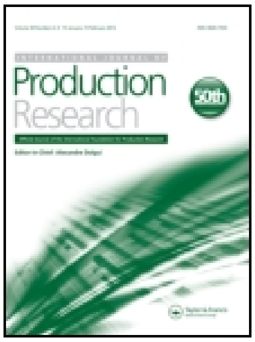

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Incorporating human factors in order picking planning models: framework and research opportunities

Eric H. Grosse[a]*, Christoph H. Glock[a], Mohamad Y. Jaber[b] and W. Patrick Neumann[b]

[a]*Carlo and Karin Giersch Endowed Chair "Business Management: Industrial Management", Technische Universität Darmstadt, Darmstadt, Germany;* [b]*Department of Mechanical and Industrial Engineering, Ryerson University, Toronto, Canada*

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Order picking (OP) activities, essential to logistics operations, are laborious and time-intensive. Humans are central actors in the OP process and determine both OP effectiveness and efficiency. Many researchers have developed models for planning OP activities and increasing the efficiencies of such systems by suggesting different warehouse layouts, OP routes or storage assignments. These studies have, however, ignored workers' characteristics, or human factors, suggesting that they cannot be substantiated, which led to only partially realistic results. This paper proposes a conceptual framework for integrating human factors into planning models of OP activities and hypothesises that doing so improves the performance of an OP system and workers' welfare. The framework is based on a systematic literature review that synthesises findings documented in the OP and human factors literature. The results of the paper may assist researchers and practitioners in designing OP systems by developing planning models that help in enhancing performance and reducing long-term costs caused by work-related inefficiencies.

Keywords: order picking; human factors; framework; production planning; ergonomics

1. Introduction

Order picking (OP) is the process of retrieving items from their storage locations in a warehouse to fulfil customers' orders. Its activities are labour-intensive and time-consuming, and they account for more than 50% of warehouse operating costs (Frazelle 2002; Tompkins et al. 2010). Although automating OP is possible, many firms still prefer to go manual. Their rationale for this is that humans are more flexible than machines in reacting to unexpected changes in the picking process, especially when a change requires logical reasoning to be dealt with, something that machines simply cannot do yet. De Koster, Le-Duc, and Roodbergen (2007) suggested that more than 80% of all orders processed by warehouses are picked manually, which has been confirmed in a recent study (Napolitano 2012). This suggests a managerial failure not to account for human characteristics (e.g. learning and forgetting, physical workload, body posture, etc.) when planning OP activities, which may lead to unexpected system underperformance. This makes considering human factors inevitable for operational success. 'Human Factors' (HF) – and synonymously ergonomics – research has two major objectives (Sanders and McCormick 1993, 4):

> The first is to enhance the effectiveness and efficiency with which work and other activities are carried out. Included here would be such things as increased convenience of use, reduced errors, and increased productivity. The second objective is to enhance certain desirable human values, including improved safety, reduced fatigue and stress, increased comfort, greater user acceptance, increased job satisfaction, and improved quality of life.

The reader may also refer to Woltager, Hancock, and Dempsey (1998) for a survey of various descriptions and definitions of HF and ergonomics.

In practice, one can observe an increasing attention to HF in internal logistics and manual material handling. Many firms today are continuously working to reduce ergonomic risks associated with jobs (including OP) that are manual and repetitive. Recently, many manufacturers of warehouse equipment, such as SSI Schäfer, Treston, Swisslog, Vanderlande Industries and Kaup, introduced storage tools that make manual OP tasks easier to perform by workers. These companies have combined sales of several hundreds of millions of dollars per year, with ergonomic warehousing tools gaining more and more importance. An example of such tools is the one developed by Kaup, which rotates pallets

*Corresponding author. Email: grosse@bwl.tu-darmstadt.de

after the front side has been emptied by the order picker (see Figure 1). This reduces the need by a worker to stretch and to bend to pick up items, and, subsequently, body fatigue and risks of injuries.

The reason why more and more companies develop ergonomic tools for OP is straightforward: OP activities involve repetitive tasks that may result in musculoskeletal disorders (MSD) for workers. MSD are the most reported causes for absence from work. They account for over 52% of all work-related illnesses and more than 2% of the gross national product in the European Union (Schneider and Irastorza 2010), where low back disorders are the most costly of the MSD (Marras et al. 1999). In the United States, back injuries were estimated at $12.2 billion (Dagenais, Caro, and Haldeman 2008). For this reason and in light of demographic changes and an increasing work lifetime, HF issues at work have gained importance. This is paralleled by legal initiatives in many countries, which leads to an increase in regulations that enforce occupational safety in logistics.

One may assume that the high practical relevance of HF in OP has led to substantial academic research in this area. The literature on OP, however, has focused mainly on design and control aspects, including layout design, storage assignment, routing, batching and different operating strategies (Chackelson et al. 2013). Reviews in this area are the ones of Cormier and Gunn (1992), Van Den Berg (1999), Rouwenhorst et al. (2000), Gu, Goetschalckx, and McGinnis (2007, 2010), and De Koster, Le-Duc, and Roodbergen (2007). It is worth noting that these reviews do not refer to works that explicitly study how HF interacts with the OP system. As a matter of fact, the term 'human factors' is not mentioned at all in these reviews, and 'ergonomic' is just mentioned once in a note stating that ergonomic conditions may be difficult to quantify (Rouwenhorst et al. 2000). It appears that human–system interactions in OP have inexplicably been ignored or assumed to be of constant effect and independent of the OP process in planning models (compare, for a similar discussion, Neumann and Dul 2010). Existing planning and optimisation models, therefore, provide an incomplete picture of real-world OP, which affects the quality of the planning outcome. This indicates that there is a gap between the situations studied in the literature and what is observed in practice, which suggests that there is a need to integrate HF into planning models of OP. We argue that if HF issues are integrated in OP planning models, for example, by defining a maximum acceptable pick height and depth in storage assignment, by limiting the maximum acceptable weight a picker is allowed to carry in routing policies or by modelling individual worker characteristics (e.g. learning or forgetting), then improvements can be realised in terms of long-term costs of OP, OP performance and worker well-being. New planning procedures that consider HF could then be implemented into Warehouse Management or Enterprise Resource Planning systems, which could help to generate more realistic plans for OP. There is currently no conceptual framework to facilitate such integration.

This paper contributes to the existing literature on OP by developing a conceptual framework that explores how HF can be integrated into OP planning models. It starts by breaking down an OP process into tasks and activities and then

Figure 1. Example of a tool to facilitate ergonomic OP from a pallet (Kaup GmbH & Co. KG, Germany).

identifies their HF components. Figure 2 illustrates the steps of the proposed methodology. These steps will be discussed in the subsequent sections.

The focus of this study will be on picker-to-part OP systems that are characterised by being labour-intensive. The results of this paper indicate that poor HF impede the performance of manual OP tasks and raises concerns relating to occupational health and safety of workers. The paper will also show that HF issues have mostly been ignored in the literature dealing with OP planning models. The developed conceptual framework facilitates understanding critical HF in each OP process step, and motivates future development of OP planning models that explicitly consider HF for improved OP system design.

