Application and integration of an RFID-enabled warehousing management system – a feasibility study

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Application and integration of an RFID-enabled warehousing management system – a feasibility study

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Abstract

In supply chain and logistics sectors, accuracy of inventory data can be crucial for warehouse operations, SKU planning, and inventory management and control of incoming and outgoing goods**.** For the past decade, it has been seen a sharp rise for online shopping activities across the UK. Many customers now prefer to purchase goods online and demand a fast delivery of ordered products to be dispatched directly at their door steps. Thus, there is a desire for these sectors to seek even more efficient and effective methods for storing, picking and dispatching goods in increasingly centralised distribution centres in which automation and integration of warehousing systems is inevitable. As part of a study for future generation warehouses, this paper presents an investigation into a methodology in which an RFID-based inventory management system has capability of interacting with a proposed RFID-enabled automated storage and retrieval mechanism without any human intervention. To maximise efficiency in material-handling operations and minimise operational costs, a selection algorithm was developed within the RFID-inventory management system to seek an optimal solution in which it allows a manipulation of RFID-tracked items under pre-defined rules by assigning a priority (in an order if applicable) to one of selected items to travel to a specified collection point. A pilot test was carried out for examining the feasibility and applicability of the RFID-based management system based on the developed selection algorithm. In theory, such a system can be expanded by incorporating any pre-defined selection parameters.

Keywords: warehousing systems, inventory management, RFID, automation, integration.

1. Introduction

A traditional automated warehousing system often refers to applications of automatic storage and retrieval modules, lifting equipment and conveyor systems to stack, pick and transport incoming or outgoing items of a distribution centre. These facilities are used to overcome some disadvantages of manually operated warehouses which often lead to a high frequency of human errors, a consistent increase of labour costs and a poor efficiency of material-handling operations. In recent years, it has been seen an exponentially rising number of customers who like ordering products online and expect a fast delivery of ordered goods to be dispatched directly to their door steps. Because of this type of online shopping habit, many traditional stores (or warehouses) are no longer suitable for satisfying such a demand of online shopping customers. A study of literature review shows that future generation warehouses may be designed and implemented as more centralised distribution centres that partly replace conventional stores or warehouses of manufactures, suppliers and retailers in supply chain and logistics sectors [1]. This requires a novel design of a cost-effective mechanism of storage and retrieval systems as a key element of distribution centres for sorting, storing, picking and dispatching goods. Implementation and integration of fast-growing IT technologies have demonstrated great improvement opportunities of a warehouse in terms of a tighter inventory control, a shorter response time and a greater variety of SKUs (stock keeping units). These capabilities can be enhanced by using smart-labels such as radio frequency identification (RFID) tags, automatic identification (Auto-ID) sensors, wireless communication networks and indoor warehouse management systems (iWMS).

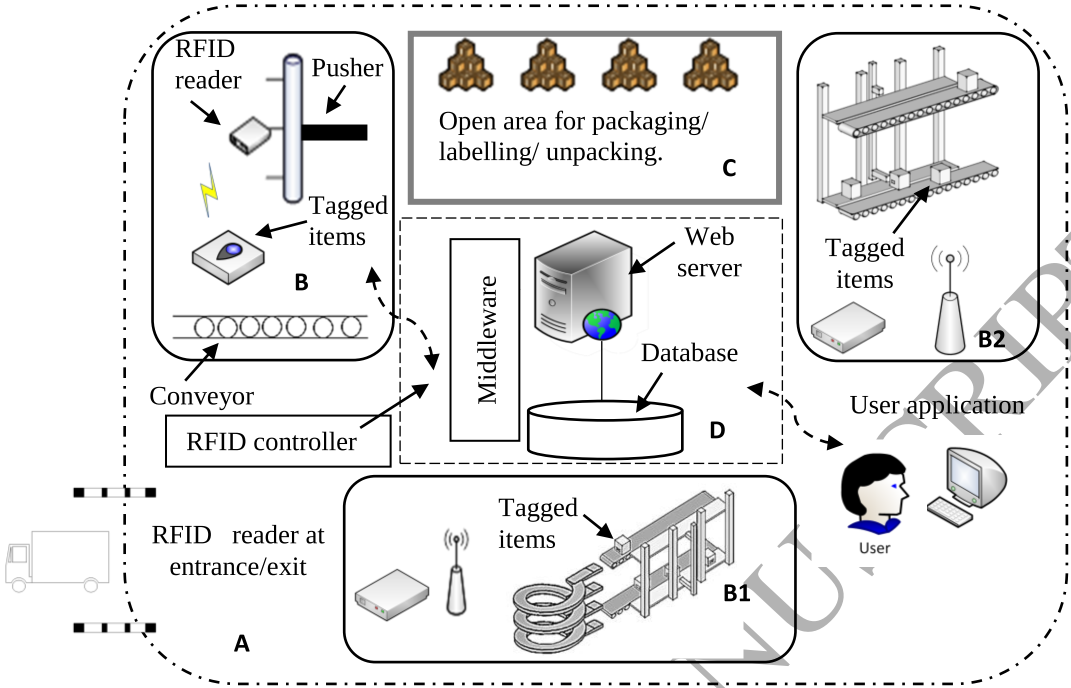
Applications of RFID-related techniques or systems have increasingly been becoming popular particularly in logistics and supply chain sectors. A latest literature review provided a summary in benefits, challenges and future trends in RFID applications [2]. Further, Sahin et al presented a literature review by examining the impact of inaccurate data records on inventory management and suggested the potential of the RFID-technology to tackle this issue [3]. Wang et al investigated the trend of future generation automated warehousing systems and proposed a framework of an RFID-enabled automated warehousing system aiming to maximise utilisation of warehouse capacity and efficiency of warehouse material-handling operations [1]. Wang et al introduced an RFID-based warehouse management system (WMS) in which events were managed and controlled under so-called event-condition-action (ECA) rules [4]. Chow et al proposed an RFID-based resource management system (RFID-RMS) in which a pure-integral-linear programming model using the branch-bound algorithm was used for determining an optimal travel distance for a material-handling forklift in a warehouse [5]. Liu et al carried out some experiments based on an RFID-based resource management system and results showed an improved utilisation of rack space and a reduction in operational errors [6]. Poon et al developed an RFID-based logistics resource management system which shares data with a warehouse database that manages order-picking operations [7]. Ting et al applied an RFID-based inventory control and management system (RICMS) into a manufacturing enterprise providing the integrity of records in transaction and location of goods [8]. Ross et al examined an RFID-based decision maker using a simulation model based on major operations (receiving, storing, picking and shipping), which occur in a typical warehouse. The decision maker can be useful for evaluating operations of a distribution centre and examining alternative RFID implementation strategies [9]. Xu et al introduced an optimisation method for implementing an RFID-enabled warehouse management based on varying SKU levels [10].

Integration of RFID with systems is an important task for future generation automated warehousing systems. Liu et al conducted a case study by integrating an RFID system into an enterprise resource planning (ERP) system focusing on two modules: an electronic receiving module and an inventory transaction module [11]. Wang et al discussed some key challenges in integration of wireless sensor networks (WSN) with RFID systems providing an infrastructure for data acquisition, distribution and processing in a manufacturing environment [12]. Zhou et al proposed an adaptive protocol for an RFID-WSN which integrates the RFID-based warehouse management system for tracking goods [13]. Jehng et al integrated the RFID system into an automatic conveyor system in which material flow was monitored and traced in a real time manner as each product was attached with an RFID tag [14]. Zhai et al presented real-time locating system (RTLS) for applications of industrial enterprise Internet of Things (IoT) providing more accurate position in interested sites, scalable system topology and flexible system capacity with multi-site and multi-tag management, high-speed and deterministic identification and position update, as well as energy-efficient design for long maintenance cycle [15]. In summary, it has been widely accepted that applications of RFID techniques can facilitate automation of storage and retrieval operations of a warehouse. Compared to a conventional warehouse using the barcode approach, implementation of RFID systems has demonstrated a significant improvement in warehouse data handling efficiency and space utilisation [16]. Within an RFID-based automated storage and retrieval mechanism, each item in a tote (or a tote containing identical items) is attached with an RFID tag so that these items can be traced, sorted and inventoried in a real-time manner under an integrated RFID-inventory management system. Ideally, this system can also interact with the control system of the automated storage and retrieval mechanism. By implementing the RFID-enabled warehousing system, each item can also be stored and dispatched in a storage rack (S/R) at any random location wherever a place is available for incoming or outgoing goods.

