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International Journal of Logistics Management

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Journal:	*International Journal of Logistics Management*
Manuscript ID	IJLM-02-2020-0110.R3
Manuscript Type:	Original Article
Keywords:	Health care logistics, Performance measurements, Supply chain processes
Research Method:	Mixed method
Geography:	Europe

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Abstract

Purpose - The objective of this paper is to propose an approach to comparatively analyze the performance of drugs and consumable products warehouses belonging to different healthcare institutions.

Design/methodology/Approach - A Cluster Analysis is completed in order to classify warehouses and identify common patterns based on similar organizational characteristics. The variables taken into account are associated with inventory levels, the number of SKUs, and incoming and outgoing flows.

Findings – The outcomes of the empirical analysis are confirmed by additional indicators reflecting the demand level and the associated logistics flows faced by the warehouses at issue. Also, the warehouses belonging to the same cluster show similar behaviors for all the indicators considered, meaning that the performed Cluster Analysis can be considered as coherent.

Research limitations/implications – The study proposes an approach aimed at grouping healthcare warehouses based on relevant logistics aspects. Thus, it can foster the application of statistical analysis in the healthcare Supply Chain Management. The present work is associated with only one regional healthcare system.

Practical implications - The approach might support healthcare agencies in comparing the performance of their warehouses more accurately. Consequently, it could facilitate comprehensive investigations of the managerial similarities and differences that could be a first step towards warehouse aggregation in homogeneous logistics units.

Originality/value – This analysis puts forward an approach based on a consolidated statistical tool, to assess the logistics performances in a set of warehouses and, in turn to deepen the related understanding as well as the factors determining them.

Keywords

Healthcare, logistics, performance management, warehouses, Cluster Analysis

1. Introduction

In the last twenty years healthcare providers in industrialized countries have faced a growing aging of population, with a consequent increase in the need for healthcare services, together with shrinking budgets, especially for those systems that are largely public funded. Thus, they have been subjected to the challenge of providing high quality treatments while cutting operations costs (Feibert and Jacobsen, 2019). Among such costs, material management and logistics play a significant role since it has been proved that they account for around 38% of the total expense, when this ratio is limited to 5% in the retail industry and to 2% in the electronics sector (Johnson, 2015).

In such a context, although some decades later than the manufacturing industry, supply chain management (SCM) has become a key lever to contain expenditures and improve competitiveness in the light of steadily increasing costs. The most popular SCM topics span different fields, from SC configuration, to procurement management, warehouse and inventory management, and drugs and other materials delivery to the patient beds, together with their administration (Mustaffa and Potter, 2009; de Vries and Huijsman, 2011).

Among them, warehouses and inventory management have been largely neglected by researchers and practitioners and only recently have gained momentum as main drivers of efficiency without compromising the level of patient care (Volland et al., 2017). However, actions to improve warehouse processes also require ways of checking whether they are successful. To this end, a performance management system, evaluating a set of appropriately defined Key Performance Indicators (KPIs), should be adopted. Based on Smith's work (Smith, 2002), performance management in the healthcare sector has three roles, namely guidance, monitoring, and response. The guidance function aims to convey strategies and objectives to policy-makers, intermediate managers, and front-line staff. The monitoring function verifies whether guidance has been followed and the associated targets achieved. Finally, the response function fosters actions to correct performance problems and to stimulate improvement.

Relatively few literature contributions assess logistics performance in healthcare organizations and in their warehouses (Gonul Kochan et al., 2018; Leksono et al., 2019; Moons et al., 2019). Such works usually focus on measuring the performance of single healthcare systems and there is a substantial lack of methodologies to numerically contrast and compare the logistics outcomes of multiple warehouses. Thus, given the relevance of warehouses in SCM in general and in the healthcare sector in particular, this is a research stream that deserves further attention, also because nowadays very often policy makers look at the redesign of healthcare warehouses and their operations as the key to reduce inefficiencies and unnecessary costs.

In order to contribute to close such a research gap this work deals with healthcare performance by taking a guidance perspective. Compared to the other two performance management perspectives suggested by Smith (Smith, 2002), the guidance one is deemed to be of paramount importance by the authors because, by enabling setting goals, it constitutes an unavoidable first step towards measuring the achievement of such objectives through KPIs (monitoring perspective) and then addressing possible criticalities (response perspective). The present research puts forward an approach based on a consolidated statistical tool, namely Cluster Analysis, to comparatively study the logistics performance in a set of warehouses and, thus, deepening their understanding as well as the factors determining them. To reach the purpose, warehouses are classified in homogeneous groups sharing common organizational features in terms of size of stocks and logistics flows. The approach has been then applied to a regional healthcare system in Italy. Finding commonalities and differences in warehouse performance in the various clusters through the proposed methodology supports decision-makers in setting appropriate healthcare logistics strategies for each of them, hence the guidance perspective function, based on the actual organizational behavior of the warehouses they manage.

The reminder of the paper is organized as follows. Section 2 performs a literature review on the major topics in which the research is framed. Section 3 presents the methodology and discusses the development of the approach, while Section 4 analyses the outcomes of its application. Finally, Section 5 conveys research implications and conclusions.

2. Literature Review

2.1 Logistics and Warehouse in Healthcare Sector

SCM concerns the optimal functioning of various logistics activities, with the aim of controlling their performance and improving their efficiency. SCM was developed initially in the context of manufacturing but its introduction is also beneficial to the healthcare sector, where it shows an important impact on hospital performance (Parnaby and Towill, 2009). In such a context SCM has the potential to reduce waste, prevent medical errors, increase productivity, improve quality of care, service and operational efficiencies (Cagliano et al., 2011a; Doerner and Reimann, 2007; Ford and Scanlon, 2007). Therefore, it becomes increasingly important to intervene in the healthcare SCM, and in particular in the healthcare logistics processes. The healthcare SCM implies to manage the entire SC (Mustaffa and Potter, 2009), that is very fragmented with many different parties at its various stages. Also, in healthcare there are typically many buying institutions and a relatively small number of suppliers. By focusing on the internal SC, processes are performed within hospitals and comprise product and information flows from receiving, replenishing, picking, etc. (Rossetti et al., 2012) including purchasing, inventory, distribution, and consumption functions. Among these activities, the warehouse ones play a crucial role.

Healthcare warehouses traditionally deliver to point of use inventories, such as ward inventories, that are typically closer to patients (Bijvank and Vis, 2012). Hospital warehouses have to manage three main types of materials, namely drugs, surgical and medical products, and consumable goods (Kumar et al., 2005) which must be supplied correctly to the patient bed. These products bring specific requirements in order to effectively support patient care and, as a consequence, pose different implications to warehouse performance. Drugs and medical devices are both vital to achieve patient health, and thus their timely availability needs to be ensured appropriately (Pinheiro et al., 2019). The variety of drugs products managed by a hospital warehouse should be consistent with the current and future medical treatment needs, taking into account that the latter are highly unpredictable, making drug demand extremely uncertain and volatile (Rosoff, 2012), especially when specific medicine specialties are concerned. Additionally, drugs are subjected to expiration dates, which negatively affects warehouse performance in case of stocking large quantities of unnecessary items. Some drugs, like for instance antiblastic ones, are also characterized by high costs, causing relevant economic values associated with stored products if not subjected to high turnover rates. Medical devices include implants and other devices that usually become part of the human body, such as for example hip prostheses, coronary stents, and artificial heart valves. Besides their obvious medical criticality, two main issues impacting on material management are their high economic values and the very heterogeneous types and sizes these products come in (Akpinar et al., 2015). Therefore, choosing the right variety of stocked items is even a more complex task than for drugs, again due to the very limited possibility to forecast demand. As a matter of fact, the necessary device size is sometimes known just when a surgery is ongoing (Blevins et al., 2020). For these reasons, medical devices are often not stored in hospital warehouses but supplied directly to their wards. Finally, consumable goods are the less challenging products to be managed in a healthcare warehouse due to their nature and value. They include, among the others, surgical gowns, masks, drapes, disinfectant solutions, but also stationary items. Being more standardized, less specific, and used in a wider range of situations than drugs and medical devices, they are characterized by a more stable and predictable demand, which, together with the limited cost and quite a long useful life, make such items more suitable for storage (Akcay and Lu, 2017). Therefore, because of the discussed features, warehouses play a crucial role to facilitate pharmaceutical logistics defined as the task of placing the right drugs and other medical supplies, in the right quantities, in the right conditions, at the right health service delivery points, at the right time, for the right users, and at the right cost (Chikumba, 2010).

Several distribution systems can be applied to a warehouse. The centralized inventory strategy (Iannone et al., 2014) is based on merging stocks managed by different warehouses in a single larger facility wherein operational activities are carried out either by internal logistics personnel or by a specialized logistics service provider. The degree of centralization or outsourcing may be different depending on the processes and materials of a hospital warehouse (Pinna et al., 2015). The centralization is also considered as a lever for reducing missing critical materials and for better controlling the supply process (Guzmàan and Garza, 2018). Although centralization could be seen as a suitable strategy for reducing the logistics cost of healthcare supplies, there are many factors that need to be taken into account in analyzing the economic impact. In fact, if the warehousing cost decreases with a lower number of warehouses, the distribution costs due to the delivery tend to increase (Lucchese et al., 2020). Further policies include collaborative inventory management (Mustaffa and Potter, 2009), vendor-managed inventory, and collaborative planning, forecast, and replenishment (Danese, 2006). Also, warehouses handle with goods that are managed as either stock or direct delivery items (Schneller and Smeltzer, 2006), two policies that are different from the centralization notion. Stock products are delivered from warehouses where there is a certain amount of inventory. Drugs, except for those ones that are very specific or with high economic values, and consumable goods are typically managed as stock items. This policy is applied to the healthcare products that are used by multiple hospital wards on a constant basis, so that keeping a reserve in a warehouse enables a prompt delivery to points of use, without running the risk of items stored for a long time wasting space and value as well as being subjected to obsolescence (Akcay and Lu, 2017; Dixit et al., 2020). On the contrary, suppliers send direct delivery products either to the warehouse or to points of use. In the first configuration, the warehouse merely plays a transit point role, where inspections are performed to check that incoming products match the order, as far as their type and quantity are concerned, and packages are undamaged. After that, direct delivery products are shipped by the warehouse to wards together with stock ones. According to the second scheme, wards are in charge of both quality and quantity inspection of received goods. In both the situations no stock of direct delivery products is kept in the warehouse, they will be just stored by wards in small quantities. Such a policy is usually applied to high value and less frequently used items, such as medical devices and certain drugs, with benefits in terms of total inventory management costs (Cooper et al., 2013). Stock and direct delivery are two material management strategies that may be combined in a same warehouse: this can also happen in centralized warehouses managing all the three types of healthcare products.

