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Mauro Dell'Amico
Manlio Gaudioso
Giuseppe Stecca
Editors

A View of Operations Research Applications in Italy, 2018

AIRO
ASSOCIAZIONE ITALIANA DI RICERCA OPERATIVA
OPTIMIZATION AND DECISION SCIENCE

Springer

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Volume 2

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Editors

A View of Operations Research Applications in Italy, 2018

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Preface

In 2017, the Italian Operations Research Society (AIRO) called upon its members to contribute detailed information about their activities in promoting the use of quantitative techniques, and in particular the operations research ones, in society and industry.

The collected information was condensed into a report presenting 74 case studies highlighting the real pervasiveness of operations research techniques. The booklet was issued for the annual AIRO conference ODS2017, held in Sorrento, and the areas covered encompassed both the public and the private sectors, involving Logistics and Transportation, Production, Services and Society, ICT, and Energy and Environment.

It was particularly exciting to observe the very productive and fruitful cooperation between the operations research people, from both academic institutions and spinoff companies, and domain experts from the diverse application frameworks.

AIRO decided that the experience gathered by so many research groups, working all over Italy and sometimes even abroad, deserved an appropriate and prestigious outlet that would assist in encouraging new and extended applications.

The best opportunity was provided by the recently established cooperation between AIRO and Springer, and a call for papers, primarily but not exclusively directed at contributors to the report, was launched at the beginning of 2018.

The present volume is the outcome of the above call. It contains 16 papers which offer an excellent view on the application of operations research in several fields by the use of effective approaches. All the published papers are based on successful collaborations with companies which confirmed the positive impact of the research on their processes (in some papers, company representatives are also co-authors).

Papers are clustered according to the application areas that they cover. In particular, papers 1–4 describe several applications in Logistics, 5 and 6 are Product Design oriented, 7 and 8 are about Production Planning and Scheduling, 9–11 are related to Social Applications, and, finally, 12–16 deal with Transportation problems with respect to both freight and people.

It is anticipated that the book will attract the interest of research scientists as well as professionals, and its use for didactic purposes is also possible.

We wish to thank all colleagues who have contributed their papers, Professor Daniele Vigo, President of AIRO, for his enthusiastic support, and Springer for having given us such an excellent opportunity.

Reggio Emilia, Italy — Mauro Dell'Amico
Arcavacata di Rende, Italy — Manlio Gaudioso
Rome, Italy — Giuseppe Stecca
May 2019

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Logistics

A Two-Phase Approach for an Integrated Order Batching and Picker Routing Problem

Martin Bué, Diego Cattaruzza, Maxime Ogier and Frédéric Semet

Abstract This article addresses an integrated warehouse order picking problem. The company HappyChic is specialized in men's ready-to-wear. A central warehouse is dedicated to supplying, every day, the shops of one brand. We focus on the picking area of this warehouse which relies on human picking system. For each picking wave (period of a working day), a set of customer orders has to be prepared. An order is a set of product references, with quantities, i.e., the numbers of items required. The problem consists in jointly deciding: (1) the division of orders into several boxes, respecting weight and size constraints; (2) the batching of boxes into trolleys, that implicitly defines the routing into the picking area. The objective function aims to minimize the total distance. To deal with the large size instances of HappyChic in short computation times, we design a heuristic method based on the split and dynamic programming paradigms. The results are very convincing: the total covered distance decreases by more than 20%. Moreover, we propose an adaptation of the algorithm to prepare homogeneous boxes with respect to classes of products. The logistic department of HappyChic is convinced by results obtained in this research work, and the warehouse management system is currently being updated in order to integrate the proposed algorithm.

Keywords Warehouse management · Order batching · Picker routing

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1 Introduction

In this paper, we focus on the warehouse management problem faced by our industrial partner HappyChic.[1] HappyChic is a French firm specialized in men's ready-to-wear. HappyChic gathers three leading brands: Jules, Brice, and Bizzbee. The logistic department of HappyChic is in charge of the three warehouses (one for each brand), and all the related logistics activities. In this paper, we consider operations in the warehouse dedicated to clothing products of the brand Jules, located in the North of France, close to the city of Lille. The warehouse supplies the shops of Jules in all France and some shops abroad. Thus, the usual customers to satisfy are the shops to which new clothing products are shipped.