2. The significance of HF in OP

Humans, being the primary actors in manual OP, work in an environment that is shaped by different OP design characteristics. In OP, the most important design characteristics are warehouse layout, storage assignment, routing and batching, and work organisation. Design characteristics can either facilitate or hinder human work. The outcome of the OP process is, however, not only influenced by the design of the system, but also by the characteristics of the order picker performing the required tasks. HF elements can be defined as interactions in a human–system relationship, and they can be subdivided into physical aspects (e.g. posture), mental aspects (e.g. competency) and psychosocial aspects (e.g. motivation or stress), which all have a direct impact on OP outcomes such as time, quality and workers' occupational health and safety (Neumann and Dul 2010). Figure 3 illustrates how HF could be considered when designing and planning processes for a system (e.g. production or OP). It is clear that in planning OP processes, the combined effects of OP design and HF have to be considered to achieve a good performance. Concentrating on the planning and optimisation of design aspects in OP without considering HF may lead to low performance, poor quality, and it may even place employees at risk of injury (Neumann 2004). For example, changes in product demand over time may require changes in storage assignments. Order pickers faced with such changes lose familiarity with an assignment, which requires them to relearn the new item locations (Grosse, Glock, and Jaber 2013). The design of shelf layouts that requires workers to adopt awkward and biomechanically disadvantageous body postures when picking items may cause discomfort and injury (NRC 2001). Both examples may result in poor worker and system performances. This illustrates that HF should be considered in OP operations and management decisions for performance, quality and employee safety considerations.

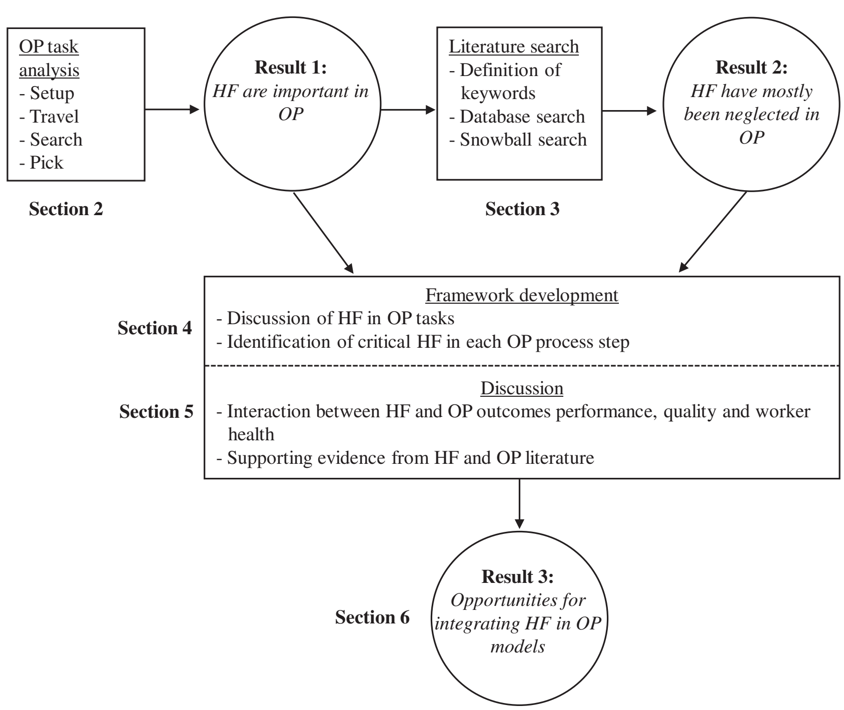

Figure 2. Approach and methodology.

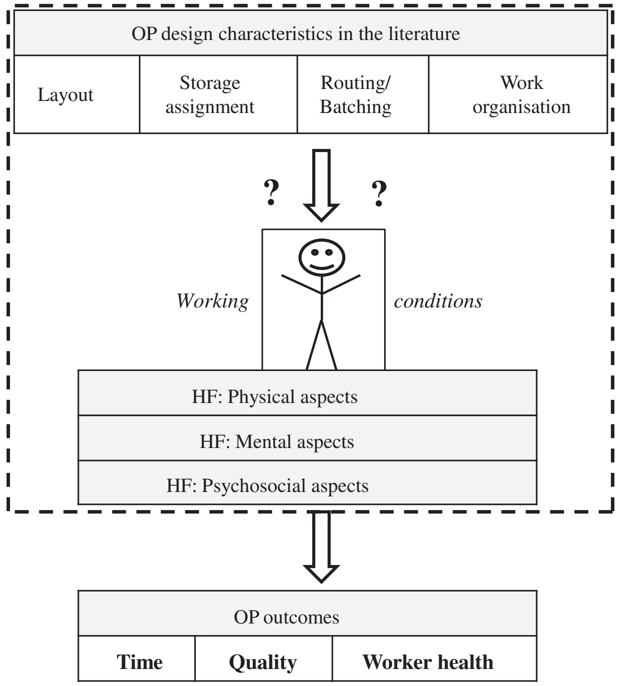

Figure 3. OP efficiency is determined by HF.

Many authors have noted that human worker characteristics have to be considered when planning production and operations management activities (e.g. Boudreau et al. 2003; Gino and Pisano 2008; Neumann and Dul 2010; Ryan et al. 2011; Neumann and Village 2012). These works are extensions of the 'Sociotechnical Systems' movement of the 1970's (Cherns 1976; Clegg 2000), an outgrowth of general systems theory (Skyttner 2001), which explicitly recognised operations systems as being made up of both technological and human elements which must work well together for improved results. Sociotechnical systems thinking has inspired hundreds of studies aimed at improving the fit between the technical system design and the human operators (e.g. Eijnatten et al. 1993). For operations management and manufacturing, Powell and Johnson (1980) and Karwowski et al. (1994) commented that workers' characteristics have to be considered as a determinant of operational outcomes. Despite these early calls, the collaboration amongst researchers from HF and operational research has been minimal (Ryan et al. 2011) and attention to HF in operations management research is rare (Dul and Neumann 2009; Neumann and Dul 2010). Lodree, Geiger, and Jiang (2009), who discussed how to incorporate HF issues into scheduling activities, mentioned that their work was inspired by the physical and cognitive challenges in OP; however, they did not study an OP process directly. Thus, for OP, incorporating HF into planning models is still lacking. Boudreau et al. (2003) criticised the operations management literature for failing to consider HF issues and for simplifying the modelling efforts by assuming that (i) workers are not a major factor, (ii) task times are deterministic, (iii) workers are homogeneous, (iv) breaks or absenteeism do not occur and (v) learning, forgetting and/or tiredness effects are ignored.

In order to identify relevant HF issues in OP tasks, a short description of the manual picker-to-part OP process is presented next. It is assumed here that the design of the OP system is already specified and that fulfilling orders is manual (see Figure 3). The OP process in a manual picker-to-part system can, briefly, be described as follows (De Koster, Le-Duc, and Roodbergen 2007): The order picker first receives information about an order on a (typically paper-based) pick list. The information specifies item identifications, the required amount to be picked, their locations and the sequence in which items should be picked. Next, the order picker moves to the storage locations, collects the required items and returns to the depot to drop-off the order. The collected items are then packed and shipped to (internal or external) customers. To fully utilise the capacity of an order picker, orders are often combined into batches, which are sorted after collection.

An OP process requires a set up to be initiated, a step that may include receiving orders from customers, sorting and prioritising them, preparing pick lists and sequencing the picks. In some warehouses, an order picker is constrained by following a predetermined pick sequence, while in other warehouses, he/she plans the pick sequence. The order picker usually receives a pick list after a previous one has been completed. After documenting and processing an order, the order picker begins collecting the required items. The activities involved are travel (reach a storage shelf), search (for the right items), pick-up (the right items and in the right quantities) and document (the pick). Collected parts are then carried, for example, by using a trolley. Upon completion, the order picker returns to the depot and completes the process by packing and sorting the items (if required) and by documenting that an order has been completed. OP time as an outcome (see Figure 3) can be split according to the tasks performed as follows (Tompkins et al. 2010):

- *Set up time*: the administrative time an order picker spends prior to the pick tour.
- *Travel time*: the time an order picker spends in the warehouse travelling to, from and between the storage locations (aisles).
- *Search time*: the time required by an order picker to identify the parts to be picked from the shelves of the warehouse.
- *Pick time*: the time to collect parts from their storage locations, which includes documentation, verifying the correctness of a pick, interruptions and restocking.

