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Impacts of Automation on the Performance of Hospital Warehouses. An Italian Application

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Abstract: Healthcare logistics involves significant complexity due to the high cost of goods purchased and stored, as well as the uncertainty of demand linked to the variability of patients' needs. Thus, effective inventory management could bring relevant benefits in terms of cost and quality of the service delivered. In such a context, automation is one of the most promising ways to improve warehouse processes. In this paper, the quantitative effects of implementing an automated storage system in a hospital warehouse are assessed. To this end, a dashboard of key performance indicators related to several dimensions is identified and measured. The results demonstrate that significant benefits have been obtained in terms of both quality and operational efficiency. In addition, the automated warehouse system has allowed relevant time savings for pharmacists who can be assigned to higher-value activities. Future research will assess the cost savings from efficiency gains achieved through warehouse automation.

Keywords: Automated warehouse; hospital warehouse; healthcare logistics; logistics performance; impacts; Italy

1. INTRODUCTION

Healthcare logistics involves the management of the flow of pharmaceutical and medical goods. The aim is to ensure the right quantity of products in the right condition for hospitals and pharmacies at the right time. Considering that this sector is not just a business but a system affecting everyone's lives, a high level of accuracy and short lead time need to be guaranteed (Rathi et al., 2022). In addition, especially in hospitals, logistics processes face relevant levels of complexity due to the large number of actors involved (e.g., floors, surgery rooms, laboratories, and administration). In the last decade, the growing demand for healthcare services has dramatically increased the demand for drugs and medical devices due to demographic changes including an aging population. At the same time, budget cuts (De Marco et al., 2012) have made healthcare agencies struggle to manage the inventory of drugs and medical devices. Indeed, logistics processes may account for about 15% of the total cost of healthcare services (Cavmak and Aksoylu, 2024). Due to the relevant expenses associated with the goods purchased and stored, inventory improvement could bring significant benefits. Within this framework, flexible warehousing systems are becoming more significant in the healthcare industry. Automated storage solutions based on Miniload systems, can positively impact the efficiency of internal logistics processes. However, while a few studies explored specific aspects of Miniload systems in healthcare settings (Baardman & Roodbergen, 2016; Füßler & Boysen, 2019) there is limited research assessing their overall impact on healthcare logistics performance, highlighting the need for further investigation. To provide practical evidence of the benefits associated with the implementation of a Miniload system, an application case is here presented. In particular, this paper assesses the effects of automation on the performance of a warehouse of drugs and other pharmaceutical products in an Italian Hospital. In particular, the objective of this paper is to assess the impacts on performance of adopting automation to manage inventories in hospitals. To this end, a dashboard of appropriate Key Performance Indicators (KPIs) is developed and these indicators are measured before and after the Miniload installation. The paper is structured as follows: it begins with a review of relevant literature on the complexity of healthcare logistics and the potential of Miniloads. Next, the application case is detailed, followed by a discussion of the main results. Lastly, the key implications and conclusions are presented.

2. LITERATURE REVIEW

2.1 Healthcare logistics processes

Logistics costs are significant for hospitals, thus managing material inventory effectively could provide significant opportunities for improvement (Volland et al., 2017). In particular, the high variability of patient diseases, the large number of suppliers, and the new drugs on the market could result in numerous medicines being available in a hospital pharmacy. In fact, a hospital warehouse may have to manage up to 35,000 different Stock Keeping Units (SKUs) with a large variety of supplies such as pharmaceutical products, medical supplies, office supplies, and cleaning products (Landry et al., 2016). However, having significant stock requires investment, which means tying up funds and utilizing substantial space to store these products. Indeed, managing the procurement and storage of products could also involve the issue of managing the expiration date of medicines. Thus, inventory management plays a crucial role in decreasing the risk of product shortage and expiration, as well as decreasing costs associated with stock (Ahmadi et al., 2022). As a result,

