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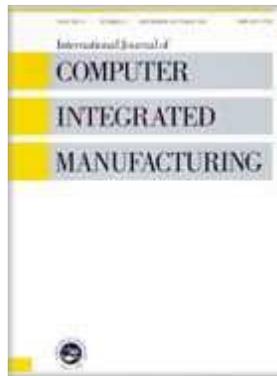
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## A new generation automated warehousing capability

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### ABSTRACT

A novel and highly adaptable concept is presented whereby automated warehouses can be built based on a series of simple modules with their inherent feature of scalability and reconfigurability. A potential application example of such a warehousing system is modelled to indicate the level of capability that the concept can provide. Physical infrastructure and operational control events within the system are illustrated in the paper. Simulation results demonstrate that this type of automated warehousing system can simultaneously deliver large numbers of items from storage modules to assigned collection locations with minimal delay. The concept is readily applicable within the wider logistics sector. The system performance can be enhanced by deploying an integrated warehouse control and management mechanism using automatic identification and data capture techniques and wireless communication networks. A framework on application of these emerging technologies in order to achieve the desired coordinated functionality of automated warehouse operations is proposed in the paper.

**Keywords:** warehouses; logistics; automation; supply chains; RFIDs; wireless networks

### 1. Introduction

The logistics industry is the fifth largest sector in the UK economy; it has over 20 million square metre of storage space employing 2.3 million people and turning over £75 billion a year. The trend of UK logistics warehouses is reported towards even larger and more centralised systems on which automation is heavily invested in recent years (Jordan-Smith 2008, Kator 2008, Maropoulos et al. 2008). This is partially because of the disadvantage of manual operation resulting in the slow storage and retrieval speed, the high labour cost, and the frequency of errors (Chang et al. 2007). Meanwhile, the growing trend for online shopping is likely to gain even greater prominence everyday. Customers prefer the lower prices that can be found online and are also demanding faster delivery. Thus, retailers require more efficient distribution centres in which improved performances of warehousing systems through automation are increasingly desirable for these companies.

In general, warehouse automation has received relatively little research attention (Baker and Halim 2007). The concept of existing automated warehouses is often referred to as usage of one or more expensive and sophisticated equipment. These equipments, which are often operated manually, may include such as palletising robots, carton flow order picking systems, automated guided vehicles (AGVs), rotary storage cabinets, and automated storage and retrieval systems (AS/RSs). One of the biggest challenges in these warehouses is to optimise manual and automatic processes in order to improve the flow of materials between storage areas and distribution centres. Integrating individuals as human actors into automation solutions is not straightforward due to unpredictable human behaviour (Preuveneers and Berbers 2009). On the other hand, early warehouses gave little consideration to space efficiency, order picking methods or material handling (Ashayeri and Gelderes 1985). Today, tighter inventory control, shorter response time and greater variety of SKUs (stock keeping units) are most important challenges for designing modern warehouses. Although these challenges can be prompted in part by

adoption of a number of management philosophies such as just-in-time or 'lean' methods as the warehouse inventory policy, the implementation of IT capabilities has demonstrated the potential for greater improvement opportunities (Gu et al. 2007). These IT capabilities can be implemented by using smart-labels such as barcodes, radio frequency identification (RFID) tags and automatic identification (Auto-ID) sensors, together with cable and/or wireless communication networks and integrated warehouse management systems (iWMS). A barcode, however, accommodates only a small amount of data typically containing information of such as a manufacturer and a product type. It needs to be scanned individually and read closely with a barcode-scanner or sensor. The barcode-reading process has been widely recognised as a time-consuming task which often involves a great deal of human intervention. In contrast, the utilisation of RFID-related technologies has increasingly become popular for the last few years and this emerging technology has generated enormous amount of interests. At present, the main effected areas using RFID technologies are highway surveillance systems, access cards, transport payments, RFID passports and product tracking systems (Berenyi and Charaf 2008). In recent years, more attention and efforts have been made in manufacturing and logistics sectors focusing on RFID-applications in inventory control and management. With a RFID-based system, inventory can be tracked more accurately in a simple, timely and more efficient manner leading to a significant reduction of processing time and labour. More importantly, the complete visibility of accurate inventory data, from manufacturer's shop floors, warehouses to retail stores, brings opportunities for improvement and transformation in various processes of the entire supply chain (Lee et al. 2004). A RFID tag can store several thousand digits and can be read in a long-distant recognition using radio frequencies via wireless communication networks. It is possible to automatically read hundreds of tags per second. In a warehouse, each item attached with a RFID tag can be traced, sorted, inventoried, routed, picked and distributed from anywhere throughout the system. For example, a RFID tag can signal an in-store item with its presence, unique identity, storage location (row, rack, section and shelf) and other user-defined