It is clear from the above that humans are primary actors in the manual OP process. The design characteristics of an OP system can affect workers positively or negatively. Despite its importance, HF has generally not been considered in OP research. To show to what extent HF have been considered in OP models in the literature so far, and to motivate our framework by the lack of prevalence of OP models that consider HF, we conduct a systematic search of the literature in the next section.

3. A systematic literature review

To get an overview of the state-of-the-art of HF research in OP, we conducted a systematic literature search based on the methodology developed by Neumann and Dul (2010), Glock and Hochrein (2011) and Hochrein and Glock (2012). To study the impact of HF on the performance of OP systems, it is necessary to consider research from several disciplines. We aim here to isolate literature at the intersection of HF and OP fields. Our search of the literature consisted of the following steps: (a) defining relevant keywords, (b) searching two databases and (c) identifying relevant papers. These steps are detailed in the following subsections.

3.1 *Keywords definition and literature search*

Two lists of keywords were prepared to identify works that study HF issues in OP. As shown in Table 1, the keywords are associated with the OP tasks described in Section 2 and divided into two groups. Group A lists two keywords: 'order picking' and 'warehouse', whereas Group B lists the HF keywords related to OP tasks. To generate the final keyword list, each keyword from group A was combined with each keyword from group B. The keywords were used to search two scholarly databases, namely Business Source Premier and Scopus. To be included in the sample, a paper was required to have at least one combined term (e.g. warehousing and learning, OP and error, etc.) from the final keyword list in its title or abstract. In a second step, the references of the papers contained in the sample of identified papers were investigated for relevance using the 'snowball approach' described in Hochrein and Glock (2012).

Table 1. Keywords used in the systematic search of two databases.

Investigation area keywords (A)	Tasks	HF keywords (B)
Order picking, Warehouse	Set up	Setting up, preparation
	Travel	Workload, carrying, pushing, pulling
	Search	Searching, remembering
	Pick	Manual handling, lifting, lowering, posture, occupational disease, low back pain
	All	Human factors, ergonomics, learning, error, motivation, boredom, stress, fatigue

3.2 *Paper selection*

Papers identified in the literature search were subjected to several selection filters in the second step. Specifically, works were only considered if (i) their language was English, (ii) they had appeared in a peer-reviewed journal and (iii) their abstract indicated that the paper focuses on OP and considers HF explicitly.

3.3 *Results*

The database search resulted in 479 papers, of which 15 papers were identified as relevant with four additional ones identified using the snowball approach, totaling 19 relevant papers. About half of the papers appeared in the International Journal of Industrial Ergonomics. Most of the 19 papers dealt with ergonomic issues (risk assessment of OP physical tasks) relating to manual material handling in warehouses. A short summary of search results is provided below:

- Result 1: Manual OP tasks are repetitive, and repetitiveness causes workers to develop MSD over time, especially if the tasks involve postures that cause discomfort on the joints and backs of workers (Garg 1986; Ljungberg, Kilbom, and Hāgg 1989; Braam, Van Dormolen, and Frings-Dresen 1996; Waters, Putz-Anderson, and Baron 1998; Kadefors and Forsman 2000; Christmansson et al. 2002; Ulin and Keyserling 2004; St-Vincent et al. 2005; Denis et al. 2006; Lavender et al. 2006, 2012).
- Result 2: Warehouse operations represent a risk environment for occupational accidents (De Koster, Stam, and Balk 2011).
- Result 3: Workers learn as they perform OP tasks repetitively. Learning was found to reduce both time needed and errors made in OP work (Grosse and Glock 2013).
- Result 4: Workers' motivation impacts the performance of an OP system (St-Vincent et al. 2006; Berger and Ludwig 2007; Lodree, Geiger, and Jiang 2009; Goomas and Yeow 2010).
- Result 5: The search of the literature identified a paucity of the work, rather a research opportunity, which incorporate HF in the design or modelling of OP systems, with two papers identified. Petersen, Siu, and Heiser (2005) compared several established storage assignment strategies and proposed one utilising the concept of 'golden zone picking' to reduce pick time, where the 'golden zone' is the area between a picker's waist and shoulders. Grosse, Glock, and Jaber (2013) considered worker learning in an OP model and studied its effect on storage assignment decisions.

The above results indicate that HF issues have not been considered to their fullest extent in OP. There is clearly a need for analytical models that measure how HF issues impact the performance of OP systems and the well-being of workers. However, there is currently no guidance in the literature that supports the development of such studies. Hence, we proceed next to develop a framework for incorporating HF in OP and identifying future research opportunities.

4. Conceptual framework

The conceptual research framework developed in this section is based on the fundamental concepts of human–system interactions that can be found in many ergonomics textbooks (Sanders and McCormick 1993; Karwowski 2005; Salvendy 2012). These concepts identify four critical elements in human–system interaction: perceptual, cognitive/mental, motor/physical and psychosocial aspects of work. Psychosocial aspects include non-physical work dimensions, such as job satisfaction, job demand and control, work monotony, work pressure, supervisory relations and feedback (Karasek and Theorell 1990; Smith 1997). They impact workers' motivation and stress level, which is linked to performance and health outcomes (Moon and Sauter 1996; Layer, Karwowski, and Furr 2009; Häusser et al. 2010). To illustrate the human–system interaction in OP, we present the following example with regard to OP: the worker receives information on a pick list, perceives the information by reading (which items to pick), searches for items on the shelves (mental task) and, finally, physically grasps items. OP time, quality and worker health present the outcomes of this process.

Based on this fundamental concept, we suggest evaluating HF, i.e. perceptual, mental, physical and psychosocial aspects, for each activity performed in the OP tasks: set up, travel, search and pick, which are summarised in Table 2. The HF aspect examples listed in Table 2 are of special importance for an OP process. To gain insights into how these aspects may influence the outcome of an OP process, Figure 3 and Table 2 are used to develop the conceptual framework for incorporating HF in OP (see Figure 4).

Table 2. Examples of critical HF aspects for each OP task type.

HF aspects	OP tasks: Set up	Travel	Search	Pick
Perceptual	• perceive set-up operations	• perceive warehouse layout	• Read pick lists	• perceive pick operations and technical support
Mental	• receive and sort pick lists • Process documents	• Understand and remember pick route	• Search and identify items • Remember item locations	• Decide how to grasp and transfer a given item correctly
Physical	• Set up workstation	• Travel between depot and pick locations • Carry items • Pull/Push trolleys	• Neck flexion extension	• Stretch, bend, reach for items • Extract, grab, pick, put down items
Psychosocial	Motivation, stress, workload, boredom, work organisation, co-worker and supervisory support			

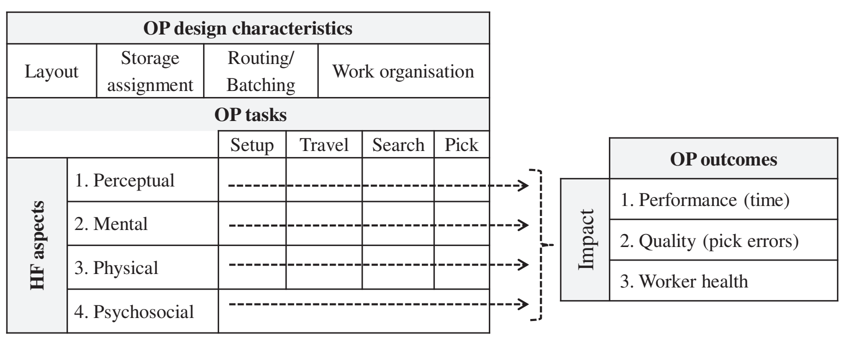

Figure 4. Conceptual framework for incorporating HF in OP.