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effective inventory management enables healthcare organizations to strike a balance between ensuring sufficient stock to satisfy patient needs and preventing surplus inventory that may result in waste or spoilage (Rubigha, 2020). In addition, inventory management within the healthcare industry plays a vital role in ensuring the availability of medical supplies, enhancing operational efficiency, and ultimately improving the quality of patient care (Leaven, 2023). One of the most promising ways to improve warehouse processes is through automation (Aziez et al., 2022). Automated warehouses have the potential to efficiently maintain the optimal inventory of healthcare supplies, supporting timely delivery to patients and various departments within a hospital system (Maestre et al., 2018). Thus, warehouse performances directly impact service quality, cost of logistics processes, and efficient distribution (Cagliano et al., 2022). A few applications of Miniloads in healthcare environments can be found in the literature. Baardman and Roodbergen (2016) addressed order scheduling for a Miniload for drugs. More recently, Füßler and Boysen (2019), focused on the interaction between the system and the warehouse operators in moving unit loads. On the contrary, scarce literature deals with assessing the performance of Miniload on healthcare logistics processes.

2.2 Miniload overview

Miniloads can be defined as automated warehouse systems able to handle small unit loads (bins, totes or trays). In these systems, products are located in trays, which are organized within long aisles of fixed shelving racks (Güller and Hegmanns, 2014). To fulfill orders, a small automated storage and retrieval machine, sometimes also named stacker crane or gripper, takes trays of products from the aisles, which are then delivered to a picker by conveyors. After the picker takes products off a tray, the tray is placed back onto the stationary racks for storage, again by means of the automated machine (Valle and Beaesly, 2021). Thus, Miniloads are largely used in those operations environments where there is the need to move small and lightweight items efficiently. The stacker cranes operate along the aisles, managing the loading and unloading of products based on the order lists provided by the control system. For instance, stacker cranes transport cartons from the input station at the lane entrance and deposit them on the racks. These racks are built from metal brackets and partitions and are commonly adopted for high-density storage. Typically, a tunnel, which consists of two racks and a stacker crane, can handle over 100 items per hour for both storage and retrieval tasks (Hechemi et al., 2012). Miniload systems offer excellent space utilization and substantial storage capacity. These flexible warehousing solutions can easily retrieve items from very high racks, maximize vertical space utilization, and save 90% or more of the storage area (We et al., 2020). Thanks to effective layouts and the assistance of smart equipment, the storage capacity significantly surpasses that of conventional single-layer warehouses, which are typically less than eight meters high. In addition, they save time and effort and greatly improve the efficiency of warehousing operations. These systems are flexible and used in various sectors like e-commerce, electronics, and automotive. They enhance warehouse space efficiency, improve inventory control, reduce goods damage and loss, and decrease the need for warehouse workers (Lerher et al., 2014). In recent years Miniloads have been also applied in pharmaceutical industries where the unit loads are small in size and responsiveness is a crucial aspect (Wauters et al., 2016).

3. APPLICATION CASE

The present application focuses on the drug warehouse of the Ordine Mauriziano Hospital, one of the largest hospitals in Torino, Italy. This 448-bed teaching hospital offers various medical specialities, including Internal Medicine, Neurology, Cardiology, Heart Surgery, Orthopaedics, and Gastroenterology.

3.1 Drug warehouse

The drug warehouse extends over 520 m^2 and its storage area is organized into five zones: refrigerated storage for keeping products at controlled temperatures, automated storage, traditional rack storage, flow racks, and stack storage for pallets containing products with a high turnover rate and a size and weight not suitable for storage in the automated cabinet. 1,449 SKUs are currently managed: 870 SKUs are stored in the warehouse (stock-managed products), while 579 SKUs are handled as products directly delivered to the floors requesting them.

3.2 Miniload automated storage system

Since 2009, the Ordine Mauriziano Hospital has focused on continuous improvement, culminating in the adoption of an automated storage system for small-sized unit loads after the pandemic, as part of the LIFEMED Research Project, funded by the Italian Ministry of University and Research.

