The impact of the design decisions of an order picking system on human factors aspects of the order pickers

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Abstract. Warehouses are crucial for supply chain management and the success of businesses in production and logistics systems. The order picking (OP) system plays a vital role in achieving short lead times and high customer satisfaction and order pickers are essential to achieve flexibility in the OP system due to their cognitive and motor skills.
However, manual order picking is time-consuming and accounts for approximately 50% of overall operating costs in warehousing. It is important to consider the human factors (HF) aspects of the order picker to avoid deviations from expected performance outcomes and reduce the risk of errors that could cause delays and financial losses. Negligence of HF could also lead to musculoskeletal disorders in the order picker.
This study aims to empirically show the impact of such decisions on the HF aspects of order pickers. The study uses case studies and survey-based empirical data to analyze the impact of decisions on the HF aspects of order pickers. The findings suggest that consideration of HF is crucial for the success of the OP system and the wellbeing of order pickers. The study highlights the need for further research on HF aspects in the OP system and provides insights for decision-makers to optimize the performance of the system.

Keywords: Order picking, Human Factors, Design decisions, Empirical study.

1 Introduction

Warehouses are considered to key players in supply chain management and are essential for the success for business in production and logistics systems [1]. Order picking (OP) systems are critical in warehousing to achieve short lead times and excellent customer satisfaction. The OP system consists different tasks such as setting up of picking list, travelling inside the warehouse, searching for the desired products, and picking the products from the desired locations in a warehouse to meet customer needs [1].
Fully automating order picking processes brings about various disadvantages, including high investment costs, the need for standardization, and reliance on computer systems, in addition to its lack of flexibility [2]. Despite the high labor costs, manual operation persists in up to 80% of order picking warehouses [2]. Thus, order pickers are vital part of OP systems to achieve high amount of flexibility to the OP system due to combination of their cognitive and motor skills. Furthermore, humans can pick complex products from storage locations, something machines and automated systems cannot do

reasonably [3]. These explanations demonstrate that the order picking system is a time-consuming operation that requires a significant amount of manual handling of products. As a result, the cost of process in warehousing accounts for approximately 50% of overall operating costs [1].

However, when manual order pickers are in the system, it is important to consider the HF aspects of the order picker. The four HF aspects are the physical, mental, perceptual, and psychosocial aspects. This is because if HF aspects are not considered then it could lead to deviation from the expected performance outcomes of an OP system [3]. This is because there could be high risk of errors in a manual OP system, as order pickers could pick wrong or incorrect number of items. As a result, these pick error could cause delay in delivering the products or financial losses [4]. The negligence of HF not only impacts the performance of the OP system, but also impacts the wellbeing of the order picker. This is because of handling heavy products in awkward body postures, which thereby increasing the chances of developing musculoskeletal disorders (MSDs), with low back disorders being the most common injury. Thus, the human factors in the OP system are one of an important player in the performance of the system [2].

Even tough, it is important to consider the HF aspects in an OP system, there has been negligence of HF in the decision making of setting up of the OP system or for the introduction of technologies into the system [5]. If these aspects are not considered, then as said before negative consequence could lead to the performance outcomes of an OP system [5]. According to [6], most OP research has concentrated on establishing a mathematical model and simulation model but has rarely included case studies and survey-based empirical data.

Therefore, the aim of this study is to conduct an empirical study to show the impact of decision regarding the system settings and technologies in an order picking system on HF aspects of the order pickers.

The remainder of the paper is organized as follows. Section 2 explains the literature review. Section 3 explains the methodology adopted in this paper. Section 4 presents the findings and analysis from the study. Section 6 summarizes the paper by highlighting key points, limitation of the study and the future research opportunities.

2 Literature review

The OP system could be classified into two method, picker to parts and parts to picker. In a picker to parts system, the order picker moves towards the desired parts which are the products remain stationary. On the other side, the order picker remains stationary, and the products moves towards the order picker. It is understood that for two different method of OP system, different system settings are required. According to [6], the system setting of an OP system could be classified into mechanization level, information availability and warehouse dimensionality. Few years ago, [7] have explained the system settings of an OP system could be categorized into layout and storage assignments. These factors are considered because they are related with the design of an OP system. The layout design is associated with the number, length, and width of aisles in the blocks and also, the shelf layout and configuration. The storage assignment defines the allocations of the products to the storage locations in the warehouse based on the product characteristics. Thus, it is important to understand the impact of human factors on the system settings. In the case of focusing human factors of order pickers with the design of the warehouse layout, [22] studied on an optimal layout problem as mixed-integer programming with the aim of minimizing the total ergonomics strain on the order pickers.

