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Comparing heuristics for the product allocation problem in multi-level warehouses under compatibility constraints

F. Guerriero [a,*], O. Pisacane [b], F. Rende [a]

[a] Dipartimento di Ingegneria Meccanica, Energetica e Gestionale, Università della Calabria, Via P. Bucci, 41C, Arcavacata di Rende (CS) 87036, Italy
[b] Facoltà di Ingegneria, Università degli Studi e-Campus, Via Isimbardi 10, Novedrate (CO) 22060, Italy

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ABSTRACT

One of the most significant activities in *warehouse management* concerns the allocation of products to the storage positions. This problem is known in the literature as the *Product Allocation Problem* (PAP). It mainly aims to optimize both the warehouse space utilization and the products handling costs (at least 40% of the total logistics cost). This paper addresses the PAP in a multi-layer warehouse, with compatibility constraints among the product classes. It has already been addressed from a modeling point of view in the literature and it has been formulated as a Mixed Integer Linear Programming model. However, solving the problem to optimality becomes impracticable in real-life settings. To this purpose, an *Iterated Local Search*-based Heuristic ($\mathcal{ILS}$) and a *Cluster*-based Heuristic ($\mathcal{CH}$) have already been proposed in the literature. This paper presents a Rollout-based heuristic whose performances are evaluated on the basis of a detailed computational phase, including also a real case study and compared with those of both the $\mathcal{ILS}$ and the $\mathcal{CH}$, in terms of the computational times and the quality of the final solutions.

1. Introduction

Warehouse managers are usually interested in providing high quality services to their customers at minimum cost. From a tactical, strategic and operational point of view, the main issues concern both the *Warehouse* and the *Inventory* Management.

Although these decisions are linked, they can be solved independently by implementing a top–down approach. Firstly, the strategic decisions are considered and then, some limits and restrictions are imposed on those to take at the tactical level. Therefore, the decisions taken at the operational level are affected by the two previous states.

Focusing attention on warehouse management, the main activities include the *receiving*, *storage*, *order picking accumulation*, *sorting* and *shipping* [1]. Indeed, a warehouse is usually divided into three parts: the *Receiving*, *Storage* and *Shipping* area [2]. In the first area, the ingoing flows are unloaded from the entering vehicles and then, they are sent to the storage zone where they are properly managed to be allocated to the storage positions (slots) and, eventually, packed to compose the final orders (picking orders operation). In order to organize the storage zone adequately, two main issues should be addressed [3,4]: the storage allocation, aimed at determining the dimension of each Stock-Keeping Unit (SKU) and the storage assignment aimed at determining the most convenient locations for the SKUs. Finally, in the shipping zone, the products

* Corresponding author.
E-mail addresses: francesca.guerriero@unical.it (F. Guerriero), ornella.pisacane@uniecampus.it (O. Pisacane), frende@deis.unical.it (F. Rende).

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are loaded into the outgoing vehicles in order to be distributed. It is worth noting that the *orders picking* operations are 65% and 50% of the total cost and of the workforce [5] respectively and they involve the allocation of products and the routing strategy. In particular, the former aims to assign the products optimally to the slots, in such a way that the most required items are placed in positions next to the I/O doors [2]. The routing strategy, instead, aims to determine the best routes for the operators employed, inside the warehouse, during the picking operations. These operations considerably affect the times required to manage the products in the storage area and to handle the orders.

This paper focuses attention on the Product Allocation Problem (PAP) in a multi-layer warehouse under compatibility constraints, taking into consideration the hypothesis already described in [6] where a first Mixed Integer Linear Programming (MILP) formulation of the problem is proposed. It is worth observing that, for real world problems, this MILP model becomes mathematically intractable. In fact, although the preliminary grouping phase of the products in homogeneous classes tends to reduce the number of items considerably (i.e., the total number of variables and constraints), the problem hardness remains a critical issue in realistic settings. In order to overcome this drawback, both an Iterated Local Search heuristic ($\mathcal{ILS}$) and a Cluster-based Heuristic ($\mathcal{CH}$) are described in the literature, as detailed in Section 2.