The warehouse under consideration consists in four main zones: (1) the *reception zone* where products delivered by suppliers are received; (2) the *storage zone* where pallets of products are stored in racks; (3) the *picking zone* where pickers pick items from cartons and prepare boxes to be sent to customers; (4) the *delivery zone* where trucks are loaded with boxes shipped to customers.

The picking operations are done manually by pickers that push trolleys with several boxes. These boxes need to be filled with items required by customers.

Each working day a set of demands has to be prepared. The demands are associated with customers, i.e. shops located throughout France and abroad. Based on the sales, the shop demands are computed during the night. Demands usually consist of several items which may not be put into a single box. The demand of each customer has then to be split in different boxes and these boxes have to be assigned to one or several trolleys. Clearly one box must contain only products associated with a single customer. On the other hand, boxes on the same trolley can be for different customers.

In this paper, we focus on the optimization of the operations in the picking zone. The problem under study consists in optimizing the productivity of the pickers by simultaneously determining: (1) the products that constitute each box to be delivered to customers; and (2) the batch of boxes to constitute a picking tour.

2 Literature Review

Warehouse management involves different optimization problems such as conceiving picking tours, batching orders, storage assignment, layout design, and zoning (see, for example, [2]). Decisions to optimize productivity in a warehouse can have different horizons and be classified as strategic, tactical and operational. Strategic decisions determine the layout of the warehouse, the disposition of each zone (receiving, storage, picking and delivery) with respect to the others, the decisions that involve the storage policy as well as picking policy (automated versus human). Tactical decisions can involve the location of products based on their forecast demand in the storage and picking zone. At the operational level, storage and picking tours need

[1] http://www.happychicgroup.com.

to be efficiently determined and coordinated. Storage tours move products from the storage to the picking zone, while picking tours aim at collecting items to satisfy the demand of customers [2, 5].

Picking operations can be classified based on the automatism introduced in the process. As in [5] five classes can be identified: picker-to-parts, parts-to-picker, pick-to-box, pick-and-sort, and completely automated picking. In the first category, pickers move around the warehouse to pick items while in the parts-to-picker class, automated devices bring loads to pickers that are in charge of picking the right quantity required by the order under consideration. In pick-to-box systems, pickers are assigned to different zones and boxes containing customer orders move using a conveyor through different zones to be filled. In pick-to-sort systems, orders are batched and pickers collect items of a certain product to satisfy orders in the whole batch. A conveyor brings all the items to the sorting area where items are assigned to orders. Finally, humans do not intervene in full automated picking systems.

Picking systems where the human presence is necessary for operations still involve the majority of the warehouses [2]. Recent studies [3, 5] show how the cost of the automation would be too high to be profitable in a short or mid-term horizons. For these reasons and since in the problem under study picking operations can be classified as picker-to-parts, we concentrate the review on papers related to this area.

In the HappyChic case, our interest is focused on the operational decisions for picking operations. It concerns order batching and picker routing problems. Usually, order batching is performed when the size of orders is smaller than the capacity of the trolley used to collect the items. Order batching consists in grouping a set of orders into picking tours to minimize the total distance traveled by pickers. This problem is NP-hard [4]. Given a set of locations to visit, the picker routing problem aims to decide the sequence of locations to visit to minimize the traveled distance. These two problems have been studied extensively as separate problems [2]. Some recent works have addressed the joint order batching and picker routing problem. Valle et al. [8] propose a branch-and-cut algorithm based on a mixed integer programming formulation, and [7] proposed an iterated local search approach.

In the HappyChic case, we face a specific batching problem. Indeed, the size of an order is usually larger than the capacity of a trolley. Hence, the batching problem has two levels. First, items of a given order have to be batched into boxes. Second, boxes have to be assigned to trolleys. It is noteworthy that these two batching levels are mutually dependent.

3 Problem Definition

In this section, we formally introduce the problem and the notation used in the paper. All along the following sections, we suppose that each working day is divided into T periods. A period is associated with a picking wave. We indicate by $\mathscr{T} = \{1, \ldots, T\}$ the period set. The warehouse considered contains a set of products $\mathscr{P}$. With each product $p \in \mathscr{P}$ is associated the volume $v(p)$ and the weight $w(p)$ of a single item.