When it comes to the focus on human factors aspects of order pickers in combination with system settings. [23] have represented a new ergonomic storage location assignment algorithm which reduces the mechanical load of the lumbar spine on the order pickers. [24] introduced a model for storage assignment problem using the integer linear optimization with consideration of the OP time, energy expenditure rate and health risk associated with the order pickers. [27] have studied on order pickers picking from different pallet rack layout considering the economic and ergonomics objectives. [8] with the help of mixed integer programming have achieved to minimize the ergonomic strain during the order picking. [9] have developed a mathematical model to address the storage assignment with respect to the fatigue level of the order pickers. [10] introduced a bi-objective approach considering the total order picking time and human energy expenditure into a storage assignment problem. [11] has talked on storage assignment decisions based on the learning and forgetting of order pickers. [12] introduced an algorithm to help in selecting the highly efficient storage locations thereby reducing the probability of mis-picks and improving the ergonomics for the order pickers.

When it comes to the technologies in OP systems, [13] have described the transition of automated order picking systems and its impact on the order picker's learning and work organization. [14] have proposed a model that considers the capacity, ergonomics, and cost of training an automated system. [15] have presented a simulation model to evaluate the fatigue on order pickers, who work in close collaboration with the picking robots. [16] has evaluated the workload and ergonomics design of workstations in picker to parts order picking system. [17] has compared the horizontal carousels with shelving systems with the consideration of space, time, and ergonomics. [18] studied the influence of paperless picking and the usage of forklifts for transportation on order picker's well-being and productivity. [19] presents an empirical analysis of learning curves in pick by voice and semi-automated OP systems.

3 Methodology

This section describes the research design, which contains a description of the study strategy, data gathering procedure, and analytic methodologies. The section begins with a thorough discussion of the research approach, followed by a description of the data gathering procedure, and continues with an overview of both descriptive and content analysis techniques.

Table 1. Research Design

Method	Technique	Purpose
Case Study	Questionnaire	To understand the well-being of the order pickers (from order pickers perspective)
	Interview	To understand the design characteristics of the warehouse (from managers perspective)
		To understand the well-being of the order pickers (from managers perspective)

3.1 Research method

The research method adopted for this study is case study. The case study is conducted with the help of a Norwegian grocery distribution centre. The case study managed to provide a detailed investigation, with the empirical data collected to deliver an analysis and the process involved in the context [20]. The main objective of the case study is to do intensive research on a specific case to highlight the essential process and relationships [21]. In this study, the focus is to find the essential system design of the three different warehouses of the case company and to evaluate their relationship with the HF aspects of the order pickers.

3.2 Data collection technique

Two types of data collection technique are used to support the case study research method: questionnaires and interviews. These data collecting techniques are described in further detail below.

Questionnaire

This study used the NASA TLX questionnaire, a multidimensional rating method that provides an overall workload score based on the weighted average of ratings on six subscales [25]. They are mental demands, physical demands, temporal demands, own performance, and frustration. Mental Demand assesses cognitive requirements and complexity. Physical Demand measures physical effort. Temporal Demand evaluates time pressure. Performance gauges perceived task success. Effort considers overall mental and physical exertion. Frustration captures emotional strain and dissatisfaction. These dimensions provide a comprehensive understanding of workload, enabling identification of high workload areas and informing task design and resource allocation improvements. The questionnaire is provided to the order picker to collect the information regarding the well-being of the order pickers. The duration of order picker to fill the questionnaire is approximately 30min. The questionnaire is distributed to all the order pickers in the warehouse.

Interview

A semi structured interview is conducted with the managers and order pickers [20]. The questions for the manager's interview would address the data regarding the design of the order picking system. For e.g., layout, storage assignment, technology etc. As a result, an understanding of the warehouse's system setting is provided. One manager, who is responsible for the order picking system, was selected for the interview. Secondly the questions for the order picker's interview would evaluate HF aspects of the order picker. One experienced order picker from each warehouse who is comfortable to communicate in English were selected for the interview. The duration of the interview with the manager and order pickers were approximately 1 hour each.

3.3 Data analysis

Triangulation is employed in the case study to enhance the validity of the acquired data by conducting two distinct types of data analysis, namely descriptive analysis and content analysis. This approach ensures a more robust and comprehensive examination of the findings. By combining these two approaches, the study benefits from a more holistic understanding of the phenomenon under investigation, strengthening the validity and reliability of the research outcomes.

