceptual framework that can help warehouse managers to choose the best RFID technologies for a warehouse environment, (iii) Finally, the paper submits an experiment design for evaluating the reading performance of semi-passive RFID tags in a warehouse environment.

***Keywords**:* Radio Frequency Identification (RFID), Reading Performance, Locating warehouse Resources.

1. Introduction

A supply chain is an important channel for sharing information among all chain parties including, suppliers, manufacturing and storage facilities, distributors and customers for facilitating the core business functions of the production, sale, and delivery of a particular product (Kaihara, 2003; and Liu et al., 2005). However, due to the effect of the globalization, many companies have expanded their businesses to global locations. Logistics experts have to deal with many channel partners who may spread at longer distances and demand greater variety of products, more statutory requirements and documentations (Vogt et al., 2005). Also, the enterprises have changed their production mode from the traditional mass production to the mass customization in order to facilitate increasing global market competition. Thus the current supply chain networks are increasingly complicated. Good supply chain management (SCM) has become one of the key success factors for integrating effectively both material flows and related information between upstream and downstream entities in this globalized demand and supply environment so as to enhance both productivity and customer service (Soroor and Tarokh, 2006).

The changes mentioned above have had a big challenge on supply chain functions including warehousing for linking and integrating all the supply chain parties and for ensuring the smooth materials flows within the network (Gu, Goetschalckx, and McGinnis, 2007). It is because a warehouse is a crucial component for linking the upstream (production) and downstream (distribution) partners in supply chain, and the performance of the warehouse operations, which are either labour- or capital-intensive, not only influences the productivity and operation costs of a warehouse, but also the whole supply chain (Harmon, 1993).With such an arrangement, it is necessary to smooth data sharing and provide the location information of the warehouse resources, such as stock- keeping units (SKUs), pallets and racks, pallet trucks and forklifts, and warehouse staff members, in order to facilitate manufacturing operations, minimize inventory levels, reduce order processing, storage, and transhipment costs, and enhance productivity within facilities (Vogt et al., 2005). Thus, information systems such as warehouse management systems (WMSs) were implemented for handling the warehouse resources and monitoring its operations (Faber et al, 2002). However, there is a gap between the existing warehouse resources management tools and warehouse operations. The current WMSs are unable to determine the real-time status and location of the resources or to provide timely and accurate warehouse operations data (Shih, Hsieh, and Chen, 2006). Also, incorrect data is inevitably input from time to time as the systems depend heavily on warehouse staff members to put operational data manually or by using bar-code and human error is unavoidable (Sexton, Thomas, and Helmreich, 2000). Therefore, it is essential to implement real-time information technique for collecting and sharing data in a warehouse in order to trace and locate accurately the positions of warehouse resources for facilitating the handling of warehouse operations effectively and efficiently (Chow et al., 2006; Poon et al., 2009; and Poon et al., 2011) .

There are various emerging real-time information techniques suggested to handle and locate the warehouse resources in the existing market. In this paper, we present an overall conceptual framework which will help warehouse managers to choose the best RFID technologies for a warehouse environment.

This paper is organized as follows. In section 2; we present a background of existing real-time data management techniques in tracking warehouse resources location and also experiments for evaluation of RFID technologies in a warehouse environment. An overall conceptual framework for RFID technologies is shown in section 3. In section 4; the research model and questions are presented. Next; a benchmark model for comparing the types of RFID tags is drawn in section 5. The paper submits an experiment design for evaluating the reading performance of semi-passive RFID tags in a warehouse environment in section 6. Finally, section 7; is devoted to give a conclusion of this study and future research.

2. Background

2.1. Existing real-time data management techniques in tracking warehouse resources location

There are some real-time data management techniques implemented for smoothing data sharing in the existing supply chain and providing object location information. As far as indoor environment is concerned, different technologies have been developed to locate objects in the buildings such as, Infrared, ultrasonic and radio frequency identification (RFID) technologies (Xu and Gang, 2006). Among those three technologies, RFID is an emerging technology that has been widely adopted in numerous areas in the supply chain activities such as manufacturing, warehousing, retailing, etc., for object identification (Mintchell, 2002; Smaros and Holmstrom, 2000; Thevissen et al., 2006; Vijayaraman and Osyk, 2006). The RFID technology has made a significant contribution to warehouse environment and many world-famous companies, such as Wal-Mart, Gillette, and Proctor & Gamble, have already implemented RFID technology for handling their warehouse resources (Chow et al., 2006; Poon et al., 2008; sahin and Dallery, 2009; Poon et al., 2009; Poon et al., 2011; Collins, 2004; and O'Connor, 2005). RFID is an automatic identification and data capture technique which is comprised of three elements: A small tag or transponder to store and retrieve data and this tag is consisting of an integrated circuit chip connected with an antenna, (Prater et al., 2005; Smith, 2005; Lahiri, 2006); a reader that emits radio signs and receives in return answers from tags, and lastly a middleware that bridges RFID hardware and business applications (McFarlane et al., 2003). The role of the antenna is to define the read range of the tag and tag is capable to respond to radio waves transmitted from the RFID reader. Also, it is capable of sending, processing, and storing data (Wu, Nystrom, Lin, and Yu, 2006). According to EPC-Global standards, the chip memory includes an Electronic Product Code (EPC) which enables the identification of each item in a unique way (Brock, 2001; Goel, 2007). There are different EPC formats such as, 64, 96, 128 bits (Lahiri, 2005). For instance, EPC of 96 bits can identify more than 268 million manufacturers, more than 16 million kinds of objects, and nearly 69 billion articles for each manufacturer (Brock, 2001). Through radio waves, RFID systems provide a real-time communication with multiple objects simultaneously at a distance, without contact or direct line of sight (Garcia et al., 2007; Gaukler, 2005).

Actually, there are three types of RFID tags: (a) active- containing a small battery, (b) passive - draws energy from the transponder and (c) semi-passive - battery powered but requires signal from the transponder for activation (Angeles, 2005).

The following figures show the difference between active and passive RFID power scheme.

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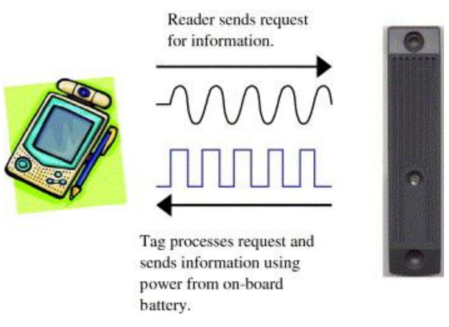

Figure 1 Passive RFID power scheme

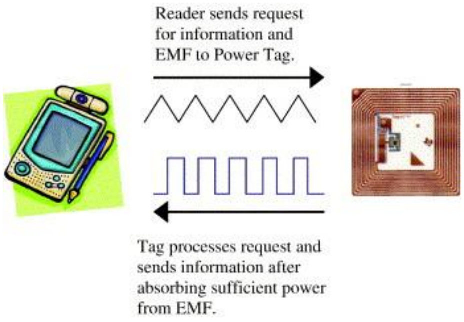

Figure 2 Active RFID power scheme

Source: Goodrum et al., (2006).