This paper presents a study into a methodology as part of design theories used for future generation automated warehousing systems [1]. It involves a framework in development of an optimisation algorithm which can be used for seeking an optimal solution to select an in-store item with an assigned priority in an order to be transported to a specified collection point based on a proposed RFID-based automated warehousing system. Within this approach, the RFID-inventory management system also has the capability of interacting with an RFID-enabled control system of the automated storage and retrieval mechanism as a key component of the RFID-based automated warehousing system. A pilot test was carried out for examining the feasibility and applicability of the RFID-based management system based on the developed selection algorithm. In theory, such a system can be expanded by incorporating any pre-defined selection parameters.

2. The RFID-based warehouse management system

Figure 1 illustrates key components of the RFID-based management system in a warehouse. At the gate of the warehouse entrance/exit, it is equipped with an RFID reader (shown at A) which collects RFID information data of RFID-tagged goods for each incoming or outgoing lorry that passes through the gate. After the process of unloading and unpacking goods (if applicable), each item will be contained in a tote entering into a storage conveyor, namely a storage rack (shown at B1). When a specific item is demanded, it can be transferred automatically from a storage rack onto an output conveyor (shown at B2) by a pusher device (shown at B). Each pusher also contains an RFID reader with its own antenna that receives wireless signals sent from each RFID-tagged item in a storage rack. Collection of inventory data by the reader is updated instantly in a warehouse management system through a controller which transmits the collected data via a middleware (shown at D). The middleware is the software translation layer between an RFID reader and the warehouse management system. Database of the warehouse management system contains records, which include data in identification, availability and other use-defined information of each item stored in the warehouse. Once an in-store item is ordered, the RFID-based inventory management system has capability to carry out an automatic check on information data of the item in database. Once the ordered item is identified by the RFID-based inventory management system, a pusher is activated by a PLC (programmable logic controller) to push the selected item in a tote onto an output conveyor. The item will then be transported by the output conveyor and it travels along an RFID-guided route to a specified destination (i.e., a collection point) for packaging (shown at C). The RFID-based warehouse inventory database will then be updated as soon as this ordered item is shifted out of the distribution centre in a lorry passing through the gate of the warehouse entrance/exit. The whole process is performed automatically without any human intervention apart from unpacking, labelling and packing operations in the warehouse.



A. RFID reader. B. Storage area. C. Open area for packaging/labelling/unpacking. D. Data center.

Figure 1: Key components of an RFID-based warehouse management system.

3. The RFID-embedded automated storage and retrieval system

Figure 2 illustrates an automated storage and retrieval rack (AS/RR) as one of the core components of the proposed RFID-based automated warehousing system. The module is designed as a standardized element for manufacturing and assembly, although each module can be of different sizes and arrays in a module that can be configured easily in many different ways, i.e., capacity of a warehouse is adjustable. The module is comprised of two types of powered conveyors aligned next to one another; these are input conveyors (storage racks) and output conveyors. The operation of both conveyor systems is controlled by a PLC that communicates with mounted sensors via a local area network (LAN). Within the RFID-inventory management system, a chosen SKU can be released by the mechanical system of AS/RR based on a number of assignment polices or rules. These include, for example, the rule of being nearest to a collection point and/or a pusher which is free or adjacent to the chosen SKU and so on, which are explained in other section below.

In the warehouse, once an item (or a tote that contains identical items) is attached with an RFID tag, it can be tracked and manipulated by the RFID-based inventory management system. An RFID tag has a unique identification and other user-defined information in association with a status of each item. It is composed of two main components which are an antenna and a computer chip. The computer chip stores data and the antenna allows data communication between an RFID tag and an RFID reader through a wireless signal transmission. A typical RFID reader is a microcontroller-based radio transceiver that powers an RFID tag using the time-varying electro-magnetic field (EMF) generated from an RFID antenna. Two types of RFID tags (active and passive RFID tags) can be used depending on a range in RFID reading performance at a location of an AS/RR. The RFID information data gathered by an RFID reader can be transferred to a host PC database for data processing and storage (as illustrated in Figure 1). By using RFID tags, a SKU can be distributed randomly at any location of an AS/RR wherever a place is available for incoming goods as illustrated in Figure 3. Thus, a SKU can also be dispatched randomly at varying locations for outgoing goods in the warehouse. This significantly facilities operations of storage, retrieval and replenishment, and improves capability, flexibility and responsiveness of the warehousing system to store and dispatch an item in/from an AS/RR.

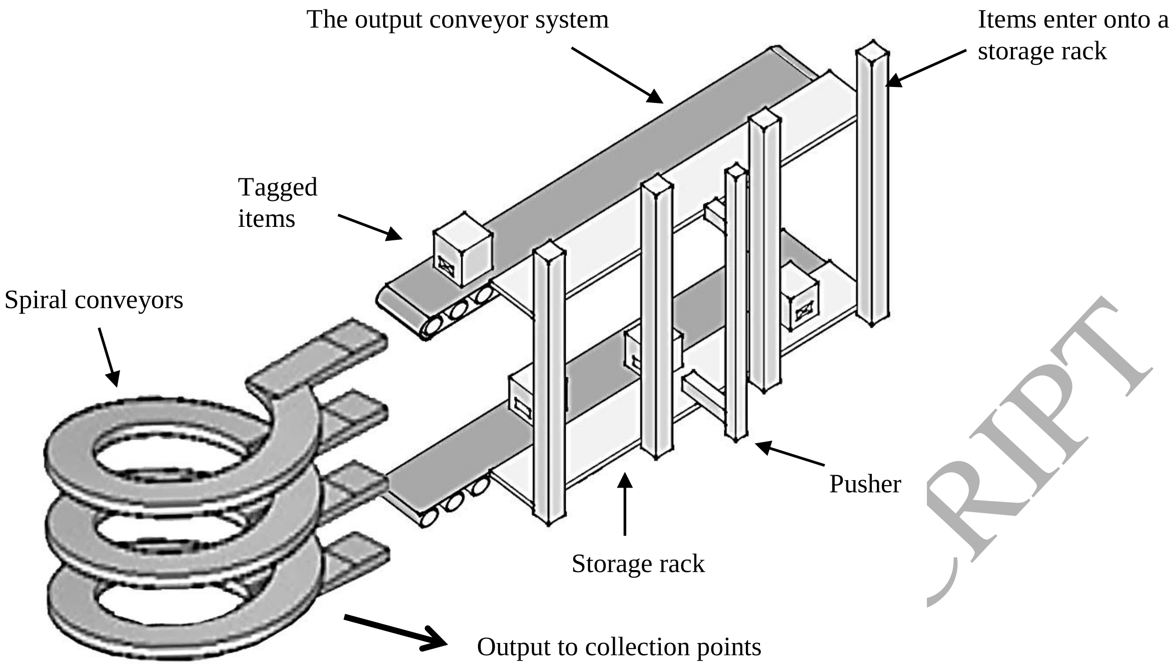


Figure 2: Structure of the automated storage and retrieval system.