information such as product details. Conventional warehouse management systems (WMSs) have been developed for monitoring and handling warehouse resources and operations. These systems, however, rely heavily on warehouse staff to enter and update daily information of such as inventory levels and locations of stock keeping units (SKUs) through a barcode-based system. Furthermore, an iWMS can be built by combining any of these smart label-reading technologies with appropriate software and operating systems (Connolly 2008); this system should have capability to indentify, store, track and control all incoming and outgoing goods of a warehouse. The iWMS can also be interfaced with enterprise resource planning (ERP) systems in order to support up-to-date data information for supply chain planning and decision-making on a global basis.

Currently, there is no such an automated warehousing system which is reported to exist through a literature review. Chow et al. (2005) proposed a RFID-based resource management system for warehouse operations in a time-saving and cost-effective approach. Lian et al. (2007) introduced a practical design and implementation of a warehouse control and management system by looking into its hardware and software using current RFID techniques. Huang et al. (2008) developed a framework by monitoring real-time WIP (work-in-progress) inventories in a shop-floor environment through a RFID-based wireless network. Ramudhin et al. (2008) described a generic framework to be used in design of an RFID-based tracking and control system based in an aircraft engine manufacturer. Moreover, data flow and exchange via a wireless network should be integrated into an information system. Poon et al. (2009) tested both active and passive RFID apparatuses covering different ranges of readers at varying locations for a RFID-based logistics resource management system (R-LRMS). Berenyi and Charaf (2008) examined how relevant information can be retrieved using data mining methods from collected RFID-related data. Martinez-Sala et al. (2009) presented architecture of an information system designed for a grocery supply chain using RFID-tagged packaging and transport units. The architecture consists

of three different frameworks; these are RFID framework, middleware framework and control and customer framework. The RFID framework may include active or passive RFID devices and their software. The middleware framework may comprise databases, application servers and middleware software. The control and customer framework may consist of hardware and software for management and control applications, customer applications and customer ERP systems. Gan et al. (2006) developed a discrete event simulation model of RFID networks for examining the data traffic in varying load conditions in order to maximise timeliness of information and minimise loss of data. Overall, it is their opinion that such intelligent systems will be the way of the future. The benefits and problems in various RFID-applications were summarised and discussed in a latest review by Huang et al. (2009). The RFID-based applications, however, have been mostly used as a means of establishing the history of the end-product, rather than as a mechanism to support the automation of customizable production (Brusey and McFarlane 2009). By mirroring the logistics landscape as a whole, automation itself also faces significant issues of both cost and operational performance. Nevertheless, whether it is a logistics hub or retail supermarket, there is always considerable potential to reduce the handling inefficiencies by replacing manual tasks with automation.

This paper investigates the potential applicability and configuration of a future generation automated warehouse concept. It describes the physical structure and operational mechanism of a reconfigurable automated system consisting of simple modules with application of the RFID-based control and management system. The mechanical system concept discussed in this paper was originated by van Esschoten and McIntosh and was described in a Dutch trade magazine (te Lindert 2007). Much work has been done to validate the early capability claimed by the conceptual design; this includes the design of modular storage, retrieval and replenishment mechanisms which can operate simultaneously. With this novel designed system, items can be stored randomly at varying locations, i.e., the same type of item may have multiple locations. A

case study in its application has been evaluated and its financial viability is being investigated. For the purposes of this paper only the concept is mainly discussed.

