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A RFID case-based logistics resource management system for managing order-picking operations in warehouses

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ABSTRACT

In the supply chain, a warehouse is an essential component for linking the chain partners. It is necessary to allocate warehouse resources efficiently and effectively to enhance the productivity and reduce the operation costs of the warehouse. Therefore, warehouse management systems (WMSs) have been developed for handling warehouse resources and monitoring warehouse operations. However, it is difficult to update daily operations of inventory level, locations of forklifts and stock keeping units (SKUs) in real-time by using the bar-code-based or manual-based warehouse management systems. In this paper, RFID technology is adopted to facilitate the collection and sharing of data in a warehouse. Tests are performed for evaluating the reading performance of both the active and passive RFID apparatus. With the help of the testing results, the efficient radio frequency cover ranges of the readers are examined for formulating a radio frequency identification case-based logistics resource management system (R-LRMS). The capabilities of R-LRMS are demonstrated in GSL Limited. Three objectives are achieved: (i) a simplification of RFID adoption procedure, (ii) an improvement in the visibility of warehouse operations and (iii) an enhancement of the productivity of the warehouse. The successful case example proved the feasibility of R-LRMS in real working practice.

1. Introduction

Due to the effects of globalization, current supply chain networks are increasingly complex. Logisticians have to deal with numerous channel partners who may be located a great distance apart and who request a greater than ever diversity of products, and who need to deal with more statutory requirements and documentation than ever before (Vogt, Pienaar, & De Wit, 2005). Therefore, the fulfillment of customers' demands with good quality products, on time product delivery and superior logistics services becomes difficult to achieve. In general, enterprises have adopted different approaches for managing the supply chain activities which include material sourcing, production scheduling, warehousing and product distribution. Logistics resource management (LRM) is one of the approaches for managing the activities of the whole supply chain efficiently. It facilitates the allocation of logistics resources to appropriate logistics functions and controls the movement of raw materials, work-in-progress and finished goods, from suppliers to customers in an efficient manner. In doing this, supply chain partners are kept satisfied.

A warehouse is an essential link between the upstream (production) and downstream (distribution) entities, and most of the warehouse operations are either labour- or capital-intensive. The performance of these operations not only affects the productivity and operation costs of a warehouse, but also the whole supply chain. Thus, information systems such as warehouse management systems (WMSs) were adopted for collecting data of warehouse operations in order to solve various problems in a warehouse, such as material handling problems. However, the current WMSs are incapable of providing timely and accurately warehouse operations information because they contain no feature of real-time and automatic data retrieval. Instead, the systems rely heavily on warehouse staff members to input operational information manually or through bar-code systems. Hence, incorrect information is unavoidably input from time to time as human error is inevitable (Sexton, Thomas, & Helmreich, 2000). Moreover, it is difficult to

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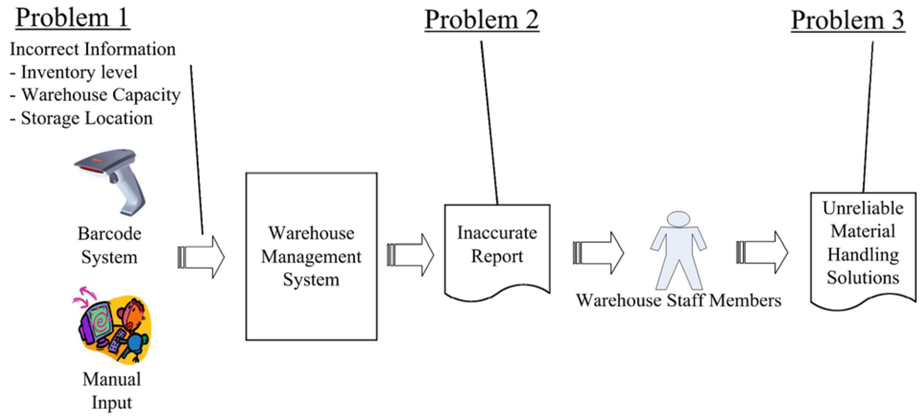


Fig. 1. Common problems frequently occur in a warehouse.

formulate reliable material handling solutions to handle different orders either by warehouse staff members (who may be biased) or through WMSs (Chow, Choy, Lee, & Lau, 2006). Therefore, it is essential to propose an intelligent system with real-time and automatic data retrieval features for solving material handling problems. Fig. 1 shows the common problems which frequently occur in a warehouse due to human error and out-of-date information. Based on the input of incorrect information in inventory level, warehouse capacity and storage location, inaccurate reports are generated from WMSs for warehouse staff members to make unreliable material handling solutions for managing the daily warehouse operations.

In this paper, a set of RFID reading performance tests is performed. The tags are placed in different positions and attached to different materials for evaluating the reading performance of the active and the passive RFID devices. Based on the test results, the efficient radio frequency cover ranges of the readers are examined and the most suitable locations for the installation of the RFID devices are determined. Besides, a RFID case-based logistics resource management system (R-LRMS) is proposed to improve the efficiency and effectiveness of order-picking operations in a warehouse by means of formulating a reliable RFID technology implementation plan. This will enable warehouse resources to be located on a real-time basis and instant material handling solutions will be suggested for handling the customer orders automatically. The feature of real-time and automatic data retrieval in the proposed system is support by the RFID technology, which also facilitates constructing an effective triangular localization scheme to determine the exact locations of warehouse resources. The collected data is then compared with the attributes stored in an embedded case-based engine to determine the appropriate material handling equipment to handle the order-picking operations. Moreover, a material handling solution formulation model is constructed by mathematic algorithms to generate the shortest pick-up sequence for the appropriate material handling equipment. In doing this, the objectives of maximizing the productivity of warehouse and minimizing the operation costs in a warehouse are achieved.

The paper is divided into six sections. Section 1 is the introduction. Section 2 presents related literature reviews on logistics resource management and the technologies of tracking items and the management of such data. Section 3 explains the design methodology of R-LRMS, while in Section 4, a case study is presented to illustrate the improvement in productivity in Group Sense Limited (GSL) with the help of R-LRMS. In Section 5, an analysis of the findings will be discussed. Finally, a conclusion about the use of R-LRMS is drawn and suggestions for future work are made in Section 6.

2. Literature review

2.1. Current approach in managing logistics resources

According to Kaihara (2003) and Liu et al. (2005), a supply chain is a valuable information sharing channel among the suppliers, manufacturing and storage facilities, distributors and customers for facilitating the key business activities of the sale, production and delivery of a particular product. Thus, the main principle of supply chain management (SCM) is to integrate effectively the material flows and related information within the demand and supply processes (Soroor & Tarokh, 2006). However, due to the global extension of supply chain networks, enterprises need to collaborate with suppliers, customers, or even competitors in different time zones, across numerous organizational boundaries, and in a variety of cultures. Under these circumstances, the challenge of allocating production, transportation, and inventory resources to satisfy demand is daunting (Simchi-Levi, Kaminsky, & Simchi-Levi, 2004). Recent trends towards the management of logistics resources have the potential to minimize the impact of the physical dispersion of supply chain members. The objective of logistics resources management (LRM) is to determine the most effective approach for allocating the appropriate logistics resources to different logistics functions, facilitate information flow and share knowledge through a supply pipeline, provide feasible collaborative channels for supply chain partners to provide superior customer services (Ross, 2003). In LRM, five logistics operations areas are covered in a supply chain network. These are: (i) freight cost and service management, (ii) fleet management, (iii) load planning, (iv) routing and scheduling, and, (v) warehouse management (Poirier & Bauer, 2000). Within these logistics operations areas, warehouse management is the most important function for linking the supply chain partners to formulate the seamless integration of the whole supply chain and for ensuring the smooth flow of products inside the network (Gu, Goetschalckx, & McGinnis, 2007). With such an arrangement, it is essential to handle the warehouse resources, such as stock keeping units (SKUs), pallets and racks, pallet trucks and forklifts, and warehouse staff members, efficiently and effectively in order to have smooth manufacturing operations, to reduce inventory, lower processing, storage, and transshipment costs, and increase productivity within facilities (Vogt et al., 2005). Within the chain, currently, warehouse management systems (WMSs) are adopted to handle the warehouse resources and operations. However, these systems are lacking in real-time information sharing ability as the data collection technique is either manual-based or bar-code based. Therefore, WMSs are incapable of capturing real-time information or of visualizing the actual working status (Huang, Zhang, & Jiang, 2007). In addition, the positions of the resources are not located accurately by current data collection techniques (Shih, Hsieh, & Chen, 2006), resulting in inappropriate resource allocation to warehouse operations. Therefore, it is essential to implement real-time data management techniques for locating the resources accurately to support warehouse operations effectively.

2.2. Current real-time data management techniques for object location tracking

There are several real-time data management techniques adopted for facilitating information sharing in the existing market. Some of the techniques are also capable of providing object location information. In the outdoor environment, the most well known technology adopted in location tracking is the global position system (GPS). It is a space-based radio-navigation system that uses 24 satellites orbiting around the Earth and receivers to locate objects, in terms of height, longitude and latitude coordinates, on Earth (Postorino, Barrile, & Cotroneo, 2006). The main application of GPS is to determine the location of vehicles and the actual traffic condition. Although it locates an object accurately in the outdoor environment, it is unable to locate objects inside the buildings. Hence, Cell of origin (COO) or Cell-ID is proposed to locate objects between indoor and outdoor environment. COO is a network-based location system which uses the latitude and longitude coordinates of the base station and transmitters serving the mobile device as the location of the user (Jagoe, 2003). Nevertheless, it is inaccurate in locating a moving object as "blind points" always occur due to defective coverage of the network, especially in the indoor environment. Hence, various technologies have been developed to locate objects in the buildings. Infrared, ultrasonic and radio frequency identification (RFID) technologies are the most common approaches for locating those objects (Xu & Gang, 2006). Among those three approaches, RFID technology is an emerging technology that has been widely adopted in different environments, such as manufacturing, warehousing, retailing, etc., for object identification. RFID uses a small tag containing an integrated circuit chip and an antenna, which has the ability to respond to radio waves transmitted from the RFID reader. It is able to send, process, and store information (Wu, Nystrom, Lin, & Yu, 2006). This technology has been widely adopted in different business operations to identify, locate and track people, animals or assets (Huang et al., 2007; Streit, Bock, Pirk, & Tautz, 2003; Thevissen, Poelman, Cooman, Puers, & Willems, 2006; Vijayaraman & Osyk, 2006). Although it is much more expensive than bar-code technology, enterprises are willing to adopt such techniques so as to improve the accuracy of data capture (Morrison, 2005). By using the RFID technology, the feature of automated data capture is established. However, the mechanism that coordinates the resource management process of analyzing information, decision support, and knowledge sharing is still neglected. This highlights the need to adopt artificial intelligence (AI) techniques integrated with RFID technology to support the management of warehouse processes. In this research, the case-based reasoning (CBR) technique is adopted as this is one of the well-known AI techniques for the development of decision support systems.

2.3. Current case-based approaches for solving problems in a warehouse

CBR is an artificial intelligence technique that utilizes previous experience to solve problems (Kolodner, 1993). Previous problems and corresponding solutions are stored as cases for reference. Besides this, case representation, case retrieval and case adaption are the major issues for developing a CBR system (Liao, 2004). Once new problems are discovered, the solutions in the similar cases are retrieved and adapted for solving the new problems. Also, the cases are updated when any new information is uncovered during the process of creating the new solution (Pal, Dillon, & Yeung, 2001). This learning mechanism of CBR has successfully contributed to different domains including manufacturing (Tsai & Chiu, 2007; Wu, Lo, & Hsu, 2008), warehousing (Chow et al., 2006), purchasing (McIvor, Mulvenna, & Humphreys, 1997) and vehicle maintenance (Kuo, Kuo, & Chen, 2005). There are various case retrieval methods employed in these domains. Some of the methods are make for fast retrieval time while others provide high accuracy of case retrieval. Sun and Finnie (2004) illustrate that the nearest-neighbour retrieval (NNR) system is one of the most simple and common CBR techniques which can provide an assessment of the degree of similarity between problem descriptions attached to a case in the case base repository, and the description of the current problem that needs to be solved. (Cheung, Chan, Kwok, Lee, & Wang, 2006) propose a nearest-neighbour-based service automation system for providing high quality customer services with fast and efficient customer responses in a semi-conductor equipment manufacturing company. However, the time spent on retrieving potential solutions for a new query is directly proportion to the number of cases stored in the case base repository. This means that a long time is taken in retrieving the case if there is large number of cases stored in the repository. Kolodner (1993) shows that it is difficult to determine the most appropriate case to represent the current query case when few cases are available in the case base. Thus, NNR is the technique which can be used to find the most appropriate case for the new query although the retrieval time is long. Some researchers have tried to reduce the retrieval time as it is a waste of time for the managers to spend a long time waiting for solutions in the actual working environment. Hence, Watson (1997) explains that the inductive approach is a technique that determines the most important features in discriminating cases and generates a decision tree type structure to organize the cases in the case base repository. Shin and Han (2001) demonstrate the effectiveness of the inductive learning approach to case indexing for business classification tasks in a bonding company. Although fast retrieval speed is achieved by this approach, a long time is needed for indexing the features of a case. As a result, a hybrid approach is proposed for solving the problems. Chow et al. (2006) propose a NNR-Inductive CBR engine to solve the order-picking problems for enhancing the performance of warehouse operations. Wang, Chiou, and Juan (2008) suggest utilizing the NNR-Inductive retrieval approach for predicting the actual restoration cost, solving order change problems, and reducing the budget review time. On the other hand, another approach is to adopt a case clustering method with NNR technique. Can, Altingövde, and Demir (2004) and Kim and Han (2001) mention that there are two steps for case retrieval in the clustering approach. The queries are first compared with the clusters or centroids which are associated by similar problem descriptions. Detailed querying is then performed on the retrieved cases. Although the time for case retrieval is varies according to the number and the size of the centroids, it is relatively faster than the other retrieval approaches. By using this clustering approach, the time spent on case indexing is eliminated and the case retrieval time is shortened.