In such an environment, warehouses have been acquiring a lot of importance in providing an appropriate level of performance to patients by delivering the service at feasible cost levels. Their integration could also enhance the overall performance of healthcare organizations (Alshahrani et al., 2018). In fact, it has been demonstrated that healthcare logistics is a significant factor in impacting patient's satisfaction (Frichi et al., 2020). Therefore, in this context, and given the complexity of the healthcare SC, it is essential to measure the behavior of operational processes, and this requires Key Performance Indicators (KPIs) (Wu and Dong, 2008) that allow the qualitative or quantitative assessment of the status of any operational and logistics activity (Ackerman, 2003).

2.2 Assessing Healthcare Warehouses Performance

Performance measurement is highly needed for any organization in order to highlight the existing problems (Dixit et al., 2020) and there is a broad stream of literature focusing on the development and on the assessment of warehouse and inventory performance, in both manufacturing and healthcare sectors. The broad interest on the topic depends on the high impacts that warehouses processes have on cost. As a matter of fact, purchasing and handling the inventory in a warehouse can reach the 30% of the budget for a healthcare organization (Ozcan, 2005). As a consequence, lower cost structures are often achieved by studying material logistics (Kotavaara et al., 2017). Thus, many indicators related to logistics processes can be taken into account. In general terms, the warehouse performance measurement requires the evaluation of the main resource inputs (typically labour and capital) and multiple outputs resulting from warehouse operations (Karim et al., 2018). The logistics processes that can be referred to a warehouse are associated with receiving, storing, picking and shipping processes.

If the aim of a study is to measure the whole behavior of a warehouse, the set of KPIs considered should be associated to each cited sub process (Kusrini et al., 2018). By focusing on the healthcare sector, the number of patients served in order to better estimate the demand, the number of stock out, the delivery time for a drug and the number of stored unit loads are indicators considered by (Castro et al., 2020) for measuring the consistency of an inventory policy in a warehouse.

Table 1 presents a review of the most relevant warehouse performance indicators developed based on logistics literature on multiple manufacturing and service sectors, including healthcare. They are classified according to the main warehouse processes and constitute the general framework supporting the selection of the KPIs considered in this contribution.

Table 1. Warehouse Performance Framework

2.3 Selected KPIs for warehouse comparison

Generally speaking, a KPI gives a synthetic measure of a particular performance aspect, which in the case at issue is associated with logistic processes in healthcare warehouses (Badawy et al., 2016). Thus, the contribution of the KPIs in the present work is providing quantitative measures about the key logistics aspects that are then applied to compare the performance of the warehouse groups out of the performed Cluster Analysis.

The set of KPIs chosen for the study is following presented, highlighting their importance in a healthcare warehouse. In particular, the indicators have been identified and measured in order to track the main logistics performance in terms of both stocks and flows. First, the number of items, intended as the number of SKUs managed in the warehouse, has been considered since is an important parameter in studying warehouse systems (Thomas and Meller, 2015). In fact, the number of SKUs drives the computation of safety stocks, the inventory investments and costs, and in turn, the responsiveness to demand changes (Teunter et al., 2017). In addition, such an indicator might influence the amount of space that is required with consequent impacts on costs (Dixit et al., 2020). In this context SKUs assume a crucial importance since, being the demand for healthcare products, their availability should be always guaranteed (Muyinda and Mugisha, 2015). In addition, the Total Value of Delivery has been taken into account. It here represents the economic value of goods that each warehouse ships to points of use (e.g. hospital wards, laboratories, etc.) on a yearly basis. The present indicator addresses the concept of the value of delivered products. In this sense it can be considered as a proxy of the inventory cost that is a key issue for each organization in managing its warehouse operations (Johansson et al., 2020). In fact, if stock-out occurs there could be even treatment problems for patients (Saha and Ray, 2019). On the other hand, holding a high level of inventory can result in high expenditures with lower availability of capital for other purposes (Maestre et al., 2018). This aspect might be also related to the lack of awareness by the medical staff about how to deal with logistics issues (Castro et al., 2020). Moreover, the average inventory level of stock products at the end of each month of the reference year for data collection is analyzed. The inventory level is a key quantity characterizing warehouse activities (Silver, EA, Pyke, DF, Peterson, 1998). As for the indicator Total Value of Delivery, it has been measured as an economic value (Lega et al., 2013), and not as number of units, because the great variety of physical sizes characterizing healthcare products does not allow a reliable assessment of the inventory level in terms of number of products stored.

Finally, the yearly number of both incoming and outgoing order lines (Stock in order lines and Stock out order lines) is measured for considering the activities that are required for managing incoming and outgoing orders (Cagliano et al., 2012). In particular, this variable is related to the need of specialized personnel devoted to material handling and order fulfillment process tasks (Stecca et al., 2016). In addition, the handling of medical items can heavily impact the operations costs (Ferretti et al., 2014). Often an order consists of one or more order lines (van der Gaast et al., 2019) and the number of orders that are processed is a typical aspect measured in studying warehouse operations, including healthcare ones (Saha and Ray, 2019), since it might also bring to a significant increase of logistics flows fragmentation (Lucchese et al., 2020). These orders are the ones placed by the hospital wards and the local healthcare agencies served by a warehouse. As the number of orders increases, the complexity that a warehouse faces grows up (Pinheiro et al., 2019).

De Vries and Huijsman (de Vries and Huijsman, 2011) identify measuring performance as one of the five main future research areas in healthcare SCM. For this purpose, different indicators can be defined, each of them assessing a specific performance related to a particular activity part of one of the processes in the healthcare delivery system. In particular, KPIs should focus on all the three process types assisting healthcare systems in converting inputs into outputs, namely clinical, management, and ancillary ones.

Following these guidelines, several authors propose performance measurement systems in different areas, not only related to SCM. One interesting contribution is offered by Kruk and Freedman (Kruk and Freedman, 2008), who develop a framework suggesting three performance categories: effectiveness, equity, and efficiency of the healthcare service. Effectiveness addresses access to care, quality of care, health status improvement, and patient satisfaction. Equity is related to fair financing, risk protection, and accountability as well as to providing the same access to care and the same quality level to all the groups of patients. Finally, efficiency analyzes healthcare administration by looking at economics aspects such as funding and cost-effectiveness of the delivered services. Another performance topic that is recently receiving attention is associated with the environment. Healthcare services rely on a significant amount of hazardous materials and produce polluting outputs. Assessing the hospital environmental performance with specific KPIs may lead to a reduction in the environmental impact and an improvement in process quality (Pasqualini Blass et al., 2017).

A significant number of authors focus on logistics performance indicators in the healthcare industry by addressing both the internal SC of a hospital and the external one linking multiple institutions. Hassan and others (Hassan et al., 2006) evaluate the performance of the internal flow of pharmaceutical products to care units by measuring indicators associated with order fulfillment, response time, inventory days of supply, storage costs, and the distance travelled during deliveries. Operating theatres are a key resource for hospitals and the required materials are as critical as drugs not only from a clinical but also from a logistics point of view, also due to their economic value which is very often significantly high. Moons and others (Moons et al., 2019) recognize such aspects and develop a literature review on performance measurement of inventory and material distribution activities in operating rooms. Quality, time, financial, and productivity KPIs are investigated. Performance indicators can also be a useful mean for benchmarking the internal logistics process of a hospital (Feibert et al., 2019).

Coming to the external SC, healthcare logistics performance is often studied together with the issue of warehouse centralization. Within this research stream, Lega and others (Lega et al., 2013) put forward and test a framework to assess the integrated SC performances in the public healthcare sector. The costs and benefits of a SC centralization strategy compared to the traditional decentralized model are discussed. The authors define a number of KPIs related to three performance dimensions, operational costs, financial benefits, and organizational benefits. By focusing on warehouse performance, the operating costs include the inventory square meters occupied, in order to help assess warehouse management costs. Additionally, as part of financial and organizational benefits, the "Warehouse Stock Value" and the "Percentage of Urgent Requests" indicators assist in monitoring inventory management efficiency and logistics process standardization respectively. More recently, Cagliano and others (Cagliano et al., 2016) develop a quantitative approach based on a pairwise comparison between logistics KPIs performed through regression analysis. The purpose is assessing the similarities and differences in the logistics management by a group of warehouses part of a regional healthcare system, with the final goal of investigating the potential feasibility of a warehouse centralization strategy. Some authors have started addressing the impact of Industry 4.0 technologies (e.g. cloud computing) on the information sharing in multi-echelon hospital SCs as well as their role in improving logistics performance and visibility (Gonul Kochan et al., 2018). Finally, the sustainability topic is more frequently becoming part of healthcare SC performance management. In fact, Leksono and others (Leksono et al., 2019) apply the Balanced Scorecard and the Analytical Network Process to build a multi-dimensional performance measurement system that includes KPIs assessing the use of green materials and technologies.

In literature there is a still limited number of attempts to address SC performance in healthcare not just from an operational point of view but also from a strategic one. Balcázar-Camacho and others (Balcázar-Camacho et al., 2016) deal with how delivery times, production costs, and customer service perceptions can be positively affected by a coordinated SC planning. Moons and others (Moons et al., 2019) point out that measuring SC performance is fundamental not only to address operational inefficiencies but also as an effective input to decision-makers in order to evaluate the implementation of alternative logistics strategies. In that way, performance indicators can be considered as an effective tool to monitor management policies such that logistics managers can make evidence-based decisions in order to optimize inventory and distribution.

However, very few studies have attempted to measure the impact of SC strategies in the public healthcare sector and provide useful insights for managers and policy-makers involved in strategic decisions in the health SC (Nollet et al., 2008). Also, although the growing interest in performance management in the healthcare sector (Silva and Ferreira, 2010), there is a lack of contributions offering quantitative and systematic approaches to compare the performance of multiple warehouses by clustering them according to similar levels of logistics service. The existing approaches to healthcare performance analysis make use of methods and tools like Discrete Event and System Dynamics simulation, decision-making models such as the Analytic Hierarchy Process, Analytic Network Process, and the Decision Making Trial and Evaluation Laboratory (Dematel), or operations research methodologies as the Data Envelopment Analysis (Gonul Kochan et al., 2018; Günal and Pidd, 2010; Leksono et al., 2019; Otay et al., 2017).

Thus, frameworks are need to simultaneously investigate the performance of a number of different warehouses under multiple dimensions. This would provide decision-makers with a comprehensive picture of the current state of the art of logistics performance in their healthcare systems useful to guide them in setting appropriate strategies. Such frameworks would benefit from the application of consolidated statistical methods, which are currently not so frequently implemented in healthcare SC performance analysis.