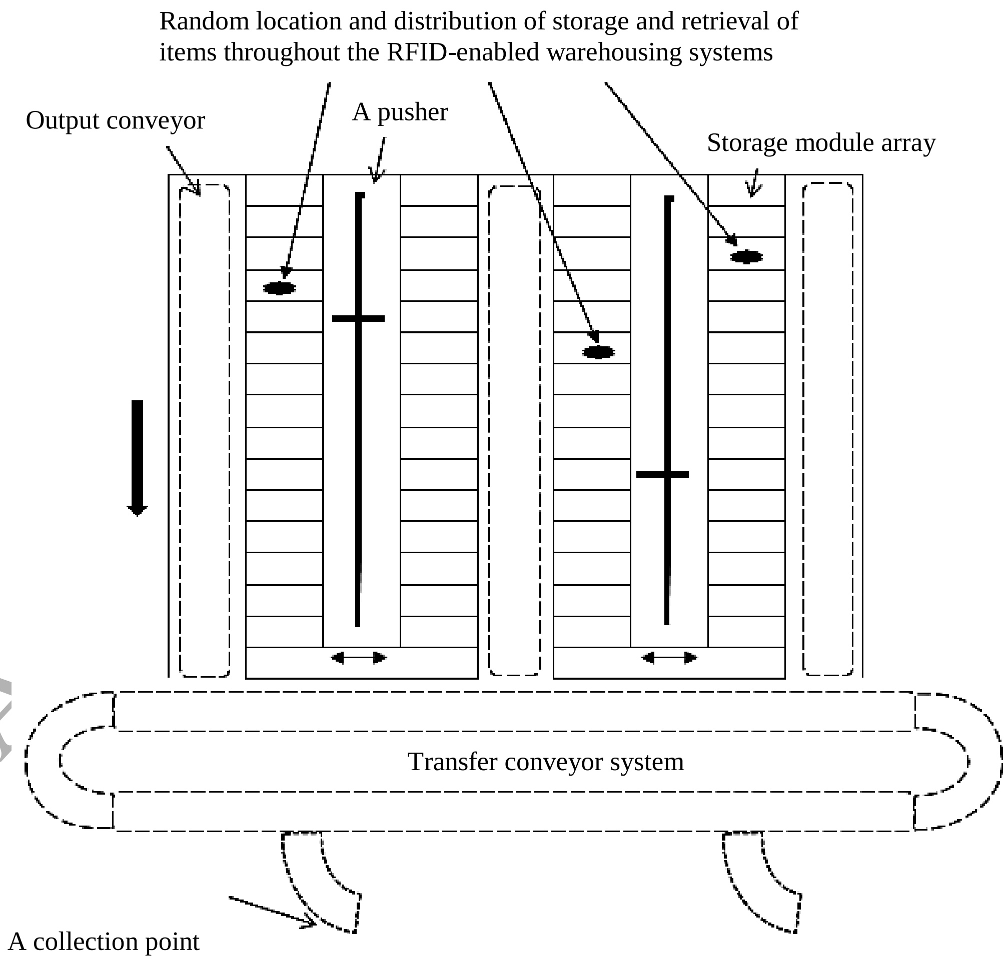


Figure 3: Random storage and retrieval locations of SKUs.

4. Measurement of the storage and retrieval system

Figure 4 illustrates the key components and corresponding geometric parameters of the proposed storage and retrieval system as illustrated in Fig. 2: 1) output conveyor; 2) storage rack containing items; 3) height of a storage rack *H*; 4) length of a storage rack *L*; 5) depth of a storage rack *D*; 6) pusher; 7) length from an end of an output conveyor to an entrance of a spiral conveyor; 8) entrance to a spiral conveyor; 9) length of a single spiral conveyor; 10) a spiral conveyor; 11) length from an end of a spiral conveyor to a collection point. The aim of the following work is to determine a total travel time an item needs from the moment when a pusher device is activated to push a selected item in a tote onto an output conveyor to the moment this item travels down to a collection point. Figure 5 shows a two dimensional cross-section diagram based on Fig. 4. The pusher can move simultaneously in both horizontal and vertical directions from one location (*i, j)* at where the pusher currently stays to another location (m_x, n_y) at where an identified item is selected to be pushed onto the output conveyor. The following assumptions are used in this case:

1. The pusher is capable of moving instantly to obtain a stable and constant speed without an acceleration/deceleration.
2. Because the pusher is capable of moving simultaneously in both vertical and horizontal directions at a stable and constant speed, this implies that the pusher can move along the linear route *Ld* to a specified location before pushing a selected item from a storage rack onto and output conveyor.
3. Each item in a tote is pushed onto an output conveyor instantly without any delay.

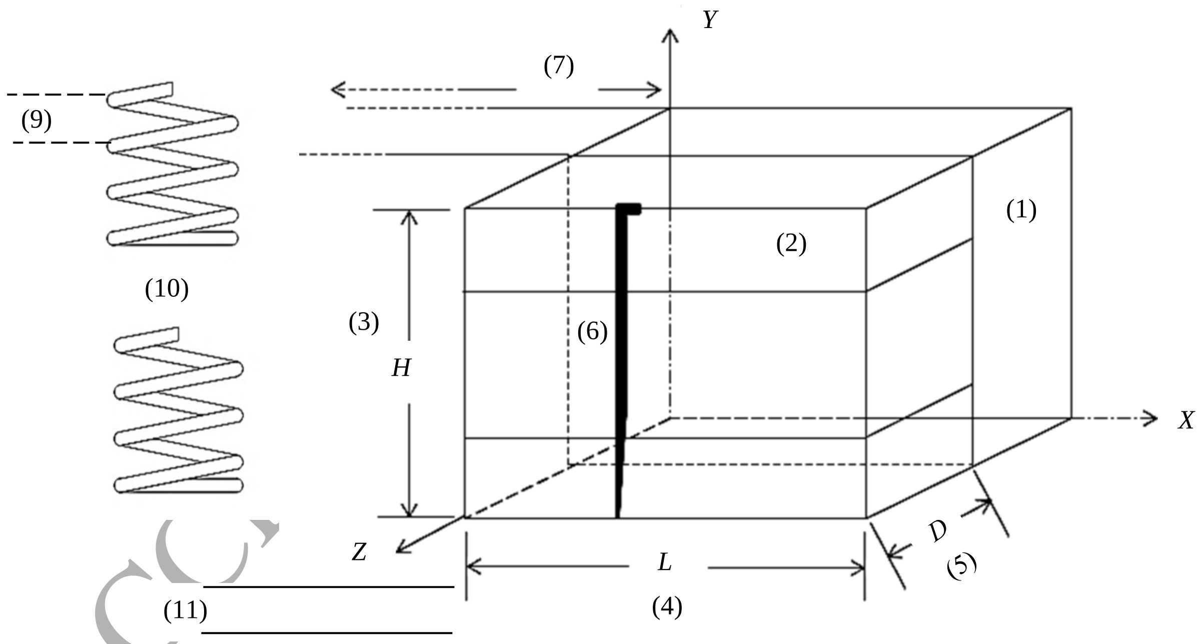


Figure 4: Geometric parameters corresponding to the key components of the storage and retrieval system.

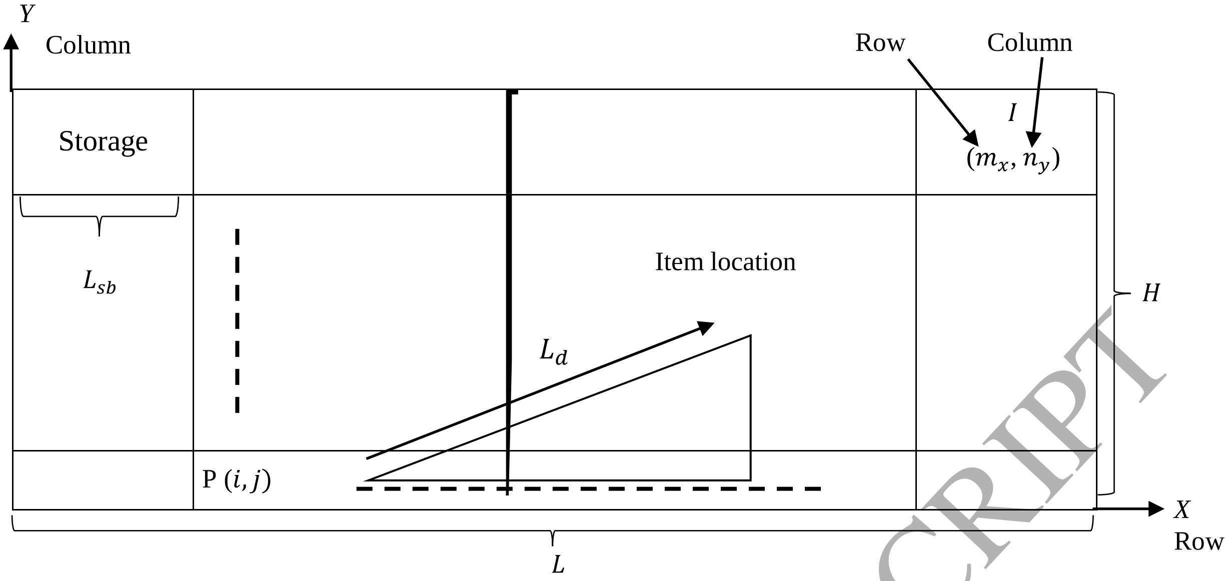


Figure 5: Geometric parameters in a storage rack.