3. Design methodology of R-LRMS

The aim of the proposed R-LRMS is to formulate and suggest the appropriate material handling solutions in a warehouse environment. In doing this, two construction phases for R-LRMS are required. They are

Phase 1 – Defining the operating specification of R-LRMS
Phase 2 – Constructing the architecture framework of R-LRMS

3.1. Phase 1: Defining the operating specification of R-LRMS

This phase is to define the operating specification of the proposed system. Five stages are involved in defining it. They are: (i) warehouse layout study, (ii) evaluation of RFID equipment, (iii) RFID reading performance tests, (iv) result analysis, and (v) system design, testing and evaluation.

Stage 1: Warehouse layout study
It is essential to perform a warehouse study before the implementation of the proposed system. This is because the layouts of warehouse vary among different companies. The physical and environmental factors, such as the size of the warehouse, the number of aisles, the number of racks, the types of racks, the types of material handling equipment, the types of products stored, etc., affect the readable range and accuracy of tags (Bhuptani & Moradpour, 2005). By studying the actual environment, the specification of the warehouse is determined for RFID equipment selection.

Stage 2: Evaluation of RFID equipment
As mentioned before, there are two common types of RFID equipment available on the existing market, namely active RFID technology and passive RFID technology. The items of equipment of these technologies vary in size, cost, reading performance, and in application domains. The most commonly used RFID equipment used in warehouses is the Active (Alien 2850 MHz Series) and the Passive (Alien 9800 series) RFID apparatus. Experiments have taken place for evaluating the reading performance of these types of equipment in order to select the most appropriate one for the actual warehouse environment.

Stage 3: RFID reading performance tests
Four tests, namely (i) orientation test, (ii) height test, (iii) range test, and (iv) Material Test, are proposed in order to evaluate the performance of the RFID device in an actual warehouse environment. Before performing the tests, it is required to install the RFID readers and tags appropriately so as to obtain reliable experimental results. A pair of antennas is placed at a fixed location and the centre of the antennas is placed 1 m from the ground. Also, tags are stuck onto objects which are placed in various locations, facing different directions and stuck onto various materials. After doing this, the read rates of the tags (total reads per minute) are taken by performing various tests.

(i) Orientation test
The test is to determine the horizontal effective RF cover range of the reader. The tags are stuck onto the front, top and side surfaces of the object and corresponding read rates of the tags are measured by moving the object different distances horizontally. The configuration of the orientation test is shown in Fig. 2.

(ii) Height test
In this test, the effective vertical RF cover range of the reader is determined. The tags are stuck onto the front surface of the object which is placed at 1 m from the reader. After that, the object is moved different distances vertically and the corresponding read rates of the tags are measured. The configuration of the height test is shown in Fig. 3.

(iii) Range test
The test is to determine the maximum RF cover range of the reader in a horizontal direction. As illustrated in Fig. 4, the object is placed 1 m from the reader and the tags are stuck onto the front surface of the object. Read rates of the tags are measured when the object is moved different distances horizontally.

(iv) Material test
In the material tests, the reading performance of RFID device is measured when the tags are placed on the front and back surfaces of various types of products in the actual environment. Similar to the orientation test, the tags are stuck onto the nearest and farthest surfaces of the object. After that, the object is moved different distances horizontally and the corresponding read rates of the tags are measured. The configuration of the material test is shown in Fig. 5.

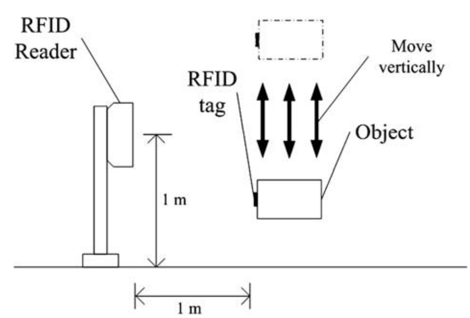


Fig. 3. The configuration of height test.

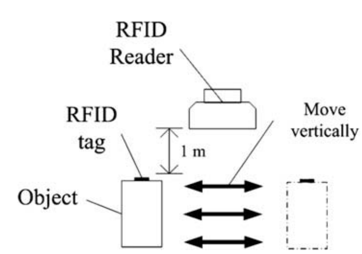


Fig. 4. The configuration of range test (top view).

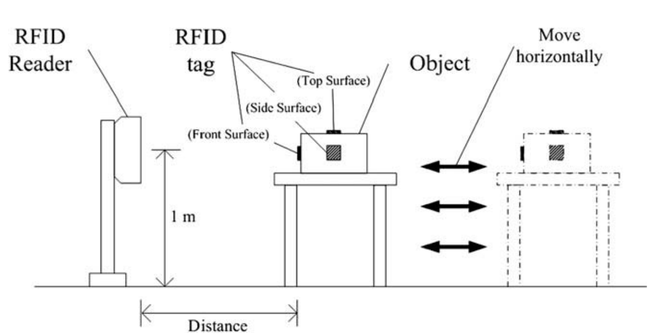


Fig. 2. Configuration of orientation test.

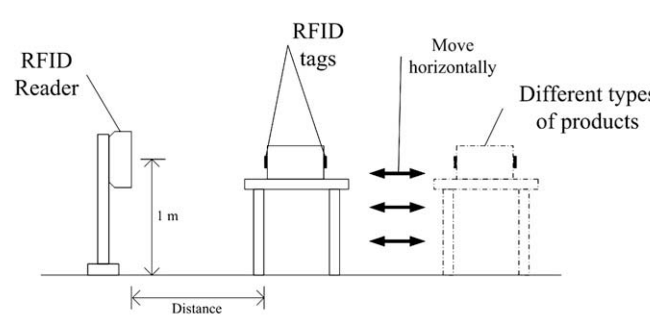


Fig. 5. Configuration of material test.

Table 1
Results from the tests.

Tests	Expected results	Final result
Orientation test	Horizontal effective RF cover range of a reader	The most effective radio frequency (RF) cover range of the reader
Height test	Vertical effective RF cover range of a reader	
Range test	Maximum RF cover range of a reader in a horizontal level	
Material test	RF performance effects in handling different materials	

Stage 4: Result analysis
The results of the tests show the most effective radio frequency (RF) cover range of the reader, as shown in Table 1. Based on the results, the RFID devices are installed in the racks, forklifts and SKUs for real-time data collection.
Stage 5: System design, testing and evaluation
After defining all the operating specification, the architecture of R-LRMS is designed. It is then tested under a simulated warehouse environment to ensure that all the equipment work within the defined specification.

3.2. Phase 2: constructing the architecture framework of R-LRMS

After finishing Phase 1, the data capture capability of the RFID part is verified. Fig. 6 shows the architecture framework of R-LRMS, which is a three-tier system. The first tier is the data collection tier, through which the raw warehouse operation information is collected. In the middle tier, the retrieved information is stored in the centralized database systematically. The final tier encompasses the relevant operation components for formulation of the pick-up routes.

Tier 1: data collection
In this tier, RFID devices are adopted for data collection in a warehouse environment. Two types of data, namely static and dynamic warehouse resources data, are captured by the RFID readers to visualize the actual status of warehouse operations. The static warehouse resources data involves the locations and quantities of SKUs stored, the types of SKUs, the available space for incoming products, etc. The dynamic warehouse resources data involves the locations of forklifts/warehouse staff members, the inventory levels in each rack, the status of order-picking operations, etc. With the help of wireless network, i.e. 801.11 g WIFI network, the warehouse resources data that was collected is transferred and stored in the centralized data. The general picture of data collection tier of R-LRMS is illustrated in Fig. 7.
Tier 2: data storage
This tier adopts the database management system (DBMS) and structured query language (SQL) statement to provide the function of data retrieval and storage for users. It helps minimize the time used and human mistakes in preparing the program statement for obtaining the required datasets are avoided. In order to increase the speed of data retrieval in the database, Query optimization technique is applied into R-LRMS.

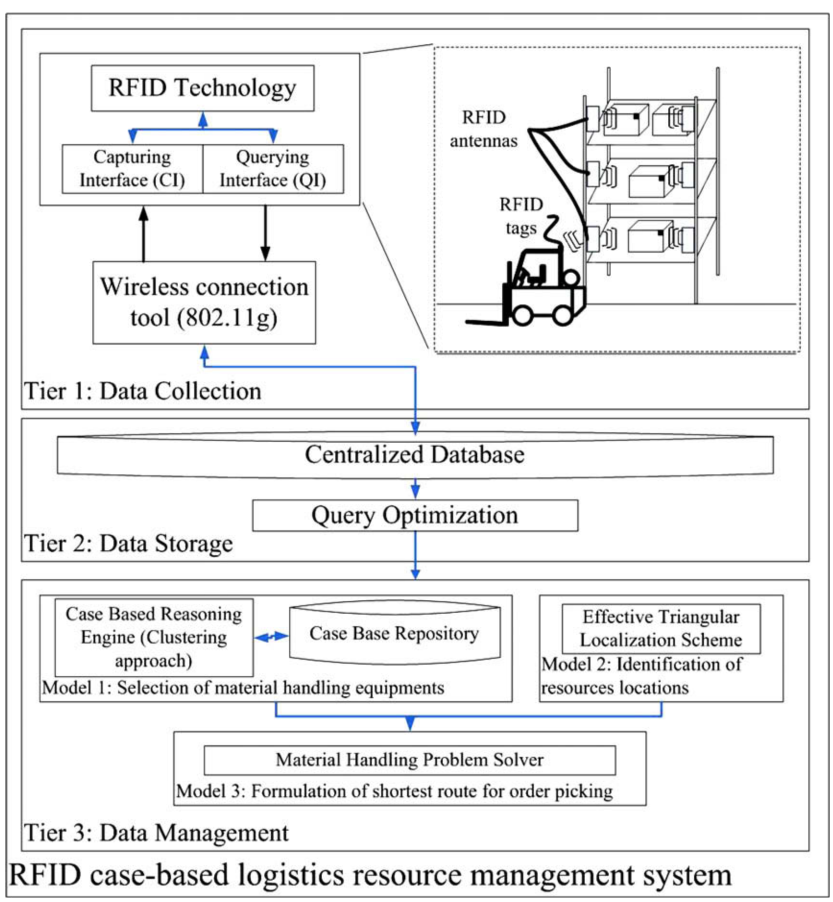


Fig. 6. System architecture of R-LRMS.

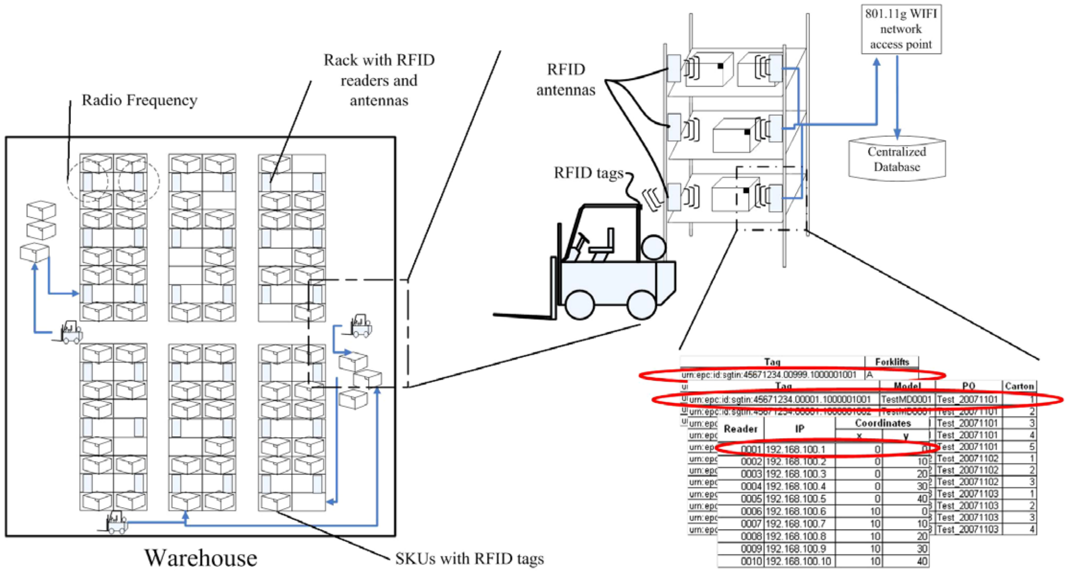


Fig. 7. General picture of data collection tier of R-LRMS.

Query optimization is the process of minimizing the time used in executing a given query expression (Polat, Cosar, & Alhajj, 2001). Its components help to determine how queries are performed. With the uses of the technique, time for information searching is reduced as redundant decision rules are eliminated and restructured (Grant, Gryz, Minker, & Raschid, 2000). Fig. 8 demonstrates a comparison between traditional and revised tree expressions when the user is going to retrieve the SKU information when the SKUs are delivered by a specific truck. It is discovered that the hierarchy of the tree has been decreased by one level by adopting query optimization (shown on the right hand side). This means that the corresponding processing time will also be shortened as the search area in the data base has also been reduced. (Claussen, Kemper, Moerkotte, Peithener, & Steinbrunn, 2000). This helps improve the performance of data retrieval from the centralized database.

Tier 3: data management

This tier is the core of the R-LRMS which manipulates the data retrieved from Tier 2 effectively and transforms the data into meaningful information for formulating efficient and reliable material handling solutions. There are three functions in this tier. They are

(i) Function 1: selection of material handling equipment.
(ii) Function 2: identification of the locations of resources.
(iii) Function 3: formulation of the shortest route for order-picking.