Descriptive Analysis

In the initial phase of the study, a descriptive analysis is conducted using quantitative data collected through a questionnaire [25]. This analysis involves presenting the raw data without manipulation to understand the trends in the HF aspects when altering the system settings for the order picker. By analysing the unprocessed data, authors can observe patterns and changes in the level of workload on the order pickers. The descriptive findings derived from this analysis provide a comprehensive overview of the observed trends, serving as a foundation for further exploration of the relationship between system settings and HF aspects. This analysis aims to gain insights into the impact on the order picker's working conditions and performance.

Content analysis

After completing the descriptive analysis, content analysis is utilized to gain a more profound comprehension of the observed trends [26]. The coding process in content analysis involves identifying significant themes, concepts, or words within the qualitative data obtained from semi-structured interviews conducted with order pickers [26]. The constructs used in this analysis may focus on the order pickers' perceptions, experiences, and attitudes towards the system settings and their impact on HF aspects. Evaluating the performance in content analysis involves examining the order pickers' narratives and identifying any references to changes in their performance or productivity resulting from the system settings. The objective of this analysis is to assess the presence, meanings, and connections of specific words, themes, or concepts, shedding light on the reasons behind the alterations in the human factors aspects when the order picker's system settings were modified.

4 Findings and analysis

4.1 Case company

The case study focuses on three key warehouses within a major Norwegian grocery distribution centre. These warehouses, namely Warehouse A, Warehouse B, and Warehouse C, have been selected for in-depth analysis.

Warehouse A is the most automated among the three, employing the parts to picker OP method with the assistance of an AS/RS (Automated Storage and Retrieval System). This means that the system retrieves the necessary parts and brings them directly to the order picker, streamlining the picking process. Warehouse B is a semi-automated warehouse that utilizes the picker to parts OP method. It incorporates pick by voice technology, where order pickers are guided by a microphone to perform various picking tasks. This technology assists them in setting up the picking list and locating and picking the required parts from designated locations. In contrast, Warehouse C is a fully manual warehouse, relying on the manual picker to parts OP method. Order pickers perform all the picking tasks manually, without the aid of automated systems or voice technology. It is worth noting that Warehouse A is the largest in size, while Warehouse C is the smallest among the three. The varying degrees of automation and manual involvement in these warehouses provide an opportunity to study and compare the effects of different system settings and technologies on the HF aspects of the order pickers.

4.2 Descriptive findings

The findings from the NASA TLX obtained from the three distinct warehouses are described in this section.

Figure 1 in the study provides a visual representation of the data collected from the three warehouses (A, B, and C) and how it is classified and categorized into four primary order picking tasks: setup, travel, search, and pick. These tasks represent different stages or activities involved in the order picking process.

To assess the workload associated with each task, the study utilizes the NASA Task Load Index (TLX), which consists of six dimensions: Mental, physical, temporal, performance, effort, and frustration. These dimensions capture different aspects of the workload experienced by order pickers during their tasks.

By evaluating each dimension within the context of the three warehouses, a comprehensive analysis of the workload is conducted. This analysis allows for a deeper understanding of how workload factors vary across different aspects of order picking and between the warehouses.