In fact, semi-passive tags may bridge the gap between passive and active RFID tags because they have a battery on board that enables them to read from a longer range (Angeles, 2005). Thereby delivering greater reading range and reading reliability than passive tags and offering much of the functionality found on active tags. Also, their prices are lower than active tags and closer to passive tags (Müller, 2008). However, the main differences between active tags and semi-passive tags are that semi-passive tags use their small onboard battery to power the chip only and still use passive response from the tag to the reader. This means that semi-passive tags are incapable of initiating the transmission from their location because they require a reader to interrogate them first. While, active tags use their own battery for both the chip and the transmission of data on the antenna and this enhance their ability to initiate the transmission from their locations (Xiao et al., 2007).

Actually, choosing the right technology for warehouse environment is a key decision factor for warehouse managers to gain the most out of RFID technologies. Analysing a warehouse environment and defining their objectives, constraints, strengths, weaknesses, opportunities, and threats are as important as analysing and evaluating different RFID technologies in order to select and implement the most efficient technology (Roberti, 2003; Porter et al, 2004; Angeles, 2005; Poon et al, 2009; Sarac, et al, 2010; and Mercer et al., 2011).

2.2.Evaluation of RFID technologies in a warehouse environment

There are different methods to study a system. Law and Kelton, (2000) present these methods in two groups:

1-Experiments with the actual system; and

2- Experiments with a model of the system that includes physical and mathematical models.

This paper focuses only on experiments of physical model because they are tests of RFID technologies which can help companies to show the difficulties, benefits, and key factors of RFID deployments in small or simple business environment (Sarac et al., 2010).

In fact, there is a few numbers of experiments which tested the reading performance of RFID equipments in a warehouse environment. The following table shows these experiments.

Authors	Title	Context	RFID Tags	Methods	Results	Limitations
Poon et al. (2009)	A RFID case-based logistics resource management system for managing order-picking operations in warehouses.	Group Sense Limited (GSL) warehouse	Active and Passive	Experimental Study/ orientation test, height test, range test, material test	Tag type, tag size, tag placement, tag orientation, tag height, tag range, reader placement, and the distance level between reader and tag have a significant effect on the reading performance of RFID	Semi-Passive RFID tags have been ignored
Poon et al. (2011)	A real-time production operations decision support system for solving stochastic production material demand problems.	Mould Manufacturing Company (ABC)	Not Available	Experimental Study/ power level-distance level test, tag angle test, reader angle test	tag angle, reader angle, and power level-distance level	Type of RFID tags has not been specified
Wang et al. (2010)	Experimental Study on RFID Performance Factors of Conveyor Belt System Using DOE Methodology.	Laboratory Tests	Passive	Experimental Study / Design of Experiment (DOE) methodology	Tag placement, angle of reader antenna and, conveyor speed, have main effect on the reading performance of RFID tags.	Active and semi-passive RFID tags have been ignored
Clarke et al. (2006)	Radio frequency identification (RFID) performance: the effect of tag	shipping containers	Passive	Experimental Study/material test, orientation test/Trail-and error approach.	The orientation of the tag does make a difference, especially when coupled with	Active and semi-passive RFID tags have been ignored

	orientation and package contents				filled package between it and the reader	
Singh et al. (2009)	RFID Tag Readability Issues with Palletized Loads of Consumer Goods	Warehouse Environment	Not Available	Experimental Study/Experimental Design	The interactions among product-package type, tag location, tag type, pallet pattern, and speed forklift have a significant effect on tag readability	Type of RFID tags has not been specified

Table 1 List of publications that conduct experiments for evaluating the reading performance of RFID tags to enhance locating of the warehouse resources.

From the above table we can observe a list of the previous publications which evaluated the reading performance of RFID tags in a warehouse environment detailed in the following.

A case study on RFID technology integration in the Group Sense Limited (GSL) warehouse has been performed by Poon et al. (2009), in order to facilitate the collection and sharing of data in real- time. They aim to formulate and suggest the most efficient RFID solution in warehousing environment the warehouse managers should choose before the implementation process. They have identified eight technological factors that have a significant effect on the reading performance of active and passive RFID tags in a warehouse environment: Tag type, tag size, tag placement, tag orientation, tag height, tag range, reader placement, and the distance level between reader and tag. These studies have stated the number of tests performed for each variable and have reported statistical analysis for the experiment results. However, there are limitations to their findings because they have only focused on active and passive RFID while, semi-passive RFID tags have been ignored.

Another case study on RFID technology integration in the Mould Manufacturing Company (ABC) has been performed by Poon et al. (2011). They aim to solve many problems in this company such as, defining the actual inventory level and locate the precise location of material handling equipments and Stock Keeping Units (SKUs) in the warehouse. They have tested RFID tag readability under different conditions, including tag angle, reader angle, and power level-distance level. They have provided statistical results and report statistical analysis. However, they did not specify the type of RFID tags used in their experiment, which is a critical issue because each RFID type has different reading performance.

An experimental study has been conducted by Wang et al, (2010), to investigate how the performance factors affect RFID system performance by using Design of Experiment (DOE) methodology. They have only focused on the following parameters: tag placement, angle of reader antenna and, conveyor speed. It was observed that the tag placement, angle of reader antenna and the interaction between them have main effect on the reading performance of RFID tags. They have only tested passive RFID tags while, active and semi-passive have been ignored.

The relationship between different product types and tag orientations on the readability of RFID tags on shipping containers in a pallet load that is driven through a portal type reader have been determined by Clarke et al, (2006).

They have concluded that the orientation of the tag does make a difference, especially when coupled with filled package between it and the reader. This means, that the content of packages can dramatically reduce the reading rate of RFID tags. This study has only used passive RFID tags, while active and semi-passive tags have been ignored.

The interactions among product-package type, tag location, tag type, pallet pattern and speed forklift through a RFID portal have a significant effect on read rate for case level tagging in a warehouse (Singh et al., 2009). However, they did not specify the type of RFID tags used in their experiment.

In summary, we conclude the above-mentioned RFID experiments research as twofold:

(1) Despite there are diverse factors affecting the reading performance of RFID technologies in a warehouse environment, all these factors can be classified either as technological, environmental, or physical contexts. Moreover, , the tag types, tag orientations, product types, and the distance levels between tag and reader are the most significant variables of RFID tags performance in a warehouse environment. Therefore, it is feasible to utilize a conceptual framework to explore the interactions among these factors in the different contexts.