The present work puts forward a new approach relying on a well-known statistical tool, namely Cluster Analysis, to analyze and compare the values of key logistics performance measures in multiple warehouses and suggest insights to better understand their performance status and its determinants. Cluster Analysis has been selected as it constitutes an objective method to determine which warehouses share a similar performance level and which do not, based on numerical computations and not just on subjective judgments, which might introduce bias in the assessment. It is a valuable characteristic in healthcare logistics management where many strategies are defined based on the personal perceptions and experience of the decision-makers involved (Cagliano et al., 2021). Moreover, this empirical approach is designed to handle a relevant quantity of observations, and thus address many warehouses, making the proposed method suitable for supporting large-scale analyses at regional levels or, in general, in homogenous geographical areas. Such a feature is also of paramount importance in healthcare because there is an urgent need to redesign logistics networks by carefully considering and efficiently exploiting the available resources on a territorial level, in order for example to avoid redundant duplications of stocks and transit points (Elhachfi Essoussi and Ladet, 2015).

Finally, even if Cluster Analysis is broadly established in operations management, it is scarcely applied to healthcare logistics processes. To the best authors' knowledge, there are very few contributions in this field, mainly related to logistics service provider selection by healthcare manufacturers (Tu et al., 2021) and logistics optimization in surgical instrument sterilization plants (Fogliatto et al., 2020). However, Cluster Analysis applications to the management of healthcare warehouses and the related performance are still missing.

In this work the warehouses under investigation are grouped into homogenous clusters sharing the same organizational characteristics as far as inventory levels and logistics flows are concerned. In other words, warehouses are classified according to the size of their stocks and flows. Thus, the performance comparison is carried out among warehouses with similar features, which allows achieving reliable results.

3. Research Methodology and Approach Development

3.1 Cluster Analysis Variables and Sample Selection

The research has been conducted through the following steps. First, the population of healthcare warehouses has been defined. For the present study it has been set as the population of warehouses part of the Italian public healthcare system, which has been object of logistics and SC interventions by several regions in the last 15 years (Lega et al., 2013). The sample is then constituted by all the warehouses part of a healthcare system in a broad regional area of Italy that is currently considering new warehouse and inventory management strategies, including centralization, to improve logistics efficiency. The names of the region and of the associated healthcare agencies and hospitals cannot be disclosed for confidential reasons.

The overall sample has been divided into four smaller samples of healthcare warehouses according to the different kinds of products and the two material policies, stock and direct delivery, presented in Section 2.1. This allows to obtain set of warehouses that are homogeneous, in terms of both products and management policies, and thus comparable within each single group. The first sample is dedicated to consumable products managed as stock items. The second one to consumable products that are directly delivered to points of use. Similarly, the last two ones are associated with drug Stock Keeping Units (SKUs) that are treated as stock and direct delivery products respectively. Medical devices have been associated to direct delivery drugs, sharing similar features in terms of both economic value and material management approach.

The variables presented in the Literature Review section considered in this study and subjected to Cluster Analysis are listed in Table 2. Such a table reports a description of the data that have been gathered for each kind of warehouse under study to numerically assess the variables included in the developed approach. The choice of analyzing the impact on performance of variables related to logistics stocks and flows is driven by the peculiar characteristics of healthcare warehouses as well as the features of the ones under study. Drug and consumable product warehouses are characterized by very limited return flows, often associated with reusable unit loads adopted for delivery to points of use (Nguyen et al., 2002). In fact, expired drugs are mainly disposed by hospital wards, without returning them to the warehouse, and consumable products either do not have an expiration date or their useful life period is quite long. Additionally, these are not retail warehouses where return flows of goods not matching customer requirements are relevant. For such reasons reverse logistics was not taken into account in the proposed approach. Then, the selected warehouses share a very low level of technology, relying on traditional storage and material handling systems (e.g. transpallets and traditional counterbalanced forklifts) and implementing manual picking operations. Therefore, technology cannot be used to differentiate the performances of these warehouses.

Data collection was performed by means of on field analyses and semi-structured interviews to both hospital and warehouse managers over a period of one year. To be more precise, the columns of Table 2 show the sample size, the mean, the standard deviation, the minimum, the first quartile (Q1), the median, the third quartile (Q3), and the maximum for every variable.

Table 2. Description of the Dataset

Primary data collection was carried out. Coherently with the variables part of the developed approach, the gathered data can be broadly divided into three groups associated with warehouse general characteristics, stock, and flows. The information about the general characteristics includes the hospitals served by each warehouse, together with their number of beds, the warehouse usable floor area, the clearance below truss, the number of operators, and the associated working hours. The stock data comprise the number of SKUs managed by each warehouse and the average inventory level over one year per SKU. This last value was recorded as both number of units and the related economic amount expressed in Euros, although only the latter is considered in the analysis. Finally, the flow information keeps track of the quantity of products delivered by each warehouse to points of use over one year, for both stock and direct delivery items. Similarly to the inventory level, both the number of units and the associated economic value were assessed, although only the latter is included in the analysis. Additionally, the yearly number of incoming and outgoing order lines of stock and direct delivered products was gathered.

3.2 Empirical Approach Development

For every warehouse sample a Cluster Analysis is conducted for identifying common patterns (Mora et al., 2019). In particular, this method aims at grouping data into a few cohesive clusters, so that the objects within a cluster have high similarity. On the contrary, they are very dissimilar to the objects in other cluster (Everitt et al., 2011). In other terms, the aim of the Cluster Analysis is to classify the observations of a sample into homogeneous groups. A group can be called homogenous if its members are close to each other, but they differ considerably from those of the another groups (Mardia et al., 1979). Similarities and dissimilarities are evaluated according to the different attributed values that describe the objects of the sample and are related to distance measures. In particular, the Pearson coefficient is used for evaluating the distance between the correlation coefficients and in turn to measure the proximity between the objects (Jung and Chang, 2016). The Ward linkage method is adopted since it is the one that ensures the smallest internal deviance (Rampado et al., 2019). When applying Cluster Analysis, the sample size is an important issue, since it might affect the statistical confidence. In particular, it should be large enough for including the possible patterns related to the process phenomena. The analysis can be conducted with a sample size N equal to 25, even if with more than 50 observations an improvement of the reliability of results can be observed (Wärmefjord et al., 2010). In the proposed research two samples show a size larger than 50 and two equal to or greater than 25.

Table 3. Results of Cluster Analysis

Table 3 shows the results of the four cluster analyses carried out for every kind of warehouse. For each category, three clusters are identified. One of the key aspects of cluster analyses is to determine an appropriate number of groups. Researchers typically face the need to balance the parsimony, in the sense that a small number of clusters allows to easily carry out comparisons and trace consistent conclusions, and the accuracy that it is expected to increase with the number of groups (Diaz et al., 2003). In general terms, the number of appropriate clusters is unknown (Sahmer et al., 2006) and it is a very challenging and difficult issue in Cluster Analysis (Yao et al., 2019). In fact, there is no commonly accepted method to establish the number of clusters in a studied population (Nylund et al., 2007) and the exact number of clusters can be difficult to be determined (Park and Kim, 2020). Lehmann (1979), indicates as a K number of clusters a value included in this interval (N/60)< K< (N/30), where N is the number of objects of the sample. However, this method has been considered to be very restrictive especially if N is small. At the same time, with very large values of N, K could be too great for carrying out consistent analysis (Diaz et al., 2003; Chrstiansen et al., 2003; Brusco et al., 2017). Therefore, the common approach is to repeatedly run the clustering algorithm several times until a satisfactory result is obtained (Zhu et al., 2019). The number of objects of every cluster is similar for three out of the four samples under study, meaning that the observations of each sample are homogeneously distributed. In addition, a one-way Analysis of Variance (ANOVA) is completed as an internal consistency procedure, in order to check if the differences come up from the Cluster

Analysis are significant and in turn confirmed. As suggested by Milligan (1996), ANOVA can be useful to validate clustering solutions.

Table 4. Cluster Mean Values

Table 4 reports the values of the means of each cluster for all the variables taken into account in the Cluster Analysis. Three variables affecting the stocks and the main logistics flows managed in a warehouse, selected according to the KPI literature framework presented in Table 1, are here added in order to deeply investigate the Cluster Analysis results and identify possible different patterns for the warehouses at issue that represent their current situation. This in turn might suggest decision-makers appropriate strategies for each warehouse cluster, according to the guidance perspective of performance management (Smith, 2002) adopted in the present work. The specific variables are chosen since they are recognized by literature as key determinants of warehouse performance. First, the Number of Beds available in a hospital is selected because it can be considered a proxy of the hospital size and in turn of the demand for both drugs and consumable products faced by the warehouses serving it (Atumanya et al., 2020; De Marco and Mangano, 2013). In other terms, the number of beds measures the capacity to hospitalize patients (Best et al., 2015; Nguyen et al., 2005) in a given time span and contributes to define the quantity of needed healthcare materials (Aptel and Pourjalali, 2001) that warehouses will have to deliver in the same period. Thus, the number of beds significantly influences the warehouse activities and its performance: this is the reason why such a variable is included in the study. Also, the usable floor area is another relevant factor for assessing warehouse operations (Gu et al., 2010; Lega et al., 2013; De Marco et al., 2010). It is part of the analysis because the warehouse physical size drives the value of its storage capacity and, consequently, the ability to make products available in order to timely satisfy the demand. In fact, the warehouse storage capacity is the amount of space to accommodate products so that a desired service level is met (Lee and Elsayed, 2005). Storage capacity, together with workforce staffing, impact the responsiveness and effectiveness of product movements (De La Fuente et al., 2019). Therefore, Full Time Equivalent (FTE) is introduced as a third variable. It is expressed by the ratio of total paid hours in a certain period over the number of working hours in that period (Kyyrä et al., 2019) and measures the actual personnel working in a warehouse. This variable is important in order to understand whether the workforce is aligned with the total warehouse workload required by receiving, storage, and delivery activities according to the healthcare material demand level.

The average values for each cluster of the variables Number of Beds, Usable Floor Area, and FTE will be compared with the mean values of the five variables involved in Cluster Analysis as discussed in Section 4.

In order to check the consistency of the results obtained with the Cluster Analysis, an ANOVA is also conducted. It is statistical methods largely applied in order to explore the differences in terms of impacts of categorical factors on a dependent variable (Aristizabal et al., 2019). Therefore, it has been selected as a suitable approach for the aim of this research. Other methods might be taken into account, such as the Kruskal-Wallis test. Even though, this no-parametric test considers the effects of categorical factors, it is focused on the value of medians, often associated with ordinal scales such as the Likert scale (Panchal et al, 2020; Mangano et al, 2021; Arditi et al., 2015). Thus, this method has been not considered as the most suitable one. Sample size is a critical issue in carrying out an ANOVA. As for many statistical approaches, the larger the sample, the more reliable are the results that are obtained. However, ANOVA could be completed even with a sample size equal to 20, with no noteworthy potential bias (Meyners and Hasted, 2021). In this analysis, the categorical factors are the three identified clusters of the Cluster Analysis and the variables used for tracing the healthcare warehouses' characteristics are the dependent ones. The null hypothesis of the ANOVA is that no significant differences exist among the different groups under study. If the p-value obtained running the test is lower that a critical threshold that is typically equal to 5%, the null hypothesis has to be rejected, and it turn it is possible to affirm a difference among the groups considered (Rezaei et al., 2018). In this paper, the final aim of the ANOVA is to check if the different clusters obtained, are actually different for every variable taken into account. Thus, the test is carried out for every kind of warehouse and for each variable of the study. A first statistical analysis checks if the response variables for the ANOVAs are approximately normally distributed (Kozak and Piepho, 2018) by using the normal probability plot (De Marco et al., 2012). When data show a non-normality of records, a logarithmic transformation is applied to the response variables at issue, so that the transformed variables result to be normal distributed and can be used as response factors (De Marco and Mangano, 2011). Figure 1 shows an example of variable that becomes normal after the logarithm transformation.