In this paper, a rollout-based approach to solve the problem under investigation is designed. The Rollout Heuristics ($\mathcal{RH}$), originally introduced in [7,8], can be used to solve NP-hard combinatorial optimization problems. The basic idea is to use the cost obtained by applying a heuristic method, called base heuristic $\mathcal{H}$, to discriminate among several search options at each step. These algorithms are very appealing from the practical point of view. Indeed, $\mathcal{RH}_s$ have been successfully used to solve both deterministic and stochastic problems in sequential and parallel computing systems (see [9–12]. Experimental results have shown that $\mathcal{RH}$ significantly improves the performances of $\mathcal{H}$ in terms of solution quality. Moreover, it is more robust than other techniques (e.g.,*Tabu Search* and *Simulated Annealing*, as shown in [8]) since it does not require to fix any input parameter a priori.

The $\mathcal{RH}$, here proposed, is a hybrid procedure, in the sense that $\mathcal{H}$ is obtained by combining a constructive heuristic with a local search method. To the best of our knowledge this is the first work that proposes rollout approaches for solving the PAP in multi-layer warehouses with compatibility constraints.

For the sake of completeness, the developed solution strategy is also compared with $\mathcal{ILS}$ and $\mathcal{CH}$ on a large set of instances. The numerical comparisons are discussed in terms of both computational times and solution quality. It is worth noting that the quality of a solution is evaluated with reference to both the handling costs and the penalties. The proposed approach is also evaluated on a real case.

The rest of the paper is organized as follows: Section 2 revises the previous related work from both the modeling and the methodological point of view; Section 3 gives the problem statement; while Section 4 outlines the proposed $\mathcal{RH}$; Section 5 shows the numerical comparisons; finally, Section 6 concludes the work.

2. Related works

The *Storage Location Assignment Problem* (*SLAP*) aims at allocating the products to the slots in a warehouse, minimizing both the handling costs and penalties and maximizing the space utilization. The allocation mechanism follows the principle that the highly demanded products are allocated in slots next to the I/O doors in order to reduce the total handling times (especially during the picking activity).

Among the several proposed strategies, the *dedicated storage policy* always assigns a fixed number of slots to the same product type. It is very easy to be implemented, but it has the disadvantage that an empty slot cannot be used for a different product type. For this reason, it leads to a waste of space especially in cases where the goods are subjected to the seasonality factor [13]. To overcome this limit, in [14], a heuristic based on the *Duration of Stay* (DOS) concept is proposed. In particular, DOS(i) represents how long the item i stays in the warehouse. The items with the lowest DOS (i.e., highly demanded) are then assigned to slots next to the I/O doors.

When the information on the products is available, SLAP can be heuristically solved through local searches. For example, a *Random storage* (RS) approach allocates each item unit to a slot, randomly chosen among the free ones. Thus, each free slot is equally likely to be chosen. This allows for a more uniform warehouse space utilization with the possibility of operators sometimes taking long routes. Alternatively, in [15], a *Closest Open Location Storage* approach is described in which the slots are chosen directly by the operators among the free ones closer to them. This strategy does not allow uniformly distributing goods in the warehouse since it usually tends to allocate the units to the slots next to the I/O doors. On the contrary, a *Dedicated Storage* (DS) strategy places each item unit in a specific limited area inside the warehouse. On the one hand, a free slot cannot be used for assigning items of different types; however, a fixed assignment policy ($slot, item$) could help the operators in picking activities.

This paper takes into consideration a *Class-based Storage* (CS) location strategy in which the products are assumed to be grouped into different classes (according to a specific criterion). The approach firstly ranks the classes and then, it allocates them by starting from the most critical ones. Finally, it assigns the more profitable slots to the groups. However, the criterion followed for grouping the products into classes still remains a critical issue [6].

The storage assignment policies here described do not take into consideration the possible relations among the items. In some cases, in fact, the customers could require a set of items of different types and thus, it could be convenient to allocate different classes next to each other (i.e., the *Family Grouping* policy). Alternative approaches are both the *Complementary-Based Method* and *Contact-Based Method*. The former consists of a grouping phase of the products, according to the demand