Computers & Industrial Engineering 66 (2013) 696–709

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Static and dynamic policies with RFID for the scheduling of retrieval and storage warehouse operations ☆

Francisco Ballestín [a,*], Ángeles Pérez [a], Pilar Lino [a], Sacramento Quintanilla [a], Vicente Valls [b]

[a] Dpto. de Matemáticas para la Economía y la Empresa, Facultad de Economía, Universitat de València, Avda Naranjos s/n, 46021 Valencia, Spain
[b] Dpto. de Estadística e Investigación Operativa, Facultad de Matemáticas, Universitat de València, C/Dr. Moliner, 50, 46100 Burjasot, Spain

ARTICLE INFO

Article history:
Received 11 February 2013
Received in revised form 20 September 2013
Accepted 22 September 2013
Available online 29 September 2013

Keywords:
Warehouse operations management
RFID technology
Order management policies
Simulation

ABSTRACT

Warehouses are essential components of logistics and supply chains. The performance of warehouse operations significantly affects the efficiency of the whole chain it belongs to. Radio frequency identification (RFID) is an emerging technology capable of providing real-time information about the location and properties of tagged object(s), such as people, equipment or products. The objective of this article is threefold, to propose and compare different offline and online policies for the scheduling of warehouse operations, to design a tool that allows the decision maker to compare policies and environments without putting them into practice, and to study the benefits that can be obtained if RFID is used in a particular type of warehouse. To this end, we have developed a stylised model that captures and generalises the main characteristics of the structure, routing and sequencing operations of a given real warehouse. The model incorporates several realistic features never or rarely discussed in the literature in the presence of RFID, for example, due dates in the orders that have to be performed and congestion in the warehouse due to the presence of multiple vehicles performing the orders. We have also developed a set of heuristic routing and sequencing procedures that take and, alternatively, do not take into account real time information, and compare their performance via simulation on a set of randomly generated, although realistic, warehouse scenarios. Computational results show the effect in terms of due data fulfilment and tardiness minimisation if the RFID technology is installed and offline and online management policies are considered.

1. Introduction

In the supply chain, a warehouse is an essential component for linking 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 operational costs of a warehouse, but also the whole supply chain. Therefore, it is necessary to enhance the productivity and reduce the operational costs of the warehouse.

Warehouse management systems (WMSs) have been developed for handling warehouse resources and monitoring warehouse operations in order to increase their efficiency and effectiveness. However, most often the current WMSs have been designed for conventional material-tracking systems and are incapable of providing timely and accurate warehouse operation information because they contain no feature of real-time and automatic data retrieval. It is difficult to update daily operations of inventory levels, locations of forklifts and stock keeping units (SKUs) in real-time with systems that rely heavily on warehouse staff members to input operational information manually or through bar-code systems.

Radio frequency identification (RFID) is an emerging technology that is increasingly being used in business and industry (Ngai, Moon, Riggins, and Yi (2008) and Liao, Lin, and Liao (2011)); particularly in logistics and supply chain management (see for example Wang, Chen, and Xie (2010), Chow, Choy, Lee, and Lau (2006), García, Chang, and Valverde (2006), Chow, Choy, and Lee (2007) and Poon et al. (2009) and the literature reviews of Visich, Li, Khumawala, and Reyes (2009) and Sarac, Absia, and Dauzère-Pérès (2010)). RFID is intended to replace traditional barcodes in many ways. Its wireless tracking nature allows a reader to activate a transponder on a radio frequency tag attached to, or embedded in an item, allowing the reader to remotely read and/or write data on the RFID tag. With both identification and tracking characteristics, RFID may dramatically change an organisation's capability to obtain real-time information about the location and properties of tagged object(s), such as people, equipment or products. Real-time

☆ The manuscript was handled by the Area Editor Manoj Tiwari, Ph.D.

* Corresponding author. Tel.: +34 963828396; fax: +34 961625448.
E-mail addresses: francisco.ballestin@uv.es (F. Ballestín), angeles.perez@uv.es (Á. Pérez), pilar.lino@uv.es (P. Lino), maria.quintanilla@uv.es (S. Quintanilla), vicente.valls@uv.es (V. Valls).

0360-8352/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.cie.2013.09.020

information can be obtained without RFID, but using this technology facilitates obtaining it. As stated in Lim, Bahr, and Leung (in press), "interest in RFID in warehousing is rather stagnant and relatively small in comparison to other research domains". According to this review, neither due dates nor congestion, both key concepts in our paper, have been studied in the context of RFID.