Figure 1. Example of Normal Probability Plot before and after the logarithm transformation

18 ANOVAs are completed overall. The cases of tests carried out with the logarithm of the response variable are shown in italics font. Table 5 shows the results obtained.

Table 5. Results of the ANOVA

Through the ANOVA it can be demonstrated the consistency of the Cluster Analysis carried out. As a matter of fact, all the tests prove to be significant, meaning that the Cluster Analysis has been able to properly group the warehouses in the samples. In addition, the R-Squared is considered as a measure of the explanatory power of the model (De Marco et al., 2017). It represents the percentage of the variability that an empirical model is able to capture (Everitt and Skrondal, 2002). An appropriate R-Squared value depends on the application fields and the values derived from the present study are in most of the cases higher than 50%, that can be considered as acceptable (Newbold et al., 2012).

4. Analysis of Results

As a preliminary statement, it is worth highlighting that the aim of the developed approach is comparing and contrasting the outcomes obtained for the three clusters in each of the four samples under investigation. As a matter of fact, based on what discussed in Section 2 and Section 3, clusters in different warehouse samples cannot be compared because of the heterogeneous characteristics of the managed products (drugs vs consumables) and the different material management policies (stock vs direct delivery).

In order to address the results obtained by the proposed methodology, and in particular explain the outcomes of the Cluster Analysis, the following ratios have been computed with the average cluster values of the warehouse variables previously presented, both the five ones involved in the Cluster Analysis and the additional variables presented in Section 3.2 (Table 6). The main purpose of calculating these ratios is confirming the behavior of each of them is aligned with that of the variables used to identify the three clusters resulting from the Cluster Analysis. The first ratio compares the number of yearly outgoing order lines with the FTE value, thus assessing the operators' productivity. It has been included in the analysis because it is one of the key factors of global warehouse productivity (Karim et al., 2018) and is useful to assess whether the current warehouse workforce is consistent with the amount of logistics flows they have to support (Klodawski et al., 2018). Such flows are measured as the number of order lines picked and prepared for delivery because, as already mentioned, the warehouses at issue are usually equipped with traditional storage racks accommodating entire unit loads. This makes the workload required by receiving and putting away incoming products significantly lower than that related to picking and packaging single outgoing boxes (Cagliano et al., 2016). The ratio of the number of SKUs to the usable storage floor area has been then considered because it gives an idea of the item storage density and in turn of how adequate the warehouse space is compared to the amount of products to be stocked (Faber et al., 2013). The present ratio has been taken into account because an optimal utilization of the storage space is crucial for undersized warehouses or expensive storage areas like the ones associated with refrigerated systems (Gamberini et al., 2008). The total yearly economic value of delivered products over the inventory economic value, namely the Inventory Turnover ratio, is a reliable measure of how fast the inventory is replenished. A high value means products spend a short time in stock and thus it proves a good inventory management (Silver, EA, Pyke, DF, Peterson, 1998). The Inventory Turnover ratio is a performance indicator that can guide strategic decisions (Wan et al., 2020) and show how successful are organizations in reducing inventory waste (Demeter and Matyusz, 2011). The last two ratios have been assessed just for stock products, while for direct delivery products they have been replaced by the Total Value of Delivery divided by the number of SKUs. This indicator shows in economic terms the amount of products delivered for each SKU over one-year period and is useful because it allows to make considerations on the appropriateness of managing such items by applying the direct delivery strategy. In fact, the inventory policy of each SKU is also influenced by the yearly sale volume (van Kampen et al., 2012). Finally, all the four warehouse samples have been compared through the ratio Total Value of Delivery over Number of Beds in order to obtain a normalized value estimating the level of demand of the hospitals served by each warehouse (Aptel and Pourjalali, 2001).

Table 6. Variable Ratios

For the Stock Consumable Products, the first cluster includes the largest warehouses, with many SKUs managed and a lot of inventory stored, together with a large amount of orders delivered. This result is reflected by the average number of beds and by the FTE value that are the highest ones in this cluster. On the contrary Cluster 3 is made up by small warehouses with a limited number of SKUs and, as a consequence, fewer logistics activities that need to be carried out. Cluster 2 presents intermediate values for the variables considered meaning that for the Stock Consumable Products warehouses, the Cluster Analysis has been able to clearly group the observations of the sample.

Looking at the same warehouse sample, the results of the ratio between the number of orders lines processed and the FTE are not coherent with the outcomes of the Cluster Analysis. In particular, both Cluster 1 and Cluster 2 show values more than 100% greater compared with Cluster 3. This means that there is not a proper balance of the workload among the warehouses of the sample and a more effective organization of the human resources should be addressed. This results might also depend on the fact that the warehouses of the analysis are managed by different local healthcare agencies with different inventory policies and more in general different approaches for carrying out logistics processes.

On the contrary, the warehouse floor area exploitation is aligned with the outcomes of the Cluster Analysis. This means that warehouses managing a large number of SKUs also tend to have a relevant number of items stocked per each square meter. Similarly, fewer SKUs per square meter might show that the available storage floor area is not consistent with the total number of items handled. Such an outcome reflects a utilization of the warehouse area that might not be coherent with the number of items that need to be stored, due to a high level of product heterogeneity in terms of both type and size. Also, the availability of new storage floor areas does not always keep the pace with the current logistics needs. Although the Inventory Turnover does not fully reflect the Cluster Analysis results, it proves to be of the same order of magnitude in each cluster. Its values show an acceptable performance that could be the result of the recent public budget cuts that have forced more careful inventory policies (Malovecka I et al., 2015). On the contrary, the values of the ratio between the Total Value of Delivery and the Number of Beds are completely coherent with the outcomes of the Cluster Analysis and reflect an appropriate demand level based on the size of the served hospitals.

By observing the Direct Delivery Consumable Products, Cluster 3 includes the largest warehouses. However, this group is made up of only two observations that can be considered as outliers. The number of SKUs is not much higher compared with Cluster 2, even if the value of the delivered goods and the number of order lines managed is significantly greater. Also the human workload appears to be larger. In Cluster 1 there are smaller warehouses although the value of FTE is quite similar to the Cluster 2 one. This might be due to the fact that the workforce required by some organizational activities associated with logistics, such as the administrative ones, is independent from the number of handled products (Krajnc et al., 2012). The dissimilar economic values of yearly deliveries among the three clusters, caused by the heterogeneous types of consumable products that are usually managed as direct deliveries based on hospital needs, are reaffirmed by the delivery values per each hospital bed. This result is also stressed by the fact that the difference in the average number of beds served in each cluster is not so high. A more detailed analysis of this product category is not feasible since the quantity and type of items not stocked but directly delivered to points of use are extremely volatile among different healthcare agencies and sometimes even among warehouses of the same institution. In fact, the products at issue are associated with specific therapeutic requirements and might not be used on a regular basis. Such an organizational structure is reflected by the outcomes of the Cluster Analysis that has assigned only two observations to a cluster, meaning that it could be difficult to clearly identify evident patterns.

In the sample of Stock Drug warehouses, Cluster 1 presents the highest values in all the analyzed variables, especially regarding to the Total Value of Delivery. Cluster 2 shows intermediate values, and in Cluster 3 smallest warehouses can be observed. As already highlighted in the previous sample, the FTE value for Cluster 2 and 3 is almost the same. Considering the ratio of Stock Out Order Lines to FTE, it can be stated that the differences in its values among the clusters are not significant. This might be due to the fact that different warehouses, dealing with a different amount of yearly order lines, have coherent workloads assigned. Similarly, the behavior just outlined can be observed in the values of the number of SKUs managed per each square meter that are quite similar for every cluster.

As matter of fact, the size of drug product packages is quite standardized, enabling an appropriate planning and management of the storage area.

The Inventory Turnover confirms the results of the empirical analysis. The related values are higher than the stock consumable products ones because drugs typically have shorter expiration dates that stimulate a frequent stock replacement (Leaven et al., 2017). In addition, drugs are usually more expensive than consumable products, thus the effects of reduced public budgets are even stronger for the warehouses managing such a kind of products. In fact, in order to avoid waste of money, they tend to always keep in stock an amount of goods able to cover the demand over a limited time period. On the contrary, the yearly economic value of deliveries per each hospital bed is only partially consistent with the Cluster Analysis outcomes due to the very small average number of beds served by the warehouses in Cluster 3.

Finally, for the Direct Delivery Drug sample the values associated with the 32 warehouses in Cluster 3 are the lowest ones, followed by Cluster 1 and then Cluster 2. As in the Cluster Analysis, for the warehouses in Cluster 3 the ratio between Stock Out Order Lines and FTE is significantly low. Such an evidence can be explained by the relevant number of local drug warehouses grouped together in this cluster that, due to their nature, have a smaller number of order lines delivered per year than hospital warehouses. In fact, according to the Italian public healthcare system, local drug warehouses are smaller logistics units located throughout a geographical area in charge of distributing products to patients affected by particular pathologies or who have specific therapies. This causes a small level of logistics flows that in turn requires a low amount of workforce. The yearly economic value delivered for each SKU is coherent with the Cluster Analysis. It is important to highlight that these values are higher than the corresponding consumable products ones because the present item category includes very specific and often expensive drugs that would not be efficiently managed with a stock strategy. Finally, the ratio of the delivery value over the number of beds is consistent with the Cluster Analysis results. Cluster 3, which includes many local drug warehouses, shows the lowest value for this indicator due to the low value of deliveries and the reduced number of beds. In fact, local drug warehouses do not serve hospital beds and usually manage more stock products than direct delivery ones. Direct delivery products are more typical of hospital pharmacies, which may need particular drugs only in certain situations.