The framework focuses particularly on the following outcomes:

(1) Performance (e.g. time per order or product position),
(2) Quality (e.g. percentage of pick errors of total volume) and
(3) Occupational health and safety (e.g. number of work-related illness cases per year).

Each of these will now be addressed briefly.

4.1 *Performance impact*

Reducing travel time is what all OP systems managers would like to attain (De Koster, Le-Duc, and Roodbergen 2007). Although various case studies (e.g. Denis et al. 2006; Van Zelst et al. 2009) showed that activities other than travelling contribute to OP time, travel time is often regarded as the dominant component. This is why most studies in the literature focused on minimising travel time and ignored other time components such as set up, search and pick time. Certainly, in practice, these time contingents can have a significant impact on OP performance as they are dependent on HF. For example, an order picker who is not familiar (less experienced) with a storage location assignment may need much more time to search for and identify items on shelves than an experienced one who can locate items faster (Grosse and Glock 2013). Similarly, fatigue, or discomfort and pain, can affect the performance of the worker. Most papers, however, explicitly or implicitly assumed that the pick time is of a constant value (Larco 2010). This is unrealistic due to the heterogeneity of warehouse layouts and stored items. Furthermore, worker travel speed can have a significant impact on total travel time (Hong 2014). Bartholdi, Eisenstein, and Foley (2001) and Van Zelst et al. (2009) noted that work speed of an operator should be taken into account in OP models. Hence, HF that impact all OP tasks and thus time contingents have to be investigated and should be considered as a system variable.

4.2 *Quality impact*

A picked order is subjected to quality control in many cases to ensure that no errors occurred during picking. This step can either be performed by an order picker in real time, or after the order has been received at the depot by an inspector, either visually or using some technology (such as barcode scanners). It may happen that some wrong parts of an order are picked, which is not possible to avoid completely. Picking the wrong parts makes correcting a pick necessary, which increases the order delivery lead time. In a worst case scenario, a wrong order delivered to a manufacturer, for example, may result in an interruption of the production process, longer than usual lead time, shortages and disruption in the supply chain, which may subject the warehouse (supplier) to additional costs and penalties. Pick errors occur when a wrong item and/or a wrong quantity is picked, for example, as a result of perceptual errors or when items and orders are misplaced. Pick errors result from storage methods, picking methods and other environmental and design factors, such as light, noise, package, design of the pick list or coordination among pickers (Burinskiene 2010). If, for example, the design of item address labels includes small font, low contrast printing and long numeric strings, then perceptual and cognitive errors are likely to result in pick errors and associated costs. As pick errors are an important issue, HF affecting the quality of picks need to be discussed.

4.3 *Occupational health issues*

The size, weight, volume, location and position (depth and height) of an item to be picked affect the well-being of an order picker. For example, the order picker needs to travel along the aisles of the warehouse to retrieve items, which may in some cases be excessive and accumulate muscle, knee and ankle fatigue causing injury at some point in time, especially if carrying. To retrieve items from the shelves of the warehouse, bending and stretching the body may be necessary. The excessive manual handling of material in OP systems, i.e. peak and/or accumulated load, poses a great risk of workers developing MSD (Norman et al. 1998). This remains to be a challenging problem to many managers and system designers as MSD and related absenteeism from work cause high long-term costs (Punnett and Wegman 2004). In addition, sickness presenteeism, the phenomenon that operators remain at work despite health problems such as musculoskeletal pain, may lead to substantial economic losses due to decreased on-the-job performance and longer recovery time (Meerding et al. 2005; Schultz and Edington 2007). Thus, the impact of HF in OP on worker's health needs to be discussed and the results should be incorporated into planning the OP process.

4.4 *Results of the systematic literature review in light of the developed framework*

Table 3 classifies the 19 papers (with percentage share) noted in Section 3 in accordance with the framework proposed in Section 4. Table 3 is arranged into a 4×4 matrix, with rows representing HF aspects and columns OP tasks. The results in Table 3 reveal that, with some notable exceptions with regard to physical workload in picking tasks, HF issues have largely been ignored with respect to the key tasks of OP. However, there is literature available that helps understanding the impact of HF in each OP tasks. Thus, the approach carried out in the next section is to review and discuss the research relevant for integrating HF in OP.

5. Discussion

In this section, the conceptual framework presented in Section 4 will be used to analyse OP tasks. That is, HF aspects of each task are studied to evaluate how they impact OP performance, quality and worker occupational health. Supporting evidence from the literature will be used for every HF aspect. We discuss the impact of each HF aspect on

Table 3. Identified papers in light of the developed framework.

		OP tasks			
		Set up	Travel	Search	Pick
HF aspects	Perceptual	0	0	0	0
	Mental	0	0	2 (11%)	0
	Physical	0	0	0	13 (68%)
	Psychosocial	4 (21%)			

OP outcomes in sequence as listed in Figure 4. Based on this discussion, research opportunities for integrating HF in OP planning models are presented in Section 6.

5.1 *Perceptual aspects*

5.1.1 *Perceptual aspects and performance impact*

In OP, perceiving the task information by reading a pick list is critical. Thus, OP time is affected by the design of the information system, in this example the way in which the order picker receives and processes the information and converts it to useful knowledge. For manual OP systems, which use paper-based pick lists, the design, content and layout of the pick list need to be studied with regard to the possible influence on, mainly, search time. For example, if the font size is very small or the items' numbers are very complicated to read and recall, the order picker may need to spend more time reading and perceiving the information on the pick list. Pick list design has not yet been explicitly studied in the context of OP. However, some works referred to methods that could be used to improve pick lists. Brynzér and Johansson (1995) suggested improving a pick list by transforming it into a sort of map by reproducing the storage locations on the list and by marking the pick location with the appropriate number of items to be picked. This approach is similar to that of Weaver et al. (2010), who empirically studied the impact of using an optimised paper-based pick list. They included a graphical representation of the layout of the shelves and order bins in combination with a highlighted number representing the number of items to be picked in the list. They observed that the order pickers needed less time to identify which items need to be picked if the modified pick list was used, as compared to a classical pick list. Bishu, Donohue, and Murphy (1991) implemented colour and spatial positions on the pick lists and observed reduced search time in a laboratory study. Furthermore, the authors touched upon the issue of how numbers should be presented to reduce search times. They also proposed to use shorter item numbers and eliminate extraneous information. To give further recommendations for pick list and item number design, we refer the reader to works on legibility of printed materials (Hartley, Fraser, and Burnhill 1974), font size/style (Wogalter and Vigilante 2003), number of digits per item on the paper (Conway et al. 2002) and highlights in text (Lorch 1989). Some studies recommend that font size be in the range of 9 to 12 points (Arditi and Cho 2005) in combination with light levels between 538 and 1076 lux (Charness and Dijkstra 1999). The studies mentioned here also apply to the labelling and coding typography of shelves in OP warehouses. Bishu, Donohue, and Murphy (1992) recommended from their laboratory study that a shelf coding is to be read from left to right and from top to bottom with a continuous presentation of the location address.

Although this paper focuses on traditional OP systems with paper-based pick lists, it is noted here that paperless information technologies, such as pick-by-light (Hanson, Medbo, and Medbo 2012) or pick-by-vision (Schwerdtfeger et al. 2011), may support human information processing and reduce search time. In addition, the time needed for information input can be considerably reduced by bar code scanning and radio frequency identification, e.g. scanning the bar code label on the pick list and the bar code on the shelve position instead of searching, writing and checking pick list positions (Gudehus and Kotzab 2012). However, HF issues should also be considered by employing paperless information technologies; for example, the use of pick-by-vision may lead to excessive eye strain.