Each product p is also associated with a single location $l(p)$ in the picking zone. This assumption is satisfied for the HappyChic case since if a product is located in several locations, the locations are emptied based on a FIFO rule: first demands use the first location, and when this location is emptied, the second one is used. More precisely, let us detail this FIFO rule on a small example. Let us consider a product p located in two locations l_1 and l_2, such that location l_1 has to be emptied before l_2 according to the FIFO rule. We denote by Q_1 and Q_2 the available quantities of the product in locations l_1 and l_2 respectively. Then, instead of considering a single product p, we will consider two products p_1 and p_2 such that $l(p_1) = l_1$ and $l(p_2) = l_2$. These products have the same volume and weight. In the FIFO rule, demands are considered in a certain order. If the first demand requires $q_1 < Q_1$ units of p, then we consider q_1 units of product p_1 for this demand. Then location l_1 contains $Q'_1 = Q_1 - q_1$ available units of p_1. If the second demand requires q_2 units of p, such that $q_1 + q_2 > Q_1$, then we consider Q'_1 units of product p_1 and $q_2 - Q'_1$ units of p_2 for this demand. For the following demands of product p, only product p_2 will be considered since there is no more available quantity in location l_1. This FIFO rule is applied by HappyChic before the picking process and questioning this practice is not in the scope of the present work. So, given a demand, we can consider that there is no choice on the location to pick a product. Hence if a product is located in several locations, different products can be considered with the same volume and weight, and with only one unique location for each product.

3.1 Warehouse Description

The warehouse under consideration is depicted in Fig. 1 that represents the four zones dedicated to reception, storage, picking and delivery.

Trucks carrying products from the suppliers arrive at the reception zone of the warehouse. Here dedicated employees unload the trucks, and pallets of cartons are prepared to be stored. Then, employees driving forklifts move cartons from the reception zone into the racks of the storage zone. Other employees are dedicated to supplying the picking zone. They pick up cartons from pallets in the storage zone and bring them, using forklifts, into the picking zone. They are allowed only to go through cross-aisles 1, 3 and 5 and to leave cartons at the top or the bottom of the different aisles (see solid gray lines in Fig. 1).

All along the article, we make the distinction between *carton* and *box*. A carton contains items of a single product. Cartons are received by the warehouse on pallets and stored in the storage zone. They are then moved to the picking zone. There, items are picked from the cartons and put into boxes by dedicated employees called *pickers*. Thus, a box contains customer demands and possibly items of different products.

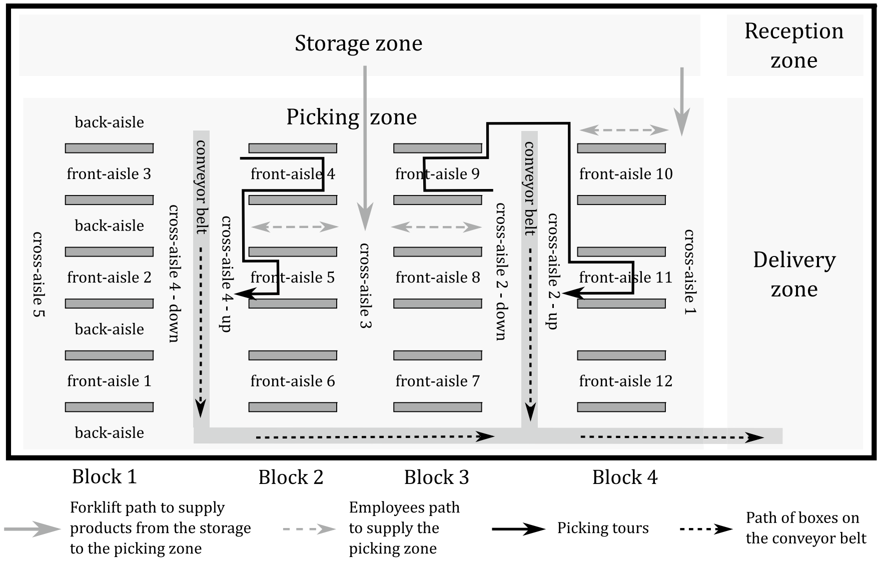

Fig. 1 The warehouse

3.2 Picking Zone

The picking zone of the warehouse consists of four blocks (see Fig. 1). Let us call these blocks, block 1 to 4. Each block contains different aisles having racks on one or both sides. Contrarily to standard cases presented in the literature (see for example [7]), we distinguish the two sides of the racks: the front and the back side. Cartons are inserted into racks from the back side and products are picked from the front side. Racks are situated in such a way that a front (resp. back) side always faces another front (resp. back) side of another rack (except, of course, for the first and the last rack). This placement defines a front-aisle and a back-aisle (see Fig. 2).