(2) Most of the prior studies consider the evaluation of active and passive RFID tags in a warehouse environment. To date, however, no prior literature has evaluated the reading performance of semi-passive RFID tags in a warehouse environment. This neglected gap will prevent warehouse managers and decisions makers from choosing and implementing the most efficient RFID technology in their warehouses which will affect the operational efficiency of a warehouse. In addition, in an RF harsh environment, it is often highly beneficial to test and evaluate RFID systems prior to their installations in order to select and adopt the right and most efficient RFID technology, which is an important decision for organizations to obtain the most out of RFID technologies (Roberti, 2003; Porter et al, 2004; Angeles, 2005; Poon et al, 2009; Sarac, et al, 2010; and Mercer et al., 2011). This highlights the need to test the reading performance of semi-passive RFID in a warehouse environment in order to report a statistical analysis and provide a comprehensive RFID performance comparison. Resulting in an appropriate reference to help enterprises to select the most appropriate RFID equipment for their warehouse environment. Therefore, this study will carry out a full factorial experiment design which is a systematic test procedure in order to determine the relationship among different product types, tag orientations, and distance levels on the tag readability of semi-passive RFID.

3. Conceptual Framework:

A wide range of factors which affect the reading performance of RFID tags has been found in the literature review. These factors are shown in figure.3.

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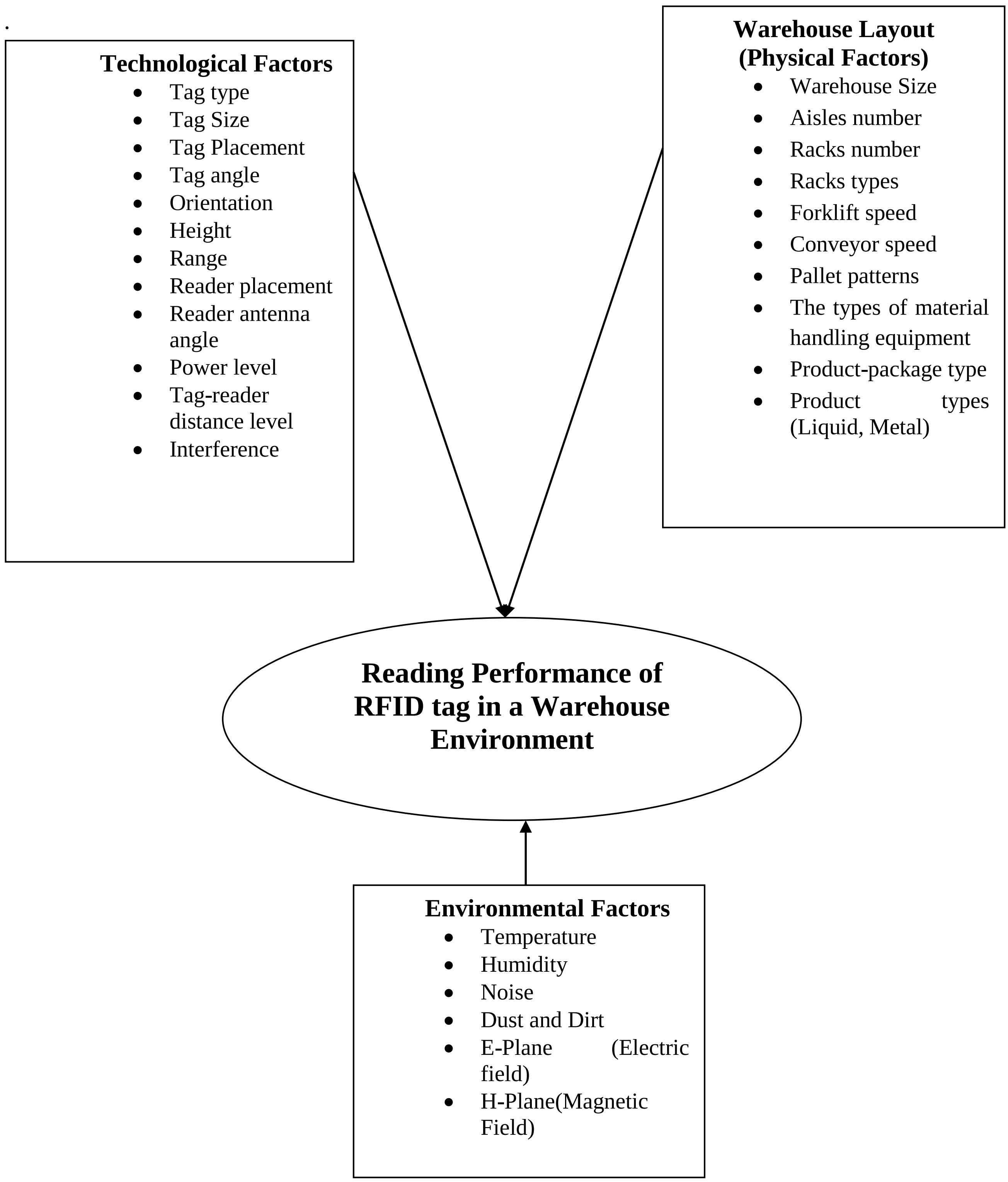

Figure3 Factors affecting the reading performance of RFID tags

From figure 3, we can see that there are twenty six determinants which affect the reading performance of RFID tags in a warehouse environment. Instead of repeating them, this study will find out the interrelationships among the factors. Then, it will focus on identifying the factors that are believed to have a direct effect on the RFID performance in a warehouse environment in order to propose the research model.

3.1. Technology Context

There are many technological factors which have a significant effect on the reading performance of RFID tags in a warehouse environment (Singh et al., 2008; Poon et al., 2009; Ammu et al., 2009; Wang et al., 2010; Aryal et al., 2010; and Poon et al., 2011): Tag type, tag size, tag placement, tag orientation, tag height, tag range, reader placement, the distance level between reader and tag, angle of reader antenna, tag angle, conveyor speed, and power level. The relationships among these factors and their effects on the reading performance of RFID tags are indicated as following.

3.1.1. Relationship among tag type, tag orientations, and distance level

There are three main types of RFID tags: Active, passive, and semi-passive. Each type of these RFID tags has different reading performance. In a warehouse environment, Poon et.al (2009) have performed orientation test to determine the relationship between the tag type and tag orientation. Orientation test is to determine the horizontal effective RF cover range of the reader. The tags have been stuck onto the front, top and side surfaces of the object and corresponding read rates of the tags have been measured by moving the object different distances horizontally. They found that the reading performance of active and passive tags stuck on the front surface on the SKU (direct facing) is better than when they stuck on the top surface (horizontal) or the side surface (vertical) of the SKU. In addition, they have tested the tag-reader distance/proximity between Minimum 20cm – Maximum 1000cm. It was observed that the effective cover range of reader can be achieved when the distance between the tags and the reader is nearly 200cm. Moreover, the reading performance of active RFID tags in any orientation and at any distance level is better than that of passive RFID tags. However, there are limitations to their findings because they have only tested active and passive RFID tags while, semi-passive tag has been ignored in their study.