- *Function 1: selection of material handling equipment*

Function 1 is designed for selecting the appropriate material handling equipment for managing the order-picking operations. It contains a CBR engine for searching for similar cases in the case-based repository and for the proposed reliable solutions for handling the pick-up orders. The three-step process of selecting appropriate material handling equipment using the case-clustering retrieval approach are described below:

Step 1: cluster the case in the case- based repository

A list of previous cases is retrieved from the case-based repository and is divided into n clusters according to their order specifications. The value of each cluster is calculated by the k-NN method.

Step 2: retrieve the cluster which has potentially the highest degree of similarity

When a new pick-up order is released, different order attributes such as SKU type, weight, dimensions and shape, are adopted as the problem description. The problem description of the current query is compared with the clusters by the following evaluation function (Chow et al., 2006).

$$\sum_{i=1}^{n} w_i \times \mathrm{sim}(f_i^I, f_i^{CR}) \tag{1}$$

where w_i is the importance of feature f_i, sim is the similarity function, and (f_i^I, f_i^{CR}) are the value for feature f_i in the input and retrieval clusters/cases, respectively.

Step 3: suggest suitable material handling equipment for the order from the potentially useful cases in the retrieved cluster

Once the cluster with the highest similarity is discovered, the current query is then compared with the cases in the retrieved cluster by Eq. (1). According to the degrees of similarity, a list of order handling solutions about association of material resources equipment and orders is generated. By doing this, less

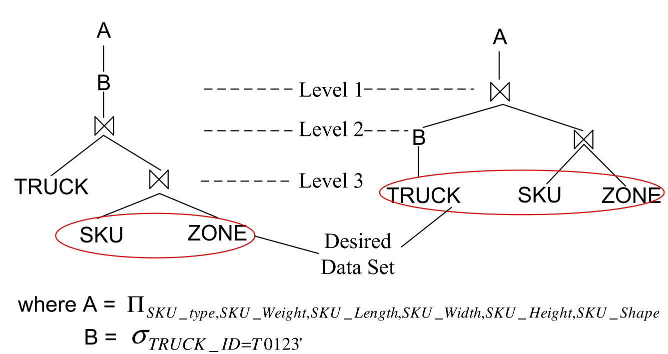


Fig. 8. Comparison between tree expressions for retrieving SKU information with specific criteria.

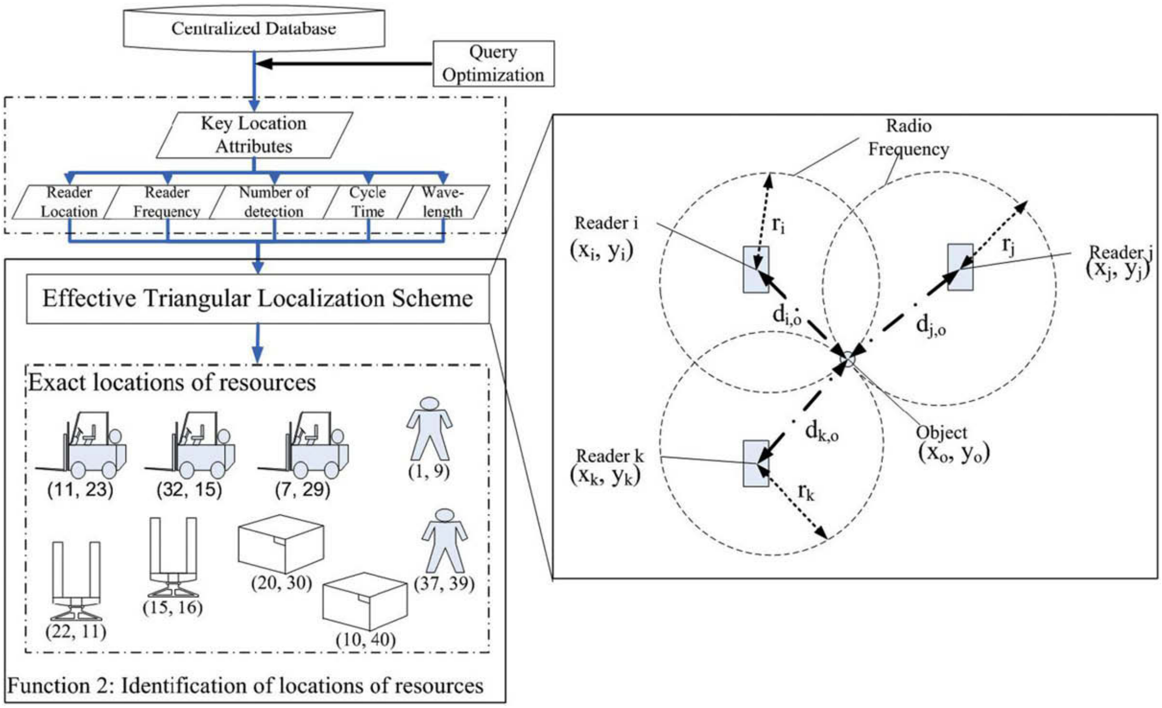


Fig. 9. The mechanism of function 2: identification of resources locations.

time is spent on assigning appropriate resources to different orders, resulting in the best resource utilization and highest productivity.

- *Function 2: identification of locations of resources*

Function 2 is designed for identifying the exact locations of the resources in a warehouse in order to enhance the visibility of warehouse operations, as illustrated in Fig. 9. With the invention of the effective triangular localization scheme and the pre-set location information in each reader, the exact locations of the resources are determined. There are two steps for identifying the exact locations of the resources. The detailed description of this is given below:

Parameters

f_x	frequency provided by reader x
v_x	wavelength of frequency provided by reader x
(x_x, y_x)	location of reader x
(x_o, y_o)	location of object (forklift)
r_x	maximum radius of frequency provided by reader x can be reached
$d_{x,o}$	distance between object and reader x
p_x	period of time for tag detection
c_{x_x}	number of tag detection within a period of time

Step 1: calculate the distance between the reader and the object
By using the specification of the reader, the distance between the reader x and the object is determined as below:

$$d_{x,o} = (f_x \times v_x \times p_x)/(2 \times c_x) \tag{2}$$

Step 2: determine the corresponding coordinates of the object
By using the geometrical calculation, the distance between reader i and the object is identified, i.e.

$$d_{i,o} = \sqrt{(x_i - x_o)^2 + (y_i - y_o)^2} \text{ where } i = 0, 1, 2, \ldots, n \tag{3}$$

For just considering 2 readers $[(x_i, y_i)$ and $(x_j, y_j)]$ and the object (x_o, y_o)

$$x_o = \frac{(d_{i,o}^2 - d_{j,o}^2) - (y_i^2 - y_j^2) - (x_i^2 - x_j^2) + 2(y_i - y_j)y_o}{-2(x_i - x_j)} \tag{4}$$

Sub (3) into the equation formulated by the remain point (x_k, y_k)

$$y_o^2 + \frac{2(Ax_kD + CD - A^2y_k)y_o}{(A^2 + D^2)} + \frac{(C^2 + 2Ax_kC - A^2B)}{(A^2 + D^2)} = 0 \tag{5}$$

where

$A = 2(x_i - x_j)$
$B = d_{k,o}^2 - y_k^2 - x_k^2$
$C = (d_{i,o}^2 - d_{j,o}^2) - (y_i^2 - y_j^2) - (x_i^2 - x_j^2)$
$D = 2(y_i - y_j)$
$i = 0, 1, 2, \ldots, n$
$j = 0, 1, 2, \ldots, n$
$k = 0, 1, 2, \ldots, n$
$i \neq j \neq k$

By solving the Eqs. (4) and (5), the exact locations of the objects are identified.

- *Function 3: formulation of the shortest route for order*

This function is to formulate the shortest route for picking the required SKUs in the pick-up orders and determine the appropriate material handling solutions for order-picking operations. With reference to Cheung, Choy, Li, Shi, and Tang (2008) Choy, Li, Shi, and Cheung (2006), a material handling problem solver is developed for constructing the most cost-effective and efficient material handling solution.

For the material handling problem solver, six steps are involved in constructing the material handling solution. The description is shown as follows:

Parameters

s_s	starting point of the pick-up sequence
s_f	end point of the pick-up sequence
e	point of depot area
n	number of pick-up points of the orders
p_{ij}	pairwise connection of point i and j
t_{ij}	actual travel time from point i to j
f	number of items available of material handling equipment
o_k	operation cost of material handling equipment k
c_k	capacity of material handling equipment k
d	number of pick-up order
w_i	weight of goods to be picked up at point i for a pick-up order ($w_i = 0$ if no such order)

Step 1: determine the starting point and the end point of pick-up sequence for the order
Two pick-up points of the order are selected randomly. If they are farthest from each other, i.e. $\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} > \alpha$ and $\sqrt{(x_i - x_e)^2 + (y_i - y_e)^2} < \beta$ (where α and β are the constants specified in advance), then select point i as the starting point s_s and point j as the end point s_f, otherwise, *Step 1* is performed again.
Step 2: find the appropriate connections of the remaining points with the shortest distance
Two of the remaining pick-up points in the order are selected randomly. If they are closest to each other, i.e. $\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} < \gamma$ (where γ is a constant specified in advance), a pairwise connection p_{ij} is constructed and the corresponding route is $i \to j$ when $w_i > w_j$, otherwise, corresponding route is $j \to i$. By applying a similar approach, a set of pairwise connections of the remaining points in the order is constructed eventually.
Step 3: formulate an initial routing plan for the order
In this step, the distances between the pairwise connections and the starting point s_s are first calculated. After that, the closest p_{ij} is selected and inserted between the starting point s_s and the end point s_f. The pick-up sequence is then refined as $s_s \to i \to j \to s_f$ if $w_i > w_j$, or $s_s \to j \to i \to s_f$ if $w_j > w_i$. With a similar approach, the initial routing plan of shortest pick-up routes is formulated by inserting all the pairwise connections.
Step 4: select the appropriate material equipment for handling the pick-up sequence
By using the effective triangular localization scheme in *Function 2*, the exaction locations of the material handling equipment are identified as (x_k, y_k) where $k = 1,2,\ldots,f$. The closest material handling equipment, i.e. $\mathrm{Min}\sqrt{(x_k - x_{s_s})^2 + (y_k - y_{s_s})^2}$, is assigned to handle the order with the shortest pick-up route formulated in *Step 3* and the initial material handling solution is constructed.
Step 5: refine the initial material handling solutions
Dramatic solution improvement is achieved by re-allocating the material handling equipment until the total travelling time and operation cost for order-picking operations are minimal

$$\text{i.e. Min} \quad \sum_{x=0}^{d} \sum_{i=k}^{e} \sum_{j=k}^{e} t_{ij} \tag{6}$$

subject to:

$$c_k \geqslant \sum_{i=0}^{n} w_i \text{ for } k = 1,2,3,\ldots,f \tag{7}$$

$$o_k \leqslant \mathrm{Max}(o_l) \text{ for } k,l = 1,2,3,\ldots,f \; k \neq l \tag{8}$$

Step 6: formulate the optimized material handling solutions
After the refinement procedures, the most cost-effective material handling solutions are constructed under the constraint of minimal total travelling time for fulfilling the order-picking operations.

4. Case study

In order to validate the proposed R-LRMS, the system has been piloted in group sense limited (GSL). GSL, one of the world's leading manufacturers of electronic dictionaries and other handheld information devices, was founded in June 1988. It launched the first English/Chinese electronic dictionary in Hong Kong in 1989. This has become a leading consumer brand in the Greater China market. In 1996, GSL launched the world's first Personal Digital Assistant (PDA) which operated on a Chinese language platform, together with the functions of inputting Chinese characters in handwriting, and built-in electronic dictionaries. Moreover, GSL manufactures many hi-tech, original design manufacturing (ODM) electronic products for major customers in Japan and Europe. Over the years, GSL has been granted numerous awards such as Consumer Product Design (1995), Technological Achievement (1997), Productivity (1999), Quality (1999) by Hong Kong Awards for Industry and more than 10 other awards in different categories. As GSL is an international electronic device provider, large numbers of customer orders are received every day. Currently, GSL adopts a manual-based order pickup and delivery mechanism in its warehouse and manually records the documents of warehouse inventory status and the location of SKUs. Several problems have occurred: It is

- Difficult to define the actual inventory level in the warehouse
- Difficult to locate the forklifts and SKUs
- Difficult to select appropriate forklifts to handle the pick-up orders
- Difficult to select appropriate space to handle SKUs
- Difficult to deliver products on time

In order to solve these problems, a radio frequency identification case-based logistics resource management system (R-LRMS) for tracking the SKUs and the forklifts is proposed. GSL decided to trial run the R-LRMS in the warehouse in Dongguan, China in October 2007 for a period of two months. As shown in Fig. 10, there are totally seven operating steps in the R-LRMS.