5.1.2 *Perceptual aspects and quality impact*

In addition, poor perception may affect the quality of an OP job. Brynzér and Johansson (1995) reported frequent causes of pick errors such as reading mistakes or inappropriate exposition of parts, among others. Pick errors were also observed to decrease by using paperless information technologies (Lindau and Lumsden 1999; Reif et al. 2010; Schwerdtfeger et al. 2011; Yeow and Goomas 2014).

5.1.3 *Perceptual aspects and health impact*

Although there is no evidence in the OP literature that perceptual aspects impact worker health, there are works reporting visual discomfort in the office ergonomics literature (Aarås et al. 2001) that may be linked to reading pick lists or using paperless displays in OP. We note, however, that under poor visual conditions, people may adopt an awkward posture as they strain to read the required labels – a physical loading response that can contribute to neck and back strain over the long term. Next, the second of the identified HF aspects, i.e. mental, is discussed.

5.2 *Mental aspects*

The design of the OP system can influence the mental load on employees, the memory demands and the procedural aspects related to special cases or error recovery routines. Mental (cognitive) tasks in OP are largely repetitive in each process step. Thus, mental tasks in OP may be subject to the phenomenon of learning-by-doing. Learning may improve the capabilities of an order picker requiring him/her less time to complete an order as more and more picks are performed. As a consequence, the time required to pick orders may follow a learning curve (Grosse and Glock 2013), where an order picker remembers and acquires knowledge over time about the warehouse layout, shortest path/pick route, location of parts/items on shelves, retrieval procedure or verification/validation. Searching for items on shelves and validating their conformance to the records on a pick list is a cognitive task that involves learning. Other OP tasks, such as travelling and picking, may involve lower levels of learning (motor task). The application of the learning curve to different industrial settings is well documented in the literature (e.g. Anzanello and Fogliatto 2011; Jaber 2013). However, consideration of learning (and, consequently, forgetting) in OP models is rare.

5.2.1 *Mental aspects and performance impact*

As hypothesised in Table 2, learning-by-doing may impact every OP process step. The fact that worker's learning reduces OP time was empirically validated by Grosse and Glock (2013), who deduced that it happens most in the search activities. Bishu, Donohue, and Murphy (1991, 1992) conducted a laboratory experiment of an OP process to study the influence of cognitive task elements, e.g. colour, position, coding and address information, on the speed of recognition and perception of humans, i.e. search time. They were also able to observe learning effects by simulating the search process. Several studies suggested a potential relationship between worker familiarity with storage assignment and reduced search time (Wäscher 2004; Bindi et al. 2009; Van Zelst et al. 2009; Chuang, Lee, and Laih 2012). These authors linked worker familiarity (which implicates learning) with the dedicated storage assignment strategy, where each product is stored at a fixed location in the warehouse. With a random storage assignment in use, order pickers may have significant difficulties getting familiar with the storage locations of items as they are stored in different locations over time. Random storage is typically used in situations where the product assortment changes too fast, making it difficult to produce reliable statistics about demand frequency. Thus, design aspects (storage assignment) may impact HF directly by influencing the picker's learning ability, and it may thus determine performance as OP time components are not constant.

As indicated above, remembering pick routes and how to perform the picks involves cognition. Another related aspect is that complex OP routes may cause confusion and induce the order picker to question the routes, which may lead to an increase in OP time. Some authors mentioned that routes with clear patterns reduce the time spent by order pickers searching for locations (Roodbergen and De Koster 2001; Petersen and Aase 2004). Gademann and Van De Velde (2005) mentioned that order pickers may deviate from a specified pick route if they think it is illogical. The authors noted that empirical evidence of this phenomenon has been reported by Dekker et al. (2004); however, they did not study the reasons and implications of such human behaviour.

5.2.2 *Mental aspects and quality impact*

Besides their effect on the performance of an OP system, mental tasks may also affect the quality of a pick. Grosse and Glock (2013) empirically observed that pick errors reduce as the number of executed orders increases. This corroborates the note of Brynzér and Johansson (1995) that pick errors occur when the information about the storage locations of items has been changed or the storage assignment is confusing or incorrectly conceived by the order picker. In addition, Roodbergen and De Koster (2001) noted that routes having a clear pattern also reduce the risk of pick errors, which confirms these results.

5.2.3 *Mental aspects and health impact*

Besides items' locations, the order picker has to remember how to pick items correctly. Workers can improve their posture in manual handling tasks by trial and error over time. However, training to get the correct posture improves workers' performance faster (Winstein et al. 1996), in particular, in manual warehousing tasks with a high impact on fatigue and injury risks, such as lifting (Chaffin et al. 1999; Lavender, Lorenz, and Andersson 2007; Holmes et al. 2008; Faber, Kingma, and Van Dieën 2011). The impact of mental aspects on worker health is also linked to psychosocial aspects, so we refer to the discussion in Section 5.4. Following the framework illustrated in Figure 4, we discuss the impact of physical aspects on OP outcomes in the following section.

5.3 *Physical aspects*

Manual material handling tasks in OP involve physical activities, such as traveling between and along the racks, carrying loads, pushing/pulling trolleys, stretching, bending, lifting and extracting items (see Table 2).

5.3.1 *Physical aspects and performance impact*

Excessive manual handling may manifest in muscle fatigue and discomfort, which may decrease performance. Only few authors noted a relationship between physical tasks in OP and performance (Landers et al. 1994; Gong and De Koster 2011). These authors mentioned, for example, that pick time can depend on the size, weight and number of items per pick and ergonomic issues such as accumulated fatigue, but did not elaborate how. The work of Petersen, Siu, and Heiser (2005) is the only one that incorporates the idea of a layout-dependent pick time in storage assignment strategies. The authors compared several established storage assignment strategies and proposed the concept of 'golden zone picking'. According to this concept, high-demand items should be stored in the area between a picker's waist and shoulders to improve picking performance and to reduce picker fatigue.

It is surprising that OP research has not yet followed up on this line of thought, although there are many studies available in the literature that focus on factors that affect pick time in similar settings, especially in the manual material handling literature. In their experimental study, Finnsgård and Wänström (2013), for example, focused on manual picking at assembly lines and observed that factors such as packaging, part size and weight as well as shelf layout, vertical pick distance and level/angle of exposure impact the speed of manual picking significantly. Other authors who studied picking in assembly lines observed a variable pick time depending on the weight of items (Nordander et al. 2004; Escorpizo and Moore 2007; Lavender et al. 2012), the layout of shelves and the reach distance to pick an item, i.e. the distance between the vertical plane containing the ankle and shoulder joints, which is known to affect human isometric strength exertion capability (St-Vincent et al. 2005; Wänström and Medbo 2009; Hanson, Medbo, and Medbo 2012).

5.3.2 *Physical aspects and quality impact*

As discussed in the previous sections, pick errors occur in OP mainly due to cognitive mistakes. However, physical aspects may also contribute to impact quality. This is the case when pick errors occur to so-called 'slips'. A slip is defined as an action not in accord with the actor's intention (Zapf and Reason 1994). A slip in OP occurs, for example, when the operator drops an item accidently or a wrong item is picked due to distraction. There has been little research in this area of immediate use for OP system design.

5.3.3 *Physical aspects and health impact*

Our literature review showed this to be the most studied aspect of HF in OP system design, especially in travel and pick tasks.