3.1.2. Relationship between tag type and tag height

An experimental study by Ammu et al, (2009), tested tag readability under different conditions, including tag type, height of tag, and the proximity of the tag to the reader. It was concluded that tag type and tag height has a main effect on tag readability. However, they have evaluated only passive RFID tags, while active and semi-passive RFID tags have been ignored. Another study observes that the interaction between tag type and tag height has a direct effect on RFID tag readability (Poon et al., 2009). They have found that the reading performance of active tags stuck onto the front surface of the object, which is placed at 1 m from the reader and is moved different distances vertically (0cm-180cm) , is better than that of passive RFID tags. Also, the effective cover range of reader can be obtained when the tags height (active and passive) is between 160-180cm.

3.1.3. Relationship among tag type, tag range, and distance level

The relationship among tag type, tag range, and distance of the tag from reader has a strong effect on the reading performance of RFID tags (Poon et.al 2009). For instance, the reading performance of RFID active tags is better than that of passive RFID tags when the object is placed 1 m from the reader and the tags are stuck onto the front surface of the object which is moved different distances horizontally. In addition, the maximum RF cover range of the reader in a horizontal direction and the highest likelihood of successful read of tags can be achieved when the distance between the tags (active and passive) and the reader is nearly 200cm.The study states the number of tests performed for each variable, and reports the statistical analysis of the experiments results. However, only active and passive RFID tags have been tested in this study, while semi-passive RFID tag has not been evaluated. This will prevent warehouse managers and decisions makers from selecting and implementing the most efficient RFID technology in their warehouses which will affect the operational efficiency of a warehouse.

3.1.4. Relationship among tag size, tag orientations, tag height, and distance level

The importance of the relative tag size, tag orientation, and the distance level between the tag and the reader is disputed. Many researchers claim that the interaction among tag size, tag orientation, and the proximity of the tag to the reader has a significant effect on the reading performance of RFID tags. An experimental study by Deavours, (2007), concludes that the tag size, read distance, and orientation of tag all affect the reading performance. However, they did not apply a systematic test procedure or report statistical analysis. Also, they did not mention which type or RFID tag has been used in their study. Another experimental study finds that the reading performance of the passive large-sized tags is better than the passive middle-sized and small-sized tags in any orientation, at various heights, or at any distance level. Moreover, the effective cover range of reader can be achieved when the distance between passive tag and the reader is almost 200cm (Poon et al., 2009). Although, this study provides the number of tests performed for each variable, and reports clearly statistical results and statistical analysis. There are limitations to their findings because they only determine the effect of passive RFID tags with different sizes on tag readability, while active and semi-passive RFID tags have been ignored.

3.1.5. Relationship among tag placement, tag angle, reader angle, and power level-distance level

The experiment result of Wang et al, (2010), shows that tag placement, angle of reader antenna and the interaction between them have main effect on the reading performance of RFID tags. Specifically, they have found that when the angle of reader antenna is set at 15 degrees, the maximum average read rate overall can be achieved. Another experimental study by Poon et.al (2011), tested tag readability under different conditions, including tag angle, reader angle, and power level-distance level. They performed reader angle test to measure the read counts of RFID tags per second with different reader antenna angles and when the object is moving at the aped 1.5m/s in front of antennas. They indicated that the readability of the reader antennas increases when the angle between the two reader antennas increases. The optimum readability of reader can be obtained when the reader antennas angle is set at 120°. Furthermore, the reading performance of RFID tags when tag angle between 0° and 30° is slightly lower than that between 135° and 180°. In addition, the reading performance becomes stable when the tag angle is between 45° and 120°. That means it is not essential to place the tag parallel to the reader surface.

On the other hand, Poon et al (2011) determined the relationship between the power level and distance from the tags to the antennas (the centre point of the two antennas). Both the tag and reader antennas are perpendicular to the E-plane. Also, the tag is moved along the intersection line of the E-plane and the Hplane. It is observed that the minimum RF power level needed to detect a tag is 7 dB, and the maximum distance is 200 cm. Besides, the maximum average read count is around 8.6 times per second and the read count is comparatively stable at the maximum level. However, the readability between the tag and the reader drops meaningfully when there is an increase in distance level or a decrease in power level. Thus, it is concluded that using a higher power level can provide a better and larger RF cover range.

Although, the both studies provide statistical results and report statistical analysis. They did not specify the type of RFID tags used in their experiment which is a critical issue because each RFID type has different reading performance.

3.1.6. Effect of interference on RFID performance

There are many factors that can cause radio frequency interference in a warehouse environment and affect negatively the reading performance of RFID tags such as, operating equipment (forklifts) and processing/filling equipment, and also the electromagnetic interference. Porter et al. (2004) have performed warehouse RFID passive interference tests to assess the read rate of a system when tags were adhered to different containers under different conditions. The results of the tests showed that metal and liquids in the environment cause the passive RFID system to read unreliably. There are limitations to their findings because they have tested only passive RFID tags in a warehouse environment. However, before any RFID system is selected for implementation, it is advisable that such systems undergo a rigorous set of operational tests to ensure that they able to meet all the performance requirements of a particular application. This means, that there is still a need for evaluating other types of RFID tags which are, active and semi-passive RFID tags in a warehouse environment. Another study by (Arnaud-Cormos et al., 2007), analyzes the influence of electromagnetic waves interference on an UHF passive RFID system produced by applications (GSM communication) located nearby. The study showed that the reading range of the passive RFID is considerably reduced by a GSM communication. However, it should be noted that these effects correspond to particular cases of specific commercial RFID systems and should not be generalized unless tested on various RFID systems.

3.2. Environment Context

3.2.1. Effect of temperature, humidity, dust, dirt, and noise on RFID Performance

All RFID tags are robust and can cope with harsh environments (e.g. a warehouse environment) with excessive dirt, dust, moisture, and in temperature extremes (Finkenzeller, 1999; Wyld, 2006; Huber et al., 2007). However, the temperature and humidity extremes that the tagged products are exposed to have a significant effect on the reading performance of RFID tag. It is essential to select the tags which are rated to operate within those extremes. A special coating or adhesives on the label face may also be needed to resist water (Sirico, 2011). Also, noise in the warehouse environment has negative effect on the reading performance of RFID tags. Passive RFID tags are subject to noise, but active RFID tags are better noise immunity (Tajima et al, 2007).

3.3.Warehouse Layout Context

It is essential to perform a warehouse study before the implementation of RFID systems (Bhuptani, et al., 2005). This is because the layouts of warehouse vary among different companies. The physical factors, such as warehouse size, aisles number, racks number, racks types, the types of material handling equipment, and the products types affect the readable range and accuracy of RFID tags. By this way, warehouse manager will know exactly the amount of products, tags, metal, and liquid that they have in their warehouse environment which will help them to choose the most suitable RFID tags for this warehouse. For example, active RFID tags have higher data transmission rates, more tags can be read simultaneously, and suitable for RF-challenging environments such as, inside food pallets, or pharmaceutical containers, or around metals and liquids. However, passive RFID tags have lower data transmission rates, fewer tags can be read simultaneously, and metals and material of high water content decrease its reading range to less than (1) meter (Mercer, 2011).