Step 1: study the actual warehouse environment in GSL
In this step, it is essential to have a clear picture of the actual warehouse environment in GSL for adopting appropriate RFID equipment with the most suitable specifications. Finished products such as personal digital assistants, electronic dictionaries, etc., and corresponding electronic parts are stored in the GSL warehouse, The warehouse consists of six aisles and 24 two-level racks. The height of each rack is about 4 m and the width of the aisle is 6". There are three means of handling material: forklifts, manual trucks and warehouse staff members. These are all used for handling the pickup orders in GSL. The warehouse attributes mentioned above are the selection criteria for RFID equipment.
Step 2: select the appropriate RFID equipment
Table 2 shows the reading performance comparison between active and passive RFID equipment. The reading performance of active RFID technology is better than that of passive RFID technology.
However, the costs of active RFID readers and related equipment are relatively high (between USD$2000 and USD$3000 for readers and USD$20–30 for tags), compared to the costs of passive RFID devices (between USD$1000 and USD$2500 for readers and USD$0.07–1.00 for tags) (Speakman and Sweeney, 2006). It is difficult to implement the active RFID devices for item-level RFID tagging in the warehouse environment due to

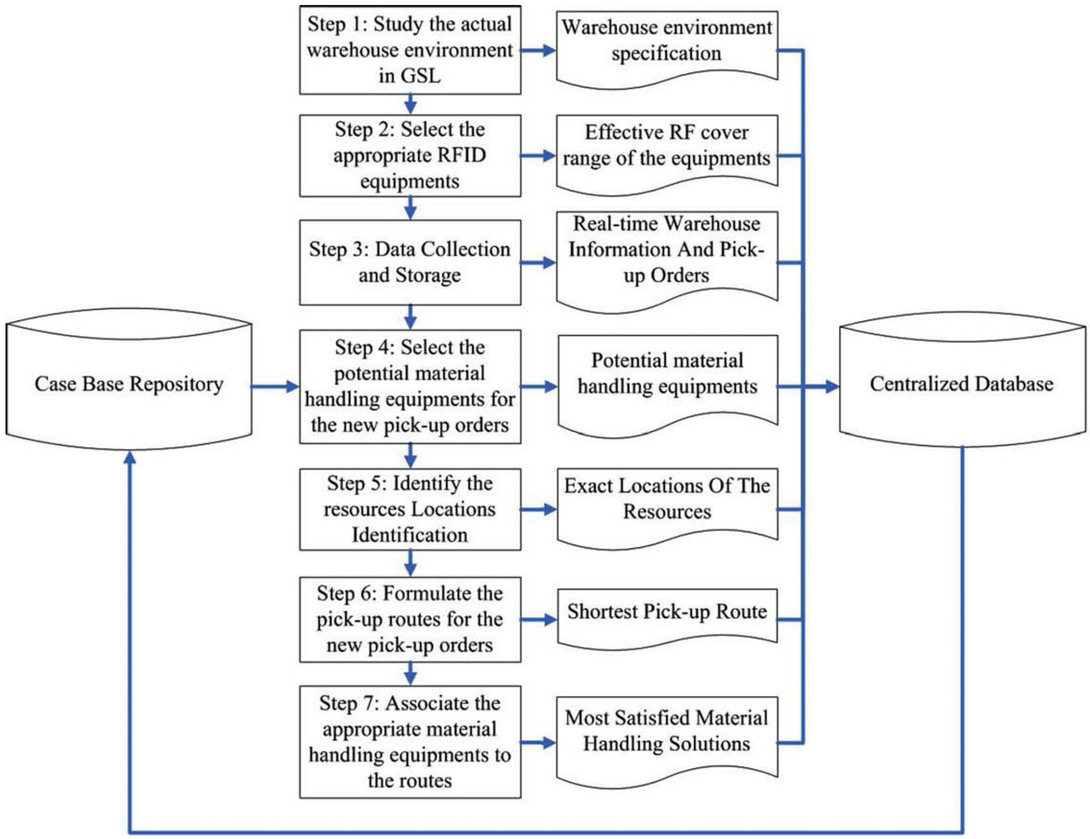


Fig. 10. Seven operating steps in the R-LRMS.

high implementation cost. To overcome this problem, a full passive RFID implementation plan is suggested for implementation in GSL.

According to Table 3, the reading performance of the passive large-sized tag is the best among the three passive tags. However, it is not suitable to adopt in tracking the material handling equipment, such as forklifts, as the reader is unable to detect the tags which are stuck on the metal. Thus, the passive middle-sized tags are adopted in this paper.

From Appendix 2 it can be seen that the effective radio frequency (RF) cover range of the reader is about 2 m when middle-sized tags are selected. Therefore, one set of reader and antenna is installed in each level of the rack which is fully covered by the RF from the RFID reader and antenna, as illustrated in Fig. 11. Besides this, the middle-sized passive RFID tags are stuck onto the surfaces of forklifts and SKUs which are directly facing the RFID readers and antennae. A unique internet protocol (IP) (in terms of *x*-, *y*- and *z*- coordinates) is set in each reader (antenna) to represent exact locations of the reading points.

Step 3: data collection and storage

In this step, instant warehouse resources data is captured by the RFID device and stored in the centralized database, as shown in Fig. 12. By utilizing the RFID technology, information about

Table 2
Reading performance comparison between active and passive RFID equipment.

Test	Average results (total counts/second)	
	Active RFID equipment	Passive RFID equipment
Orientation test	1157	349
Tags stuck on the front surface on the SKU	1482	447
Tags stuck on the top surface of the SKU	1474	313
Tags stuck on the top surface of the SKU	516	287
Height test	2465	436
Range test	646	95
Material test	1117	202
Tags placed in front of the SKU	1492	389
Tags placed behind the SKU	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

Table 3
Reading performance comparison among the passive RFID equipment.

Test	Average results (total counts/second)		
	Large-sized tag	Middle-sized tag	Small-sized tag
Orientation test	611	357	80
Tags stuck on the front surface on the SKU	716	527	99
Tags stuck on the top surface of the SKU	396	544	0
Tags stuck on the top surface of the SKU	720	0	142
Height test	532	595	182
Range test	200	84	0
Material test	266	339	0
Tags placed in front of the SKU	556	611	0
Tags placed behind the SKU	590	535	0
Tags placed in front of the metal	0	14	0
Tags placed behind the metal	194	305	0
Tags placed in front of the water	195	304	0
Tags placed behind the water	60	265	0

Fig. 11. RFID technology implementation in a warehouse environment.

forklifts is captured when the forklifts pass the antennas. The retrieved information is then stored systematically in the centralized database for further processing, such as location tracking of SKUs and optimization of the pick-up routing plan of the forklifts.

Step 4: select the potential material handling equipment for the new pick-up orders by case base reasoning engine

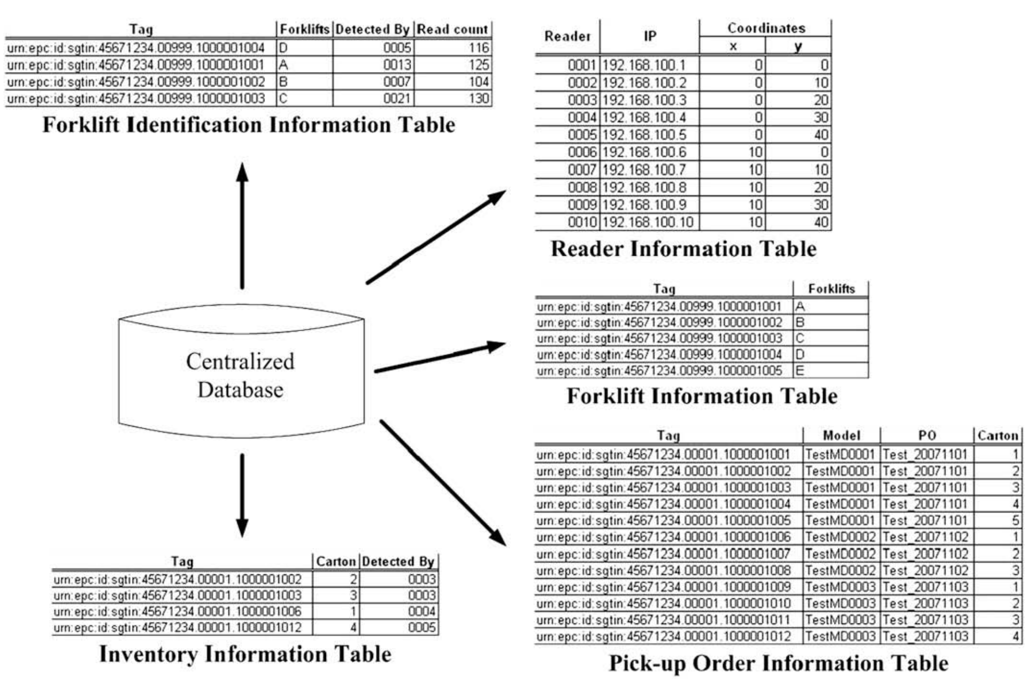
Before performing the selection of material handling equipment, 501 pick-up orders performed in GSL are transformed as cases and stored into a case-based repository. By adopting a case clustering method, the cases are divided into ten clusters based on four key attributes: order size, SKU dimension, SKU weight, and SKU shape. The clusters are then indexed by the *k*-NN method. Once the new pick-up order is released from the customer, the order is compared with the clusters by using Eq. (1) for selecting the clusters with a potentially high degree of similarity. By using a similar approach, these potentially useful cases are retrieved from the selected clusters as reference cases and the corresponding material handling equipment is suggested as the equipment for handling the current query. As illustrated in Fig. 13, *Cluster B* is the first choice for solving new pick-up order "*PL001*" as its similarity value of *Cluster B* is 99%, which is the highest among the ten clusters. By using a similar approach, case "*PA231*", the similarity value of which is 95%, ranks as the first resource choice for handling "*PL001*".

Step 5: identify the locations of the resources by effective triangular localization scheme

With the use of Eq. (2), the warehouse operation data is used as the input parameters for calculating the distance between the forklifts and RFID readers. The result of the calculation is used to determine the exact location of the resources. For example, the radio frequency of the RFID reader 0013 is 915 MHz and the corresponding wavelength is 33 cm. When forklift *A* with an embedded RFID tag passes through the RFID reader 0013, it is detected and the corresponding read out within a fixed period of 5 s by reader 0013 is identified and stored in the centralized database. Then, by using the Eq. (2), the distance between the forklift *A* and reader 0013:

$$d_{0013,A} = (915\ \text{MHz} \times 33\ \text{cm} \times 5\ \text{s})/(2 \times 250)$$
$$= 301.95\ \text{cm} \approx 3\ \text{m}$$

After calculating the distances between the readers and the objects, the exact locations of the objects, in term of *x*- and *y*- coordinates, are determined by applying the Eqs. (4) and (5),



Tag	Forklifts	Detected By	Read count
urn:epc:id:sgtin:45671234.00999.1000001004	D	0005	116
urn:epc:id:sgtin:45671234.00999.1000001001	A	0013	125
urn:epc:id:sgtin:45671234.00999.1000001002	B	0007	104
urn:epc:id:sgtin:45671234.00999.1000001003	C	0021	130

Forklift Identification Information Table

Reader	IP	Coordinates	
		x	y
0001	192.168.100.1	0	0
0002	192.168.100.2	0	10
0003	192.168.100.3	0	20
0004	192.168.100.4	0	30
0005	192.168.100.5	0	40
0006	192.168.100.6	10	0
0007	192.168.100.7	10	10
0008	192.168.100.8	10	20
0009	192.168.100.9	10	30
0010	192.168.100.10	10	40

Reader Information Table

Tag	Forklifts
urn:epc:id:sgtin:45671234.00999.1000001001	A
urn:epc:id:sgtin:45671234.00999.1000001002	B
urn:epc:id:sgtin:45671234.00999.1000001003	C
urn:epc:id:sgtin:45671234.00999.1000001004	D
urn:epc:id:sgtin:45671234.00999.1000001005	E

Forklift Information Table

Tag	Model	PO	Carton
urn:epc:id:sgtin:45671234.00001.1000001001	TestMD0001	Test_20071101	1
urn:epc:id:sgtin:45671234.00001.1000001002	TestMD0001	Test_20071101	2
urn:epc:id:sgtin:45671234.00001.1000001003	TestMD0001	Test_20071101	3
urn:epc:id:sgtin:45671234.00001.1000001004	TestMD0001	Test_20071101	4
urn:epc:id:sgtin:45671234.00001.1000001005	TestMD0001	Test_20071101	5
urn:epc:id:sgtin:45671234.00001.1000001006	TestMD0002	Test_20071102	1
urn:epc:id:sgtin:45671234.00001.1000001007	TestMD0002	Test_20071102	2
urn:epc:id:sgtin:45671234.00001.1000001008	TestMD0002	Test_20071102	3
urn:epc:id:sgtin:45671234.00001.1000001009	TestMD0003	Test_20071103	1
urn:epc:id:sgtin:45671234.00001.1000001010	TestMD0003	Test_20071103	2
urn:epc:id:sgtin:45671234.00001.1000001011	TestMD0003	Test_20071103	3
urn:epc:id:sgtin:45671234.00001.1000001012	TestMD0003	Test_20071103	4

Pick-up Order Information Table

Tag	Carton	Detected By
urn:epc:id:sgtin:45671234.00001.1000001002	2	0003
urn:epc:id:sgtin:45671234.00001.1000001003	3	0003
urn:epc:id:sgtin:45671234.00001.1000001006	1	0004
urn:epc:id:sgtin:45671234.00001.1000001012	4	0005

Inventory Information Table

Fig. 12. Data collection and storage.