Travel: Table 2 shows that physical tasks, such as carrying loads and pushing/pulling trolleys, are necessary when travelling in warehouses. In this step, the physical capacity constraint of the order picker and/or the capacity constraint of the pick device become major factors. Repetitive wrong body posture, overexertion of force lifting, carrying or moving items and excessive travel within the warehouse may have the workers develop MSD. There is evidence that energy expenditure during walking increases linearly with the weight of the carried load and may cause fatigue. The effects of carrying load (Abe, Muraki, and Yasukouchi 2008), pushing/pulling carts (Jung, Haight, and Peacock 2005; Hoozemans, Kingma, and De Vries 2008; Nimbarte et al. 2013) and the layout of carts/trolleys (Shoaf et al. 1997; Al-Eisawi et al. 1999) on the risk of developing MSD have been studied widely in the ergonomics literature. Thus, physical tasks in OP travel can be confirmed to impact worker health. Hence, it is surprising that these aspects have not yet been considered in the OP literature. A closer look at the literature reveals that the carrying capacity of the order picker has been considered in the order batching problem (Gu, Goetschalckx, and McGinnis 2007). In order batching, orders are consolidated and/or divided into sets of orders to form a single pick route in light of the pick device capacity. The objective typically is to minimise the total travel time required for picking and sorting all items contained in the batch (Gademann and Van De Velde 2005). Research on order batching thus far expressed the limited capacity of the order picker or pick device as a maximum number of items that can be picked per route (e.g. Bozer and Kile 2008; Glock and Grosse 2012; Henn and Schmid 2013). This is unrealistic due to the heterogeneity of the items stored in warehouses and the impact of physical workload on workers' health. To the best of the authors' knowledge, there is only one study that formulated a capacity constraint by referring to item weight (Kulak, Sahin, and Taner 2012).

Pick: Table 2 illustrates that physical aspects involve pushing, pulling, carrying, lifting, lowering, reaching and bending for items. As discussed, these tasks may not only have a performance impact, but also a health impact (NRC 2001). Properly designed pick tasks can increase the workers' productivity, but also reduce the risk of injury on the job (Neumann et al. 2002; Neumann and Medbo 2010). Although many of the published works on manual materials handling tasks and the associated health risks appeared in the ergonomics literature (for surveys and reviews, see for example Ciriello and Snook 1999; Vieira and Kumar 2004; Denis et al. 2008, and for the effects of lifting on low back load in particular see Waters, Putz-Anderson, and Garg 1993; Hoozemans, Kingma, and De Vries 2008), few of those papers deal specifically with OP and/or warehousing directly. Some authors observed awkward postures, heavy load lifting, physical stress, discomfort and, thus, high risk for workers to develop MSDs due to poor ergonomic design in warehouse operations using experimental approaches with questionnaires and/or video recordings (Garg 1986; Ljungberg, Kilbom, and Hāgg 1989; Kuorinka, Lortie, and Gautreau 1994; Braam, Van Dormolen, and Frings-Dresen 1996; Waters, Putz-Anderson, and Baron 1998; Kadefors and Forsman 2000; Christmansson et al. 2002; St-Vincent et al. 2005, 2006; Ryan and Haslegrave 2007; Lavender et al. 2006, 2012). Examples for ergonomic evaluations of potential hazards of repetitive lifting, excessive work pace and stress associated with OP tasks in warehouses were given by some authors (Putz-Anderson et al. 1993; Wick and Deweese 1993). There are also works available that study the effects of physical warehousing operations, such as lifting, and gender differences on worker well-being (Garg and Saxena 1985). Other authors presented examples of successfully implemented ergonomic intervention programmes in warehouses (Marklin and Wilzbacher 1999; Ulin and Keyserling 2004; Lavender et al. 2010) aimed at reducing physical workload and associated injury risks for workers.

The next section discusses the impact of psychosocial aspects on OP outcomes according to the framework in Figure 3.

5.4 *Psychosocial aspects*

Psychosocial aspects are relevant for each task in OP (see Table 2) and may have a significant impact on all outcomes performance, quality and worker's health. Psychosocial aspects, which we consider to be important in OP, are motivation, stress and workload, boredom, structure of workforce and work assignment. The reader may further refer to Moon and Sauter (1996) for the basic demand-control model with regard to the impact of psychosocial aspects on worker health and performance.

Motivation: Lodree, Geiger, and Jiang (2009) noted that human motivation is fundamental to assessing performance and that it needs to be considered when scheduling human tasks. Motivation increases performance and can be promoted, for example, by bonus programmes, shares and other incentives (Goomas and Ludwig 2007), feedback and work satisfaction (Shikdar and Das 2003), and new challenges (Hackman and Oldham 1976). In addition, motivation can be promoted by the number, placement and duration of rest times during a work period, which also impacts performance (Lodree, Geiger, and Jiang 2009). Flexible work assignments and the suitable assignment of workers to shifts affect worker productivity (Attia, Duquenne, and Le-Lann 2014). Besides, to increase motivation, work/rest and vacation periods scheduling should be included in planning OP processes (Maceachen, Polzer, and Clarke 2008; Larco 2010). In turn, motivation can be compromised by poor system design, e.g. OP systems that do not consider HF and thus lead to poor working conditions. Some authors also identified motivation in terms of feedback to reduce pick errors in OP tasks. Berger and Ludwig (2007) and Goomas and Yeow (2010) observed a significant reduction in pick errors after implementing a voice-assisted selection tool that provides immediate feedback when errors occurred. Bateman and Ludwig (2004) showed that when feedback is combined with goals and incentive programmes, pick errors can be reduced.

Stress and workload: Human performance and health can be heavily influenced by workload, stress and fatigue (Marras et al. 2000; Lodree, Geiger, and Jiang 2009). Stress and workload on the job, especially in warehousing, can be provoked by time pressure (St-Vincent et al. 2006), occupational/environmental hygiene factors such as light level, temperature, noise, air quality, workplace cleanness and safety (Naqvi, King, and Rook 2001; De Koster, Stam, and Balk 2011) as well as system failures that block performance, such as illegible printouts, machine breakdowns or bad information. In experimental studies, physical work, such as manual lifting, lowering, carrying and turning tasks, were found to be mentally fatiguing (Mital, Founooni-Fard, and Brown 1993; Chen, Jung, and Peacock 1994). Pick errors are also supposed to be influenced by fatigue or time pressure which forces rushing (Jaber, Givi, and Neumann 2013). However, this aspect has not been studied in the OP literature. Evidence for the connection of human errors and fatigue or working speed can be found in the aviation literature (Latorella and Prabhu 2000), for example.

Boredom: There is significant and positive correlation between the performance of repetitive tasks and worker boredom, which can be decreased, for example, by job rotation strategies (Azizi, Zolfaghari, and Liang 2010).

Structure of workforce and work assignment: Psychosocial well-being of an order picker may also be influenced by human resource management strategies, such as workforce structure and labour turnover (Autry and Daugherty 2003; Min 2007), ratio of temporary to tenured workers (Stratman, Roth, and Gilland 2004; Techawiboonwong, Yenradee, and Das 2006), as well as workforce age (Shin, Nance, and Mirka 2006). There is also evidence that the experience of psychosocial working conditions is different for immigrant workers, e.g. due to specific language skills (Hoppe, Heaney, and Fujishiro 2010).

6. Research opportunities

6.1 *Planning models*

Our survey indicates that the design and organisation of OP processes and their interdependencies with HF can have a significant impact on the efficiency of the OP system. We have identified several important issues that should be considered in the design of OP systems, which is supported by the development of suitable OP planning models that explicitly consider HF. These issues are:

- Humans are central to OP systems, and the human–system interaction can be a determining factor for system performance, quality and worker health.
- Task times are not deterministic.
- Workers are heterogeneous.
- Human errors occur.
- Human learning, forgetting, boredom and tiredness occur.
- Workers are exposed to occupational health and safety issues.