Back-aisles are used by employees to bring cartons from the top or the bottom of an aisle to their exact location (see dotted gray lines in Fig. 1). Only front-aisles are involved in the picking operations and are used by pickers to collect products from cartons.

The cross-aisles in the picking zone are not all walkable by pickers. For security reasons, cross-aisles 1, 3 and 5 are dedicated to forklifts that supply the picking zone from the storage zone. Pickers are allowed to walk only across cross-aisles 2 and 4. Moreover, these cross-aisles are equipped with a conveyor belt that automatically brings boxes prepared by pickers from the picking zone to the delivery zone. The conveyor belt divides cross-aisles 2 and 4 into two sub-cross-aisles. Let us use the words *up* and *down* to distinguish between these two sub-cross-aisles.

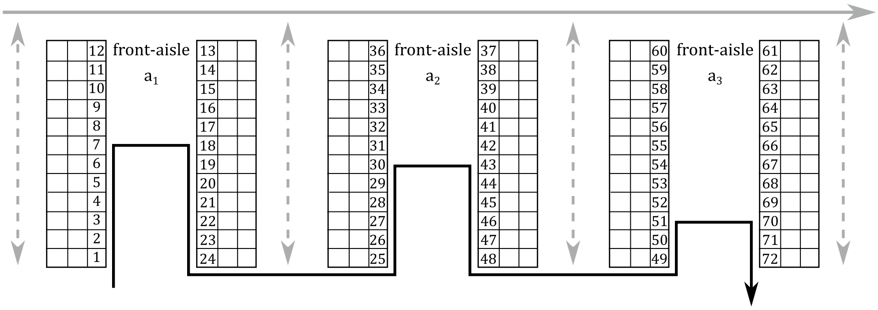

Fig. 2 Front-aisles and back-aisles. Legend as in Fig. 1. Locations are numbered following the walking order

Pickers walk around the warehouse pushing a trolley that contains up to f boxes. Due to the particular warehouse layout, the pickers cannot cross the cross-aisle 3. As a consequence, picking tours are limited to blocks 1 and 2 or to blocks 3 and 4.

Moreover, all the pickers follow the same circular path orientation and always walk following a clockwise walkway. This is due to space limitations in the aisles, and also facilitates picking operations since all routes are in the same direction. Thus, in a given route, the location names follow a topological order. We call this particular policy the *walking policy*. It is formally defined as follows.

First, aisles of blocks 1 and 2 and aisles of blocks 3 and 4 are ordered starting from the bottommost aisle of blocks 1 and 3 to the bottommost aisle of blocks 2 and 4 following the clockwise sense. Let $\mathscr{A}$ be the set of front-aisles. Given two front-aisles $a_1, a_2 \in \mathscr{A}$, aisle a_1 precedes aisle a_2 and we write $a_1 \prec a_2$, if a_1 comes before a_2 in this given order.

The set of all possible locations in the aisles of the picking zone is indicated by $\mathscr{L}$. A particular order is imposed on locations. Let us define the function $a : \mathscr{L} \to \mathscr{A}$ that associates each location with its aisle. Given two locations l_1 and l_2 such that $a(l_1) \neq a(l_2)$, we say that l_1 precedes l_2, and we indicate it by $l_1 \prec l_2$, if $a(l_1) \prec a(l_2)$. On the other hand, if $a(l_1) = a(l_2)$, we define the following rule. Entering a front-aisle from the cross-aisle, locations on the left are ordered from the beginning to the end of the front-aisle, while locations on the right are ordered on the opposite way. Thus, when $a(l_1) = a(l_2)$, we write $l_1 \prec l_2$ if:

- l_1 is on the left-side of the aisle, while l_2 on the right;
- l_1 and l_2 are both on the left-side and l_1 is nearer to the beginning of the aisle than l_2;
- l_1 and l_2 are both on the right-side and l_1 is nearer to the end of the aisle than l_2.

This order is called walking order or walking policy. An example is given in Fig. 2, where the numbers on each location follow the walking order. This walking policy corresponds to the return policy [2] where a picker enters and leaves each aisle from the same end.