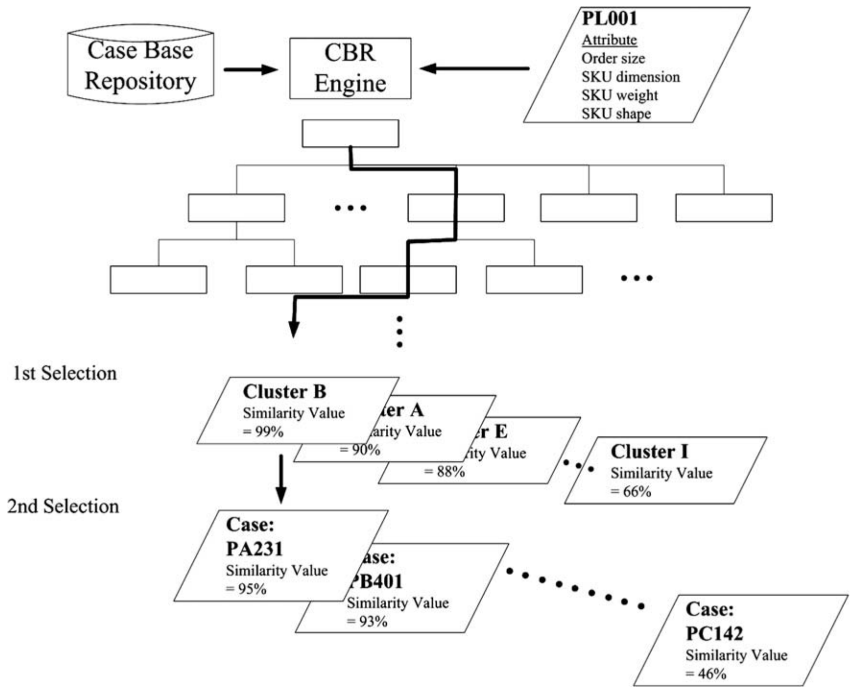


Fig. 13. Select the potentially useful material handling equipment for the new pick-up orders.

respectively. Use forklift A as the example, substitute the distances among readers 0013, 0014 and 0018 and corresponding locations of the readers into Eq. (4)

$$y_A^2 + \frac{2(Ax_{0018}D + CD - A^2y_{0018})y_A}{(A^2+D^2)} + \frac{(C^2 + 2Ax_{0018}C - A^2B)}{(A^2+D^2)} = 0$$

where

$$A = 2(x_{0013} - x_{0014}) = 2(20-20) = 0$$

$$B = d_{0018,A}^2 - y_{0018}^2 - x_{0018}^2 = 1 - 400 - 400 = -799$$

$$C = (d_{0013,A}^2 - d_{0014,A}^2) - (y_{0013}^2 - y_{0014}^2) - (x_{0013}^2 - x_{0014}^2)$$
$$= 9 - 25 - 400 + 900 - 400 + 400 = 484$$

$$D = 2(y_{0013} - y_{0014}) = 2(20-30) = -20$$

Thus, the equation becomes

$$y_A^2 + \frac{2[484*(-20)]y_A}{(400)} + \frac{(484^2)}{(400)} = 0$$

$$y_A^2 - 48.4y_A + 585.64 = 0$$

$$\therefore \quad y_A = 24.2$$

Sub. $y_A = 24.2$ into (3)

$$x_A = 17.06$$

As a result, by using the effective triangular localization scheme, the exact location of forklift A is (17, 24).

Step 6: formulate the pick-up routes for the new pick-up orders by material handling problem solver

In this step, the shortest pick-up route for each order is formulated by the material handling problem solver. For example, there are 8 items, *i, j, k, l, m, n, o* and *p*, involved in pick-up order "*PL001*" and their corresponding coordinates are (11, 21), (55, 48), (33, 27), (05, 13), (42, 23), (21, 10), (34, 32) and (26, 13), respectively. The location of depot D is (70, 30). First, the starting point and ending point of the pick-up sequence are determined.

Distance from item i to D is $\sqrt{(11-70)^2 + (21-30)^2} = 59.6825 \approx 60$ m

Distance from item j to D is $\sqrt{(55-70)^2 + (48-30)^2} = 23.4307 \approx 23$ m

Distance from item k to D is $\sqrt{(33-70)^2 + (27-30)^2} = 37.1214 \approx 37$ m

Distance from item l to D is $\sqrt{(05-70)^2 + (13-30)^2} = 67.1863 \approx 67$ m

Distance from item m to D is $\sqrt{(42-70)^2 + (23-30)^2} = 28.8617 \approx 29$ m

Distance from item n to D is $\sqrt{(21-70)^2 + (10-30)^2} = 52.9245 \approx 53$ m

Distance from item n to D is $\sqrt{(34-70)^2 + (32-30)^2} = 36.0555 \approx 36$ m

Distance from item p to D is $\sqrt{(26-70)^2 + (13-30)^2} = 47.1699 \approx 47$ m

The distance between item l and depot D is the farthest while the shortest distance between item j and depot D is determined. As a result, the position of item l and the position of item j are the starting point and the end point of the pick-up sequence, respectively. After that, the distances among the remaining points are determined, as shown in Table 4.

Based on the results in Table 4, the distance between item k and item o is the shortest. Thus, there is a pairwise connection between item o and item k. Similarly, there is connection between item n and item p. However, the distance between the remaining item i and item m is not the shortest. Therefore, the connections should be reconstructed until the pick-up sequence is the shortest. After several modifications, the shortest pick-up route for order "*PL001*" is item $l \rightarrow$ item $i \rightarrow$ item $n \rightarrow$ item $p \rightarrow$ item $k \rightarrow$ item $o \rightarrow$ item $m \rightarrow$ item $j \rightarrow$ depot D.

Step 7: associate the appropriate material handling equipment with the routes

In this step, the most appropriate material handling equipment is assigned to the shortest pick-up sequence formulated in *Step 6*. For example, there are three forklifts, *A, B and C*, in the warehouse and their locations are (17, 24), (31, 22) and (40, 35), respectively. It is discovered that the forklift A is the closest

Table 4
Distances among the remaining points (in meters).

From	To *i*	*k*	*m*	*n*	*o*	*p*
i	0	23	31	14	25	17
k	23	0	10	21	5	16
m	31	10	0	25	12	19
n	15	21	25	0	26	6
o	25	5	12	26	0	12
p	17	16	19	6	12	0

one to the item *l*, which is the starting point of the order "*PL001*". As a result, forklift A is assigned as the material handling equipment of order "*PL001*" if minimal total travelling time is achieved by solving Eq. (6). Fig. 14 is the screenshot of the material handling solution suggested by the proposed R-LRMS.

5. Lessons learnt from the case study

After the pilot run in the case study, the benefits of the proposed R-LRMS are examined and described in this session. These insights are the references for the enterprises who are interested in adopting the RFID solution in their own situations.

(i) *Simplify the RFID adoption procedure*
Through the proposed reading performance tests, the reading performances of active and passive RFID devices are determined in different scenarios, such as in different locations, with different materials being handled. According to the results shown in B, the distance at which an active tag is able to receive a signal is about 10 m but a passive tag can not receive a signal beyond a distance of approximately 2 m. The reading performance of an active RFID device is better than that of a passive RFID device. Besides this, the results reveal that all of the tags have the best performance when placed at the same level as the antennas. Based on the results, the procedures for the RFID equipment selection are simplified, and the locations suitable for the installation of RFID devices in the GSL warehouse are easily determined.

(ii) *Improve the accuracy of retrieved information*
Once the RFID equipment is installed effectively, the accuracy of retrieved warehouse information is significantly improved. As shown in Table 5, the inventory level recorded by R-LRMS is exactly the same as the actual level. It is better than using manual documents to record this information. In addition, R-LRMS provides the exact location of material handling equipment. The visibility of warehouse is significantly increased.

(iii) *Enhance the productivity of the warehouse*
As the RFID technology and query optimization technique are adopted in the R-LRMS, the performance of retrieving and storing information are significantly enhanced. The times for retrieving and storing specific warehouse information are reduced from 1 min and 10 s to 5 s and 2 s, respectively, as shown in Table 6.

Moreover, the job assignment process is changed from being manual-based to being automatic. The speed of assigning pick-up jobs and formulating material handling solutions for fulfilling customers' demands is significantly enhanced. Previously, the average time for formulating one material handling solution is about two minutes. However, it is greatly reduced to fifteen seconds when R-LRMS is implemented, as illustrated in Table 7. This helps enhance the productivity of the warehouse.

6. Conclusions and future work

In this paper, a radio frequency identification case-based logistics resource management system (R-LRMS) is proposed for formulating and suggesting the appropriate material handling solutions in a warehouse environment. In doing this, two construction phases for R-LRMS are required. With the help of Phase 1, the effective radio frequency (RF) cover ranges of the RFID technology are revealed and operation specifications of R-LRMS are determined. These results are the references to help enterprises to select the most appropriate RFID equipment and to install the equipment in the most suitable locations for data collection in the environment where it is being used. In Phase 2, three technologies are adopted in R-LRMS. They are: (i) a case-based reasoning engine, (ii) an effective triangular localization scheme and (iii) a material handling problem solver. The case-based reasoning engine is adopted for searching for the similar cases in the case-based repository and for proposed reliable solutions for handling the pick-up orders. The effective triangular localization scheme is developed for identifying the exact locations of the resources in a warehouse. The material handling problem

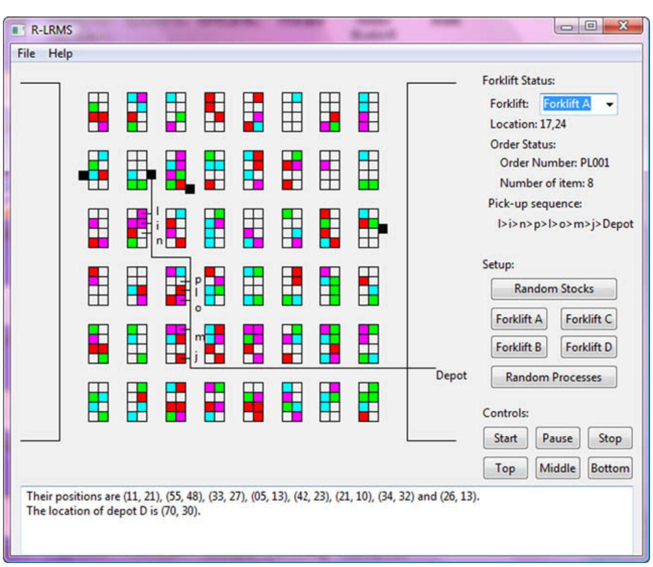


Fig. 14. Suggested material handling solution.

Table 5
Improvement in the accuracy of retrieved information.

	Previous situation (manual document/bar-code)	R-LRMS (RFID)	Actual
Inventory in warehouse	1547 Units	1574 Units	1574 Units
Inventory in specific locations (level 2 of rack 6)	No record	43 Units	43 Units
Location of material handling equipment (forklift A)	Zone A	(17, 24)	(18, 23)

Table 6
Time reduction in retrieving and storing information.

	Previous situation (manual document/ bar-code)	R-LRMS (RFID/ query optimization)
Time for retrieving warehouse information		
Inventory in warehouse	30 s	2 s
Inventory of specific type of product	1 min	5 s
Time for recording warehouse information (weight of SKU A)	10 s	2 s

Table 7
Time reduction in formulating the material handling solutions.

	Previous situation	R-LRMS
Time for formulating one material handling solution		
Determine the appropriate material handling equipment	15 s	15 s
Determine the shortest pick-up route	45 s	
Modify the solution if not feasible	1 min	
Total	2 min	

solver is designed for constructing a cost-effective and efficient material handling solution. The integration of these technologies in the proposed R-LRMS helps enterprises improve the operational efficiency of their warehouse. It not only facilitates the real-time information sharing and resolves the communication problems among the supply chain parties, but also helps transferring the raw data to meaningful material handling solutions. The capabilities of R-LRMS are demonstrated in GSL Limited. Three objectives are achieved, they are: (i) a simplification of RFID adoption procedure, (ii) an improvement in the visibility of warehouse operations and (iii) an enhancement of the productivity of the warehouse. The successful case example proved the feasibility of R-LRMS in real working practice.

Nevertheless, there is still room for improvement. Three areas should be considered in future work for improving the capabilities of the proposed system.

There is still one more type of RFID tag that has not been examined in this paper. It is the semi-passive tag, which is battery-assisted with greater sensitivity than passive tags but cheaper than active tags. It is essential to evaluate the reading performance of this tag in a warehouse environment in order to provide a comprehensive RFID performance comparison for formulating an efficient RFID solution.

In this paper, an effective triangular localization scheme is developed for locating the moving objects in warehouse environment. However, it is only applied by the passive RFID technology. Therefore, it is essential to modify the effective triangular localization scheme for applying it in active RFID equipment as well.

Nowadays, people are more conscious of all their different partners in the entire supply chain performance. The generic R-LRMS described in this paper is able to manage the logistics resources for improving the operation performance in such a supply chain. In future, studies on different parties, such as production, distribution, etc., should be considered to determine the requirements for modifying the current architectural framework of the R-LRMS to fit the whole supply chain network.