The following notations are used in this model.

- *I*: an item located at a row m_y and a column n_x, i.e., (m_x, n_y) in an AS/RR.
- *P*: a pusher at a location (*i, j)*.
- *Lsb*: length of a tote in a storage room of an AS/RR.
- *Lsc*: length from a position of a selected item in a tote to be pushed onto an output conveyor to a position where this item in a tote travels at an end of an output conveyor.
- *Lss*: length of a single spiral conveyor.
- *Lsp*: length from an end of a spiral conveyor to a collection point.
- *Ld*: distance between a pusher and a selected item.
- *Vc*: speed of an output conveyor.
- *Vp*: speed of a moving pusher along *Ld*.
- *Vpp*: speed of a moving pusher to push an item onto an output conveyer.
- *Vs*: speed of a spiral conveyor.
- *ci:* chosen item, (where ci = 1, 2….., n)
- *Tm_ci*: time needed for a pusher to move to a selected (chosen) item *ci*.
- *Tp_ci*: time needed for a pusher to push a selected item *ci* onto an output conveyor from an input conveyor (i.e., a storage rack).
- *Ts_ci*: travel time of a selected item *ci* in a tote along an output conveyor to a spiral conveyor.
- *Tsc_ci*: travel time for a selected item *ci* in a tote to move from the top level to the bottom level of a spiral conveyor.
- *Tse_ci*: travel time of a selected item *ci* from an end of a spiral convey to a collection point.
- *n:*number of chosen items.
- *Ttt_ci*: total travel time of each of selected items from the moment when the pusher is activated to push the selected item to the moment when the selected item arrives at a collection point.
- *Ttt:* least travel time of one of selected items from the moment when the pusher is activated to push the selected item to the moment when the selected item arrives at a collection point.

Illustrated in Fig. 5, assuming an item is located at (m_x, n_y) and a pusher has a random location at $(i,\ j)$ in a storage rack. Thus, a distance L_d between the activated pusher and the selected item is given by:

$$L_d = \sqrt{(m_x - i)^2 + (n_y - j)^2} \tag{1}$$

Therefore, the travel time T_m is given by:

$$T_m = \frac{L_d}{V_P} \tag{2}$$

Where, V_P is a speed of the moving-pusher along L_d. We define T_p is a travel time from the moment when the pusher starts to push a selected item to the moment that the selected item has been pushed onto an output conveyor, it is given by:

$$T_p = \frac{D}{V_{PP}} \tag{3}$$

Where, D is a depth of the storage rack at which the selected item is located. Vpp is a constant speed of the moving-pusher to push the selected item onto the output conveyer. Knowing L_{SC} refers to a distance from the centre of the tote at the end of the conveyor. L_{sb} is a length of a storage room containing each item in a tote, n_x refers to the number of columns in row m_y, V_c is the constant speed of the output conveyor. Thus, T_s is given below:

$$T_s = \frac{L_{sb} \times (n_y - 0.5) + L_{sc}}{V_C} \tag{4}$$

The item travels down through a powered spiral output conveyor from the top level to the bottom level towards a collection point where the item is collected for packing. Thus, T_{sc} is calculated by:

$$T_{sc} = \frac{m_x \times L_{ss}}{V_S} \tag{5}$$

Where, L_{ss} is the length of the single level spiral conveyor. m_x refers to the number of rows in column n_y. As T_{se} is a travel time that the item needs from the end of the spiral conveyor to a collection point. L_{sp} is a travel distance between the end of a spiral conveyor system and a collection point. Therefore, the travel time between the end of a spiral conveyor and a collection point is given by:

$$T_{se} = \frac{L_{SP}}{V_C} \tag{6}$$

Hence, the total travel time T_{tt_ci} for the selected item is obtained by:

$$T_{tt\_ci} = T_{m\_ci} + T_{s\_ci} + T_{sc\_ci} + T_{p\_ci} + T_{se\_ci} \tag{7}$$

Where, ci= (1, 2, ……n). The selected item that needs a minimal travel time T_{tt}, which is identified by the RFID-inventory management system throughout the storage and retrieval system, can be obtained by

$$T_{tt} = \min\ (T_{tt1}, T_{tt2}, \ldots\ldots\ldots\ldots\ldots, T_{tt\_ci}) \tag{8}$$

The longest travel time *Tmax* of the one of selected items to a collection point can be obtained by

$$T_{\max} = \max[\mathrm{T}_{tt\_ci}\ , \mathrm{T}_{tt\_ci+1}\ , \ldots\ldots\ldots, \mathrm{T}_{tt\_ci+n}\ ] \tag{9}$$

After an order for multiple items are made by a customer, the RFID-inventory management system will need to determine which item has a longest travel time and will subsequently issue a priority to this item to be dispatched first. Figure 6 illustrate the multi-directional trajectory of a pusher which travels to a selected item. Assuming that an item has a random location (m_x, n_y) and a pusher is located at the centre $(i_c,\ j_c)$. of a storage rack; this is a default location of the pusher to be activated. The pusher P can move simultaneously in both horizontal and vertical directions from the centre location $(i_c,\ j_c)$ at where the pusher currently stays to a location (m_x, n_y) at where the selected item awaiting to be pushed onto the output conveyor by the pusher mounted in AS/RR. As stated previously, when an order for multiple items is executed, the pusher can only push one item at a time according to the estimated travel time determined by RFID-based inventory management system (illustrated in Figure 11). Therefore, it is desired to determine an overall estimated waiting time for an order that contains multiple items from the moment when a pusher is activated to push the first selected item with a longest travel time to a specified collection point to the moment that the last selected item with the least travel time arrives at the same collection point. With this approach, it gives a minimum waiting time for all the items to meet at the specified point.

The following notations are used.

- *Pc*: a pusher at a centre location (i_c, j_c).
- *V1* : a constant speed of an output conveyor.
- *V2*: a constant speed of a spiral conveyor.
- *1B* : identified items in each row at different columns of an AS/RR.
- *1L* : identified location of each of ordered items in each row at different columns of an AS/RR.
- *Tmax*: longest travel time of the one of the selected items.