5. Implications and Conclusions

The study proposes a quantitative approach for classifying healthcare warehouses according to several relevant logistics aspects, such as the number and type of products managed (Teunter et al., 2017), the demand faced by each warehouse (Johansson et al., 2020), and the inventory level (Lega et al., 2013). The addressed warehouses deal with drugs and consumable products, managed as both stock and direct delivery items. The purpose of the research is to identify common patterns in warehouse management by taking a guidance perspective as suggested by Smith (Smith, 2002). In fact, his approach is based on measuring performance in healthcare systems in order to capture how they currently behave. Thus, the methodology proposed in this work aims to facilitate policy-makers in understanding the logistics status of different groups of warehouses, so that they are able to develop more tailored strategies for each of them.

To this end, an empirical analysis is carried out. In particular, the selected method is the Cluster Analysis that is broadly used in many fields of applications (Anuşlu and Fırat, 2019). However, the use of this statistical approach appears to be quite limited in healthcare in order to address the behavior of logistics systems, and in particular warehouses. Through such a methodology, in the proposed analysis each warehouse is grouped with other similar ones by taking into account main stock and flow variables, such as the inventory level and the incoming and outgoing order lines just to mention some of them. This avoids comparing warehouses with heterogeneous behaviors in terms of their logistics processes. In fact, a more precise comparison can be carried out among similar warehouses belonging to the same cluster. The similarity in warehouse behavior, supporting the clustering purpose of this work, is established through specific logistics KPIs that are numerically evaluated in order to provide quantitative and objective measures to base the comparison on. Thus, KPIs, together with Cluster Analysis, play an essential role in making the developed approach more coherent than other approaches comparing warehouses and their performance based on subjective criteria or less structured methodologies (Zhu et al., 2019). As a matter of fact, the comparison is completed among warehouses belonging to the same cluster, thus avoiding analyzing warehouses with significantly different sizes in terms of stocks and logistics flows. The outcomes appear reliable and coherent. In fact, the warehouses belonging to the same cluster show similar behaviors for all the indicators considered. The results of the empirical model have been evaluated by carrying out a confirmatory ANOVA, which showed the consistency of the developed Cluster Analysis. This has also been proved by observing other parameters that contribute to determine the demand for healthcare products, the warehouse storage capacity, and its ability to handle the current material flows.

The proposed work might be able to support a performance analysis including a plethora of warehouses belonging to different healthcare institutions. This is an important point since quantitative and structured approaches to performance management are often related to single organizations (Feibert and Jacobsen, 2019; Hassan et al., 2006) and mostly refers to single warehouses (Moons et al., 2019). On the contrary, the developed contribution takes a comprehensive perspective on multiple warehouses of different healthcare agencies and it identifies a number of clusters, each of them with homogeneous behavior. In this way, by observing the cluster features, it is possible to easily define the general performance level of a specific warehouse group. As mentioned before, such an objective has been achieved by proposing an approach integrating two main statistical tools, namely the Cluster Analysis, for grouping the sample observations, and the ANOVA for confirming the consistency of the obtained groups.

This work originates several both academic and practical implications. From an academic perspective, the present paper enlarges the body of knowledge on healthcare warehousing operations by highlighting the need for properly comparing their performance comprehensively to support the identification of any existing criticality (Dixit et al., 2020). Additionally, performances are here compared and contrasted according to their similarities and differences, which could be a first phase towards the development of a research stream aimed at an accurate warehouse system assessment based on a combined view of different logistics performance aspects. Finally, the present study is likely to stimulate research exploiting statistical methods. In fact, statistics is still scarcely used in healthcare SCM although this sector might benefit from it through the implementation of consolidated methods providing objective results. In fact, the combination of the Cluster Analysis and the ANOVA has provided reliable outcomes, although, as highlighted by literature, their use is not completed established in logistics healthcare studies (Otay et al., 2017).

From a practical point of view, the proposed Cluster Analysis might support healthcare systems in comparing the performance of their warehouses more properly and accurately. In particular, thanks to a deep understanding of the logistics activities provided by the developed approach, it is possible to easily assign a warehouse to a specific cluster according to its performance features, in order to define appropriate management policies. Also, healthcare decision-makers might be supported in the design of guidelines tailored to the peculiar logistics processes of the different warehouse groups.

In addition, each warehouse is not analyzed independently from the others but in a comparative way, which gives that level of detail about logistics processes that is necessary to healthcare policy-makers. The issue related to performance has been gaining a lot of importance especially in the case of public healthcare systems that have been facing significant cuts of public financial budget (De Marco and Mangano, 2013) and consequently have to address more carefully their expenses. Within such an operational environment, this work could support comprehensive investigations of the managerial similarities and differences that can be considered as a first step towards warehouse aggregation in homogeneous logistics units (Cagliano et al., 2016). Appropriately assessing healthcare warehouse performance has acquired a critical importance during pandemic periods, such as the current SARS-CoV-2, wherein inventory strategies tailored to specific warehouse characteristics are key levers for ensuring timely and accurate supply of drugs and individual protection devices (Cundell et al., 2020). In addition, the performance aspects of warehouses associated with the inventory management and the distribution of vaccines for SARS-CoV-2 are demonstrating to be crucial for ensuring a proper and diffused vaccination campaign among the population (Arnold, 2020).

Moreover, the offered warehouse categorization could be considered as a method to assist policy-makers in formulating SC strategies tailored to the peculiar characteristics of each set of warehouses. This appears to be crucial also in the facility design or renovation phase, when potentially expensive aspects, such as the warehouse size or the storage capacity, need to be defined.

Warehouses are a system of the healthcare SC that might be significantly improved in order to increase its efficiency, especially in the light of the current trends requiring higher service level to patients by reducing costs at the same time. To this end, it is crucial to be focused on a SC more integrated with no stock redoubling, with consequent cost redoubling. In order to achieve higher levels of integration, it is important to know in detail the performance of every warehouse, considering that different groups of warehouses can have different behaviours and in turn different performance. Thus, the performance benchmark should be carried out among warehouse structurally similar. Therefore, Cluster Analysis allows to group different warehouses in different clusters, and within every cluster it is possible to perform the benchmark. Through the benchmark, and after groups of homogenous warehouses are found, it is possible to undertake their centralization according to geographical and managerial conditions. In such a way operations efficiency might be more easily achieved. In this perspective, the present work is a preliminary contribution for more easily implementing the warehouse centralization strategy, which is actually already exploited in many industrial sectors, including new-born ones. As a matter of fact, the centralization of the warehouses for electric vehicle batteries is a phenomena that can be clearly observed (Rafele et al., 2020). To conclude, the proposed approach might be useful in those operations contexts requiring a unique control of many different healthcare warehouses in a specific geographical area.

However, the present work suffers from some limitations. In particular, the proposed approach is mainly focused on a limited number of variables associated with healthcare warehouses. For instance, the effects on performance of the layout or the material handling systems are not addressed, although they recognized role in determining the operational performance (Huertas et al., 2007; Ramli et al., 2017). Also, the application of the approach refers only to one regional healthcare system. A further limitation is related to the number of investigated warehouses. In fact, if on the one hand the number of drug warehouses looks appropriate, on the other hand the number of consumable product warehouses is actually limited. Such a sample characteristic, of course, impacts the empirical analysis performed and it is reflected by the size of the associated clusters. However, the number of consumable product warehouses in both the geographical area at issue and the entire Italian territory is quite reduced and this fact also dramatically emerged as one of the causes for the shortage of personal protective equipment (e.g. masks and gloves) and disinfectants experienced by Italian hospitals during the first phase of the Covid-19 pandemic (Veritti et al., 2020).

Thus, future research will be addressed towards enlarging the number of variables taken into account so that to include a more complete set of performance indicators in the Cluster Analysis, also related to warehouse design and equipment characteristics. Furthermore, the application of the developed approach will be extended to warehouses of other healthcare systems by also deepening the feedbacks from the associated healthcare practitioners about the results obtained by the proposed methodology. This will ultimately enable the comparison of the outcomes from the different healthcare systems studied.

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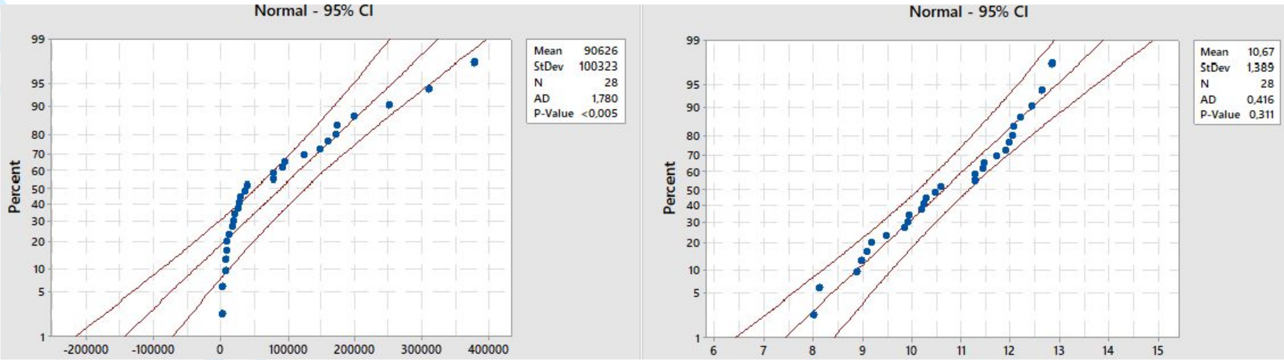

Figure 1. Example of Normal Probability Plot before and after the logarithm transformation

Warehouse Process	Main Key Performance Indicators	References
Receiving	Total number of incoming order lines; Receiving completeness; % Receipts processed accurately; Receipts per man-hour; Receiving processing time	Faber et al., 2013; Kritchanchai et al., 2018; Matopoulos et al., 2010 Frazelle, 2016
Storing	Putaway time; Putaways per man-hour; Inventory level; Inventory turnover; Inventory days on hand; Inventory Accuracy; Stock-out rate; Inventory carrying cost; Storage space cost per item; Useful warehouse area; Inventory per warehouse square foot; Warehouse storage capacity; Temperature-controlled storage capacity; Number of stored SKUs	Cagliano et al., 2011b; De Koster et al., 2007; Dixit et al., 2020; Faber et al., 2013; Gallmann and Belvedere, 2011; Gu et al., 2010; Lao et al., 2011; Rimiene, 2008; Staudt et al., 2015
Picking	Order picking time; Order lines picked per man-hour; Picking error rate	Yang and Chen, 2012; Zeng et al., 2019
Shipping & Delivery	Good preparation timeliness Order fill rate; Total number of outgoing order lines; Orders prepared for shipment per man-hour; Economic value of delivered products; % Urgent deliveries; Number of served hospital beds; Shipment error rate; Delivery reliability	Aptel and Pourjalali, 2001; Chen at al., 2021; Dixit et al., 2020; Kritchanchai et al., 2018; Ramaa et al., 2012; Schneller and Smeltzer, 2006; Staudt et al., 2015