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Appendix A. Basic description of the testing equipment (Source: http://www.alientechnology.com)

Reader specification	**Active RFID Reader** 	**Passive RFID Reader** 
Brand	Alien Technology	Alien Technology
Name	Nanoscanner Reader	Alien Multi-Port General Purpose RFID Reader
Model Number	B2450R01-A	ALR 9800
Frequency	2410 MHz – 2471.64 MHz	902.75 MHz – 927.25 MHz
Antenna Polarization	Circular	Linear

Antenna	**Active** 	**Passive** 
Frequency	2410 MHz – 2471.64 MHz	902-928 MHz
Polarization	Circular	Linear

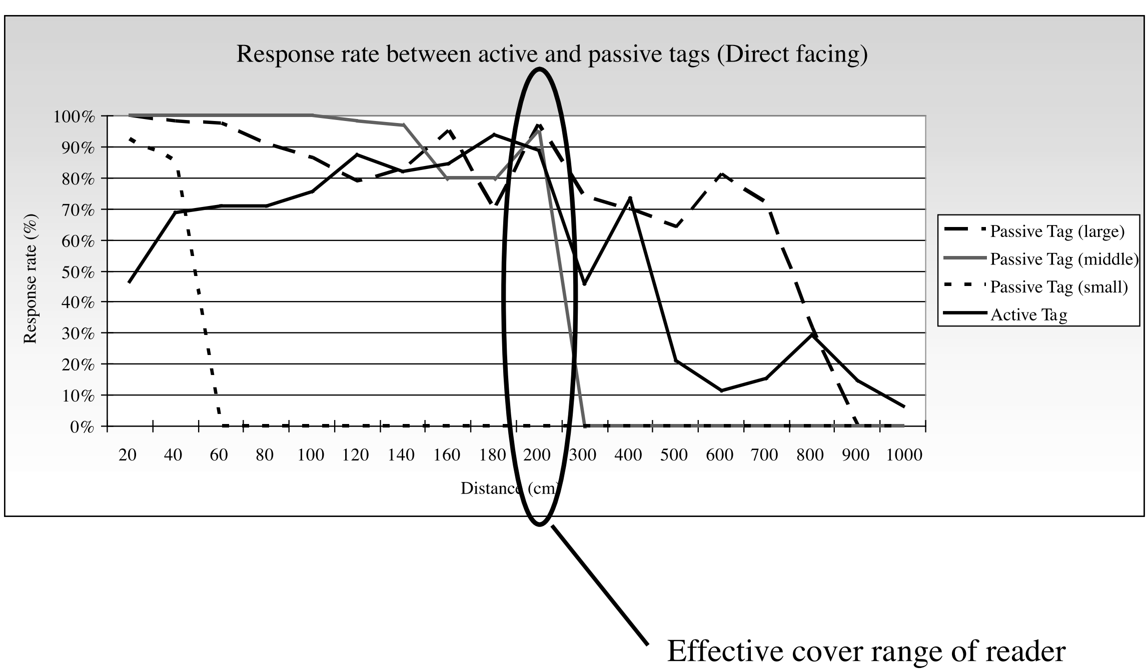
Tag				
Nature	Active	Passive (large)	Passive (middle)	Passive (small)
Dimension (cm)	8 x 2.5 x 1.2	9 x 4.5	9.5 x 3	4 x 2.5

Appendix B. Results of feasibility study of active and passive RFID devices

B.1. Orientation test

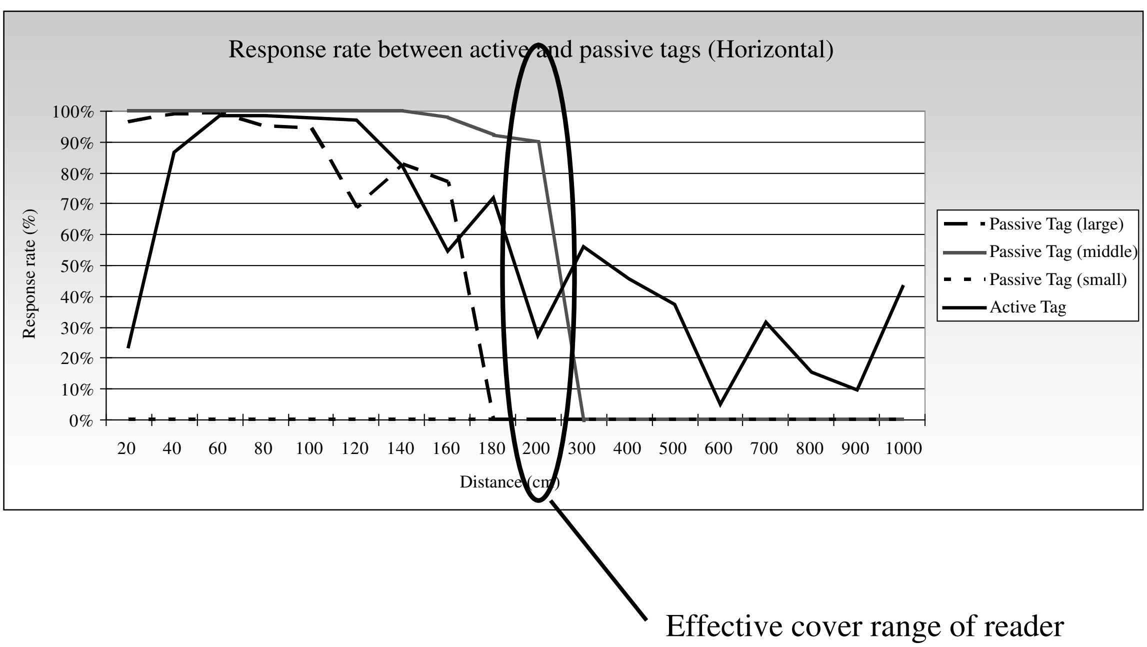
B.1.1. Tags stuck on the front surface of SKU

	Total Read in 1 Min (Active)						Total Read in 1 Min (Passive large)						Total Read in 1 Min (Passive middle)						Total Read in 1 Min (Passive small)					
Distance (cm)	1	2	3	4	5	Average	1	2	3	4	5	Average	1	2	3	4	5	Average	1	2	3	4	5	Average
20	1100	1100	1700	1500	900	1260	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	900	900	928	950	946	924.8
40	2000	2100	2000	2100	1100	1860	988	985	982	978	976	981.8	1000	1000	1000	1000	1000	1000	850	878	856	850	854	857.6
60	2000	1900	1600	2100	2000	1920	975	970	978	968	975	973.2	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
80	1900	2000	2000	2100	1600	1920	907	910	908	905	910	908	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
100	1900	2000	2000	2400	1900	2040	850	866	856	865	880	863.4	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
120	2500	2200	2400	2300	2400	2360	760	790	780	800	805	787	980	980	982	980	980	980.4	0	0	0	0	0	0
140	2200	2000	2000	2300	2600	2220	831	850	770	840	854	829	960	965	966	980	960	966.2	0	0	0	0	0	0
160	2200	2200	2200	2400	2400	2280	970	953	936	940	960	951.8	800	800	800	800	800	800	0	0	0	0	0	0
180	2500	2500	2900	2500	2300	2540	710	668	680	714	705	695.4	800	800	800	800	802	800.4	0	0	0	0	0	0
200	2500	2500	2600	2400	2000	2400	970	970	975	975	972	972.4	978	920	890	970	965	944.6	0	0	0	0	0	0
300	1100	1100	1100	1900	1000	1240	734	730	730	746	750	738	0	0	0	0	0	0	0	0	0	0	0	0
400	1800	2000	2000	2200	1900	1980	700	690	698	702	700	698	0	0	0	0	0	0	0	0	0	0	0	0
500	380	420	360	900	800	572	660	655	664	620	610	641.8	0	0	0	0	0	0	0	0	0	0	0	0
600	200	260	230	300	550	308	830	790	799	825	823	813.4	0	0	0	0	0	0	0	0	0	0	0	0
700	390	480	440	490	270	414	715	720	717	740	699	718.2	0	0	0	0	0	0	0	0	0	0	0	0
800	1000	700	770	800	700	794	300	298	314	340	317	313.8	0	0	0	0	0	0	0	0	0	0	0	0
900	450	480	400	250	380	392	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1000	170	130	180	150	220	170	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0



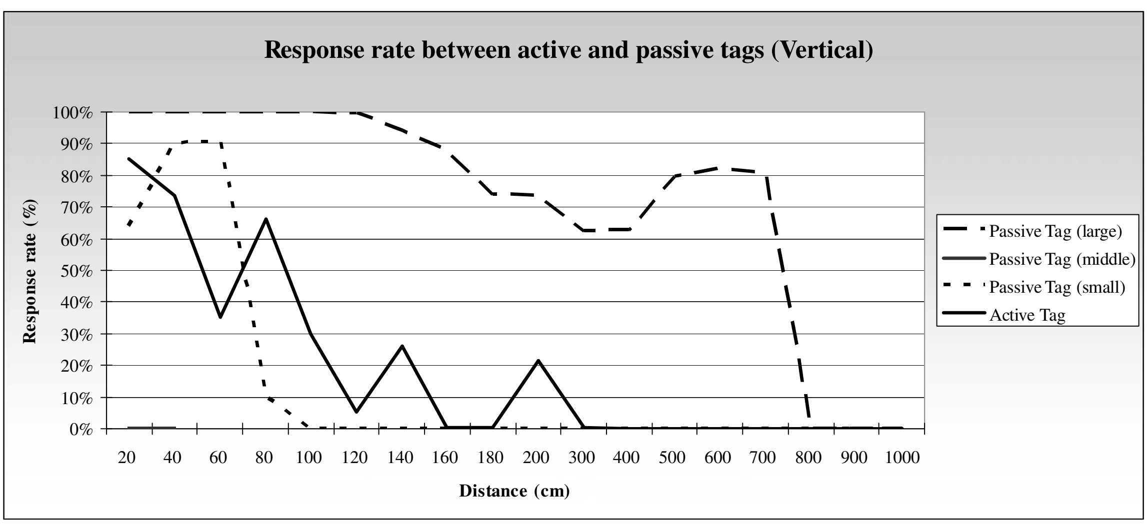
B.1.2. Tag stuck on the top surface of SKU

	Total Read in 1 Min (Active)						Total Read in 1 Min (Passive large)						Total Read in 1 Min (Passive middle)						Total Read in 1 Min (Passive small)					
Distance (cm)	1	2	3	4	5	Average	1	2	3	4	5	Average	1	2	3	4	5	Average	1	2	3	4	5	Average
20	900	750	500	450	600	640	960	966	967	959	966	963.6	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
40	2400	2300	2400	2300	2300	2340	974	995	996	978	998	988.2	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
60	2600	2700	2600	2600	2800	2660	992	994	998	978	995	991.4	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
80	2800	2600	2700	2500	2700	2660	914	990	995	920	924	948.6	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
100	2800	2500	2700	2600	2600	2640	996	956	940	921	924	947.4	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
120	2600	2500	2700	2600	2700	2620	833	877	20	850	854	686.8	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
140	2300	2300	2200	2200	2100	2220	820	819	825	830	836	826	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
160	1500	1500	1600	1500	1300	1480	772	780	750	756	790	769.6	980	984	978	975	982	979.8	0	0	0	0	0	0
180	2100	1800	2000	1900	1900	1940	0	0	0	0	0	0	906	925	926	926	921	920.8	0	0	0	0	0	0
200	700	700	770	797	712	735.8	0	0	0	0	0	0	900	890	899	880	924	898.6	0	0	0	0	0	0
300	1712	1674	1200	1700	1300	1517.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
400	1175	1322	1271	1210	1188	1233.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
500	914	910	974	1026	1246	1014	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
600	162	154	160	100	100	135.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
700	787	922	925	945	700	855.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
800	374	413	490	429	366	414.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
900	271	332	282	251	180	263.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1000	1234	1065	1204	1076	1235	1162.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0



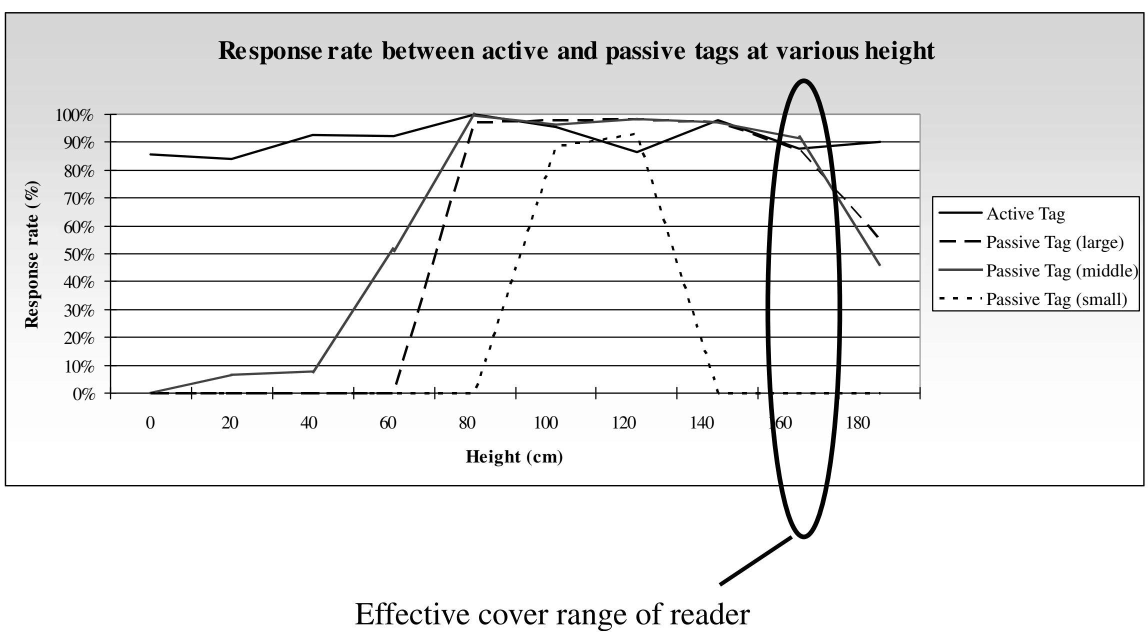
B.1.3. Tags stuck on the side surface of SKU

	Total Read in 1 Min (Active)						Total Read in 1 Min (Passive large)						Total Read in 1 Min (Passive middle)						Total Read in 1 Min (Passive small)					
Distance (cm)	1	2	3	4	5	Average	1	2	3	4	5	Average	1	2	3	4	5	Average	1	2	3	4	5	Average
20	2300	2366	2346	2180	2309	2300.2	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0	600	904	599	550	554	641.4
40	2000	1978	2000	2100	1862	1988	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0	900	900	900	900	900	900
60	942	915	948	1035	908	949.6	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0	900	905	921	921	900	909.4
80	2030	1700	1700	1830	1700	1792	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0	100	100	100	104	102	101.2
100	800	760	850	900	750	812	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0	0	0	0	0	0	0
120	124	216	160	100	100	140	990	998	990	1000	998	995.2	0	0	0	0	0	0	0	0	0	0	0	0
140	550	680	800	700	780	702	950	956	954	920	925	941	0	0	0	0	0	0	0	0	0	0	0	0
160	20	10	15	14	10	13.8	882	889	890	854	873	877.6	0	0	0	0	0	0	0	0	0	0	0	0
180	6	10	7	15	12	10	721	745	756	755	720	739.4	0	0	0	0	0	0	0	0	0	0	0	0
200	500	500	650	600	640	578	750	721	750	724	728	734.6	0	0	0	0	0	0	0	0	0	0	0	0
300	0	0	0	0	0	0	600	635	625	641	620	624.2	0	0	0	0	0	0	0	0	0	0	0	0
400	0	0	0	0	0	0	600	603	666	667	600	627.2	0	0	0	0	0	0	0	0	0	0	0	0
500	0	0	0	0	0	0	820	825	799	780	754	795.6	0	0	0	0	0	0	0	0	0	0	0	0
600	0	0	0	0	0	0	820	750	898	854	787	821.8	0	0	0	0	0	0	0	0	0	0	0	0
700	0	0	0	0	0	0	830	820	780	745	860	807	0	0	0	0	0	0	0	0	0	0	0	0
800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
900	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0