The interactions among product-package type, tag location, tag type, pallet pattern and speed forklift through a RFID portal have a significant effect on read rate for case level tagging in a warehouse (Singh et al., 2009). It was observed that the reading performance greatly varies for different product-package types, with paper towels producing near-perfect reads, followed by bottled water and carbonated soda cans. Moreover, the best pallet patterns were dependent on the product-package type. For instance, the best pallet pattern for bottled water was column, and the interlocking pattern for carbonated soda. In addition, the slower the forklift truck speed, the better the reading performance across the board.

On the other hand, Wang et al. (2010) have investigated the effect of conveyor speed on the reading performance of RFID tags. They found that it is not true that the slower conveyor moves, the higher read rate gets.

The environmental components such as metallic materials and water have already been reported to affect RFID performances, especially for higher frequencies (Bhuptani et al., 2005; Dobkin et al., 2005; Clarke et al., 2006; Griffin et al., 2006; Poon et al., 2009; and Singh et al., 2009). It is a fact of physics that metal and water have a detrimental effect on radio waves. Metal reflects, and water absorbs and/or reflects them. Many products include metal and/or water, such as canned food, detergents and drinks. Water has been found to affect the reading performance of RFID tags, especially in the UHF range. Onderko, (2004), has found that RFID tags performed successfully when reading through frozen beef, but not when the beef was thawed, illustrating the liquid water problem. There are indications that the absorption/reflection problem can be solved with a carefully chosen tag orientation. Clarke et al., (2006) have determined the relationship between different product types and tag orientations on the readability of passive RFID tags. They have found that the content of packages can dramatically reduce the reading rate. Poon et al, (2009) have determined the interactions among product types, tag orientations, tag sizes, and distance levels on the tag readability of active and passive RFID tags. It was observed that the reading performance of active RFID tags when placed in front of SKU (Paper box), metal, or water is better than that of tags placed behind the paper box, metal, or water. The highest reading performance in the both orientations can be achieved when the distance level between active tag and reader antenna is between 180-200cm. Moreover, the reading performance of the passive large-sized tag is better than that of passive large-sized and small-sized tags placed in front of or behind SKU (Paper box), metal, or water bottle and at any distance level. However, passive large-sized tag is not suitable to adopt in tracking the material handling equipment, such as forklifts, because the reader is unable to detect the tags which are stuck on the metal.

In a warehouse environment, tag types, tag orientations, product types, and the distance levels between tag and reader are the most obvious and significant variables of RFID tags performance (Clarke et al., 2006; Singh et al., 2009; and Poon et al., 2009). These studies have stated the number of tests performed for each variable and have reported statistical analysis for the experiment results. However, there are limitations to the findings of these studies because the previous researchers have focused only on active and passive RFID. Although, the reading performance of active RFID tags is better than that of passive RFID tags. The costs of active RFID readers and related equipments are comparatively high, compared to the costs of passive RFID devices. It is difficult to adopt the active RFID tags for item-level RFID tagging in the warehouse environment due to high implementation cost. Thus, it is essential to test semi-passive RFID tag, which is battery- assisted with greater sensitivity than passive tags and cheaper than active tags, in warehousing environment. Figure.4. shows all these types of RFID tags.

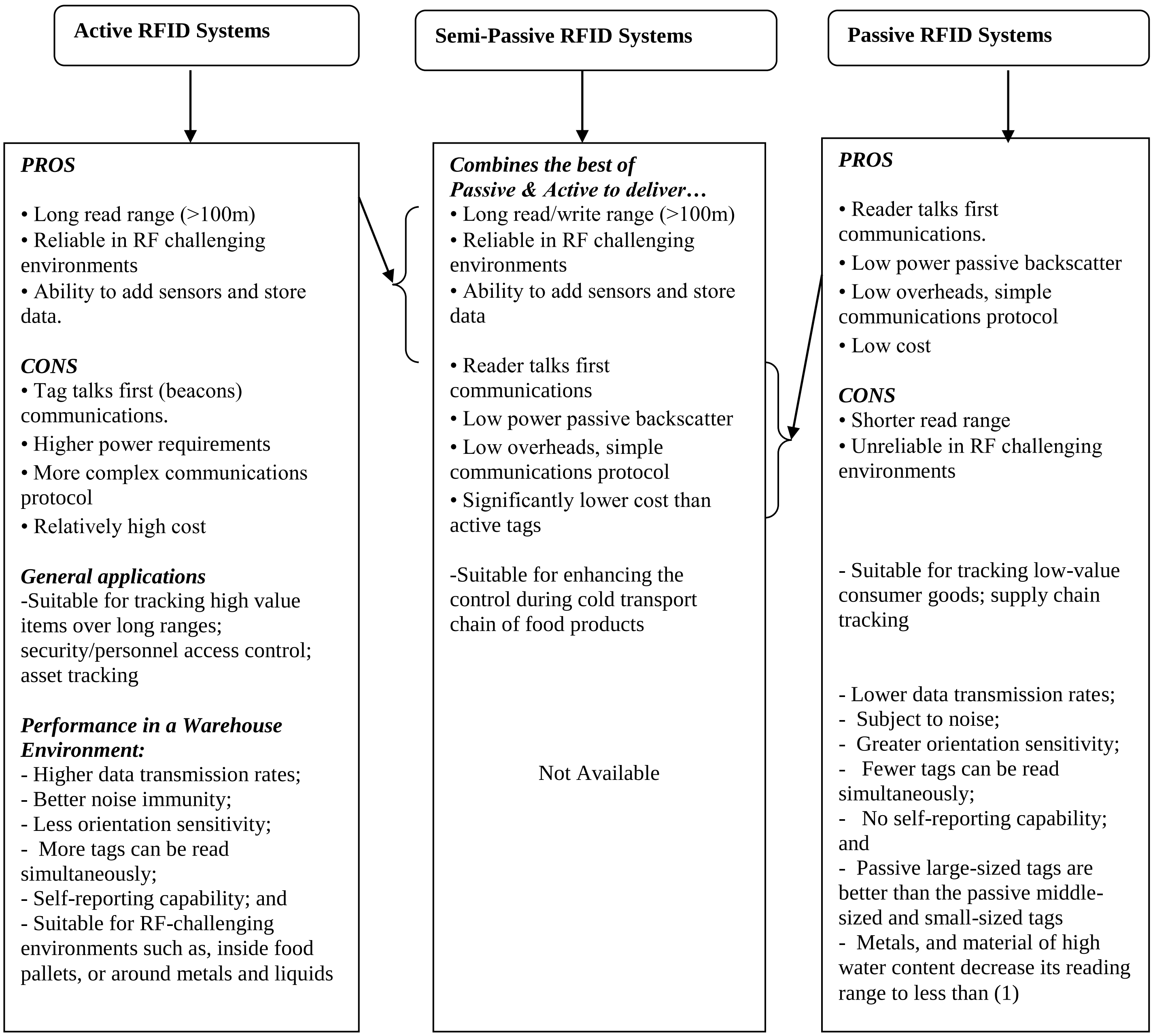

Figure 4 Comparison among RFID Types

(Juels & Pappu, 2003; Angeles, 2005; Want, 2006; Tajima, 2007; Domdouzis et al, 2007; Jedermann et al, 2008; and Poon et al, 2009)