Given two locations i and j, distances $d_{i,j}$ and $d_{j,i}$ are determined. They represent the distance of the path that goes from one location to the other following the walking order. Due to logistic constraints in the warehouse, it can be impossible to reach location j from location i (and/or vice versa). In this case, the distance $d_{i,j}$ is infinite. Location 0 represents a location where a tour starts and ends. Picking tours start and end at any place along the conveyor belt. This can be approximated by the entry point or exit point of an aisle. Hence location 0 is a fictive point that represents entrance or exit of an aisle. We then consider distance $d_{0,l}$ as the distance from the entrance point of aisle $a(l)$ to location l, and distance $d_{l,0}$ as the distance from location l to the exit point of aisle $a(l)$.

At a given period $t \in \mathscr{T}$, each location contains items of the same product. For each period t, we assume that the storage level in the picking zone is sufficient to satisfy the total demand.

3.3 Pickers

A team of employees is in charge of collecting items from the cartons in the picking zone and to fill the boxes that will be delivered to shops. These employees are called pickers. It is supposed that the number of pickers is large enough to ensure the preparation of the total demand to be prepared within a given period.

A picker walks around the warehouse respecting the walking policy. The picker pushes a trolley with up to f boxes available. He/she picks products from cartons and put them into the boxes. Once the all required items are picked, he/she walks to the conveyor belt on which he/she places the boxes. He/she then starts another picking tour with a trolley containing empty boxes. Then, the picker is allowed to walk against the walking policy to locate him/herself at the beginning of the next tour. Note that, due to the particular walking policy considered in the warehouse, the set of locations to visit to pick the items directly implies the path that a picker needs to follow to collect the items.

3.4 Demands

A set of demands $\mathscr{D}$ is to be prepared during a working day. The set $\mathscr{D}$ is partitioned in T subsets/periods, in which the working day is divided. Subset $\mathscr{D}_t$, $t \in \mathscr{T}$, contains all the demands that need to be prepared during period t.

For each demand $d \in \mathscr{D}$, a set of $n(d)$ products $\mathscr{P}_d = \{p_1^d, \ldots, p_{n(d)}^d\} \subseteq \mathscr{P}$ needs to be collected. A quantity q_j^d is associated with each product p_j^d in demand d. This corresponds to items of the same product, situated at the same location $l(p_j^d)$, and needed to prepare d.

Whenever useful for the presentation of this work when there is no ambiguity about the index of demand d, notations are lightened as follows. Given a demand d, the set of products is written $\{p_1, \ldots, p_n\}$. Each product p_j is associated with a quantity denoted as q_j, and a location l_j.

3.5 Boxes

Boxes to be delivered to shops must respect a maximal volume v_{box}^{max} and a maximal weight w_{box}. Moreover, each box must satisfy a minimal volume v_{box}^{min} of products. A box, that is not filled at least as much as the minimal volume, can be crushed by other boxes during transportation. Filling up a box increases its strength. Note that it may happen that a demand is too small to ensure the minimal volume capacity constraint. It is then the decision of the managers of the warehouse to decide if this demand is prepared (with violation of the capacity constraint) or delayed to another day. Here, we minimize the number of boxes that violated the minimal volume constraint and consider that they are integrated into the proposed picking tours.

3.6 Objective and Constraints

The problem consists in simultaneously determining for each period $t \in \mathscr{T}$: (1) the partition of each demand $d \in \mathscr{D}_t$ into boxes; (2) the batching of boxes into groups of up to f boxes, i.e., the determination of a picking tour in order to minimize the number of boxes that violate the minimal volume constraint and the distance covered by the pickers while satisfying the maximal volume and weight constraints, the walking policy imposed into the picking zone, and the trolley capacity.

Note that the objectives are prioritized. First, we minimize the number of boxes that violate the minimal volume constraint, and second, the walking distance. Moreover, even if the objective is to minimize the total distance walked by the pickers, the industrial partner wants to ensure the number of tours remains reasonable. Indeed, since there is not a unique starting location (a tour can start at any place along the conveyor belt), minimizing the distance could lead to generate a large set of small tours. This is not acceptable since starting a new tour requires some time for the picker, that can be viewed as a fixed cost. Hence, we impose a fixed distance penalty on all tours.

4 Algorithmic Approach

In this section, we describe the algorithm that has been developed to tackle the problem. Our algorithm includes two phases. The first phase splits each demand into different boxes (Sect. 4.1) while the second phase generates picking tours once the boxes have been determined (Sect. 4.2).