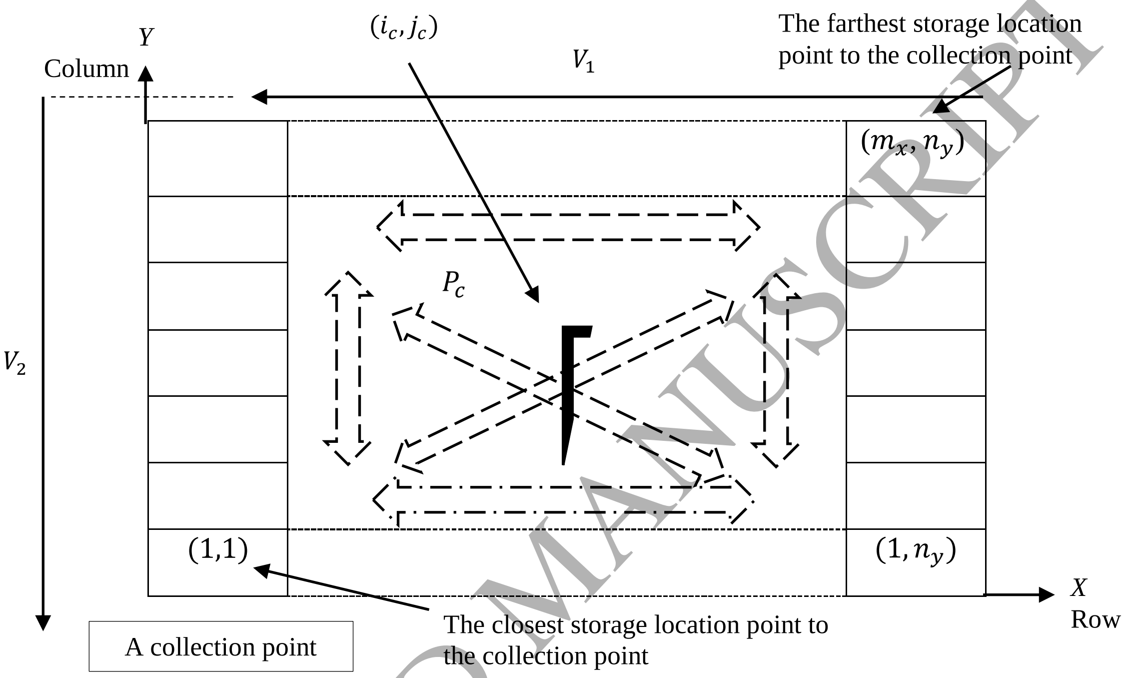


Figure 6: Multi-directional trajectory of a pusher which travels to selected items.

Let B be the set of random locations (m_x, n_y) for each of items in AS/RR.

$$1_B(m_x, n_y) = \begin{cases} 1 & \text{if } (m_x, n_y) \in B \\ 0 & \text{if } (m_x, n_y) \notin B \end{cases} \quad (10)$$

As an example, if $1_B(m_x, n_y) = 1$, it indicates that an ordered item is identified by the RFID-inventory management system, i.e., this ordered item is available at this particular location (m_x, n_y). If $1_B(m_x, n_y) = 0$, it indicates that an item is not ordered. Figure 7 illustrates this process. Assuming that there are multiple items ordered by a customer, the inventory management system will then search and identify a location of each ordered item in an AS/RR. The system will search and identify a location of each ordered item from location $(1, 1)$ to location $(1, n_y)$ in a row across each storage rack of an AS/RR as shown in Figure 6. Figure 7(a) shows the process of searching and identifying locations that contain ordered items from left to right in row 1 of the storage rack. Figure 7(b) shows a number of identified locations containing ordered items in a storage rack by issuing a value 1 for each of the ordered items and a value 0 for a non-ordered item at a location (m_x, n_y). Figure 7(c) shows the final result of selected locations which contain ordered items in this storage rack.

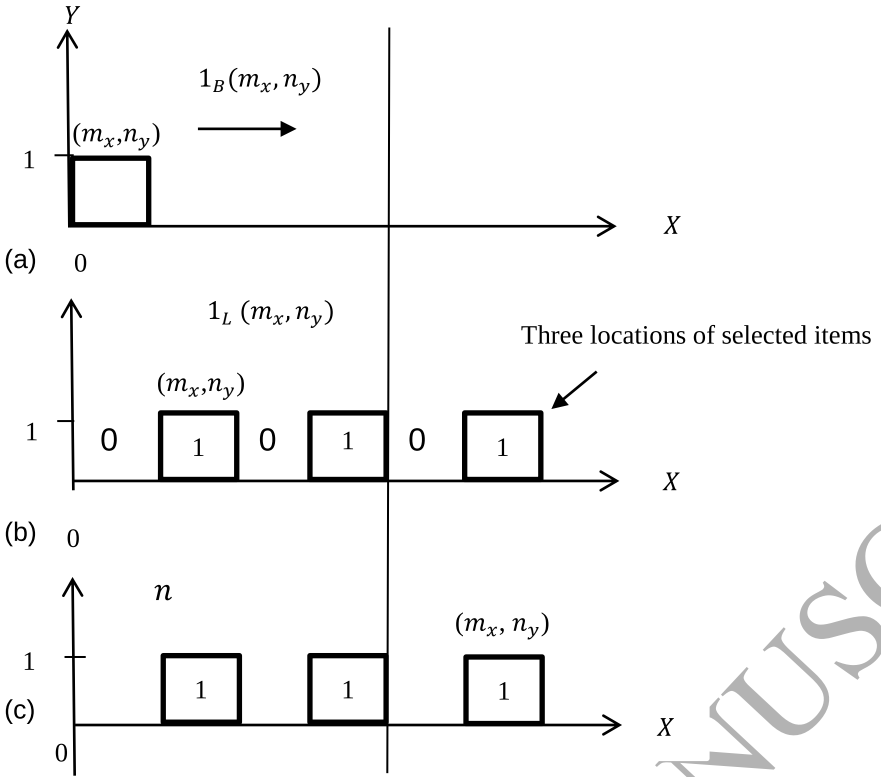


Figure 7**:** Mechanism of searching and selecting an ordered item in a storage rack.

Hence, a total number of ordered items *n* can be obtained by

$$n = 1_{B(m_x, n_y)} \times 1_{L(m_x, n_y)} \qquad (11)$$

Figure 8 illustrates the routing algorithm for a pusher to be given the priority to travel to one of selected items. Let us define *Ttt* which refers to the total travel time needed for a selected item to travel from the moment a pusher is activated to push the ordered item to the moment this item arrives to a specified collection point. Assuming that a number of items *n* are ordered from the warehouse, these items are randomly placed at different location *ci* (where *ci*= 1, 2, …..n) in the AS/RR. The total travel time for each of selected items is denoted by *Ttt_ci*. The RFID-inventory management system calculates an estimated travel time *Ttt_ci* for each of the selected items to a specified collection point in order to determine the item with a longest travel time to be given a priority to be pushed onto the output conveyor by the pusher. The system will then repeat the same process by determining the second item with a longest travel time among the remaining items until the last item with a least travel time to be pushed onto the output conveyor. With this approach, the pusher can also travel through in an optimal route to ensure that all the selected items will arrive and meet at the specified collection point with a minimal waiting time for packers to receive these items.

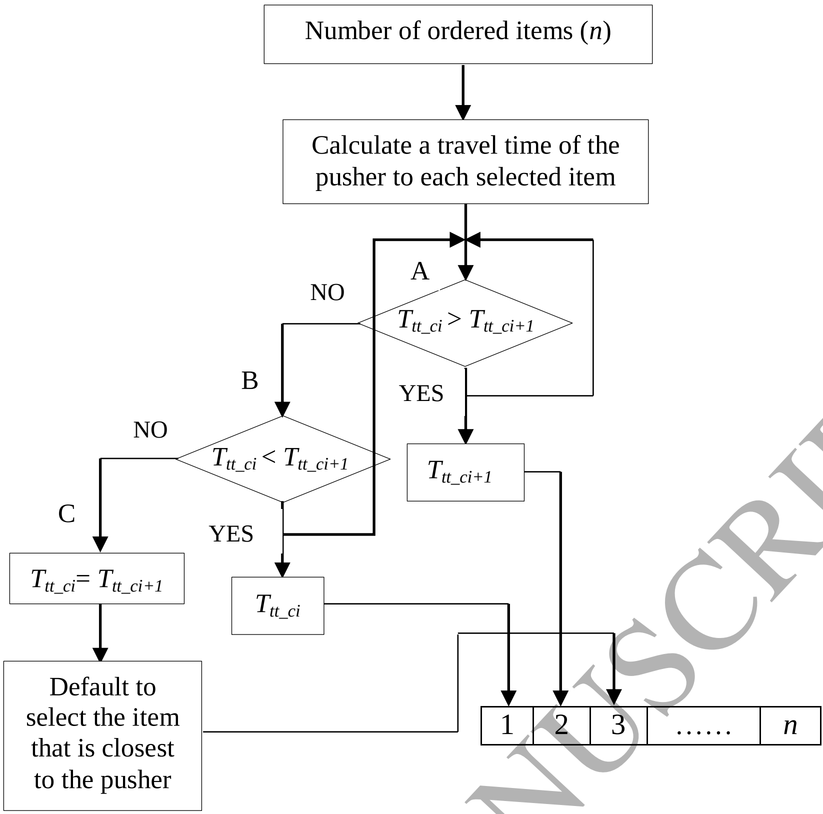


Figure 8: The routing algorithm for a pusher to travel to each of selected items.