Table 1. Warehouse Performance Framework

Stock Consumable Products

Variable	Sample Size	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
SKUs [units]	28	2,643	2,369	292	613	1,533	5,393	6,373
Total Value of Delivery [€/year]		5,902,937	5,711,784	64,852	925,703	33	8,709,731	20,585,726
Inventory Value [€]		863,763	844,770	5,821	156,070	438,502	1,487,007	2,601,625
Stock in Order Lines [units/year]		8,671	8,066	364	1,469	6,418	14,378	32,604
Stock out Order Lines [units/year]		90,626	100,323	3,068	14,677	38,162	156,520	378,060

Direct Delivery Consumable Products

Variable	Sample Size	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
SKUs [units]	25	2,412	2,589	11	178	1,566	3,792	9,531
Total Value of Delivery [€/year]		3,309,188	4,196,041	1,759	203,593	2,221,978	488,995	15,161,807
Direct Delivery in Order Lines [units/year]		6,636	6,706	65	728	4,108	13,208	22,945
Direct Delivery out Order Lines [units/year]		6,969	6,827	78	1,040	4,888	11,232	22,464

Stock Drugs

Variable	Sample Size	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
SKUs [units]	95	1,463	854	38	825	1,365	1,990	3,888
Total Value of Delivery [€/year]		7,912,467	5,798,919	7,995	3,095,020	6,883,501	11,519,671	24,453,122
Inventory Value [€]		676,191	494,018	21,779	302,389	530,932	979,781	1,891,574
Stock in Order Lines [units/year]		5,250	3,906	52	2,500	4,108	7,228	15,589
Stock out Order Lines [units/year]		49,237	45,073	104	14,560	36,146	71,344	185,369

Direct Delivery Drugs

Variable	Sample Size	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
SKUs [units]	63	749	772	18	62	572	1,208	3,425
Total Value of Delivery [€/year]		1,949,631	2,110,917	5,325	194,809	1,180,044	2,834,173	8,524,569
Direct Delivery in Order Lines [units/year]		2,151	2,102	35	316	1,716	3,380	8,528
Direct Delivery out Order Lines [units/year]		2,676	2,636	36	320	1,820	4,368	9,724

Table 2. Description of the Dataset

Storage Consumable Products	Cluster 1	Cluster 2	Cluster 3
	10	7	11
Direct Delivery Consumable Products	Cluster 1	Cluster 2	Cluster 3
	14	9	2
Storage Drugs	Cluster 1	Cluster 2	Cluster 3
	26	31	38
Direct Delivery Drugs	Cluster 1	Cluster 2	Cluster 3
	18	13	32

Table 3. Results of Cluster Analysis

Stock Consumable Products	**Mean Cluster 1**	**Mean Cluster 2**	**Mean Cluster 3**
SKUs [units]	4,730	2,871	599
Total Value of Delivery [€/year]	12,286,189	4,306,781	1,115,716
Inventory Value [€]	1,758,359	725,297	138,606
Stock in Order Lines [units/year]	17,245	7,606	1,554
Stock out Order Lines [units/year]	171,396	80,351	23,235
Number of Beds	395	321	268
Usable Floor Area [m2]	1,255	1,165	612
Full Time Equivalent [units]	19	8	5
Direct Delivery Consumable Products	**Mean Cluster 1**	**Mean Cluster 2**	**Mean Cluster 3**
SKUs [units]	897	4,302	4,513
Total Value of Delivery [€/year]	1,196,814	4,141,021	14,352,549
Direct Delivery in Order Lines [units/year]	1,632	11,630	19,195
Direct Delivery out Order Lines [units/year]	2,410	10,714	22,035
Number of Beds [units]	281	321	478
Usable Floor Area [m2]	647	949	3,000
Full Time Equivalent [units]	8	9	25
Stock Drugs	**Mean Cluster 1**	**Mean Cluster 2**	**Mean Cluster 3**
SKUs [units]	2,173	826	1,520
Total Value of Delivery [€/year]	15,460,325	1,996,056	7,387,421
Inventory Value [€]	1,212,430	241,001	664,312
Stock in Order Lines [units/year]	8,885	2,141	5,247
Stock out Order Lines [units/year]	62,697	27,000	46,763
Number of Beds [units]	212	110	87
Usable Floor Area [m2]	467	202	248
Full Time Equivalent [units]	9	4	5
Direct Delivery Drugs	**Mean Cluster 1**	**Mean Cluster 2**	**Mean Cluster 3**
SKUs [units]	955	1,774	217
Total Value of Delivery [€/year]	2,170,104	5,139,612	529,627
Direct Delivery in Order Lines [units/year]	2,885	5,089	545
Direct Delivery out Order Lines [units/year]	3,757	6,375	565
Number of Beds [units]	172	285	107
Usable Floor Area [m2]	359	472	220
Full Time Equivalent [units]	7	11	5

Table 4. Cluster Mean Values

	SKUs	Total Value of Delivery	Inventory Value	IN-Order Lines	OUT Order Lines
Stock Consumable Products					
p-value	*0*	*0*	*0*	*0*	*0,002*
R-Squared Adjusted	*76,74%*	*70,22%*	*65,42%*	*79,49%*	*34,63%*
Direct Delivery Consumable Products					
p-value	0,001	0	-	*0*	0
R-Squared Adjusted	40,48%	71,61%	-	*82,51%*	75,87%
Stock Drugs					
p-value	0	0	0	*0*	*0*
R-Squared Adjusted	34,54%	84,65%	57,30%	*45,82%*	*19,88%*
Direct Delivery Drugs					
p-value	0	0	-	0	0
R-Squared Adjusted	71,65%	70,61%	-	73,79%	78,71%

Table 5. Results of the ANOVA

Stock Consumable Products	**Cluster 1**	**Cluster 2**	**Cluster 3**
Stock out Order Lines/FTE [units/year/person]	9,166	10,301	4,647
SKU/Usable Floor Area [units/m2]	3.8	2.5	1.0
Total Value of Delivery/Inventory Value [dmnl]	7.0	5.9	8.0
Total Value of Delivery/Number of Beds [€/year/units]	31,104	13,417	4,163
Direct Delivery Consumable Products	**Cluster 1**	**Cluster 2**	**Cluster 3**
Direct Delivery out Order Lines/FTE [units/year/person]	301	1,231	889
Total Value of Delivery/SKU [€/year/units]	1,334	963	3,180
Total Value of Delivery/Number of Beds [€/year/units]	4,259	12,900	30,026
Stock Drugs	**Cluster 1**	**Cluster 2**	**Cluster 3**
Stock out Order Lines/FTE [units/year/person]	7,376	7,105	8,823
SKU/Usable Floor Area [units/m2]	4.7	4.1	5.1
Total Value of Delivery/Inventory Value [dmnl]	12.8	8.3	11.1
Total Value of Delivery/Number of Beds [€/year/units]	72,926	18,146	84,913
Direct Delivery Drugs	**Cluster 1**	**Cluster 2**	**Cluster 3**
Direct Delivery out Order Lines/FTE [units/year/person]	529	569	123
Total Value of Delivery/SKU [€/year/units]	2,272	2,897	2,441
Total Value of Delivery/Number of Beds [€/year/units]	12,617	18,034	4,328

Table 6. Variable Ratios

~~Analyzing performance in~~Classifying healthcare warehouses~~: a proposed~~ according to their performance. A Cluster Analysis-based approach

Abstract

Purpose - The objective of this paper is to propose an approach to comparatively analyze the performance of drugs and consumable products warehouses belonging to different healthcare institutions.

Design/methodology/Approach - A Cluster Analysis is completed in order to classify warehouses and identify common patterns based on similar organizational characteristics. The variables taken into account are associated with inventory levels, the number of SKUs, and incoming and outgoing flows.

Findings – The outcomes of the empirical analysis are confirmed by additional indicators reflecting the demand level and the associated logistics flows faced by the warehouses at issue. Also, the warehouses belonging to the same cluster show similar behaviors for all the indicators considered, meaning that the performed Cluster Analysis can be considered as coherent.

Research limitations/implications – The study proposes an approach aimed at grouping healthcare warehouses based on relevant logistics aspects. Thus, it can foster the application of statistical analysis in the healthcare Supply Chain Management. The present work is associated with only one regional healthcare system.

Practical implications - The approach might support healthcare agencies in comparing the performance of their warehouses more accurately. Consequently, it could facilitate comprehensive investigations of the managerial similarities and differences that could be a first step towards warehouse aggregation in homogeneous logistics units.

Originality/value – This analysis puts forward an approach based on a consolidated statistical tool, to assess the logistics performances in a set of warehouses and, in turn to deepen the related understanding as well as the factors determining them.

Keywords

Healthcare, logistics, performance management, warehouses, Cluster Analysis

1. Introduction

In the last twenty years healthcare providers in industrialized countries have faced a growing aging of population, with a consequent increase in the need for healthcare services, together with shrinking budgets, especially for those systems ~~which~~that are largely public funded. Thus, they have been subjected to the challenge of providing high quality treatments while cutting operations costs (Feibert and Jacobsen, 2019). Among such costs, material management and logistics play a significant role since it has been proved that they account for around 38% of the total expense, when this ratio is limited to 5% in the retail industry and to 2% in the electronics sector (Johnson, 2015).

In such a context, although some decades later than the manufacturing industry, supply chain management (SCM) has become a key lever to contain expenditures and improve competitiveness in the light of steadily increasing costs. The most popular SCM topics span different fields, from SC configuration, to procurement management, warehouse and inventory management, and drugs and other materials delivery to the patient beds, together with their administration (Mustaffa and Potter, 2009; de Vries and Huijsman, 2011).

Among them, warehouses and inventory management have been largely neglected by researchers and practitioners and only recently have gained momentum as main drivers of efficiency without compromising the level of patient care (Volland et al., 2017). However, actions to improve warehouse processes also require ways of checking whether they are successful. To this end, a performance management system, evaluating a set of appropriately defined Key Performance Indicators (KPIs), should be adopted. Based on Smith's work (Smith, 2002), performance management in the healthcare sector has three roles, namely guidance, monitoring, and response. The guidance function aims to convey strategies and objectives to policy-makers, intermediate managers, and front-line staff. The monitoring function verifies whether guidance has been followed and the associated targets achieved. Finally, the response function fosters actions to correct performance problems and to stimulate improvement.

Relatively few literature contributions ~~focus on assessing~~assess logistics performance in healthcare organizations and in their warehouses (Gonul Kochan et al., 2018; Leksono et al., 2019; Moons et al., 2019). Such works usually focus on measuring the performance of single healthcare systems and there is a substantial lack of methodologies to numerically contrast and compare the logistics outcomes of multiple warehouses. Thus, given the relevance of warehouses in SCM in general and in the healthcare sector in particular, this is a research stream that deserves further attention, also because nowadays very often policy makers look at the redesign of healthcare warehouses and their operations as the key to reduce inefficiencies and unnecessary costs.

