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Human energy expenditure in order picking storage assignment: A bi-objective method

Daria Battini [a], Christoph H. Glock [b], Eric H. Grosse [b], Alessandro Persona [a], Fabio Sgarbossa [a,*]

[a] Department of Management and Engineering, University of Padova, Stradella San Nicola, 3, 36100 Vicenza, Italy
[b] Institute of Production and Supply Chain Management, Technische Universität Darmstadt, Hochschulstr. 1, 64289 Darmstadt, Germany

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A B S T R A C T

Order picking is the most time-consuming and labor-intensive activity in warehousing. Due to the need to frequently handle items, order picking requires high human energy expenditure and poses a risk environment for workers to develop musculoskeletal disorders. The storage assignment policy in use has a significant impact on human energy expenditure and fatigue during the picking process, but this impact is usually not considered in (management-oriented) decision support models for storage assignment.

This paper models and analyzes the integration of human energy expenditure as one dimension of ergonomics into the storage assignment problem using a bi-objective approach that considers both total order picking time and human energy expenditure. Time and energy expenditure depend on the main features of the order picking system, such as item characteristics, item popularity, order profiles, and physical dimensions of the shelf and locations. Pareto frontiers are constructed to understand the impact of the storage assignment policy on the objective functions. Subsequently, a quantitative approach is developed to integrate the energy expenditure rate into the time estimation for a general order picking system based on the introduction of rest allowance. Finally, the results of the model are analyzed and suggestions for the practical application of the model are presented.

1. Introduction

Nowadays, the optimization of warehouse processes becomes more and more important for several reasons. First, warehouses are seen as cost centers that tie up large sums of capital. Secondly, warehouse activities require a high amount of human work both in terms of time and physical effort. Modern global supply chains have increased the complexity of warehouse processes in recent years, requiring a great variety of products in small quantities, high service levels and short delivery times. This poses a challenge to logistics managers, who have directed their attention to improving the efficiency of feeding systems, the design of supermarkets, or logistics processes that take place in warehouses (Battini, Faccio, Persona, & Sgarbossa, 2009). In light of these developments, order picking, i.e. the process of retrieving items from the warehouse to complete customer and production orders, continues to be seen as one of the main drivers of warehouse flexibility and efficiency.

Despite the various advantages warehouse automation offers, order picking is still characterized by a high share of manual human work in many companies. Picker-to-part systems, where the operators walk or drive along the aisles of the warehouse to pick items from storage locations, are still dominant in industry (De Koster, Le-Duc, & Roodbergen, 2007; Napolitano, 2012). Typical manual tasks in picker-to-part systems involve walking, grasping, lifting, lowering, sorting, pushing, and pulling. Excessive and repetitive manual materials handling in warehouses, however, renders the order picking process a risk environment for workers to develop musculoskeletal disorders (MSDs), among them back injuries, sprains, strains, and/or tears (Punnett & Wegman, 2004). MSDs are the most common work-related health problem, with 25% of European workers complaining about backache and 23% about muscular pains, for example (Schneider & Irastorza, 2010). In the US, MSDs accounted for 34% of all injury and illness cases in 2012, where stock and material movers had the highest number of MSD cases (BLS, 2013). The economic burden of MSDs, as measured by compensation costs, lost wages, and lost productivity, are estimated to range between $45 and $54 billion annually in the US (NRC, 2001), and to account for up to 2% of the Gross National Product in the EU, with €23.9 billion solely in Germany (Schneider & Irastorza, 2010). To reduce the risk of MSDs, various ergonomic methods and tools have been developed in the past to support engineers and managers in evaluating ergonomic issues in an industrial context.

To support the design and management of picker-to-part systems, various mathematical decision support models have been

* Corresponding author.

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developed over the last decades (see, for a review, De Koster et al., 2007). The most common objective of these decision support models is to minimize the travel distance or the picking time of an order by determining the facility layout, the internal configuration of shelves and aisles, the routing of order pickers, and the assignment of products to storage spaces.

A recent study of Grosse, Glock, Jaber, and Neumann (2015), however, showed that the large majority of these decision support models solely concentrated on the (short-term) economic impact of order picking, but neglected the influence of the order picking process on the human operator. To guarantee a high level of productivity and efficiency and to make sure that decision support models reflect reality as good as possible, it is necessary to consider human factors in addition to economic aspects in designing labor-intensive manual order picking systems. As was demonstrated in Battini, Faccio, Persona, and Sgarbossa (2011), including ergonomics evaluations in the human operations analysis is a win-win approach due to the interaction between productivity, motion efficiency and operational safety. In addition, some authors noted that considering ergonomic aspects is not only relevant for reducing health risks, but that it may also improve the performance and quality of order picking significantly (Grosse et al., 2015). Existing works in this area include a variable pick and materials handling time depending on materials exposure and its position on the shelf (Finnsgård & Wänström, 2013; Finnsgård, Wänström, Medbo, & Neumann, 2011; Neumann & Medbo, 2010), as well as a variable search time and a pick error rate depending on human learning (Grosse & Glock, 2013). Due to the impact of ergonomic aspects on the performance of order picking, several authors recently called for the integration of ergonomic aspects into decision support models for order picking (Boysen, Emde, Hoeck, & Kauderer, 2015; Grosse et al., 2015). Thus, a promising research opportunity is the integration of ergonomic aspects into decision support models for storage assignment, which is an important planning problem in order picking.