## 2. A novel conceptual design for a modular automated warehouse

The core element of the automated warehouse is the storage module illustrated in Figure 1. The module comprises two types of powered conveyors aligned next to one another; these are storage conveyors and output conveyors. The entire operation of each type of conveyor is controlled by a PLC (programmable logic controller) that communicates with mounted sensors via a local area network (LAN). Items are pre-loaded onto pallets named totes; totes need not be of identical sizes. If a tote contains different types of items, each item is attached with a RFID tag to indicate its identification only for this item. If a tote contains the same type of items, each item is matched to a unique identifier of that tote with an RFID tag; the item is thereafter tracked and manipulated throughout the system within the tote. Two types of RFID tags (using active and passive RFID readers) are selected based on criteria of their reading performance tests at different locations and their costs throughout the system.

**Fig. 1.**

An item enters storage in a tote onto the end of a storage conveyor row. When a specific item is demanded from store it will be transferred onto the output conveyor from the storage conveyor by a pusher device (tote pusher). The space previously occupied by the tote is then filled with all succeeding totes moving forward along the storage row; an item's position on a storage row is therefore not fixed in time. Readers mounted on the push-arm identify the tote as required by reading RFID tags via a wireless local area network (IEEE802.11). These data captured by RFID devices contain information of types, quantities and locations of SKUs in store; and inventory

levels in each rack indicating the availability of space for incoming products. The collected RFID data are stored in a centralised database. Position knowledge of all totes on all storage levels is acknowledged and updated each time a pusher arm traverses a module via a RFID-inventory system shown in Figure 2. The arm's position travelling along the storage row is determined and activated by a modular controller, which receives instructions for mechanical operations from the warehouse control system via the LAN. The control system also maintains up-to-date information of such as what in-store items are and where these items are located in one or more modules of the entire warehouse via the RFID-inventory system.

**Fig. 2.**

Figure 3 schematically illustrates the overall design of a distribution system modelled by the authors. It consists of a series of individual modules in which all levels of output conveyors are interconnected to equal levels of a looped and cross-linked conveyor system, which also includes output spiral conveyors with collection points. These conveyors, which also act as delivery paths as well as buffers, form the output zone of the warehousing system. An independent replenishment zone (the delivery conveyor system shown in the Figure) is not discussed in this paper. Selected items are sequenced and routed by a RFID-guided system along the delivery path and they subsequently arrive at an assigned pick location for re-packing. The multiplicity of parallel routes ensures that substantive congestion problems should not arise.

**Fig. 3.**

Notably through its modular design, the warehouse can be adapted according to specific customer needs. Each module is designed as a standardised element for manufacturing, although single modules can be of different size and arrays in a module can be configured in many

different ways. The capacity of an overall warehouse can be changed easily by either adding or removing modules to accommodate the changing environment and demand from customers and retailers. The RFID-based control system permits large numbers of parallel events to occur at any given time throughout the warehouse. By using RFID tags, SKUs can be distributed randomly at varying locations wherever a place is available for incoming goods as shown in Figure 4. A chosen SKU can be released by the system based on for example 'being nearest to a collection point and/or a modular arm which is free or adjacent to the chosen SKU. Overall, this will significantly increase the capability, flexibility and responsiveness for the warehousing system to dispatch items.

**Fig. 4.**

Intelligent control software is needed to realise the potential offered by this design. Input variables in the control software can be classified into three broad categories, namely application parameters, hardware parameters and software parameters. Application parameters may include such as numbers of different SKUs handled by the system, the storage information of each SKU, the number of items per request, the number of requests per time unit, and the number of concurrent users etc. Hardware-related parameters may include factors such as the height and depth of each rack, the number of racks per aisle etc. Software parameters may cover scheduling and optimisation algorithms used for job priorities to assign or dispatch items to/from arrays of each individual storage modular element. For achieving this, a material-handing solution should be constructed based on optimal algorithms in order to generate the shortest pick-up sequence and route for the material-handing equipment; this will maximise the efficiency and minimise the total material-handing cost in the warehouse.

### **3. Modelling a novel distribution system capability**

The designed warehouse shown in Figure 3 can be modelled as a discrete event system in which the system's behaviour is stochastic rather than deterministic as a customer order arrives randomly with a random order size each time. Computer simulation was used to provide an aid for evaluating alternative designs by observing a visual insight of material flows, work-in-process levels and possible bottlenecks which may incur in the designed system. The simulation model was also used to observe dynamic changes of system performance by altering a number of system variables. These variables include numbers of collection points, different configurations of spiral conveyors shown in Figure 5, varying SKU levels, different loading/unloading tote sequencing algorithms and varying speeds of conveyors. Several issues were considered when modelling the warehousing system.