In order to contribute to close such a research gap this work deals with healthcare performance by taking a guidance perspective. Compared to the other two performance management perspectives suggested by Smith (Smith, 2002), the guidance one is deemed to be of paramount importance by the authors because, by enabling setting goals, it constitutes an unavoidable first step towards measuring the achievement of such objectives through KPIs (monitoring perspective) and then addressing possible criticalities (response perspective). The present research puts forward an approach based on a consolidated statistical tool, namely Cluster Analysis, to comparatively study the logistics performance in a set of warehouses and, thus, deepening their understanding as well as the factors determining them. To reach the purpose, warehouses are classified in homogeneous groups sharing common organizational features in terms of size of stocks and logistics flows. The approach has been then applied to a regional healthcare system in Italy. Finding commonalities and differences in warehouse performance in the various clusters through the proposed methodology supports decision-makers in setting appropriate healthcare logistics strategies for each of them, hence the guidance perspective function, based on the actual organizational behavior of the warehouses they manage.

The reminder of the paper is organized as follows. Section 2 performs a literature review on the major topics in which the research is framed. Section 3 presents the methodology and discusses the development of the approach, while Section 4 analyses the outcomes of its application. Finally, Section 5 conveys research implications and conclusions.

2. Literature Review

2.1 Logistics and Warehouse in Healthcare Sector

SCM concerns the optimal functioning of various logistics activities, with the aim of controlling their performance and improving their efficiency. SCM was developed initially in the context of manufacturing but its introduction is also beneficial to the healthcare sector, where it shows an important impact on hospital performance (Parnaby and Towill, 2009). In such a context SCM has the potential to reduce waste, prevent medical errors, increase productivity, improve quality of care, service and operational efficiencies (Cagliano et al., 2011a; Doerner and Reimann, 2007; Ford and Scanlon, 2007). Therefore, it becomes increasingly important to intervene in the healthcare SCM, and in particular in the healthcare logistics processes. The healthcare SCM implies to manage the entire SC (Mustaffa and Potter, 2009), that is very fragmented with many different parties at its various stages. Also, in healthcare there are typically many buying institutions and a relatively small number of suppliers. By focusing on the internal SC, processes are performed within hospitals and comprise product and information flows from receiving, replenishing, picking, etc. (Rossetti et al., 2012) including purchasing, inventory, distribution, and consumption functions. Among these activities, the warehouse ones play a crucial role.

Healthcare warehouses traditionally deliver to point of use inventories, such as ward inventories, that are typically closer to patients (Bijvank and Vis, 2012). Hospital warehouses have to manage three main types of materials, namely drugs, surgical and medical products, and consumable goods (Kumar et al., 2005) which must be supplied correctly to the patient bed. These products bring specific requirements in order to effectively support patient care and, as a consequence, pose different implications to warehouse performance. Drugs and medical devices are both vital to achieve patient health, and thus their timely availability needs to be ensured appropriately (Pinheiro et al., 2019). The variety of drugs products managed by a hospital warehouse should be consistent with the current and future medical treatment needs, taking into account that the latter are highly unpredictable, making drug demand extremely uncertain and volatile (Rosoff, 2012), especially when specific medicine specialties are concerned. Additionally, drugs are subjected to expiration dates, which negatively affects warehouse performance in case of stocking large quantities of unnecessary items. Some drugs, like for instance antiblastic ones, are also characterized by high costs, causing relevant economic values associated with stored products if not subjected to high turnover rates. Medical devices include implants and other devices that usually become part of the human body, such as for example hip prostheses, coronary stents, and artificial heart valves. Besides their obvious medical criticality, two main issues impacting on material management are their high economic values and the very heterogeneous types and sizes these products come in (Akpinar et al., 2015). Therefore, choosing the right variety of stocked items is even a more complex task than for drugs, again due to the very limited possibility to forecast demand. As a matter of fact, the necessary device size is sometimes known just when a surgery is ongoing (Blevins et al., 2020). For these reasons, medical devices are often not stored in hospital warehouses but supplied directly to their wards. Finally, consumable goods are the less challenging products to be managed in a healthcare warehouse due to their nature and value. They include, among the others, surgical gowns, masks, drapes, disinfectant solutions, but also stationary items. Being more standardized, less specific, and used in a wider range of situations than drugs and medical devices, they are characterized by a more stable and predictable demand, which, together with the limited cost and quite a long useful life, make such items more suitable for storage (Akcay and Lu, 2017). Therefore, because of the discussed features, warehouses play a crucial role to facilitate pharmaceutical logistics defined as the task of placing the right drugs and other medical supplies, in the right quantities, in the right conditions, at the right health service delivery points, at the right time, for the right users, and at the right cost (Chikumba, 2010).

~~There are several~~Several distribution systems ~~that~~ can be applied to a warehouse. The centralized inventory strategy (Iannone et al., 2014) is based on merging stocks managed by different warehouses in a single larger facility wherein operational activities are carried out either by internal logistics personnel or by a specialized logistics service provider. The degree of centralization or outsourcing may be different depending on the processes and materials of a hospital warehouse (Pinna et al., 2015). The centralization is also considered as a lever for reducing missing critical materials and for better controlling the supply ~~of the materials~~process (Guzmàan and Garza~~.,~~, 2018). ~~Even if~~Although centralization could be seen as a suitable strategy for reducing the logistics cost of healthcare supplies, there are many factors that need to be taken into account in analyzing the ~~costs.~~economic impact. In fact, if the warehousing cost decreases with a lower number of warehouses, the distribution costs due to the delivery tend to increase (Lucchese et al., 2020). Further policies include collaborative inventory management (Mustaffa and Potter, 2009), vendor-managed inventory, and collaborative planning, forecast, and replenishment (Danese, 2006). Also, warehouses handle with goods that are managed as either stock or direct delivery items (Schneller and Smeltzer, 2006), two policies that are different from the centralization notion. Stock products are delivered from warehouses where there is a certain amount of inventory. Drugs, except for those ones that are very specific or with high economic values, and consumable goods are typically managed as stock items. This policy is applied to the healthcare products that are used by multiple hospital wards on a constant basis, so that keeping a reserve in a warehouse enables a prompt delivery to points of use, without running the risk of items stored for a long time wasting space and value as well as being subjected to obsolescence (Akcay and Lu, 2017; Dixit et al., 2020). On the contrary, suppliers send direct delivery products either to the warehouse or to points of use. In the first configuration, the warehouse merely plays a transit point role, where inspections are performed to check that incoming products match the order, as far as their type and quantity are concerned, and packages are undamaged. After that, direct delivery products are shipped by the warehouse to wards together with stock ones. According to the second scheme, wards are in charge of both quality and quantity inspection of received goods. In both the situations no stock of direct delivery products is kept in the warehouse, they will be just stored by wards in small quantities. Such a policy is usually applied to high value and less frequently used items, such as medical devices and certain drugs, with benefits in terms of total inventory management costs (Cooper et al., 2013). Stock and direct delivery are two material management strategies that may be combined in a same warehouse: this can also happen in centralized warehouses managing all the three types of healthcare products.

In such an environment, warehouses have been acquiring a lot of importance in providing an appropriate level of performance to patients by delivering the service at feasible cost levels. Their integration could also enhance the overall performance of healthcare organizations (Alshahrani et al., 2018). In fact, it has been demonstrated that healthcare logistics is a significant factor in impacting patient's satisfaction (Frichi et al., 2020). Therefore, in this context, and given the complexity of the healthcare SC, it is essential to measure the behavior of operational processes, and this requires Key Performance Indicators (KPIs) (Wu and Dong, 2008) that allow the qualitative or quantitative assessment of the status of any operational and logistics activity (Ackerman, 2003).

2.2 Assessing Healthcare Warehouses Performance

Performance measurement is highly needed for any ~~healthcare~~ organization in order to highlight the existing problems (Dixit et al., 2020) and there is a broad stream of literature focusing on the development and on the assessment of warehouse and inventory performance, in both manufacturing and healthcare sectors. The broad interest on the topic depends on the high impacts that warehouses processes have on cost. As a matter of fact, purchasing and handling the inventory in a warehouse can reach the 30% of the budget for a healthcare organization (Ozcan, 2005). As a consequence, lower cost structures are often achieved by studying material logistics (Kotavaara et al., 2017). Thus, many indicators related to logistics processes can be taken into account. In general terms, the warehouse performance measurement requires the evaluation of the main resource inputs (typically labour and capital) and multiple outputs resulting from warehouse operations (Karim et al., 2018). The logistics processes that can be referred to a warehouse are associated with receiving, storing, picking and shipping processes.

If the aim of a study is to measure the whole behavior of a warehouse, the set of KPIs considered should be associated to each cited sub process (Kusrini et al., 2018). By focusing on the healthcare sector, the number of patients served in order to better estimate the demand, the number of stock out, the delivery time for a drug and the number of ~~boxes that are~~ stored unit loads are indicators considered by (Castro et al., 2020) for measuring the consistency of an inventory policy in a warehouse.

Table 1 presents a review of the most relevant warehouse performance indicators developed based on logistics literature on multiple manufacturing and service sectors, including healthcare. They are classified according to the main warehouse processes and constitute the general framework supporting the selection of the KPIs considered in this contribution.

Table 1. Warehouse Performance Framework

2.3 Selected KPIs for warehouse comparison

Generally speaking, a KPI gives a synthetic measure of a particular performance aspect, which in the case at issue is associated with logistic processes in healthcare warehouses (Badawy et al., 2016). Thus, the contribution of the KPIs in the present work is providing quantitative measures about the key logistics aspects that are then applied to compare the performance of the warehouse groups out of the performed Cluster Analysis.