Form figure 4, it shows that, semi-passive RFID tags combine the best of active and passive RFID tags. Semi-passive RFID tag is an emergent technology that is being used increasingly in many applications. Recently, Jedermann et al. (2008) examined the spatial temperature profiling by semi-passive RFID loggers for perishable food transportation. For instance, they found that these devices are valuable tools for enhancing the control during the cold transport chain of food products and detecting weaknesses by monitoring environmental variables such as the temperature of chilled food refrigerated products, identifying specific problem areas, and raising alarms. However, these loggers need manual handling due to their low reading range. Similarly, Michigan State University conducted a study by using semi-disposable sensor-enabled RFID tags with data loggers, which are battery-assisted passive tags offering temperature and humidity logging to determine temperature variation in different size refrigerated trailers. They found that refrigerated trailers have micro-climates that exist even when a trailer is correctly loaded. These micro-climates lead to perceivable temperature deviations that had not been forecasted (Bert, 2007). Ford Motor Company also uses semi-passive tags to track parts boxes once they have arrived in their immense assembly plants (Mital and Ives, 2003). Semi-passive tags are also often used in pallet-level tracking or tracking ingredients like automobile parts during manufacture. Furthermore, electronic tollbooths often use semi-passive tags by initiating a query to these tags which are typically attached to the inside of a car's windshield. By this way it can read an account identifier from the tag when the car passes through a tollbooth (Weis, 2009).

Although semi-passive tags have made a significant contribution to different business environments. There still are significant challenges when implementing these tags in various business areas. For example, semi-passive tags use some battery power to preserve their internal volatile memory but may still depend on the reader's signal to power their transmission. Also, they are more fragile and larger than passive tags (Liu, et al., 2009). Müller, (2008) mentioned that the main challenge of semi-passive RFID tags is to maximize the backscatter efficiency on the tag side and to provide a high sensitivity on the reader side because semi-passive tags don't actively send RF power back to the reader. Furthermore, there is a problem of incomplete reading of sensing value stored in the semi-passive sensor tag. So, Soohan et al. (2009) presented dynamic resizing of bundle and recovery mechanism for complete reading of semi-passive sensor tag. These techniques improve the reliability of reading process and accelerate the mass data reading .In addition; semi-passive RFID tags have shorter lives because they rely on battery power which only offers a temporary solution due to their finite lifetime. Hence, Lai et al. (2005) conducted an experiment in using ambient vibration energy to power a semi-passive RFID tag. They found that the ambient vibration energy offers an unlimited life and maintenance free solution in powering semi-passive tags.

Academics and practitioners have produced much wide ranging literature concerning semi-passive RFID tags innovation since its emergence. Extensive academic debate focused on the benefits of semi-passive RFID tags and the contribution that this technology could make to overall supply chain performance. Also, they focused on the implementation challenges and the corresponding strategies to enable semi-passive RFID tags in business environment. To date, however, no prior literature has evaluated the reading performance of semi-passive RFID tags in a warehouse environment. This neglected gap will prevent warehouse managers and decisions makers from choosing and implementing the most efficient RFID technology in their warehouses which will affect the operational efficiency of a warehouse. In addition, in an RF harsh environment, it is often highly beneficial to test and evaluate RFID systems prior to their installations in order to select and adopt the right and most efficient RFID technology, which is an important decision factor for organizations to obtain the most out of RFID technologies (Roberti, 2003; Porter et al, 2004; Angeles, 2005; Poon et al, 2009; Sarac, et al, 2010; and Mercer et al., 2011). This highlights the need to test the reading performance of semi-passive RFID in a warehouse environment in order to report a statistical analysis and provide a comprehensive RFID performance comparison. Resulting in an appropriate reference to help enterprises to select the most appropriate RFID equipment for their warehouse environment. Therefore, this study will carry out a full factorial experiment design which is a systematic test procedure in order to determine the relationship among different product types, tag orientations, and distance levels on the tag readability of semi-passive RFID.

4. Research Model and Questions:

The research model was proposed as shown in Figure.5. This model will help to determine the effect of interaction among relationship among different product types, tag orientations, and distance levels on the tag readability of semi-passive RFID. The research questions are proposed as follow.

1- What is the reading performance of semi-passive RFID tag stuck on top, front, back, side, and down surface of water box at different distance levels?

2- What is the reading performance of semi-passive RFID tag stuck on top, front, back, side, and down surface of metal box at different distance levels?

3- What is the reading performance of semi-passive RFID tag stuck on top, front, back, side, and down surface of empty box at different distance levels?