5. The RFID-enabled warehouse management system and its integration

The RFID-inventory management system automatically performs an inventory searching process of ordered items by executing a set of pre-defined selection rules, which include an availibilty check of each of ordered items, locations of ordered items, a shortest path for the ordered item traveling to a specified collection point, expiry date of each of ordered items if applicaple and other user-defined selection criteria. Figure 9 illustrates the inventory selection process of ordered items to be dispatched by the warehouse. If an item is selected from a group of the same type of items stored in multiple locations in the warehouse, the RFID-inventory management system will issue a priority based on the pre-defined selection rules to be given to a selected item and initialise a demand to push the selected item onto the output convyeor as illustrated in Figure 2. To schedule a job priority for the selected item to be dispatched from the warehousing system, an algorithm was developed to seek an optimal solution for selecting an item which has a priority over other items of the same type. Table 1 shows part of the programming codes which demonstrates the data process of ordered items using the developed algorithm.

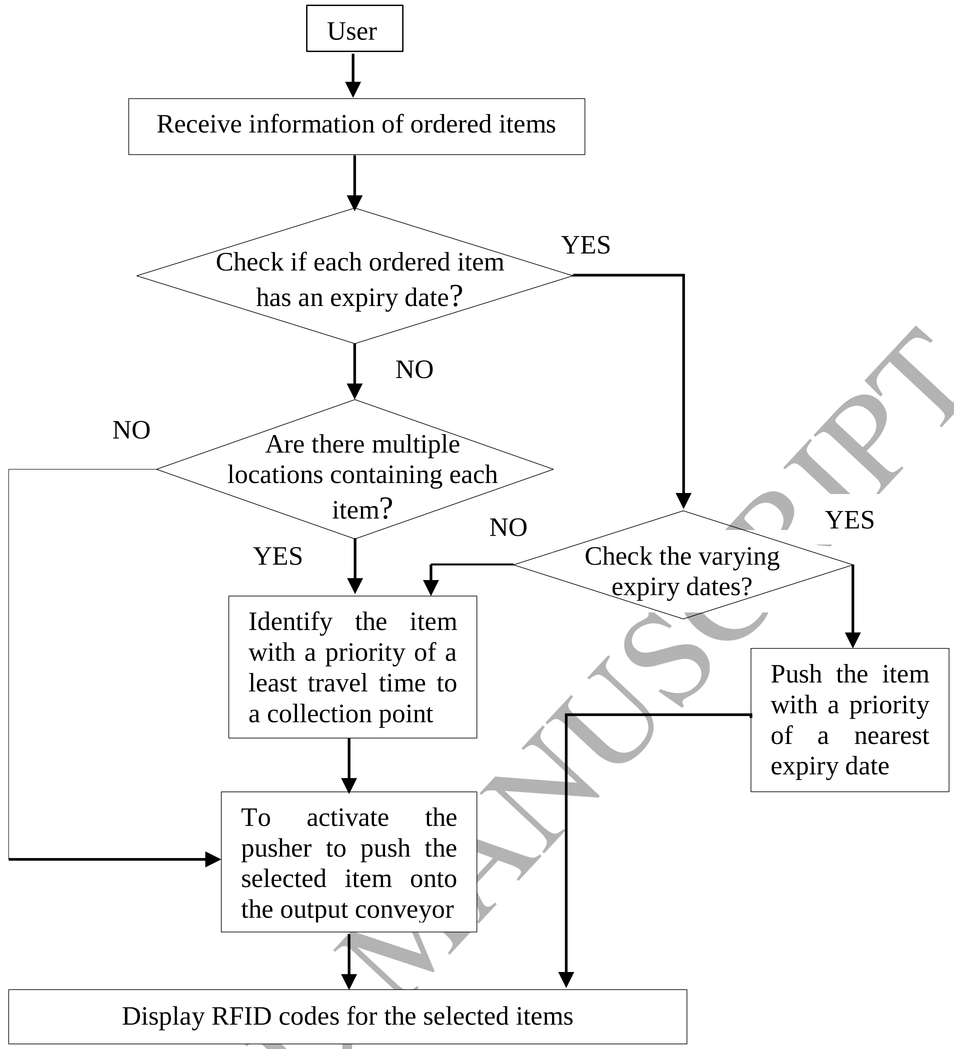


Figure 9: The inventory selection algorithm for ordered items to be selected and dispatched from the warehouse.

Table 1 Part of MATLAB programming codes showing data processing on the developed algorithm.

```
================================================================================
Data Processing
disp('Please Input The Name of Ordered Item!')
OrderedItem='Milk      '; % Change the name of ordered item.
Find and save the location information which contains the ordered item
No=0; % Starting number of ordered item
Location=[]; % For storing the location information of ordered item
Calculate the computation time
           Tm=sqrt((PP(1)*Hf-Location1(1)*Hf)^2+(PP(2)*L-
Location1(2)*L)^2)/Vp;
           Tp=D/Vpp;
           Ts=((Location1(2)-0.5)*L+Lsc)/Vc;
           Ti=(rack-Location1(1))*Lss/Vs;
           Te=Lsp/Vc;
           Tt=Tm+Tp+Ts+Ti+Te;
```

Figure 10 shows key components for a pilot test of the RFID inventory management system, which has a capability of interacting with the mechanical control system of the proposed RFID-embedded automated storage and retrieval rack (AS/RR). The system hardware includes a host computer, an ultra-high frequency (UHF) Impinj RFID reader, an Impinj far-field antenna, and a number of passive tags. The RFID reader is attached with the antenna in a range of 902~928 MHz (using the EPC global Gen2 ISO18000-6C standard) in a direction of 70° to capture data transmitted from the passive RFID tags and these gathered data are stored in a laptop for data processing [17]. The RFID-based inventory management system was developed under the Imping Octane SDK, which is a package for configuring settings of the RFID reader using a Low Level Reader Protocol (LLRP). LLRP offers a high-level control in reader settings, tag query and tag-writing operations. The RFID reader API (application program interface) package provides a common programming interface to allow an interaction between the RFID hardware and the RFID application software hosted in an MVS (Microsoft Visual Studio) environment. The software also defines a high-level object-oriented interface that permits the communication with the RFID reader.

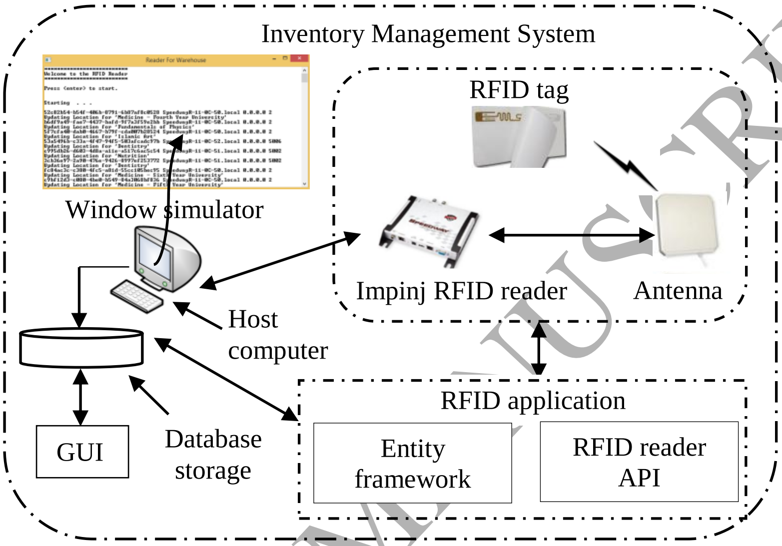


Figure 10: Key components of the RFID inventory management system for a pilot test.