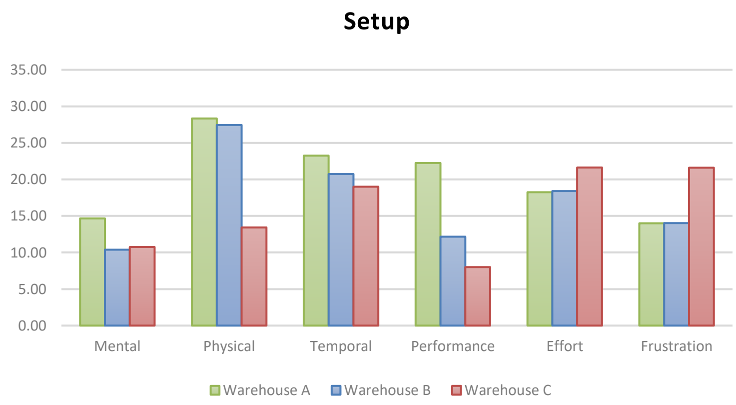

Fig. 1. Descriptive findings of the setup task

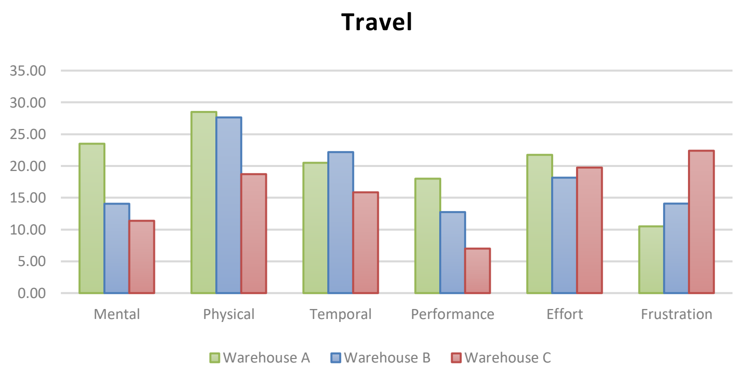

Fig. 2. Descriptive findings of the travel task

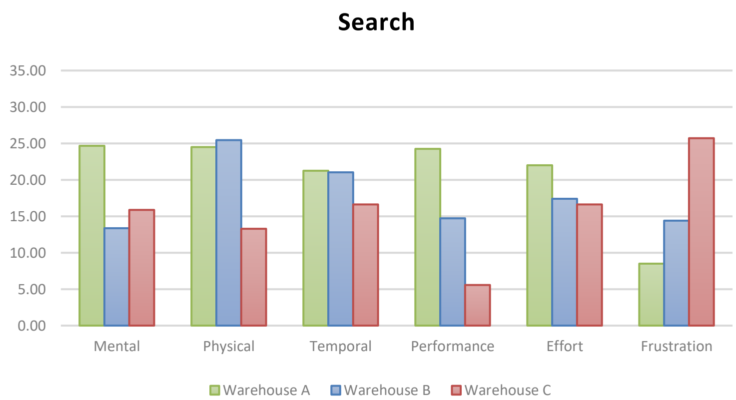

Fig. 3. Descriptive findings of the search task

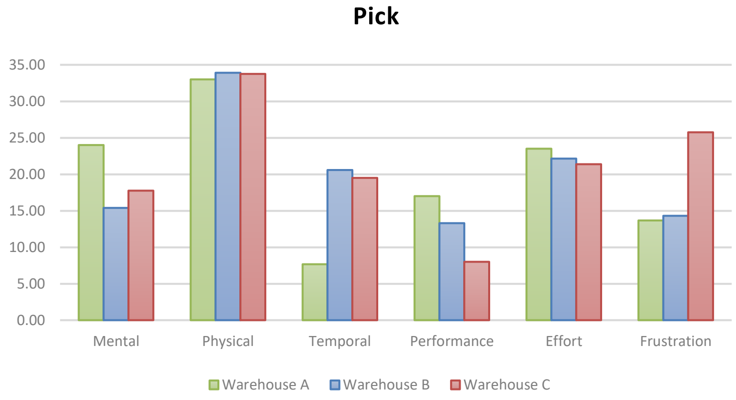

Fig. 4. Descriptive findings of the pick task

4.3 Content analysis

Moreover, the content analysis provides a detailed exploration of the trends identified in the previous section, offering further explanations and insights specific to each order picking task. This analysis delves deeper into the findings, providing a more comprehensive understanding of the factors and patterns influencing performance within each task of the order picking process.

Setup

Of all the dimensions, the physical demand is reported more from all the warehouses and the least for mental demand. The mental demand is least in the setup task for the warehouse B because the search list for the picking is prepared by the pick by voice technology. This could reduce the mental demand for the operators to make decisions on picking the orders and warehouse A has the most mental fatigue because the order pickers have reported that the system crashes in between and this would annoy the order pickers in picking the orders and order pickers have also reported that they have to reboot the system to retrieve the picking list from the system. It is also more physically demanding for the warehouse A and least for warehouse C because order pickers from warehouse A notified that the standing in the same position for preparing the collection could case back pain to the operators and in warehouse C the order pickers feel less fatigue because order pickers have less parts to pick compared to other warehouses. The temporal demand for creating the setup list is equally same for all the three warehouses but bit high for the warehouse A and less for warehouse C because warehouse A being the biggest with huge movement of goods than warehouse C, the pressure on order pickers from warehouse A is more when compared with the warehouse C.
When it comes to performance, the warehouse A is performing better than the remaining warehouses and the least performance was reported by warehouse C because the order pickers of warehouse A stated that if the system work without crashing then they could prepare more picking list faster than the conventional paper picking list of

warehouse C. Also, in case of effort and frustration both the warehouse A and B has shown equal level and warehouse C has the highest because the warehouse C has conventional picking list, that causes order pickers more frustration and effort on cross checking the orders that they need to pick.

Travel

When it comes to the travel tasks, the mental demand is reported in warehouse A and the least for the warehouse C because the order pickers of warehouse C are used to follow the same route all the time which led them with least mental demand. On the other hand, the order pickers of warehouse A travel less often only when there is need of intervention with the AS/RS. Secondly, the physical workload is rated the most among all the dimensions. The physical demand is stated more for warehouse A and least for warehouse C because during the time of intervention for warehouse A, the order pickers has to climb to check the problem, which causes more fatigue to the them. Thereafter, the temporal demand is more for warehouse B and the least for warehouse C because warehouse B is bigger than warehouse C and the order pickers from warehouse B has to cover a greater distance to meet their picking target.