The Miniload storage system (Figure 1) is 15 m long and made up of several modules. It features a loading unit with an input hopper and a collaborative robot that can automatically load up to 1,000 drug packages at once. A gripper moves along the racks at 5 m/s, enabling vertical and horizontal movement simultaneously. The gripper can handle packages up to 18 cm wide, 30 cm long, 12 cm high, and with a maximum weight of 1 kg. The storage system is equipped with 6 picking bays, thus allowing 6 orders to be processed concurrently. The storage capacity of the automated cabinet is 30,000 unit loads and up to 36 unit loads can be placed on each rack. All the drugs and pharmaceutical products managed by the warehouse are stored in the Miniload, except for enteral products, infusion solutions, and products to be stored at a controlled temperature. Information flows associated with the Miniload storage system are managed by a dedicated Warehouse Management System (WMS), which is integrated with the software application to issue orders by hospital floors and the hospital information management system.

3.3 Methodology

The following steps subsume the methodology adopted that was adapted from Eales et al. (2024): (1) Analysis of the logistics processes involving the automated storage system. (2) Definition of the expected outcomes of the adoption of the automated storage system. (3) Selection of KPIs based on the expected outcomes and scientific literature; definition of a KPI dashboard. (4) KPI measurement before and after the implementation of the Miniload storage system. (5) Analysis of results and identification of process improvements.

Figure 1. Automated Miniload storage system

3.4 Logistics processes

The Miniload storage system plays a key role in the drug warehouse's flows at the Mauriziano Hospital. As far as the inbound logistics process is concerned, upon receiving products, quality and quantity checks are conducted before assigning items to storage zones. For the automated cabinet, operators choose between semi-automated and fully automated storage. In semi-automated mode, items are scanned, their sizes recorded, if new, and moved to storage via the gripper. In fully automated mode, products pass through a measurement area; discrepancies in size cause ejection, while verified packs are stored. The inventory level of products in the storage system is updated automatically in the WMS. In the outbound logistics process, floor staff compile orders for drugs and other pharmaceutical products based on therapy needs. These are reviewed by a pharmacist and processed by the WMS into picking requests. The gripper picks items stored in the Miniload, while items not stored there are picked manually. Products are then organized for delivery, with inventory updates maintained by the WMS. One or more packs can be picked at a time from the Miniload and up to 300 packs can be dispensed per hour.

3.5 Expected outcomes

The expected outcomes were defined to identify KPIs for assessing the impacts of the automated storage system on logistics processes. Various brainstorming sessions with the warehouse's Pharmacist Director and Pharmacist managing drugs helped to define these outcomes based on both their experience and the authors' one. They include: (1) Increasing the inventory turnover of drugs and pharmaceutical products. (2) Eliminating any discrepancies between the actual inventory level and the associated value recorded in the WMS. (3) Increasing the accuracy and efficiency of inventory counting, while reducing the time required to perform it. (4) Improving the management of expired products. (5) Reducing picking and order preparation time. (6) Increasing the accuracy and efficiency of floor order fulfilment. (7) Reducing product shortages both in the drug warehouse and hospital floors. (8) Reducing the overall number of human resources dedicated to the logistics process.

4. ASSESSING THE PERFORMANCE OF THE MINILOAD STORAGE SYSTEM

This section outlines the process for building a KPI dashboard, including quality and operational metrics. It describes the selected indicators and analyzes the Miniload system implementation results since its integration with the WMS enables real-time data for KPI calculation.

4.1 KPIs selection

Volland et al. (2017) identified four key areas of material logistics management in hospitals: supply and procurement, inventory management, distribution and scheduling, and holistic supply chain management. Two of these areas will be addressed in the present study. In particular, since distribution processes are a direct extension of inventory activities, monitoring warehouse performance effectively requires analysis of both inventory and distribution processes (Staudt et al., 2015). These areas of analysis can be approached by focusing on two types of indicators: quality and operational (Abdul et al., 2023). The first metrics assess how effectively an activity is performed, ultimately ensuring safe patient care and minimizing medical errors. The second ones focus on measuring the efficiency or the effectiveness of specific process activities, improving information flow and, ultimately, the care services delivered (Moons et al., 2019a).

