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Diagonal cross-aisles in unit load warehouses to increase handling performance

Marco Bortolini [a], Maurizio Faccio [b], Mauro Gamberi [b,*], Riccardo Manzini [a]

[a] *Department of Industrial Engineering, University of Bologna, Viale Risorgimento 2, 40136 Bologna, Italy*
[b] *Department of Management and Engineering, University of Padova, Stradella San Nicola 3, 36100 Vicenza, Italy*

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ABSTRACT

This work proposes a non-conventional easy-applicable configuration for unit load (UL) warehouses, with the aim of improving the handling performance in terms of the travelled distance. The impact of the adoption of one or more straight diagonal cross-aisles within a traditional warehouse is investigated under single command operations. The closed-form of the mean travel time with random storage assignment of the ULs is provided and the design parameters of such a warehouse are evaluated. In the optimal configuration, the travelled distance savings range from 7% to 17%. The loss of storage area related to the presence of the diagonal cross-aisles is, also, evaluated, leading to define the profitability regions, best balance between the distance saving and the storage area loss, driving the choice of the most effective number of diagonal cross-aisles to include within the storage system.

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1. Introduction

Unit load (UL) storage systems receive, store, and ship products in UL quantities, typically pallets (Meller and Gue, 2009). Such systems are known as *simple warehouses* as opposed to the so-called *order fulfilment centres* that receive and store products in UL quantities but break them down to fulfil the demand for orders in less-than-unit-load quantities (Bartholdi and Hackman, 2014). The effective design of both the UL systems and the order fulfilment centres is a crucial aspect for operation managers and practitioners due to the high impact of the inbound logistics on the company cost structure (Rouwenhorst et al., 1999, Accorsi et al., 2014).

The recent literature addresses the warehouse design and optimisation issue by proposing a large set of models, methods and approaches referring to multiple aspects. Gu et al. (2010) classify the following five major decisional areas:

– The overall structure and conceptual design of a warehouse to determine the functional departmental features, e.g. the storage department number, the adopted technologies, how orders are assembled, etc.;
– Design and sizing to define the warehouse storage capacity, the required plant area, the volume and to estimate the construction and operating costs;
– Department layout planning, facing the layout or re-layout issues within each warehouse department and storage plant area;
– Equipment and process selection to address the level of automation, the type of storage and the material handling systems;
– Assignment strategies and operations defining the storage policy, i.e., the use of randomised storage, dedicated storage, class based storage and order selection strategies, if present.

The introduced warehouse design decisions are strongly correlated and cross-dependent, making it difficult to define sharp boundaries among them. Integrated approaches to face such issues are strongly encouraged by the scientific community and operation managers.

Furthermore, other important aspects supporting the classification of the storage systems deal with the number of Input/Output (I/O) points and the types of command cycles adopted to store/retrieve the loads. In particular, the UL warehouses use single-command and dual-command cycles or, frequently, a mix of both (Gue and Meller, 2009).

Concerning the physical structure and layout, the industrial warehouse racks are traditionally arranged to form parallel and straight picking aisles. One or more orthogonal aisles sometimes facilitate the storage/retrieval activities. Such aisles, generally, contain no loads. Recently, innovative and non-conventional structures are proposed, with the aim of speeding up the warehouse activities. Gue and Meller (2009) describe warehouse designs in which the parallel picking aisles and the orthogonal

* Corresponding author. Tel.: +39 0444 998735; fax: +39 0444 998888.
E-mail address: mauro.gamberi@unipd.it (M. Gamberi).

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cross-aisle constraints are relaxed. In their Flying-V and Fishbone design approaches, cross-aisles together with traditional ones are present (Fig. 1). Such new design approaches reduce the storage density while increasing the storage/retrieve performances, despite some rising difficulties in arranging the storage racks, especially if the cross-aisles are introduced into an existing storage system. The authors estimate a maximum 10% reduction in the expected travelled distance for a 42,000 UL storage system with a storage capacity loss of 8.5% in the worst-case scenario.

This work addresses the layout planning issue by proposing a new model to support the design of unit-load storage systems to reduce the travelled distance for the load storage/retrieval. Compared to the conventional picking aisles to access the warehouse bays, the proposed model analyses the impact on the travelled distance of straight, i.e., rectilinear, diagonal aisles crossing the racks (Fig. 1). Such a configuration is simpler than those already proposed by the literature; it is innovative and not obtainable from the existing ones. The diagonal cross-aisle is straight, as the conventional vertical aisles, and the new layout does not require to change the traditional vertical parallel configuration of the racks making it applicable to both existing and new storage systems, upgrading their performances. Furthermore, the impact of multiple diagonal cross-aisles on the travelled distance is studied.

The analytic models to compute the average travelled distance in the case of two, four and six diagonal cross-aisles are presented. The models focus on the right half of the storage system, only, due to the problem symmetry (see Fig. 1) so that the models are referred as one, two and three diagonal cross-aisle models, respectively. A load randomised storage assignment strategy is adopted. The results are compared to the performances of conventional storage areas with no diagonal cross-aisles by computing the expected travelled distance savings.