- Determining the resources and their characteristics that mostly affect the system performance;
- Formulating a description that represents these resources and their relationships;
- Determining the performance measures of interest under given scenarios.

To simplify the simulation, it was assumed that the picking system of item supply and the replenishment system occur independently. The simulation results do not include the effect of the picking and replenishment systems in this case study. The modelling and simulation process was divided into three steps:

- System model development;
- Experimental frame development;
- Data analysis.

The system model describes the physical elements and their logical interrelationship by placing and interconnecting a thread of simulation modules with specific rules to form a model of the system from its engineering description. The experimental frame defines the experimental conditions, including the analyst's specification, under which the model is run to generate specific output data. The experimental conditions were specified externally through a developed platform of user-friendly MS Excel worksheets, which interact with the developed simulation model using Witness. Once the system model and the experimental frame have been defined, they can be linked and executed by Witness to generate output data files, which can be automatically exported to be displayed on external MS Excel worksheets in the form of both statistical data records and plots for analysis.

**Fig. 5.**

Table 1 shows a study on the impact of system performance by comparing simulation results based on the alternative designs using three major variables. These variables are two different conveyor speeds (0.4m/s and 0.6ms), two different sequencing algorithms: nearest-neighbour (NN) and shortest-leg (SL), and three different types of output spiral conveyors (Type A, B and C). One of key design tasks in achieving a better system performance is to reduce the waiting time of all items per order delivered from the first arrival of an item(s) to the last arrival of an item(s) at a pick location. As indicated in Table 1, the system, which is set at the same conveyor speed and the same sequencing algorithm, will have the longest waiting time using Type A spiral conveyor and the shortest waiting time using Type C spiral conveyor. With the design using the SL sequencing algorithm, the system will have a shorter waiting time compared to the design using the NN sequencing algorithm at the same conveyor speed. By increasing the overall conveyor speed, the waiting time can be significantly reduced; this is a particular case with the design using the SL sequencing algorithm and Type C spiral conveyor.

**Table 1**

The comparison can be further illustrated in Figure 6a, 6b, 6c and 6d respectively. Each figure shows the distribution of arrival times as a function of the varying number of items per order delivered from the first arrival to the last arrival at an assigned pick location for a specified customer. The system parameters for each testing scenario are shown in Table 1. It can be seen in Figure 6a that the arrival time is widely distributed in a range between 30 seconds and 240 seconds through test 7 using Type A spiral conveyor. The gap between the first arrival time and the last arrival time can be narrowed through test 8 using Type B spiral conveyor shown in Figure 6b; and this gap can be further narrowed through Test 9 using Type C spiral conveyor shown in Figure 6c. By jointly studying all the tests, the best result was obtained from test 12 shown in Figure 6d, it indicates that the arrival time is normally distributed approximately between 20 seconds and 90 seconds, in which about 95 % arrival times take place between 30 seconds and 80 seconds for each customer to collect all the items.

**Fig. 6.**

#### **4. Discussion and conclusions**

This paper draws a framework of designing a new generation warehouse that is expected to cope with the increasing challenges in logistics in future. The simulation model and results were used to illustrate the level of capability that the conceptual system may offer. A case study investigation with a major UK mail order company has indicated potential advantages in staffing levels, response rates and volume throughput capability. This capability can be enhanced by implementing a number of emerging technologies such as RFID tags and wireless

communication networks on its existing automated distribution centres. A mechanism by integrating these IT technologies into the proposed warehousing system is presented in this paper.

The new design has shown advantages by being more compact, requiring greatly reduced numbers of staff and yet outperforming the design of the existing warehouse at the company. Despite these potential improvements, the research to date suggests that the application of bar-coding systems will not be replaced by RFID systems overnight. The widespread adoption of using RFID-based systems hinges on a significant drop in costs and development of standards for RFID-related products and communication networks (Jun et al. 2009, Cao et al. 2009). A costing study of a modular automated warehousing system to replace a conventional automated warehousing system at the mail order company has also been researched. The design developed during this exercise was estimated to be approximately 15% more expensive to build and install the new system.

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