The MVS supports a NuGet which is an open source package manager providing a number of application tools including the entity framework, which is an object relational mapping (ORM) mechanism. Within the ORM mechanism, it can create classes based on database tables in which each entity framework allows a web application to communicate with the database. The inventory management system contains a transaction database using the Microsoft SQL server. The database can automatically update an existing location of an RFID-tracked item at any time when a change of it takes place. As an example, when an RFID event (e.g. a reader reads an RFID tag) occurs, the database automatically updates the record of the collected information relating to this event. The inventory management system then runs the associated program using the selection algorithm to determine the updated location of an RFID-tracked item in the warehousing system and the location of this item can be displayed in the GUI (graphical user interface) as shown in Figure 11. The GUI was developed in MATLAB and it allows for visualizing changing locations of any possibly selected item in the warehousing system. MATLAB toolbox supports communications using the open database connectivity (ODBC) that can link with any compatible database such as Microsoft SQL. An ODBC is a middleware application program interface that allows an access of the management system database. Table 2 shows a list of records of searched items which contain RFID-inventory information within the SQL database. The GUI also allows a matrix manipulation of item locations and it can interface with other programs written in different languages such as C, C++, C#, Java etc. For instance, a user can search an ordered item in the GUI by clicking on the Search button and entering the item's name (.e.g. ''Milk''). The GUI office will then indicate where the item is located in the map of storage racks. Once the item is identified, information of this item can also be found by clicking on the Display button with the displayed information including the identity of the ordered item, the state of the ordered item (e.g., milk expiry date), the location of the ordered item (rows and columns of storage racks), the number of the ordered items available and the nearest item of the same type to a collection point.

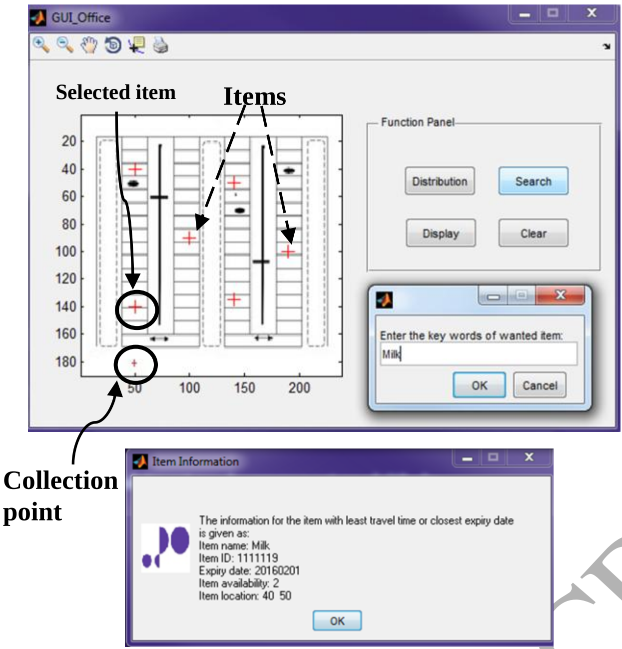


Figure 11: Display of an optimal location of one of a selected item in the GUI.

Table 2: Part of information data within the SQL server.

Items	Item location	Expiry date	RFID Tag id	Label number
'Milk'	(40, 50)	'20160201'	'3008-33B2-DDD9-0140-0000-0001'	1111119
'Milk'	(50,30)	'20160222'	'3008-33B2-DDD9-0140-0000-0000'	1111118
'CD'	(90,60)	'00000000'	'3008-33B2-DDD9-0140-0000-0002'	1111120
'Mobile'	(80,20)	'00000000'	'3008-33B2-DDD9-0140-0000-0003'	1111121
'Bread'	(70,10)	'20160203'	'3008-33B2-DDD9-0140-0000-0004'	1111122

6. MATLAB simulation results

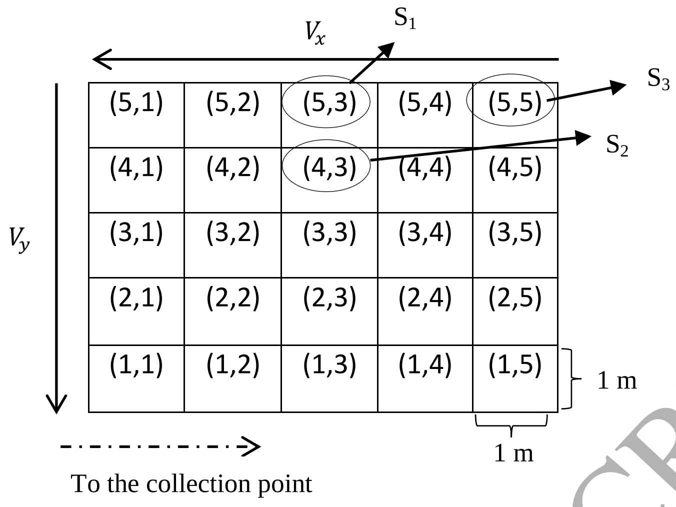
A MATLAB programming model of the integrated inventory system was developed based on simulation study by Lee et al, that the travel speed of V_x is 210mm/s and the same travel speed was assumed for V_y as shown in Table 3, which explains the determination of an item with a longest travel time in an AS/RR [18]. Assuming there are three items which are located in storages namely S_1 (5, 3), S_2 (4, 3) and S_3 (5, 5), respectively. Let us V_x refer to a speed of an output conveyor and V_y refer to a speed of a spiral conveyor. As stated previously, a standby pusher has a default location at the centre (3, 3) of the AS/RR. Assuming each grid, which represents a standard storage space of the AS/RR, has coordinating dimensions in height and width of 1 x 1 meter.

To calculate the total travel time T_{tt_ci} for each selected item is obtained by:

$$T_{tt\_ci} = T_h + T_v = \frac{Number\ of\ Rows}{V_x} + \frac{Number\ of\ Coloumns}{V_y}$$

Where T_h and T_v refer to the horizontal and vertical travel time of a selected item, respectively.

Table 3: The determination of an item with a longest travel time in an AS/RR to the collection point.



$$T_{tt\_ci}(S_1) = \frac{5 * 1000}{210} + \frac{3 * 1000}{210} = 38.09\ sec$$

$$T_{tt\_ci}(S_2) = \frac{4 * 1000}{210} + \frac{3 * 1000}{210} = 33.32\ sec$$

$$T_{tt\_ci}(S_3) = \frac{5 * 1000}{210} + \frac{5 * 1000}{210} = 47.6\ sec$$

Based on these calculated results, the RFID-inventory management system can determine the optimal route for the pusher to travel to select an item in a sequence as shown in Figure 12.

Figure 12 shows the MATLAB simulation result which determines an item with a longest travel time from the selected items to be pushed in a sequence onto the output conveyor by a pusher from an AS/RR, i.e., the item with a longest travel time is given a priority to be pushed by the pusher to travel to a specified collection point until the last selected items with the least travel time arrives to the same destination. This allows a minimum waiting time for packers to receive all the selected items at the collection point. As shown in Figure 12 as an example, the result indicates that the selected item at S_3 (5, 5) has a longest travel time of 47.6 seconds and this item should be given the highest priority to be pushed onto an output conveyor travelling to the specified collection point. The selected item at S_2 (4, 3), however, has a least travel time of 33.32 seconds and this item (i.e., the last remaining item shown in Figure 12) should be given the least priority to be pushed onto an output conveyor travelling to the specified collection point. The selected item at S_1 (5, 3) has a travel time of 38.09 seconds and therefore it should be the second item to be pushed onto an output conveyor towards the same destination. However, if there are two ordered items which have the same travel time, the RFID-based management system will be set as a default to select the ordered item that is close to the pusher. The result was generated by the RFID-inventory management system according to the pre-defined selection rules and the system subsequently issues a priority to be given to the selected item. The mechanical control system then initialise a demand to push the selected item onto an output conveyor and this item will be transported along the RFID-guided route to the collection point.