For warehouses that keep inventories, the basic warehouse operations are to receive Stock Keeping Units (SKUs) from suppliers, store the SKUs in storage locations, receive orders from customers, retrieve SKUs from storage locations, assemble them for shipment and ship the completed orders to customers (surveys can be found at De Koster, Le-Duc, & Roodbergen, 2007; Gu, Goetschalckx, & McGinnis, 2007; Gu, Goetschalckx, & McGinnis, 2010; Roodbergen & De Koster, 2001). Storing and retrieving are the most expensive operations because they tend to be either very labour intensive or very capital intensive. The routing and sequencing decision in storage/retrieval order operations determines the best sequence and route of locations for storing and/or retrieving a given set of items where the storage/retrieval location of an item is given. Oliveira (2007)studies the problem of scheduling the truck load operations in an automatic storage/retrieval system. The problem is modelled as a job-shop problem by considering the loads as jobs, the pallets of a load as job operations and the forklifts as machines. A genetic algorithm for makespan minimisation is also presented. Zäpfel and Wasner (2006) formulate a warehouse sequencing problem in a steel supply chain as a dynamic job shop sequencing problem and present a heuristic algorithm for its resolution. Ho and Sarma (2009) present an abstract warehouse model to evaluate the location assignment problem in warehouse systems. They rely on RFID to keep track of items even if they are distributed non-contiguously across a warehouse. The study in Fosso and Chatfield (2010) provides support for the enabling role of RFID technology in effecting warehouse process optimisation. Poon et al. (2011) describe a real-time warehouse operation planning system for solving small batch replenishment problems. Real-time production and warehouse operations are monitored by RFID.

One of the objectives of this research is to show how real-time information allows us to design better management policies for the scheduling of storage/retrieval warehouse operations. Another goal of the paper is to study the benefits than can be obtained if RFID is used in a particular type of warehouse. The work provides some insights that can be drawn from the RFID technology in the context of warehouse storage/retrieval operations management that can be used to decide whether or not this technology is installed. To address both issues, we develop a stylised model that captures and generalises the main characteristics of the structure and routing and sequencing operations of a given real warehouse in which the Stock Keeping Units (SKUs) are pallets and the storage/retrieval operations are performed by means of forklifts. The model incorporates several realistic features not previously dealt with in the literature in the presence of RFID. They are the following: (1) Due to the confined and narrow travel paths in a warehouse and also for security reasons, some restrictions on forklift movements have to be considered such as security distances, avoiding forklift intersection policies and aisle entrance blocking policies. The non-consideration of these constraints could lead to the proposal of unreliable plans of action and to meaningless results. (2) The expected arrival time of trucks to collect goods or the production requirements impose temporal limits on the fulfilment of retrieval operations. These temporal limits are reflected in the model as due dates on the fulfilment of groups of retrieval orders. It seems that in practice the fulfilment of these due dates is an objective more important than the usually considered objective of makespan minimisation.

We have developed a set of order sequencing and routing heuristic procedures that take, and, alternatively, do not take into account, real time information and compare their performance via simulation. We have considered two types of order management settings: static (S) and dynamic (D), depending on whether the forklift driver is provided at the start of the working period with an ordered list of orders to be fulfilled or is provided with a single order at the beginning of the working period and each time he arrives at the depot after he has completed the previous order.

Furthermore, to facilitate the accurate estimation of durations, the time to fulfil an order is calculated as the sum of several main times: the travel time, the waiting time, the depot time and the storage/retrieval time. Also to compute each of these main times we have considered the times needed to perform different elementary actions: travel time (to traverse an arc in a storage aisle or in a cross aisle); depot time (to assimilate a new order, to manually identify a pallet, to automatically identify a pallet and to deposit or remove a pallet from the depot ground); storage/retrieval time (to position the forklift in front of the storage location, to manually and automatically identify a pallet, to lift up the pallet to the proper level, to bring down the forks, to temporally deposit on the ground and pick up afterwards the carried pallet and one or more pallets already stored if necessary; to manoeuvre the forklift to a position that allows it to traverse the aisle). This detailed decomposition also facilitates the identification of features of the current warehouse status that influence the quality of the generated plans as is the case with area congestion (see Section 4).

The problem has been motivated by the study of a warehouse of a Spanish company that produces beauty products (shampoo, creams, lotions, and so on) for one of the most important supermarket chains in the country. This company is interested in knowing the benefits that can be obtained in terms of due data fulfilment and tardiness minimisation if the RFID technology is installed and some management policies are considered. To address this concern we considered the design of the warehouse and times to fulfil orders based on actual data from this company. However the layout corresponds to a rectangular layout whose use is widespread and times correspond to the usual speed of forklifts.

The rest of the paper is organised as follows: In Section 2 we describe the main characteristics of the type of warehouse we are considering. We also define a mathematical model for the optimisation problem dealt with in this paper. In Section 3, we introduce the types of order management settings and the technological environments we analyse throughout the paper. Section 4 is devoted to present the solution approach adopted. We describe the algorithm and the different policies proposed to solve our problem. An example is included to facilitate the understanding of the algorithm. We also present a simulator that simulates the structure and operations in a warehouse. The simulator will be used to evaluate the performance of a given order management policy. In Section 5 we carry out several experiments to analyse the performance of our procedures and the benefits of using the RFID technology. To do that we have also devised a procedure capable of generating test instances similar to our case. Finally, conclusions are given in Section 6.

2. Warehouse description and model specification

In this section we describe the main characteristics of the warehouse we are working with. We also represent the warehouse as a graph, which will help us to develop a program that simulates the movements in the warehouse. Finally, we define a mathematical model for our problem.

2.1. Warehouse description and problem characteristics

In this paper we consider rectangular warehouse layouts (Fig. 1) with a certain number of parallel storage aisles and parallel cross