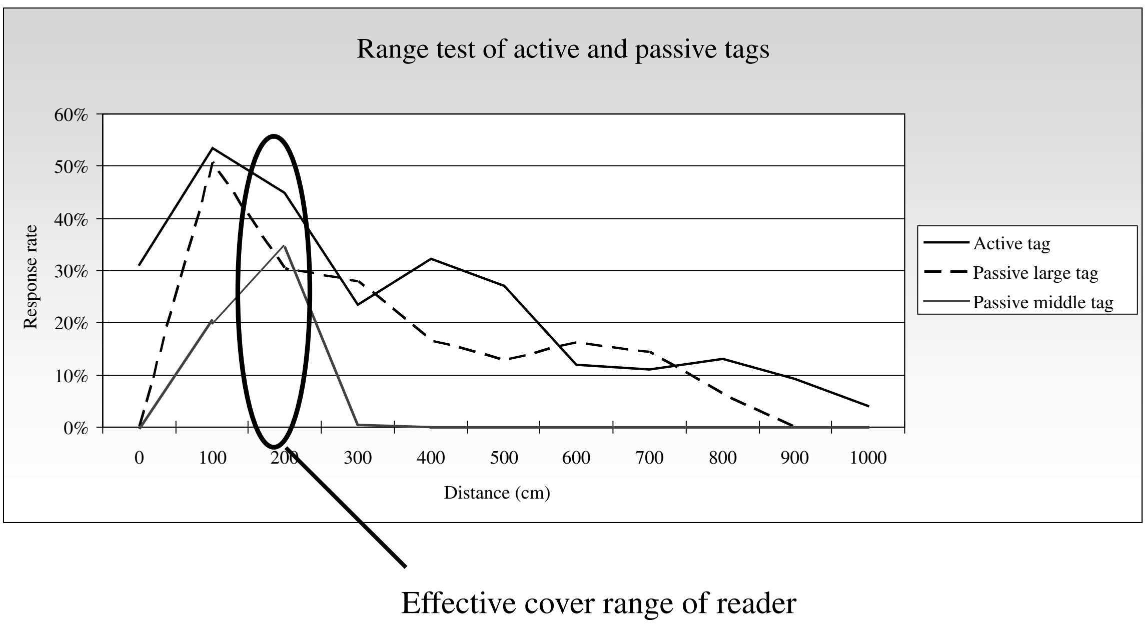
B.2. Height test

Height (cm)	1	2	3	4	5	Average	1	2	3	4	5	Average	1	2	3	4	5	Average	1	2	3	4	5	Average
0	2300	2200	1980	2500	2600	2316	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	1950	2300	2000	2450	2650	2270	0	0	0	0	0	0	66	57	70	79	60	66.4	900	890	850	905	880	885
40	1990	2800	2500	2550	2690	2506	0	0	0	0	0	0	73	79	65	90	91	79.6	950	948	880	920	955	930.6
60	2400	2500	2550	2470	2550	2494	0	0	0	0	0	0	516	540	499	526	480	512.2	0	0	0	0	0	0
80	2690	2680	2750	2750	2650	2704	970	976	969	972	960	969.4	996	998	990	998	998	996	0	0	0	0	0	0
100	2900	2800	2500	2400	2300	2580	980	988	982	979	970	979.8	944	950	980	970	972	963.2	0	0	0	0	0	0
120	2200	2400	2200	2600	2300	2340	980	982	985	985	990	984.4	980	984	990	979	982	983	0	0	0	0	0	0
140	2600	2400	2700	2700	2800	2640	977	980	965	962	965	969.8	976	960	965	978	976	971	0	0	0	0	0	0
160	2500	2400	2450	2500	1980	2366	880	860	866	879	882	873.4	920	920	900	905	925	914	0	0	0	0	0	0
180	2550	2650	2500	2450	2000	2430	570	490	565	572	540	547.4	480	520	375	450	490	463	0	0	0	0	0	0



B.3. Range test

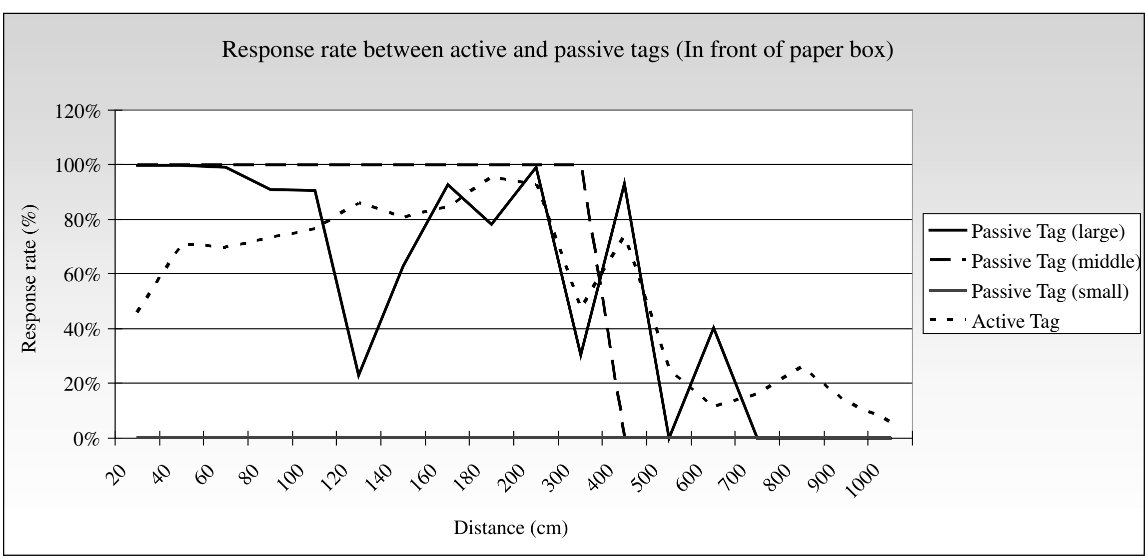
Distance at Y/X axis	0	100	200	300	400	0	100	200	300	0	100	200	0	100	200	300	400
0	0	2400	1250	500	<10	0	0	0	0	0	0	0	0	0	0	0	0
100	1900	2000	1800	780	800	850	860	804	0	1000	0	0	0	0	0	0	0
200	2000	480	1330	500	1500	970	545	0	0	978	760	0	0	0	0	0	0
300	1000	270	677	400	550	734	419	262	0	0	27	0	0	0	0	0	0
400	1900	600	450	950	700	700	143	0	0	0	0	0	0	0	0	0	0
500	800	1500	850	280	140	660	0	0	0	0	0	0	0	0	0	0	0
600	550	920	<5	<10	750	830	0	0	0	0	0	0	0	0	0	0	0
700	270	800	400	<10	0	715	0	0	0	0	0	0	0	0	0	0	0
800	700	700	287	0	0	300	0	0	0	0	0	0	0	0	0	0	0
900	380	825	<10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1000	220	350	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0



B.4. Material test

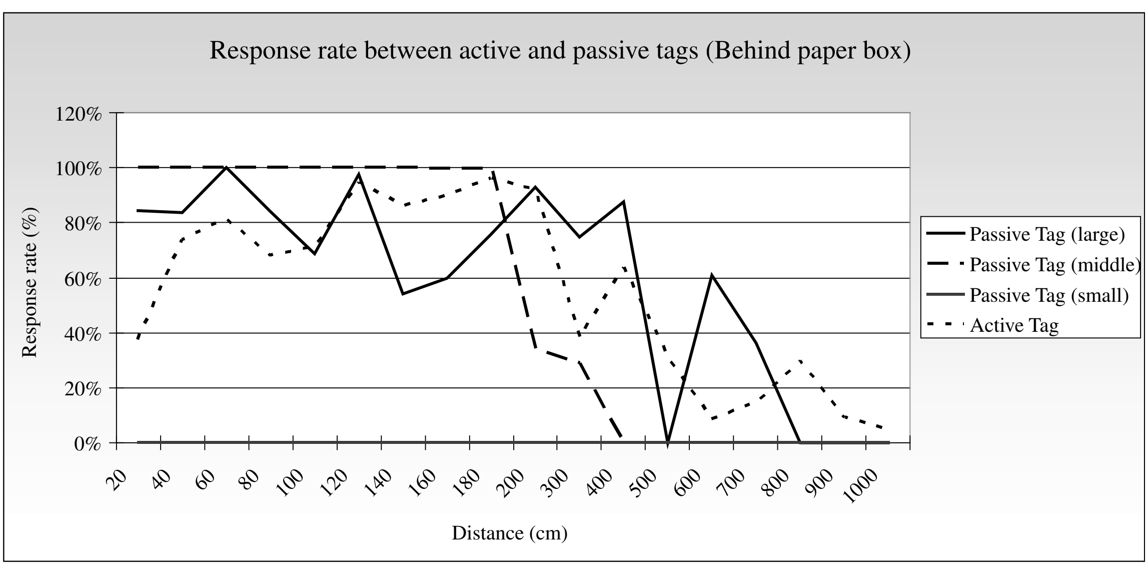
B.4.1. In front of the SKU

	Total Read in 1 Min (Active)						Total Read in 1 Min (Passive large)						Total Read in 1 Min (Passive middle)						Total Read in 1 Min (Passive small)					
Distance (cm)	1	2	3	4	5	Average	1	2	3	4	5	Average	1	2	3	4	5	Average	1	2	3	4	5	Average
20	1100	1100	1500	1400	1100	1240	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
40	2000	2100	1900	2100	1500	1920	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
60	1900	1900	1700	2100	1800	1880	998	992	994	987	985	991.2	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
80	2000	2000	2000	2100	1800	1980	928	967	819	933	903	910	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
100	1900	2100	2100	2300	1900	2060	932	900	898	894	914	907.6	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
120	2500	2400	2100	2200	2400	2320	480	239	211	84	142	231.2	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
140	2200	2200	2000	2100	2400	2180	635	570	580	687	677	629.8	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
160	2200	2100	2500	2400	2200	2280	952	938	911	925	916	928.4	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
180	2400	2500	2800	2800	2400	2580	804	825	789	724	771	782.6	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
200	2500	2400	2500	2400	2700	2500	998	996	970	996	995	991	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
300	1100	1100	1200	1800	1200	1280	306	295	307	312	297	303.4	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
400	1800	1800	2000	2200	2200	2000	951	920	947	907	938	932.6	0	0	0	0	0	0	0	0	0	0	0	0
500	850	750	420	900	480	680	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
600	200	260	230	300	550	308	417	407	355	420	414	402.6	0	0	0	0	0	0	0	0	0	0	0	0
700	380	500	450	450	370	430	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
800	750	680	600	800	700	706	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
900	350	380	480	280	270	352	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1000	155	110	150	200	180	159	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0



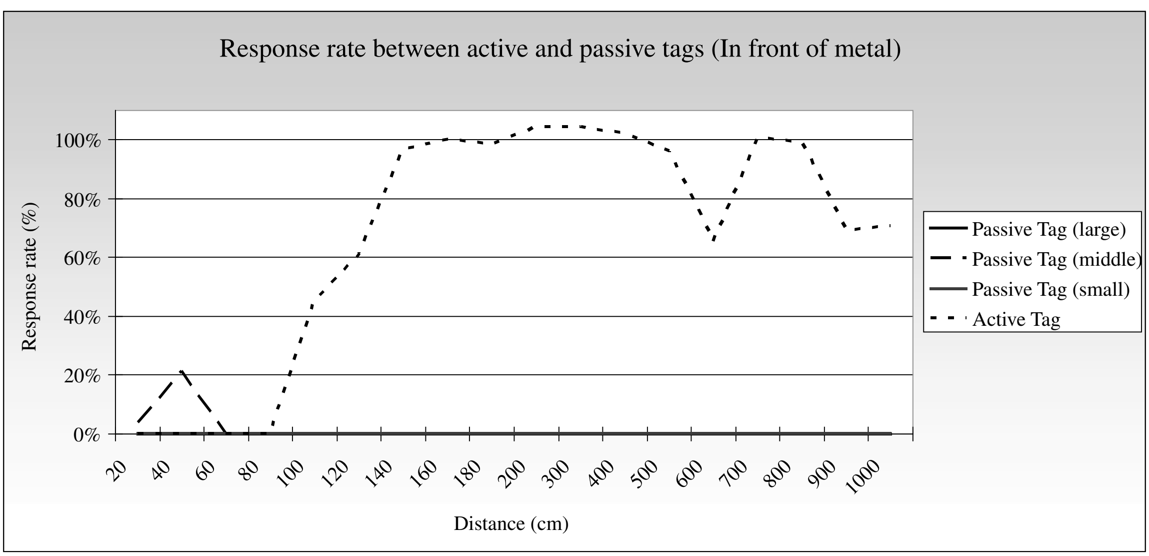
B.4.2. Behind the SKU

	Total Read in 1 Min (Active)						Total Read in 1 Min (Passive large)						Total Read in 1 Min (Passive middle)						Total Read in 1 Min (Passive small)					
Distance (cm)	1	2	3	4	5	Average	1	2	3	4	5	Average	1	2	3	4	5	Average	1	2	3	4	5	Average
20	1100	1000	900	950	1100	1010	834	847	855	846	844	845.2	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
40	2000	1900	1950	2100	2000	1990	811	816	845	872	846	838	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
60	2100	2200	2200	2400	2100	2200	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
80	1700	2000	1900	1900	1700	1840	847	827	836	853	846	841.8	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
100	1900	2000	2000	1900	1800	1920	875	844	583	527	599	685.6	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
120	2500	2580	2600	2520	2600	2560	992	984	930	989	988	976.6	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
140	2200	2400	2300	2350	2360	2322	540	539	544	538	553	542.8	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0
160	2400	2380	2500	2400	2420	2420	633	568	661	577	549	597.6	994	998	1000	995	998	997	0	0	0	0	0	0
180	2500	2580	2650	2650	2600	2596	779	727	796	710	778	758	997	998	996	1000	996	997.4	0	0	0	0	0	0
200	2466	2500	2550	2400	2500	2483.2	907	958	928	930	925	929.6	334	356	366	338	318	342.4	0	0	0	0	0	0
300	1100	980	1000	1020	1050	1030	771	745	740	724	767	749.4	470	139	249	280	300	287.6	0	0	0	0	0	0
400	1800	1750	1650	1600	1800	1720	980	890	875	880	756	876.2	0	0	0	0	0	0	0	0	0	0	0	0
500	800	900	780	900	850	846	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
600	200	250	247	250	200	229.4	608	598	620	644	580	610	0	0	0	0	0	0	0	0	0	0	0	0
700	380	385	390	420	380	391	415	377	420	350	246	361.6	0	0	0	0	0	0	0	0	0	0	0	0
800	780	800	850	850	750	806	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
900	200	250	377	240	200	253.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1000	130	87	125	150	120	122.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0