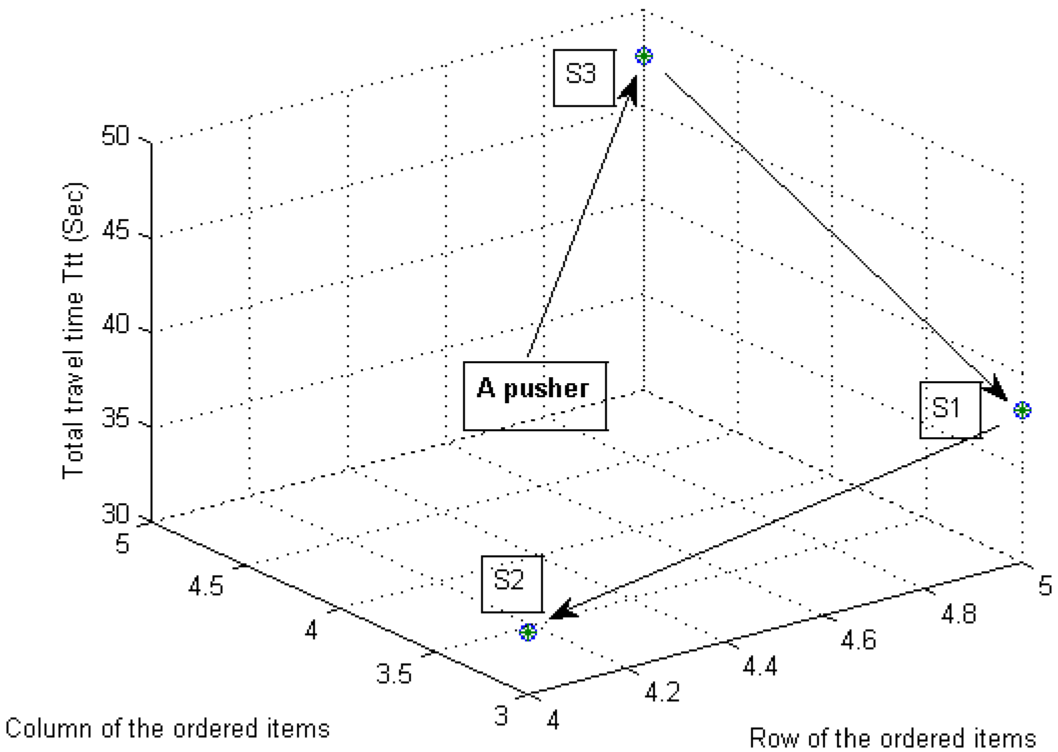


Figure 12: Determination of a longest travel time among ordered items.

Figure 13 shows the accumulating results of travel times for each selected item which travels through the five different sections along the RFID-guided route from the moment when the pusher is activated to the moment these selected items arrive at a collection point. It shows the travel time T_{ij} in minutes between the activated pusher *i* and the selected item *j*. T_{jk} refers to a travel time from the moment when the pusher *i* starts to push a selected item *j* to the moment that the selected item *j* is pushed onto an output conveyor *k*. T_{kl} refers to a travel time of a selected item *j* which travels at a constant speed along an output conveyor *k* to the entrance point of a spiral conveyor *l*. T_{lm} refers the travel time from the top level *l* to the bottom level *m* through a powered spiral output conveyor. Finally, T_{mn} refers to the travel time between the end of the spiral conveyor *m* and the collection point *n*. As shown Figure 13, item 3 has the longest travel time T_{ij} of 15.6 seconds, whereas item 2 has the least travel time of 3.23 seconds as the default location of the pusher is closer to item 2. All the selected items have the same travel time T_{jk} as the storage space for each item has a standard height and width of 1 x 1 meter. Either of items 2 or 3 has the same travel time T_{kl} of 12 seconds because these items are located at the same column in the AS/RR. Overall, item 3 has the longest accumulative travel time of 47.6 seconds and item 2 has the least travel time of 33.32 seconds. Thus, the developed programing model of the RFID-enabled inventory management system can generate the priority list of selected items to travel in a sequence from the first item with a longest travel time to the last item with a least travel time, accordingly.

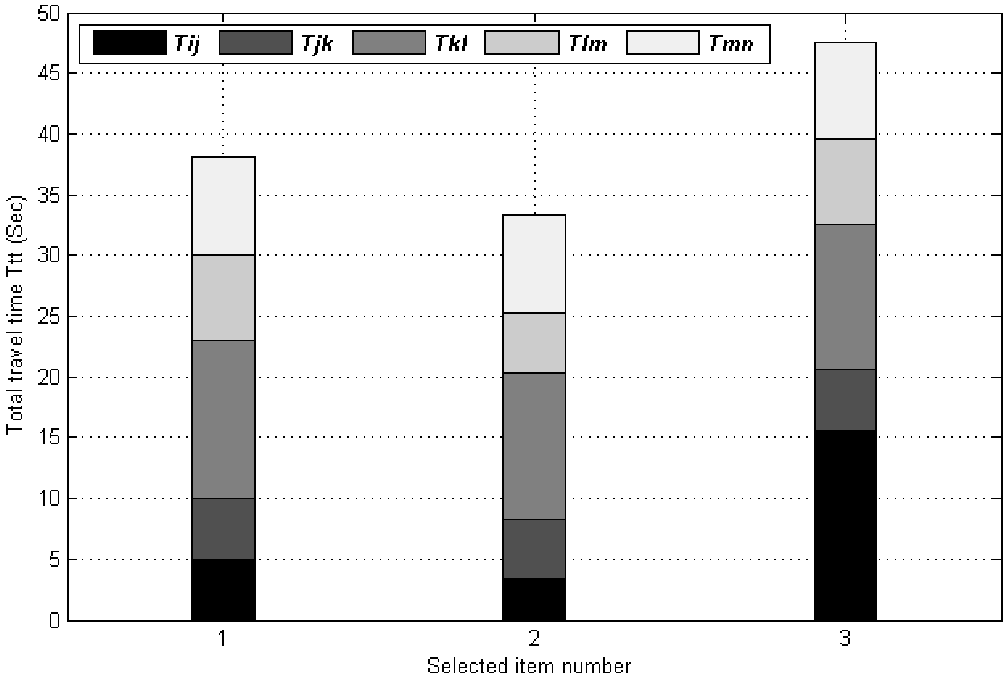


Figure 13: The results of selected items with accumulating travel times.

7. Conclusions and discussions

In supply chains and logistics sectors, accuracy of inventory data is essential as these information data can be crucial for warehouse operations, SKU planning, management and control of incoming and outgoing goods. This paper presents a research work aimed at examining the developed methodology through which the RFID-enabled inventory management system can perform an automatic availability check and update information data of ordered items from the warehouse database. Simultaneously, the RFID-embedded mechanism of the AS/RR can automatically dispatch these items from the warehouse without any human operation. Within the RFID-inventory management system, a selection algorithm was developed to seek an optimal solution to determine a selected item with a longest travel time to be given a priority over other selected items. This includes a transaction database which allows a manipulation of RFID-tracked items under pre-defined rules by assigning a priority to one of selected items. A pilot test was carried out to examine the developed algorithm applied into the RFID-based management system which, in theory, has a capability of interacting with the mechanical control system of the RFID-embedded AS/RR. To synchronize these systems to act coordinately, both the warehouse RFID-inventory management system and the warehouse control system of the AS/RR need to be integrated through a developed interface which allows an effective communication between these two systems. The further study is needed. For instance, the pilot test was executed based on a limited number of tagged items. In a real warehouse, there are massive numbers of RFID-tagged items which need to be tracked and processed in a real time manner through the integrated information systems. Within such a large scale environment, RFID signal-overlapping and collision can cause a serious problem to synchronize the operations of the entire automated warehouse. Moreover, it is highly desirable for the future work to seek and use a computer-based modelling simulation tool as an aid for alternative system designing strategies of the proposed RFID-enabled warehouse system.

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