To monitor inventory performance, a KPIs dashboard has been defined to cover both quality and operational metrics. Inventory counting accuracy is a crucial quality metric in the healthcare system due to its critical nature (Kritchanchai et al., 2018). It aims to compare recorded stock levels with the actual stock on hand (Moons et al., 2019b). High accuracy in inventory counting helps prevent discrepancies, ensuring that the warehouse data reliably reflects available resources (Villegas-Ch et al., 2024). This indicator aims to measure the expected outcome (2) in Section 3.5. Moreover, coming to operational metrics, firstly operational efficiency indicators have been identified due to the time-sensitive nature of hospital logistics (Nagurney and Nagurney, 2012). Thus, the average inventory counting time has been selected according to the expected outcome (3) in Section 3.5, since the inventory check is a very time-consuming activity (Wijffels et al., 2016). Furthermore, related to the first expected outcome (in Section 3.5), inventory turnover has been selected to evaluate how quickly goods move through the warehouse over a given period, providing insights into stock usage rates and potential excess (Moons et al., 2019a). In particular, in this application, inventory turnover has been assessed over a semester. The percentage of expired products over the inventory level is closely related to the inventory turnover issue (expected outcome (4), in Section 3.5). It highlights potential losses due to overstocking and aids in optimizing inventory levels to minimize waste (Duong et al., 2020). Secondly, operational effectiveness metrics have been identified. In particular, to monitor the expected outcome (7), in Section 3.5, inventory counting frequency has been defined to ensure that stock records remain up-to-date and accurate, while the number of incoming order lines processed per person per day (De Koster and Balk, 2008) has been defined as a KPI to monitor the expected outcome (8), in Section 3.5.

Similar to inventory performance, a KPI dashboard has been identified to monitor the outbound handling of products according to quality and operational dimensions. Regarding the first type of metric, Frazelle (2016) states that shipping accuracy is a critical metric for warehouse performance, with the percentage of order lines shipped with errors being an indicator of distribution quality. Four specific KPIs have been identified to provide detailed insights into the root causes of shipping errors, focusing on two types of distribution issues: delays and non-compliance with order specifications. For each type of error, separate KPIs are defined to address the different categories of material requests by hospital floors: scheduled and urgent ones (Ton et al., 2024). This distinction allows for a more in-depth evaluation of quality in the distribution process and highlights areas where improvements may be necessary to achieve the expected outcome (6) in Section 3.5. Moreover, according to the second type of metrics, two KPIs have been selected to assess the operational efficiency of distribution management (expected outcome (5), in Section 3.5): average picking time for each item and average time for order preparation (AL-Shboul, 2023). Indeed, order picking is one of the most time- and cost-intensive activities in warehouse operations (Calzavara et al., 2017). Thus, underperformance in this area can significantly impact service levels and increase operational costs within the warehouse and across the entire supply chain (De Koster et al., 2007). Finally, in the same way as the inventory operational effectiveness related to the order lines, an indicator has been defined for distribution: the number of outgoing order lines processed per person per day, which also contributes to the measurement of the expected outcome (8), in Section 3.5.

4.2 KPIs analysis

The selected KPIs have been assessed before and after implementing the Miniload system at Ordine Mauriziano Hospital, showing significant improvements in terms of warehouse performance, ultimately contributing to enhanced inventory management and patient care support. In particular, the inventory turnover rate per semester increased from 4.1 to 8.5, meaning that goods are replaced at a double pace, which suggests optimized stock utilization. This result has been obtained thanks to a more accurate control associated with the automated warehouse solution that has brought lower levels of stock. Additionally, inventory counting accuracy raised from 20% to 80%, reflecting a better alignment between recorded stock levels and actual on-hand quantities. Moreover, the average inventory counting time dropped from 7 days to just 1 day. Such a change allows for more frequent counting, moving from a yearly process to a continuous process. These help to reduce errors and support real-time inventory tracking. The handling capacity has also been affected by the Miniload system implementation. Indeed, the number of outgoing order lines processed per person per day increased from an average of 242.5 to 480.2, while incoming order lines per day per person rose from an average of 58.2 to 85.5. These changes demonstrate the Miniload system's ability to improve worker productivity for both incoming and outgoing orders. The time required for picking and preparing orders was cut significantly, with the average picking time reduced from 2 minutes to 0.33 minutes, and order preparation time dropped from 50 to 25 minutes. These reductions lead to smoother workflows and increased efficiency in processing orders. Furthermore, introducing the Miniload system has drastically reduced delays in outgoing order lines, with delayed scheduled requests dropping from 5% to 0% and delayed urgent requests from 2% to 0%, highlighting enhanced responsiveness and reliability in distribution operations. Similarly, the non-compliance rate of outgoing order lines for both scheduled and urgent requests dropped to 0%, down from 10% and 4%, respectively, indicating better adherence to order specifications and reduced shipment errors. Finally, the higher level of control on the inventory has allowed to obtain the 0% of expired products from 3%. Overall, these findings show that the Miniload system has significantly enhanced the quality and increased the operational performance of inventory and distribution processes within the hospital warehouse, as summarized in Table 1.