According to the introduced topic and purposes, the remainder of the paper is organised as follows: Section 2 briefly reviews the recent literature, while Section 3 introduces the model assumptions and the reference scenario. In Section 4, the models with multiple diagonal cross-aisles are fully analysed by presenting the analytic solutions for one, two, three and infinite (bound) diagonal cross-aisles. Section 5 focuses on the estimation of the storage capacity loss due to the adoption of diagonal cross-aisles, while Section 6 describes the handling performance of such a warehouse. Finally, Section 7 concludes the paper by listing the key outcomes and suggesting relevant future improvements to the proposed model.

2. Literature review

The scientific literature on the warehouse design is wide and stresses the relevance of this strategic issue highly affecting the inbound performances and the company cost structure. Gu et al. (2010) classified the literature contributions according to five main topics: overall structure (1), sizing and dimensioning (2), department layout (3), equipment selection (4) and operation strategies (5). Such topics are strictly interrelated and the decisions are cross-dependent. Among all of the decisions, the aisle design, the warehouse shape and the product assignment are of strong interest in the context of the present paper, which addresses them adopting an integrated perspective.

The aisle design is among the department layout decisions. Bassan et al. (1980) developed models to determine the best location of the picking aisles assuming a conventional rack structure. White (1972) is the first contribution discussing the potential performance improvement due to a non-conventional warehouse design that introduces radial aisles crossing the racks. Arlinghaus and Nystuen (1991) mentioned the effect on the travelled distances of a diagonal link in a rectangular grid network, while Gue and Meller (2009) introduced the aforementioned Flying-V and Fishbone innovative warehouse designs for UL warehouses with randomised storage assignment. Çelk and Süral (2014) extended this issue for order picking warehouses and turnover-based storage policy. Pohl et al. analysed the impact of dual-command cycles on common warehouse designs (Pohl et al., 2009a) and on the Fishbone aisle optimisation (Pohl et al., 2009b). Furthermore, Gue et al. (2012) considered non-conventional aisle design with multiple I/O points, highlighting that there is a modest benefit with respect to the single I/O point configuration. Following that, Öztürkoğlu et al. (2014) show that UL warehouses with multiple, highly dispersed I/O points can benefit from alternative and non-conventional aisle design. Öztürkoğlu et al. (2012) developed aisle design strategies in which the picking aisles and cross-aisles have any angle and presented three optimal scenarios for increasingly large warehouses. Clark and Meller (2013) proposed a study considering the Flying-V and the Fishbone aisle designs, including the vertical travel distance. The authors concluded that the savings decrease if the height of the rack increases.

Concerning the warehouse layout and shape optimisation, preliminary studies are presented in Francis (1967) and Berry (1968), who investigated the various rectangular warehouse shapes that minimise the picking and construction costs. Bassan et al. (1980) and Rosenblatt and Roll (1984) studied the optimal layout shape, assuming single and dual command cycles. Fundamental relationships between the length and width of a rectangular warehouse are presented in Tompkins et al. (2003) and Heragu et al. (2005).

Finally, in the product assignment problems, close to the randomised strategy, dedicated storage location and dedicated storage area strategies are considered (Goetschalckx and Ratli, 1990). The former is common in order picking warehouses because of the labour cost reduction due to the assignment of the most labour intensive products to the most desirable locations (Heskett, 1963, Hausman et al., 1976, Kallina and Lynn, 1976, Roodbergen and De Koster, 2001, Gue and Meller, 2009). Such a strategy stores the so-called *fast-movers* in a triangular pattern area around the I/O point (Francis et al., 1992, Tompkins et al., 2003). Dedicated storage areas prevent the presence of empty spaces and the resulting decrease in storage density (Gue and Meller, 2009). Finally, class based storage policy creates classes of

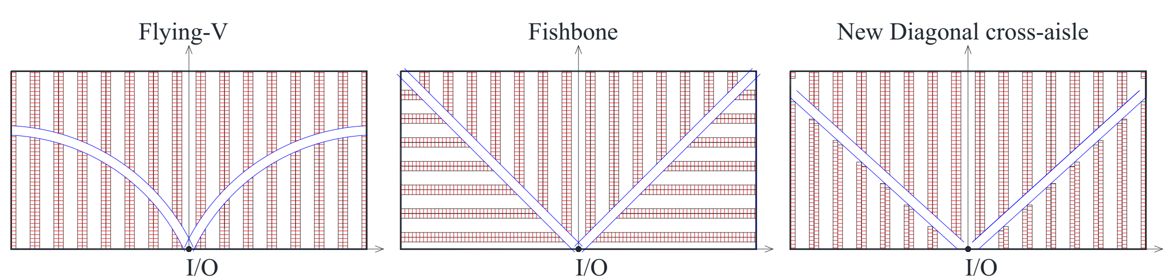

Fig. 1. Flying-V, Fishbone and the proposed diagonal cross-aisle storage area configurations.

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