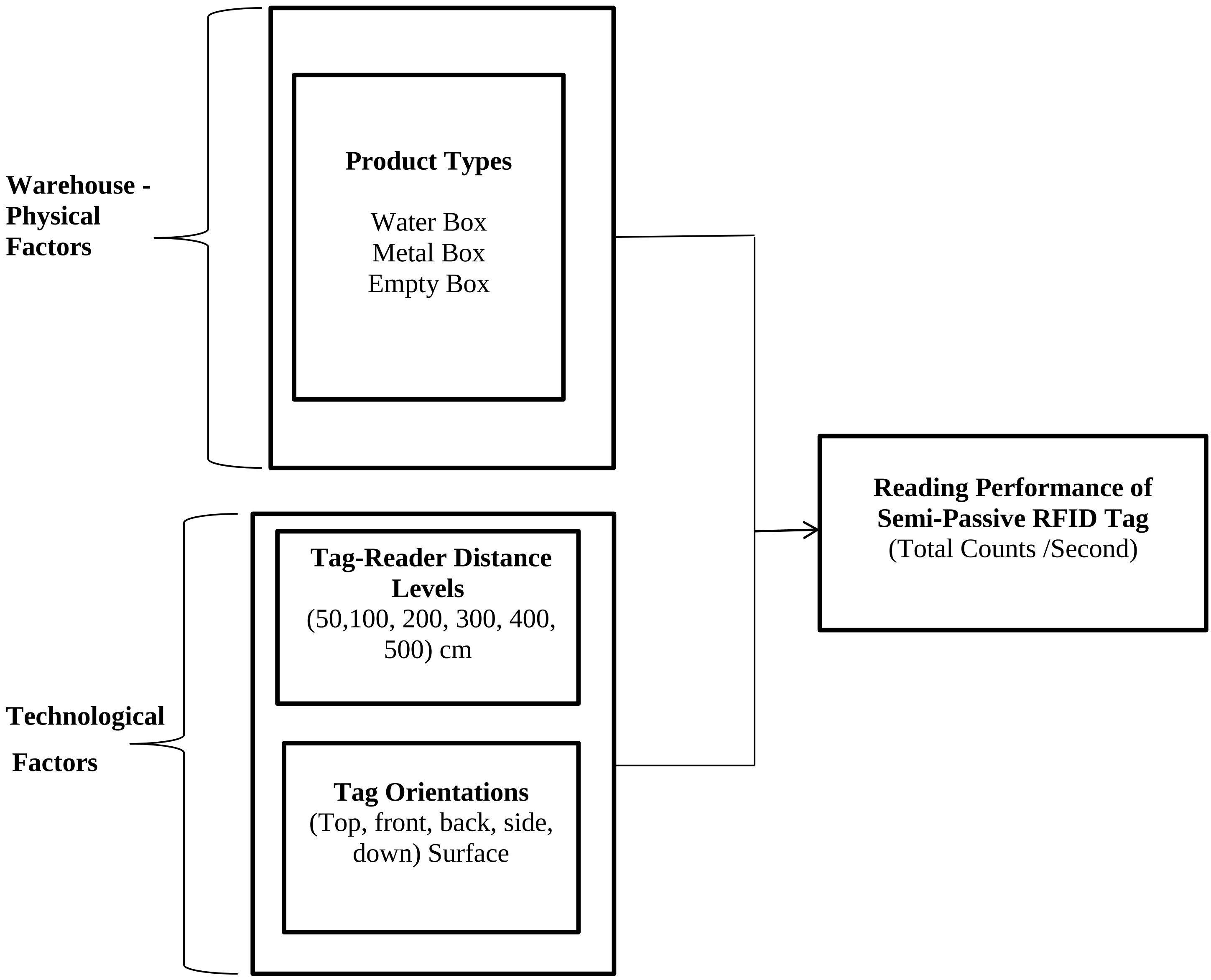

Figure 5 The Research Model

5. Benchmark Model

There are many performance benchmarks for comparing the types of RFID tags. However, in this research, only the performance benchmarks near metal and water (Section 5.1) at various tag orientations and at different distance levels (Section 5.2) are developed and presented. More detailed and formal description of the RFID performance benchmarks are as following.

5.1. RFID Reading Performance near metal and water

In an RF harsh environment such as a warehousing, the two most common and difficult materials are water and metal. Metal reflects, and water absorbs and/or reflects the radio waves. However, there are indications that the absorption/reflection problem can be solved with a carefully chosen tag orientations (Alien Technologies, 2002; Clarke et al., 2006; Singh et al., 2009; and Poon et al., 2009). Poon et al, (2009), have provided statistical results about the reading performance of active and passive RFID tags near metal and water in a real-world warehouse environment as shown in table .2.

Test	Average results(Total counts/Second)	
	Active RFID Tags	**Passive RFID Tags**
Material Test	**1117**	**202**
Tags placed in front of the SKU (Paper box)	1492	389
Tags placed behind the SKU (Paper box)	1486	375
Tags placed in front of the metal	1826	5
Tags placed behind the metal	157	166
Tags placed in front of the water	1541	166
Tags placed behind the water	199	108

Table2 Reading Performance of Active and Passive RFID Tags Near Metal and Water (Poon et al, 2009)

It is clear from the above table that the metal and water have a strong effect on the reading performance of active and passive RFID tags. However, the reading performance of active tags is better than that of passives near any material type and in any orientation except behind the metal, e.g. the reading performance of passive RFID tag is 166 counts/second while, the reading performance of actives is 157counts/second. It also clear that the metal and water problem can be solved by changing the tag orientation. For example, the reading performance of passive RFID tags is only 5 counts / second in front of the metal but, it becomes 166 counts / second when they placed behind the metal.

On the other hand, Clarke et al, (2006), have determined the relationship between different product types and tag orientations on the readability of passive RFID tags. They have found that the content of packages can dramatically reduce the reading rate. Only 25% of the tags on a warehouse's shipping containers including water-filled bottles could be read. However, rice-filled jars had a higher read rate (80.6%). Even empty boxes did not have a 100% read rate and only 74–79% of loads had all of their tags read. Tag orientation does make a difference, particularly when coupled with a filled package between it and the reader antennae. For instance, tags facing outwards, towards the reader antennae, had the highest likelihood of a successful read. However, when tags for the cases of water-filled bottles were all facing downwards, no tags were read.

5.2. Distance sensitivity

The tag-reader distance/proximity affects the reading performance of RFID tags in a warehouse environment. An experimental study by Alien Technologies, (2002), a leading RFID systems supplier, has tested the tag readability under different conditions, including proximity of the tag to the reader, tag orientation, and product type. It was concluded that the distance between the tag and the reader antenna had a direct effect on the tag readability. However, the study does not state the number of tests performed for each variable, and no statistical analysis is reported. Poon et al, (2009), have determined the relationship among product types, tag orientations, and distance levels on the readability of active and passive RFID tags in a warehouse environment. It was observed that the highest reading performance of active RFID tags can be achieved when active tags placed in front of metal, and in front of water at the distance level (200cm) between the active tag and the reader. However, at distance level 80cm, the highest reading performance of active and passive tags placed behind the metal was obtained. The highest reading performance of tags placed behind the water bottle is at distance level 40cm for active tags and 60 cm for passives. Table.3. shows the statistical results in details at different distance levels.

	Counts/ Min							
Tag type & Orientation / **Distance cm**	**Tag in front of metal**		**Tag behind metal**		**Tag in front of water**		**Tag behind water**	
	Active	**Passive**	**Active**	**Passive**	**Active**	**Passive**	**Active**	**Passive**
40	0	214	0	647.2	1920	647.2	1280	914.6
60	0	0	128	931.6	1900	931.6	980	985.4
80	0	0	906	967.8	2180	967.8	65.6	921.4
100	1230	0	59	717.6	2040	717.6	0	0
200	2880	0	466	0	2590	0	0	0
300	2836	0	309.6	0	1800	0	0	0
400	2670	0	143.2	0	1790	0	0	0
500	2596	0	0	0	1016	0	0	0

Table 3 Statistical results of RFID reading performance (Poon et al, 2009)