Table 1. KPIs dashboard

KPI	**u**	**Category**	**Before automation**	**After automation**
Inventory				
Inventory counting accuracy	%	Quality	20%	80%
Average inventory counting time	day	Op. efficiency	7	1
Inventory turnover	dmnl	Op. efficiency	4.1	8.5
% Expired products	%	Op. efficiency	3%	0%
Inventory counting frequency	dmnl	Op. effectiveness	1/year	rolling
N° incoming order lines / (day*person)	lines/ (day*person)	Op. effectiveness	58.2	85.5
Distribution				
% delayed outgoing order lines (scheduled requests)	%	Quality	5%	0%
% delayed outgoing order lines (urgent requests)	%	Quality	2%	0%
% non-compliant outgoing order lines (scheduled requests)	%	Quality	10%	0%
% non-compliant outgoing order lines (urgent requests)	%	Quality	0%	0%
Average picking time	min	Op. efficiency	2	0.33

Average time for order preparation	min	Op. efficiency	50	25
N° outgoing order lines/(day*person)	lines/ (day*person)	Op. effectiveness	242.5	480.2

5. DISCUSSION AND CONCLUSIONS

This paper discusses the implementation of a Miniload system in a hospital warehouse. A dashboard of relevant KPIs is defined to quantitatively assess its impact on performance, focusing on both quality and operational dimensions. The analysis confirms that the anticipated outcomes of the Miniload implementation were successfully achieved. In particular, the inventory turnover increases by 50%. Additionally, positive impacts on the average inventory counting time were observed, improving its accuracy and efficiency, and in turn, reducing the economic expenditure and space required (Kevasan et al., 2016). Also, the average picking time and the average order preparation time go down, increasing operational efficiency. This aspect is also affected by the improvement in the management of expired products, whose percentage is now zero. Moreover, discrepancies between actual inventory levels and the values recorded in the WMS are strongly reduced. The Miniload increases the number of both incoming and outgoing order lines per person per day, with a positive effect on the system throughput. The increased flow of materials is also associated with reduced delays in delivering both urgent and scheduled orders to hospital floors. This improvement enhances the accuracy and efficiency of floor order fulfilment while addressing product shortages effectively. Thus, the adoption of the Miniload positively influences all the dimensions of performance identified in the analysis. Indeed, the KPIs related to effectiveness and efficiency are improved, as well as those related to the quality of the logistics process under study. These remarkable improvements in logistics operations allow hospital personnel to focus more on their core activities, reducing the human resources dedicated to the logistics process while enhancing the quality of services provided (Mathy et al., 2020). This analysis demonstrates the benefits that a healthcare organization might exploit by the implementation of an automated warehouse system. Such a result is very important, considering that these systems are still not fully established in healthcare, even though they have already proven their advantages in sectors such as manufacturing (Mahdavisharif et al., 2022). As a consequence, this paper can be considered an initial contribution to stimulating the research on the use of automation in the management of internal logistics processes in healthcare warehouses. In addition, it enlarges the body of knowledge by showing the quantitative results of a real application. This work supports healthcare organizations using innovative warehousing systems to evaluate potential impacts, particularly concerning service quality KPIs. However, it lacks an analysis of the economic effects of this investment. Future research will focus on evaluating the returns on investment through a quantitative assessment of the savings related to the new organization of logistics processes. In this context, the evaluation of the KPIs here defined will be also carried out in the long run.

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