As the interaction of HF and OP system design and outcomes is largely understudied, we use the framework introduced above (see Figure 4) to develop example propositions for future research that considers HF in OP. The formulation of our propositions is based on four steps, as illustrated in Figure 5, that is:

(a) identify which HF aspects should be considered;
(b) establish a relationship between HF and OP design aspects;
(c) suggest emerging research opportunities; and
(d) propose modelling opportunities for the integration of HF into OP.

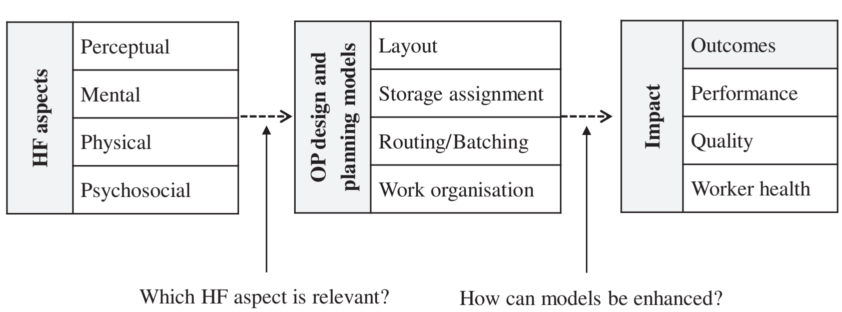

Figure 5. Formulation of propositions.

We note that each HF aspect may have an impact on each OP design aspect, so the four propositions presented here may be seen as examples of how HF could be considered in models to help design better OP systems based on this systematic framework.

Proposition 1: Further objectives besides travel time minimisation should be considered in OP system design.

Relevant HF aspect: Perceptual aspects and specifically human information processing (see Section 5.1).

Relationship to OP system design: Layout and storage assignment.

Research opportunities: Studies could investigate how pick errors can be reduced by promoting human information processing, for example, by developing alternative storage assignment strategies that help reducing pick errors, or by studying the trade-off between investment cost in paperless information technology and return on investment due to lower pick errors.

Modelling suggestions: Storage assignment policies could be developed that consider the restriction that similar items (e.g. in shape, colour, weight) are not stored close to each other to avoid confusing the order picker and reduce the chance of error. For example, items could be assigned according to their demand frequency to locations close to the depot, but a restriction could be considered that blocks storage positions close to similar items for the item to be assigned. A possible starting point could be models that assign products to shelf spaces based on multiple item characteristics, such as demand frequency or demand correlations (e.g. Glock and Grosse 2012). To evaluate the impact of this storage assignment strategy, the reduction in pick errors needs to be modelled, and it needs to be weighted against a potential increase in travel time.

The trade-off between investments in paperless information technologies, such as pick-by-light, and reduced probabilities of pick errors could be modelled, implying a higher probability of pick errors when paper-based pick lists are used. Furthermore, the design of the pick list layout (paperless or paper-based) and its impact on human perception could be studied in a layout design model. In such a model, the cost for changing an existing OP layout to promote human information processing by revising the design of pick lists and shelf presentation could be studied and compared to a benchmark scenario with poor pick list design.

Proposition 2: An OP system should be designed to promote learning.

Relevant HF aspect: Mental aspects, and specifically human learning and forgetting (see Section 5.2)

Relationship to OP system design: Storage assignment and routing.

Research opportunities: Studies could investigate how storage assignment affects learning, and if learning also occurs when storage assignment is random. In addition, revised routing policies that reduce memory demands without demotivating or boring the order pickers could be developed.

Modelling suggestions: Learning and forgetting could be considered in OP planning models by integrating learning and forgetting curves, which allow the modelling of performance improvements over time. For example, it could be assumed that pick errors, search time or travel time are subject to learning, and that they reduce as a function of the cumulative number of orders processed by the order picker. Possible topics could be to model the trade-off between shorter search time as a result of learning (dedicated storage) and low space utilisation because of reserved space for every item type in the warehouse. Along this line of thought, changing an existing storage assignment will probably lead to a reduction in the performance of the OP system, as order pickers have to relearn the new assignment (Grosse, Glock, and Jaber 2013). In addition, the structure of the workforce, i.e. the ratio of temporary workers (with low skill levels) to permanent workers (with high skill levels), may also impact OP performance and should be studied in detail, for example, by modelling different starting points of the learning curve of both worker types and by investigating how their performance improves over time. The impact of employee turnover on the skill level of the workforce may also be worth investigating in a storage assignment planning model.

In addition, future research could also integrate the concept of learning and forgetting curves into OP routing policies. Research could, for example, develop routing policies that are not necessarily optimal, but rather logical to order pickers and thus easy to learn (Brynzér and Johansson 1996). In such scenarios, learning could be modelled as an increasing average travel speed over time or a reduction in travel time as the number of processed orders increases. There are a few works that consider driver's learning in vehicle dispatching and planning problems, where efficient routes for the delivery of orders are developed (Zhong, Hall, and Dessouky 2007; Kunkel and Schwind 2012). As this problem can be compared to routing order pickers, these works may be a starting point for quantitative research on the effect of worker learning on OP travel time.

Proposition 3: The effects of work-related injury risk factors should be considered simultaneously on OP outcomes performance, quality and worker health.

Relevant HF aspect: Physical aspects, and specifically factors that lead to worker discomfort, such as repetitive lifting or heavy loads (see Section 5.3).

Relationship to OP system design: Layout, storage assignment, routing and batching

Research opportunities: Studies could develop layout and storage assignment models that minimise worker discomfort. OP routing and batching models could integrate ergonomic principles. In addition, the effect of variable pick time, depending on item characteristics, on OP efficiency could be studied.

Modelling suggestions: Models that aim on minimising worker health risks could build on the work of Finnsgård et al. (2011), who presented an ergonomic classification of different height levels of storage locations in flow racks. Although the authors studied assembly workstations, this classification can be applied to warehouse shelves as well and could be used to develop new storage assignment strategies. As quantifying the benefit of ergonomic interventions is difficult (da Silva et al. forthcoming), the trade-off between investments in ergonomic design and lower long-term costs caused by both presenteeism and absenteeism from work due to reduced risk of developing MSD could be investigated. One example is a change in the packaging of items to improve ergonomic handling, for example, by using boxes with handles (Davis and Marras 2000). When integrating the goal of minimising worker health risks besides short travel time in an OP planning model, researchers could refer to findings from the ergonomic literature on maximum acceptable lift weights and heights (Straker, Stevenson, and Twomey 1996; Ciriello 2003), which could lead to new storage assignment policies. In addition, future research could develop models on investments in training to enable experienced workers execute pick tasks faster, which may help to improve system performance and worker welfare. In this line of thought, the use of technical equipment, such as the tool mentioned in the introduction, could be studied, with a special focus on the relationship between investments in an ergonomic warehouse design and its long-term benefits. In such scenarios, the negative effects of accumulated workload could, for example, be modelled as labour turnover.

As far as physical aspects affect performance, several factors that affect pick time need to be integrated into storage assignment models to make them more realistic. Future research could, for example, integrate a variable pick time depending on item weight, the positions of items on the shelf or shelf layout in storage assignment models to minimise total OP time. Different values for the time that is needed to pick items could be set, with lowest pick time in the golden zone and higher values for storage locations above and below the golden zone. Predicting the effects of design decisions on physical workloads, before an operator can be observed at risk, requires new kinds of analysis models.