6. Experiment Design:

An experimental design process will be conducted in this study for the effect evaluation of several parameters on reading performance of semi-passive RFID system. Experimental design is a process that is used to evaluate the system performance systematically under certain criteria (Krajewski et .al, 1987; Moeeni et.al, 1997; Lin et.al, 2001; Dowlatshahi, 2004; and Montgomery, 2005). Tag readability and read redundancy are the two types of performance measures of RFID system (Alien Technology, 2002). Tag readability (core functionality) is to determine if all tags can be read successfully per time under the given conditions. However, Read redundancy (robustness) is to determine how many times a given tag can be read (number of repeated reads). Full factorial experimental design, which is a systematic approach to assess the performance of operational parameters on single tag RFID and its optimal operating settings (Kabadurmus, et.al, 2007; Montgomery, 2009),will be conducted to evaluate the tag readability (Total reads or counts/Second) as a performance measure. Moreover, three design parameters will be used: product type, tag orientation and distance level between tag and reader. In order to examine all main categories of products, three levels are determined for product type parameters which are carton box with water-filled bottles, carton box with metal products included (metal inside box), and empty carton box (empty box). Five different orientations for semi-passive RFID tag will be determined and tested on three different product types and six different distance levels. The possible tag orientations are top surface (horizontal), side surface (vertical), front surface (direct facing), and back surface (indirect facing) of the object (Poon et. al, 2009). However, there is one more orientation for tag which is downwards (Clarke et. al, 2006). Also, according to Align Technology, (2002) there are three orientations for tag (relative to the floor): vertical, horizontal and diagonal. In this study, tags will be stuck onto the top surface (horizontal), front surface (direct facing and nearest), back surface(indirect facing and farthest) , side surface (vertical), and down surface of boxes in order to analyze the effect of metal and water (liquid) in the boxes at different tag orientations. In order to evaluate the effect of distance level between the tag and reader on the tag readability, six different distance levels will be tested (50,100, 200,300, 400, 500cm). It is because the reading performance of active and passive RFID tags have been tested before at these distance levels in a warehouse environment by Poon et al, (2009). They have clearly stated the experiment results and reported statistical analysis. Table. 2. Presented earlier, shows the statistical results of the reading performance of active and passive RFID tags. It is clear from the table that the active tags must be lower than 100cm in order to be read behind the water while, no active tags can be read when the distance level is lower than 100cm in front of metal or lower than 60cm behind the metal. In addition, the passive tags must be at a distance level lower than 60cm in order to be read in front of metal and behind the water while, they must be lower than 100cm in front of the water and behind the metal in order to be read. Moreover, the highest likelihood of successful read of active tags at various orientations can be achieved when the distance level is 200cm. However, this likelihood starts to decrease after 200cm(300-400cm) to become zero at distance level 500cm and also no active tags can be read after this distance especially, behind the metal (Poon et al, 2009). So this research will test the tag-reader distance/proximity between Minimum 50cm -

Maximum500cm in order to achieve adequate and comparable statistical results and to investigate whether the highest readability of semi-passive RFID tag at various orientations can be obtained at the same distance level (200cm), more, or less than that level.

The use of randomization in experiments is a common practice, since it is generally very difficult to eliminate bias using only the expert judgment (Hicks and Turner, 1999). In a randomized experimental design, objects or individuals are randomly assigned to an experimental group. Randomization assists to insure that treatment groups are as similar as possible and helps to eliminate effects of unknown or uncontrolled variables. However, the results of a single experiment, applied to a small number of objects or individuals, would not be accepted without question. Selecting two individuals from a group of four randomly and applying a test with "great success" usually will not convince the public of the effectiveness of the test (Hicks and Turner, 1999). For all these reasons, a full factorial and randomized design will be used to analyze the three parameters (Product type, tag orientation, and distance level) with three, five and six levels respectively. Furthermore, replication and repetition of an experiment on a large group of objects is required in order to improve the consequence of an experimental result and to provide an estimate of the experimental error (Figliola et al, 2006). Replication is repetition of the basic experiment in identical conditions. Determining the number of replications sufficient for a given situation is a critical issue for experimenter. In general, the more replicates that are used, the greater the difference that can be detected. However, experimental facilities and resources are always limited. Thus, it is important to be economical with the use of resources. There overriding rule is never to have less 3 replicates per (sub-) treatment (Wang et al, 2003; Montgomery, 2009). In this study, 3*5*6 = 90 experiments will be designed. In order to maintain statistically significant results, each of them randomly will be replicated only three times because of the time and resources constraints and totally 270 experiments will be conducted. Table .4. Summarizes the experimental design.

Design Name: Full Factorial Design 3*5*6
Design Base
Number of Experimental Factor:3
Number of Responses:1
Number of Runs:270

Randomized: Yes	
Replicated Number:3	

Factors	Type	Units	Levels	
Product Type	Categoric		3	Water Inside Box
				Metal Inside Box
				Empty Box
Tag Orientation	Categoric		5	Top Surface(Horizontal)
				Front Surface(Direct Facing)
				Back Surface(Indirect Facing)
				Side Surface (Vertical)
				Downwards
Distance Level	Numeric	cm	6	50
				100
				200
				300
				400
				500

Responses	Type	Units	Min	Max	Mean	Stdev
Tag Readability	Numeric	Total Read/Sec				

Table4 Research Design

After applying the above systematic test procedure and getting the required statistical results. This study will perform a sensitive analysis for the parameters by using ANOVA (Analysis of Variances) technique. However, a factorial experiment can be analyzed by using either ANOVA or regression analysis (Montgomery, 2009). Such a full factorial experiment design allows studying the effect of each factor on the tag readability of semi-passive RFID as a performance measure, as well as the effects of interactions between factors on the response variable (Tag readability). For instance, effect of tag orientations and different distance levels on tag readability (When tag stuck onto empty boxes). Also, effect of water, tag orientations, and distance levels on tag readability (tag stuck onto water boxes). Moreover, effect of metal, tag orientations, and distance on tag readability (tag stuck onto metal boxes). In additions, by fixing distance level and tag orientation, the performance of tags place on water, metal, and empty boxes can be observed and compared with each other in order to find out the effect of product type on semi-passive tag readability.

7. Conclusion and Future Research

The role of warehousing is changing quickly under the increased pressure to enhance overall supply chain performance. As a result, it is recognized that the Radio Frequency Identification (RFID) Systems in use is the integral part of warehousing operations in order to locate accurately the warehouse resources and obtain the requested high warehouse performance. However, an essential decision should be made on the type of RFID tags the warehouse managers should implement in their warehouses.

In a warehouse environment, tag types, tag orientations, product types, and the distance levels between tag and reader antenna are the most obvious and significant variables of RFID tags performance. All the previous researches consider the evaluation of active and passive RFID tags in a warehouse environment. However, analysing all types of RFID technologies is essential in order to choose the most appropriate RFID tags which will enhance the operational efficiency of a warehouse. Therefore, this study will carry out a full factorial experiment design which is a systematic test procedure in order to determine the relationship among different product types, tag orientations, and distance levels on the tag readability of semi-passive RFID. This experiment will report a statistical analysis and provide a comprehensive RFID performance comparison. Resulting in an appropriate reference to help enterprises to select the most appropriate RFID equipments for their warehouse environment. Thus, the contribution of this research would be of great assistance and guidance for the current users and practitioners of RFID tags in a warehousing environment, planned on implementing RFID tags, or had developed RFID systems.

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