To contribute to closing the research gap highlighted above, this paper develops an integrated storage assignment method that considers both economic aspects (in terms of order picking time) and ergonomic aspects (in terms of human energy expenditure).

The main objectives of this research and the methods used to achieve them can be summarized as follows:

(1) Investigate how the storage assignment policy impacts total order picking time and energy expenditure in order to estimate the trade-off between time and energy expenditure for different storage assignment solutions. To carry out this analysis, a bi-objective model is developed.
(2) Analyze the trade-off between order picking time and energy expenditure by varying typical warehouse parameters, such as the shelf-shape or the COI curve. The construction of Pareto frontiers supports the analysis of the outcomes.
(3) Integrate energy expenditure into the function of total order picking time. This is based on the introduction of the rest allowance formulation (Price, 1990), which converts the energy expenditure rate into a relative time value. This approach allows the calculation of an additional rest time that is required to maintain a low level of fatigue.
(4) Optimize the storage assignment problem based on the new integrated order fulfillment time function. A parametric analysis of its behavior permits the analysis of general results.

The remainder of this paper is organized as follows: the next section reviews the related literature. Section 3 illustrates the problem context and the main assumptions. Section 4 models and analyzes the bi-objective optimization problem, and then integrates the time and energy concepts by introducing rest allowance. The paper concludes in Section 5.

2. Literature review

Over the last decades, the literature on order picking had a major focus on the development of decision support models, which can be used to plan the picking process in practice (see, for reviews, De Koster et al., 2007; Gu, Goetschalckx, & McGinnis, 2007). The focus of decision support models for order picking is usually on one or more of the following planning problems: the routing of order pickers through the warehouse, the determination of the warehouse layout, the pooling and batching of orders, and the assignment of products to storage positions. The main objective of decision support models for these problems is to reduce the average distance the order picker needs to travel, and thus order picking time. As the focus of this paper is on the storage assignment problem, we give a short overview of the literature on this problem category in the following.

In general, products can be assigned to storage locations either randomly or based on certain criteria (such as the demand frequency of an item or the distance from the depot to the storage locations, for example), where the second alternative is often referred to as a dedicated storage assignment. When a random storage assignment is in use, items arriving at the warehouse are assigned randomly to open locations in the warehouse (Petersen, 1997). A special case of random storage assignment is closest open location assignment, where products are assigned to the next available storage position from the depot (De Koster et al., 2007). The major advantage of random storage assignment is high space utilization. In the case of a dedicated storage assignment, all items are assigned to fixed locations in the warehouse. A popular criterion for dedicated storage assignment is the turnover of products, where frequently-ordered products are assigned to storage locations near the depot (Rao & Adil, 2013). This method has the advantage that operators get familiar with the item assignment over time, which usually reduces the time they require for searching for items in the warehouse (Grosse & Glock, 2013, 2015). If demand rates change over time, then a turnover-based storage assignment would require a change in the product assignment according to the new demand characteristics, which might increase operation costs and lower performance as operators have to relearn the new assignment (Grosse, Glock, & Jaber, 2013). Another option is to implement a class-based storage assignment, which combines random and dedicated storage. In this case, all products are assigned to a number of different classes, for example according to demand characteristics, and each class is then assigned to a certain zone of the warehouse. Within each class area, storage is random. In the case of class-based storage, fast moving items (so-called A-items) are usually assigned to the zone that is nearest to the depot, which helps to reduce travel distance (Battini, Calzavara, Persona, & Sgarbossa, 2015; Chackelson, Errasti, Ciprés, & Lahoz, 2013; Ene & Öztürk, 2012). Another storage assignment method that aims at reducing travel distance is family storage, where products that are often ordered together are stored next to each other (Chuang, Lee, & Laih, 2012; Glock & Grosse, 2012). In addition, a storage assignment method that helps to reduce total fulfillment time is the concept of golden zone storage, where high-demand items are stored in the area between a picker's waist and shoulders (Petersen, Siu, & Heiser, 2005). This concept considers that less time is required for retrieving items from easily accessible positions than from positions that are difficult to access.

The literature on storage assignment discussed above widely focused on developing methods that reduce travel distance and