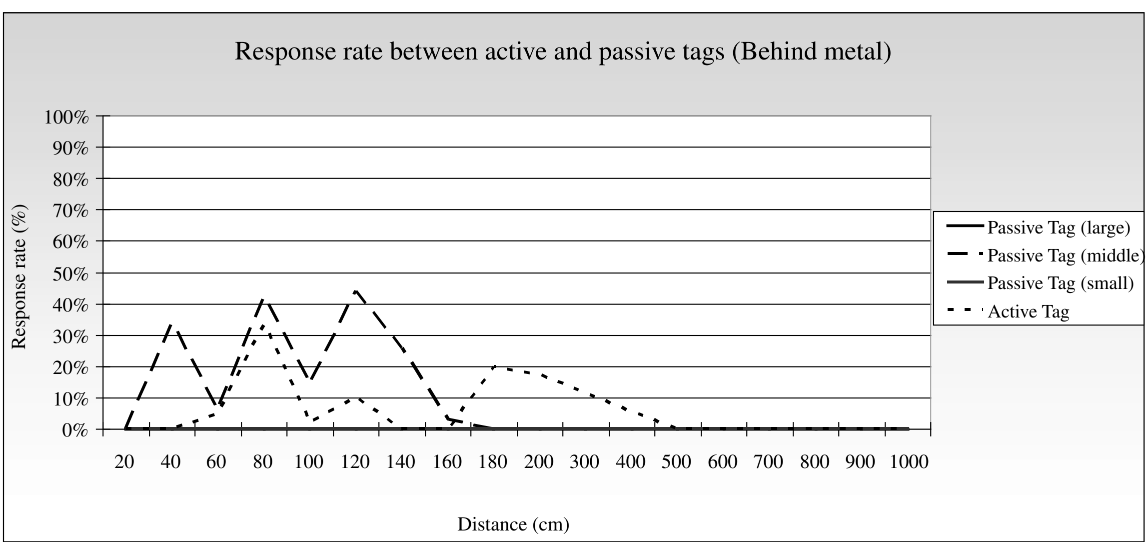
B.4.3. In front the metal

	Total Read in 1 Min (Active)						Total Read in 1 Min (Passive large)						Total Read in 1 Min (Passive middle)						Total Read in 1 Min (Passive small)					
Distance (cm)	1	2	3	4	5	Average	1	2	3	4	5	Average	1	2	3	4	5	Average	1	2	3	4	5	Average
20	0	0	0	0	0	0	0	0	0	0	0	0	25	26	24	28	89	38.4	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0	0	214	187	226	229	214	214	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100	1400	1100	1150	1200	1300	1230	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
120	1700	1750	1600	1650	1600	1660	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
140	2500	2700	2650	2660	2550	2612	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
160	2700	2716	2700	2680	2700	2699.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
180	2600	2650	2680	2658	2700	2657.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
200	2800	2900	2850	2900	2950	2880	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
300	2800	2800	2900	2880	2800	2836	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
400	2800	2750	2700	2800	2750	2760	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
500	2600	2550	2650	2600	2580	2596	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
600	1700	1800	1750	1770	1800	1764	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
700	2700	2700	2760	2750	2700	2722	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
800	2600	2650	2700	2750	2700	2680	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
900	1800	1900	1850	1900	1850	1860	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1000	1900	1850	2000	1900	1880	1906	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0



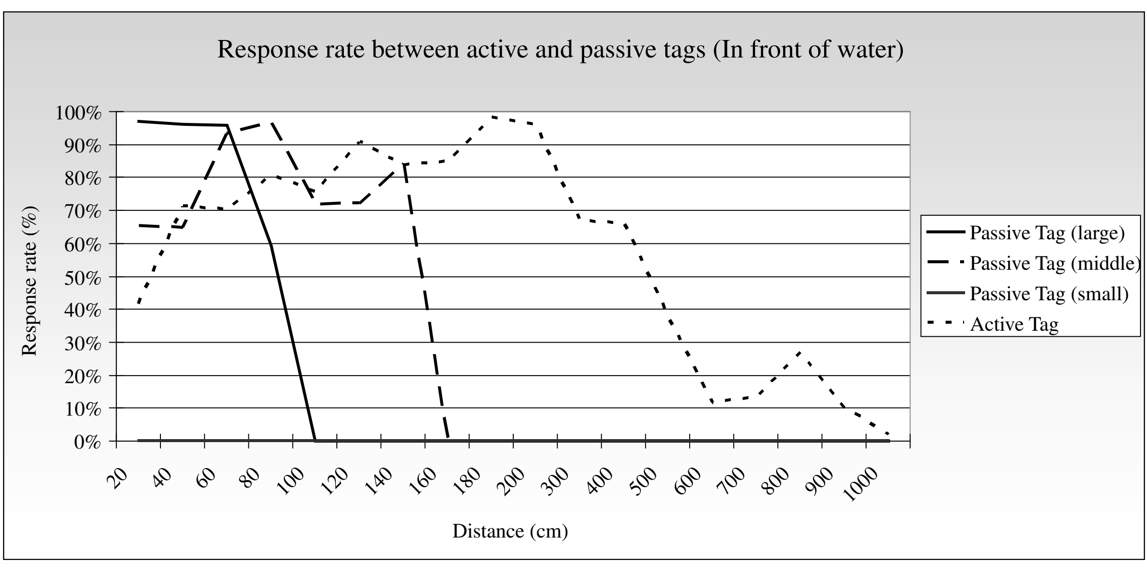
B.4.4. Behind the metal

	Total Read in 1 Min (Active)						Total Read in 1 Min (Passive large)						Total Read in 1 Min (Passive middle)						Total Read in 1 Min (Passive small)					
Distance (cm)	1	2	3	4	5	Average	1	2	3	4	5	Average	1	2	3	4	5	Average	1	2	3	4	5	Average
20	0	0	0	0	0	0	970	974	985	974	956	971.8	641	666	639	653	662	652.2	0	0	0	0	0	0
40	0	0	0	0	0	0	960	964	962	959	963	961.6	645	651	644	653	643	647.2	0	0	0	0	0	0
60	150	120	80	140	150	128	964	952	956	958	961	958.2	929	918	938	927	946	931.6	0	0	0	0	0	0
80	780	900	980	950	920	906	603	586	589	598	597	594.6	967	974	968	964	966	967.8	0	0	0	0	0	0
100	70	40	55	57	73	59	0	0	0	0	0	0	717	726	729	710	706	717.6	0	0	0	0	0	0
120	280	278	300	250	260	273.6	0	0	0	0	0	0	709	725	727	724	726	722.2	0	0	0	0	0	0
140	0	0	0	0	0	0	0	0	0	0	0	0	845	837	848	848	842	844	0	0	0	0	0	0
160	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
180	620	580	480	500	520	540	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
200	480	450	480	500	420	466	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
300	300	290	320	320	318	309.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
400	140	150	147	140	139	143.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
600	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
700	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
900	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0



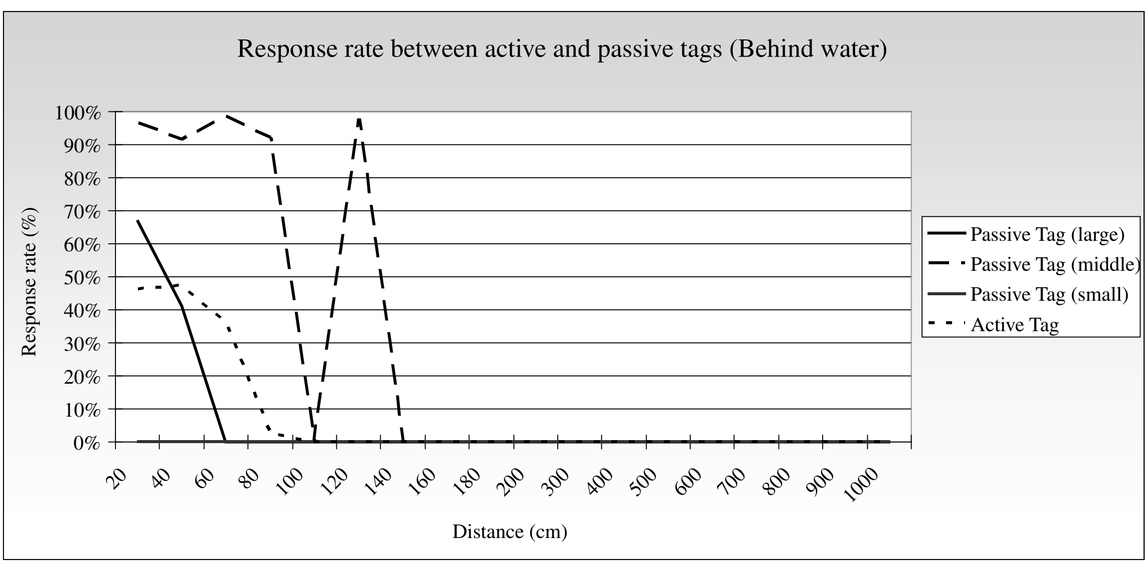
B.4.5. In front of the water bottle

	Total Read in 1 Min (Active)						Total Read in 1 Min (Passive large)						Total Read in 1 Min (Passive middle)						Total Read in 1 Min (Passive small)					
Distance (cm)	1	2	3	4	5	Average	1	2	3	4	5	Average	1	2	3	4	5	Average	1	2	3	4	5	Average
20	1200	900	1100	1300	1100	1120	970	974	985	974	956	971.8	641	666	639	653	662	652.2	0	0	0	0	0	0
40	1900	2000	1950	1850	1900	1920	960	964	962	959	963	961.6	645	651	644	653	643	647.2	0	0	0	0	0	0
60	1950	1850	1700	2000	2000	1900	964	952	956	958	961	958.2	929	918	938	927	946	931.6	0	0	0	0	0	0
80	2100	2300	2200	2200	2100	2180	603	586	589	598	597	594.6	967	974	968	964	966	967.8	0	0	0	0	0	0
100	2000	1900	2100	2300	1900	2040	0	0	0	0	0	0	717	726	729	710	706	717.6	0	0	0	0	0	0
120	2400	2550	2500	2400	2400	2450	0	0	0	0	0	0	709	725	727	724	726	722.2	0	0	0	0	0	0
140	2100	2150	2200	2350	2500	2260	0	0	0	0	0	0	845	837	848	848	842	844	0	0	0	0	0	0
160	2250	2200	2300	2300	2400	2290	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
180	2650	2550	2750	2700	2600	2650	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
200	2650	2500	2600	2700	2500	2590	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
300	1800	1700	1900	1850	1750	1800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
400	1700	1800	1700	1850	1900	1790	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
500	1100	950	1100	950	980	1016	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
600	350	257	280	300	370	311.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
700	370	300	450	400	300	364	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
800	800	780	700	700	650	726	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
900	200	275	280	290	300	269	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1000	57	87	54	20	54	54.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0



B.4.6. Behind the water bottle

	Total Read in 1 Min (Active)						Total Read in 1 Min (Passive large)						Total Read in 1 Min (Passive middle)						Total Read in 1 Min (Passive small)					
Distance (cm)	1	2	3	4	5	Average	1	2	3	4	5	Average	1	2	3	4	5	Average	1	2	3	4	5	Average
20	1200	1300	1200	1250	1300	1250	639	683	684	671	660	667.4	971	963	960	964	962	964	0	0	0	0	0	0
40	1300	1300	1250	1200	1350	1280	402	409	428	415	403	411.4	920	914	919	905	915	914.6	0	0	0	0	0	0
60	1100	950	1000	900	950	980	0	0	0	0	0	0	982	986	988	986	985	985.4	0	0	0	0	0	0
80	80	100	70	38	40	65.6	0	0	0	0	0	0	912	918	926	935	916	921.4	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
120	0	0	0	0	0	0	0	0	0	0	0	0	979	980	979	980	980	979.6	0	0	0	0	0	0
140	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
160	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
400	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
600	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
700	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
900	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0



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