However, when it comes to the performance, the warehouse A has better output and the least for warehouse C because if there is no intervention for AS/RS, there doesn't exist a need for the order pickers to travel. Secondly, the effort is most for warehouse A and the least for the warehouse B only when there is an intervention in warehouse A and the order picker has to take actions to rectify it. Finally, the order pickers faced more frustration for warehouse C and the least for warehouse A because the order pickers of warehouse C states that they have to keep on travelling over the warehouse repeatedly causing them frustration.

Search

In the search task, the mental workload in stated most in warehouse A and least for warehouse B because if there is an intervention the order picker of warehouse A takes time to find the location of the item. But, in warehouse C since the order pickers are used to pick the parts, they remember the storage locations effecting in lower mental demand. Secondly, in case of physical demand and temporal demand is equally high for warehouse A and B and the least for warehouse C because both the order pickers of warehouse A and B has to pick more items in comparison with C.

The performance is best reported for the warehouse A and least for warehouse C because order pickers from warehouse A has less travel to pick the items, but only have to travel during the need of intervention for robot. The effort is rated most for warehouse A and the least for warehouse C because during the intervention for robot in warehouse A, the order pickers has a greater effort to rectify and bring to work when compared with conventional warehouse C. As in the most cases the frustration is most of warehouse C and the least for the warehouse A because the order pickers of warehouse C has no assistive technology to help find the location of the item, which is not the case for warehouse A that provides the assistance to the order pickers to find the right item with its location.

Pick

Finally, in the case of pick task, the mental demand is rated most for the warehouse A and the least for the warehouse B because order pickers of warehouse A feels that standing at a single place and picking the items from one point is boring. The physical demand was reported equally high in all the three warehouses, but a slightly higher for warehouse B because the order pickers of warehouse B has to pick more items from the shelf when compared to other warehouses. The temporal demand is high for both the warehouse B and C and the least for warehouse A because both the warehouse B and C are parts to picker OP method and the order pickers from both warehouses has reported that they have to pick the parts from the warehouses from different locations within the provided time span to meet the picking rate.

The pick performance is high for warehouse A and the least for the warehouse C because the rate of picking is decided by the system and the order pickers has to perform the pick task based on the feedback from the system while in the case of warehouse C the rate of picking is entirely depended on the speed of the order picker. The effort for picking is rated equally in all the three warehouses because the picking task is same in all the three warehouses. Finally, the frustration is rated most for the warehouse C and the least for the warehouse A because the order pickers from warehouse C informed that the frustration for picking is due to the temporal demand of the work to keep up the picking rate.

5 Conclusion

The study has evaluated the impact of the design decisions of an order picking system on human factors aspects of the order pickers. It was fascinating to see that parts to picker OP method has better performance but could lead to more effort to order pickers if there is a need for interventions for the AS/RS. Overall, order pickers in a manual warehouse reported more frustration doing OP tasks than order pickers in a warehouse that made use of assistive technology for the picker to part OP method.

This study's managerial implications emphasize that effective decision-making by managers plays a vital role in attaining the intended performance outcomes in order picking systems. Managers can optimize system performance and align it with planned goals by taking into account human factors and making well-informed design decisions. Additionally, fostering open communication channels and prioritizing the well-being of order pickers contribute significantly to achieving the desired performance outcomes.

One significant drawback of this study is its limited scope, as it solely examines a grocery distribution centre located in Norway. By confining the research to this specific context, the findings may lack broader applicability and generalizability to other settings, limiting the validity of the findings to internal factors. However, by examining various sectors and conducting comparative analyses, researchers can enhance external validity and gain a deeper understanding of how different design choices influence order pickers' performance and well-being. Another limitation of this study is its narrow focus on a limited set of technologies within the order picking system, specifically paperless picking technologies and AS/RS. While these technologies were thoroughly examined, other emerging or alternative technologies that could impact order pickers may not have been included. To address this limitation, future steps of this research could involve exploring and evaluating the effects of a broader spectrum of technologies. By considering a wider range of technologies, a more comprehensive understanding of their impact on order pickers could be achieved. This expanded analysis would provide managers and decision-makers with a more holistic view when making informed choices about integrating different technologies into order picking systems. Additionally, it would ensure that the study's conclusions remain relevant and applicable in a rapidly evolving technological landscape.

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