Routing and batching models could be enhanced by considering maximum acceptable weights as capacity constraints for carrying loads and pushing/pulling trolleys. Load limits of 225 kg for four-wheeled carts and 114 kg for two-wheeled hand trucks were recommended in the ergonomics literature (Resnick and Chaffin 1995; Jung, Haight, and Peacock 2005). In addition, several authors provided further psychophysically determined limits for push-pull tasks which could be considered in OP models (Ciriello, Snook, and Hughes 1993; Shoaf et al. 1997). The NIOSH equation could be used as well to calculate the maximum load that can be carried (Waters, Putz-Anderson, and Garg 1993). Another interesting research topic could be the study of trade-offs between reductions in travel time (which could, for example, be achieved by setting the pick capacity to a higher value) and worker fatigue, health and related long-term costs. Fatigue may be modelled as an increasing function of accumulated load, and its outcome could be modelled as decreasing picker performance.

Proposition 4: The psychosocial effects of different working conditions should be considered when planning OP operations.

Relevant HF aspect: Psychosocial aspects, and specifically motivation, stress and workload.

Relationship to OP system design: Storage assignment, routing, work organisation (see Section 5.4).

Research opportunities: Studies could investigate how psychosocial aspects in the design of OP systems influence injury probability, OP productivity and quality.

Modelling suggestions: Researchers could assess the effect of using IT technology (e.g. bar code scanners or PDAs) on the performance of OP systems, taking account of the moderating effect of the storage assignment in use, as well as the cost of implementing IT technology. Thereby, it has to be considered that using IT technology in OP might also influence worker motivation. Another interesting way of enhancing OP by increasing motivation and reducing boredom may be to employ job rotation models, using production models as a starting point (e.g. Azizi, Zolfaghari, and Liang 2010). This, however, would have to be modelled on an aggregate level and not within a specific OP design model. The aim of the model could be to determine an optimal assignment of workers to work stations within the warehouse that minimises lead time considering the effects of different worker characteristics. Such a scenario could be studied using agent-based modelling and simulation (Pan, Wu, and Chang 2014).

Another research opportunity here is to study the effects of psychosocial hazards on OP efficiency. Psychosocial hazards, such as continuous high workload and stress forced by time pressure, could be modelled by describing labour turnover as a function of accumulated fatigue/stress, which, in turn, affects the performance of the workforce. The trade-off between costs of reducing psychosocial hazards and costs of labour turnover is worth investigating. Working conditions in warehouses, such as light level, temperature, noise level or floor type, could be expressed in routing models as variables in a function of fatigue or motivation which has an effect on maximum throughput, pick error rate and/or travel speed.

We point out that the interactions between HF such as workload, employee fatigue and discomfort, and performance suggest that robust multi-factor research studies are needed to ensure new OP system designs actually function as intended. Changes in layout may have an effect on physical workload and fatigue (discussed in Proposition 3), which could in turn affect employee learning and error making (Proposition 2), and subsequently affect employee motivation (Proposition 4). Studies which attempt to isolate individual HF aspects may be vulnerable to HF-related effects from those HF aspects that were ignored.

6.2 *Methodological considerations*

As discussed above, HF issues could be integrated in mathematical planning models to study the impact of OP system design on HF, and vice versa. To derive realistic planning outcomes, it is necessary to estimate model parameters correctly, which may make further empirical research on the interaction between HF and OP efficiency described above necessary.

Thus, HF researchers need to attend to more than just physical workload. While a few studies in ergonomics research empirically observed the manual handling processes in warehouses to be hazardous, few HF-based empirical research studies in OP address performance and quality issues. A possible starting point for empirical research could be the use of ergonomic screening tools, such as the European Assembly Worksheet (Schaub et al. 2013), to assess the physical workload of specific OP operations and to draw a relationship to performance outcomes to develop purposeful design interventions. Findings of such empirical works could then provide input for quantitative planning models that could help to improve OP in practice. However, before such an effort can be made, the interaction between the characteristics of the order picker and the attributes of the OP system need to be understood in greater detail. In this respect, particularly qualitative studies may unearth new information (Eisenhardt and Graebner 2007). There seems to be significant potential for the use of qualitative methods, such as, for example, case studies or interviews, in OP research. In this line of thought, future research could evaluate the source of slips and errors in OP using qualitative methods. If errors occur frequently, the task and the work environment should be redesigned (Helander 2005), for example, by introducing paperless information technology and immediate feedback. In addition, the behaviour of order pickers on different design parameters, such as the complexity of routes, may be worth investigating, as one can suggest that human behaviour may impact OP time in routing models. Although an OP route can be sophisticatedly planned to minimise travel time, travel time can be significantly increased in case the worker does not follow the established sequence due to confusion and/or deliberate route deviations. Further qualitative research is needed to gain more insights and to assess the consequences of human behaviour, e.g. in travel tasks, on an OP system's performance, and particularly to understand which OP design factors cause work inefficiencies. Qualitative research on its own may lead to useful indicators for better OP design, and is a prerequisite to integrate realistic parameters into quantitative OP planning models.

6.3 *Organisational considerations*

Necessary data for integrating HF in OP models may be gathered in research projects or case studies from industry, as many firms take a great interest in improving OP processes. With regards to HF, however, we note that an organisational divide still exists in many companies (Perrow 1983). HF are often considered to be only relevant for human resource management in terms of health and safety issues, blinding out its impact on performance and quality (Neumann and Dul 2010). In turn, performance and quality are traditionally seen as outcomes of operations management. Due to this organisational isolation of HF, it is difficult to consider its impact on OP outcomes. Special efforts in organisational change management are required to overcome this barrier (Neumann, Dixon, and Ekman 2012; Neumann and Village 2012). As discussed in this paper for OP, HF aspects impact outcomes performance, quality and worker health simultaneously, and thus a holistic analytic approach is needed to understand the link between HF and managerial strategic goals.

7. Conclusion

Most OP processes involve a high amount of human work and manual material handling. For this reason, a conceptual framework was developed that identifies steps in an OP process where HF issues are most prevalent, and made suggestions as to how OP models could be improved in future research. A systematic literature search was also conducted to gain insights into how HF have been considered in the OP literature. The results showed that HF issues have largely been neglected in OP planning models. As Boudreau et al. (2003) pointed out, human characteristics and behaviours such as learning, fatigue, boredom, forgetting, motivation and many others should be included in descriptive, simulation and optimisation (operations management) models to analyse and improve operating systems. Clearly, this statement is true for labour-intensive manual picker-to-part OP systems. Incorporating HF can help in developing more realistic models and in improving model predictability. This can help to increase OP system's performance. In addition, models considering HF in OP could result in fewer pick errors and, thus, lower compensation costs. On top of that, these models could contribute to less work-related illness, absenteeism and presenteeism, as well as higher workplace quality and safety in OP, which can reduce long-term costs. Ultimately, models that consider HF can help to design better OP systems.

This study was motivated by the fact that there are only few studies that discuss the effects of HF on OP systems. By developing a conceptual framework and by synthesising the literature of different disciplines, it was possible to gain insights in HF aspects involved in OP processes and into how these aspects affect the efficiency of manual OP systems. It is clear that this approach has limitations as the focus here was exclusively on the manual picker-to-part OP process, and automated or semi-automated OP systems were not addressed.

It is concluded that there are various research opportunities for integrating HF aspects in OP planning models. This paper identified a clear need for more research on integrating HF in OP models. Future research on this topic should include both quantitative and qualitative studies to provide deeper understanding of the interaction between the design of the OP system and the human operators. Qualitative research can shed new light on people's experience in operating the system, and these insights can help in developing better OP models predicting system performance. As far as OP is concerned, there are many opportunities for collaboration between operations research/management and HF, which may contribute to overcoming the organisational divide between HF and operations management in both research and practice. Considering the importance of HF in OP and the lack of research on this subject, the framework presented in this paper may be seen as a conceptual starting point. It can assist practitioners, such as warehouse managers, and researchers as guidance for considering HF in OP, and in finding topics for future research and providing insights for better OP system designs in the future.

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