The set of KPIs chosen for the study is following presented, highlighting their importance in a healthcare warehouse. In particular, the indicators have been identified and measured in order to track the main logistics performance in terms of both stocks and flows. First, the number of items, intended as the number of SKUs managed in the warehouse, has been considered since is an important parameter in studying warehouse systems (Thomas and Meller, 2015). In fact~~,~~, the number of SKUs drives the computation of safety stocks, the inventory investments and costs, and in turn, the responsiveness to demand changes (Teunter et al., 2017). In addition, ~~this~~such an indicator might influence the amount of space that is required with consequent ~~impact~~impacts on ~~cost~~costs (Dixit et al., 2020). In this context ~~the~~ SKUs assume a crucial importance since, being the demand for healthcare products, their availability should be always guaranteed (Muyinda and Mugisha, 2015). In addition, the Total Value of Delivery has been taken into account. It here represents the economic value of goods that each warehouse ships to points of use (e.g. hospital wards, laboratories, etc.) on a yearly basis. ~~This~~The present indicator addresses the concept of the value of delivered products ~~that are shipped~~. In this sense it can be considered as a proxy of the inventory cost that is a key issue for each organization in managing its warehouse operations (Johansson et al., 2020). In fact, if stock-out occurs there could be even treatment problems for patients (Saha and Ray, 2019). On the other hand, holding a high level of inventory can result in high expenditures with lower availability of capital for other purposes (Maestre et al., 2018). This aspect might be also related to the lack of awareness ~~from~~by the medical staff ~~part of techniques~~about how to deal with logistics issues (Castro et al., 2020). Moreover, ~~for stock products~~ the average inventory level of stock products at the end of each month of the reference year for data collection is analyzed. The inventory level is ~~the~~a key quantity characterizing warehouse activities (Silver, EA, Pyke, DF, Peterson, 1998). As for the indicator Total Value of Delivery, it has been measured as an economic value (Lega et al., 2013), and not as number of units, because the great variety of physical sizes characterizing healthcare products does not allow a reliable assessment of the inventory level in terms of number of products stored. ~~Considering this indicator from a financial perspective appears to be~~

Finally, the yearly number of both incoming and outgoing order lines (Stock in order lines and Stock out order lines) is measured for considering the activities that are required for managing incoming and outgoing orders (Cagliano et al., 2012). In particular, this variable is related to the need of specialized personnel devoted to material handling and order fulfillment process ~~activities~~tasks (Stecca et al., 2016). In addition, the handling of medical items~~,~~ can heavily impact the operations costs (Ferretti et al., 2014). Often an order consists of one or more order lines (van der Gaast et al., 2019) and the number of orders that are processed is a typical aspect measured in studying warehouse operations, including healthcare ones (Saha and Ray, 2019), since it might also bring to a significant increase of logistics flows fragmentation (Lucchese et al., 2020). These orders are the ones placed by the ~~hospitals for serving their~~hospital wards and ~~from~~ the local healthcare agencies ~~related to~~served by a warehouse. As the number of orders increases, the complexity that a warehouse faces grows up (Pinheiro et al., 2019).

De Vries and Huijsman (de Vries and Huijsman, 2011) identify measuring performance as one of the five main future research areas in healthcare SCM. For this purpose, different indicators can be defined, each of them assessing a specific performance related to a particular activity part of one of the processes in the healthcare delivery system. In particular, KPIs should focus on all the three process types assisting healthcare systems in converting inputs into outputs, namely clinical, management, and ancillary ones.

Following these guidelines, several authors propose performance measurement systems in different areas, not only related to SCM. One interesting contribution is offered by Kruk and Freedman (Kruk and Freedman, 2008), who develop a framework suggesting three performance categories: effectiveness, equity, and efficiency of the healthcare service. Effectiveness addresses access to care, quality of care, health status improvement, and patient satisfaction. Equity is related to fair financing, risk protection, and accountability as well as to providing the same access to care and the same quality level to all the groups of patients. Finally, efficiency analyzes healthcare administration by looking at economics aspects such as funding and cost-effectiveness of the delivered services. Another performance topic that is recently receiving attention is associated with the environment. Healthcare services rely on a significant amount of hazardous materials and produce polluting outputs. Assessing the hospital environmental performance with specific KPIs may lead to a reduction in the environmental impact and an improvement in process quality (Pasqualini Blass et al., 2017).

A significant number of authors focus on logistics performance indicators in the healthcare industry by addressing both the internal SC of a hospital and the external one linking multiple institutions. Hassan and others (Hassan et al., 2006) evaluate the performance of the internal flow of pharmaceutical products to care units by measuring indicators associated with order fulfillment, response time, inventory days of supply, storage costs, and the distance travelled during deliveries. Operating theatres are a key resource for hospitals and the required materials are as critical as drugs not only from a clinical but also from a logistics point of view, also due to their economic value which is very often significantly high. Moons and others (Moons et al., 2019) recognize such aspects and develop a literature review on performance measurement of inventory and material distribution activities in operating rooms. Quality, time, financial, and productivity KPIs are investigated. Performance indicators can also be a useful mean for benchmarking the internal logistics process of a hospital (Feibert et al., 2019).

Coming to the external SC, healthcare logistics performance is often studied together with the issue of warehouse centralization. Within this research stream, Lega and others (Lega et al., 2013) put forward and test a framework to assess the integrated SC performances in the public healthcare sector. The costs and benefits of a SC centralization strategy compared to the traditional decentralized model are discussed. The authors define a number of KPIs related to three performance dimensions, operational costs, financial benefits, and organizational benefits. By focusing on warehouse performance, the operating costs include the inventory square meters occupied, in order to help assess ~~the~~ warehouse management costs. Additionally, as part of financial and organizational benefits, the "Warehouse Stock Value" and the "Percentage of Urgent Requests" indicators assist in monitoring inventory management efficiency and logistics process standardization respectively. More recently, Cagliano and others (Cagliano et al., 2016) develop a quantitative approach based on a pairwise comparison between logistics KPIs performed through regression analysis. The purpose is assessing the similarities and differences in the logistics management by a group of warehouses part of a regional healthcare system, with the final goal of investigating the potential feasibility of a warehouse centralization strategy. Some authors have started addressing the impact of Industry 4.0 technologies (e.g. cloud computing) on the information sharing in multi-echelon hospital SCs as well as their role in improving logistics performance and visibility (Gonul Kochan et al., 2018). Finally, the sustainability topic is more frequently becoming part of healthcare SC performance management. In fact, Leksono and others (Leksono et al., 2019) apply the Balanced Scorecard and the Analytical Network Process to build a multi-dimensional performance measurement system that includes KPIs assessing the use of green materials and technologies.

In literature there is a still limited number of attempts to address SC performance in healthcare not just from an operational point of view but also from a strategic one. Balcázar-Camacho and others (Balcázar-Camacho et al., 2016) deal with how delivery times, production costs, and customer service perceptions can be positively affected by a coordinated SC planning. Moons and others (Moons et al., 2019) point out that measuring SC performance is fundamental not only to address operational inefficiencies but also as an effective input to decision-makers in order to evaluate the implementation of alternative logistics strategies. In that way, performance indicators can be considered as an effective tool to monitor management policies such that logistics managers can make evidence-based decisions in order to optimize inventory and distribution.

However, very few studies have attempted to measure the impact of SC strategies in the public healthcare sector and provide useful insights for managers and policy-makers involved in strategic decisions in the health SC (Nollet et al., 2008). Also, although the growing interest in performance management in the healthcare sector (Silva and Ferreira, 2010), there is a lack of contributions offering quantitative and systematic approaches to compare the performance of multiple warehouses by clustering them according to similar levels of logistics service. The existing approaches to healthcare performance analysis make use of methods and tools like Discrete Event and System Dynamics simulation, decision-making models such as the Analytic Hierarchy Process, Analytic Network Process, and the Decision Making Trial and Evaluation Laboratory (Dematel), or operations research methodologies as the Data Envelopment Analysis (Gonul Kochan et al., 2018; Günal and Pidd, 2010; Leksono et al., 2019; Otay et al., 2017).

Thus, frameworks are need to simultaneously investigate the performance of a number of different warehouses under multiple dimensions. This would provide decision-makers with a comprehensive picture of the current state of the art of logistics performance in their healthcare systems useful to guide them in setting appropriate strategies. Such frameworks would benefit from the application of consolidated statistical methods, which are currently not so frequently implemented in healthcare SC performance analysis.

The present work puts forward a new approach relying on a well-known statistical tool, namely Cluster Analysis, to analyze and compare the values of key logistics performance measures in multiple warehouses and suggest insights to better understand their performance status and its determinants. This goal is accomplished by grouping the warehouses under investigationCluster Analysis has been selected as it constitutes an objective method to determine which warehouses share a similar performance level and which do not, based on numerical computations and not just on subjective judgments, which might introduce bias in the assessment. It is a valuable characteristic in healthcare logistics management where many strategies are defined based on the personal perceptions and experience of the decision-makers involved (Cagliano et al., 2021). Moreover, this empirical approach is designed to handle a relevant quantity of observations, and thus address many warehouses, making the proposed method suitable for supporting large-scale analyses at regional levels or, in general, in homogenous geographical areas. Such a feature is also of paramount importance in healthcare because there is an urgent need to redesign logistics networks by carefully considering and efficiently exploiting the available resources on a territorial level, in order for example to avoid redundant duplications of stocks and transit points (Elhachfi Essoussi and Ladet, 2015).

Finally, even if Cluster Analysis is broadly established in operations management, it is scarcely applied to healthcare logistics processes. To the best authors' knowledge, there are very few contributions in this field, mainly related to logistics service provider selection by healthcare manufacturers (Tu et al., 2021) and logistics optimization in surgical instrument sterilization plants (Fogliatto et al., 2020). However, Cluster Analysis applications to the management of healthcare warehouses and the related performance are still missing.

In this work the warehouses under investigation are grouped into homogenous clusters sharing the same organizational characteristics as far as inventory levels and logistics flows are concerned. In other words, warehouses are classified according to the size of their stocks and flows. Thus, the performance comparison is carried out among warehouses with similar features, which allows achieving reliable results.

3. Research Methodology and Approach Development

3.1 Cluster Analysis Variables and Sample Selection

The research has been conducted through the following steps. First, the population of healthcare warehouses has been defined. For the present study it has been set as the population of warehouses part of the Italian public healthcare system, which has been object of logistics and SC interventions by several regions in the last 15 years (Lega et al., 2013). The sample is then constituted by all the warehouses part of a healthcare system in a broad regional area of Italy that is currently considering new warehouse and inventory management strategies, including centralization, to improve logistics efficiency. The names of the region and of the associated healthcare agencies and hospitals cannot be disclosed for confidential reasons.

The overall sample has been divided into four smaller samples of healthcare warehouses according to the different kinds of products and the two material policies, stock and direct delivery, presented in Section 2.1. This allows to obtain set of warehouses that are homogeneous, in terms of both products and management policies, and thus comparable within each single group. The first sample is dedicated to consumable products managed as stock items. The second one to consumable products that are directly delivered to points of use. Similarly, the last two ones are associated with drug Stock Keeping Units (SKUs) that are treated as stock and direct delivery products. respectively. Medical devices have been associated to direct delivery drugs, sharing similar features in terms of both economic value and material management approach.

The variables presented in the Literature Review section considered in this study and subjected to Cluster Analysis are listed in Table 2. Such a table reports a description of the data that have been gathered for each kind of warehouse under study to numerically assess the variables included in the developed approach. The choice of analyzing the impact on performance of variables related to logistics stocks and flows is driven by the peculiar characteristics of healthcare warehouses as well as the features of the ones under study. Drug and consumable product warehouses are characterized by very limited return flows, often associated with reusable unit loads adopted for delivery to points of use (Nguyen et al., 2002). In fact, expired drugs are mainly disposed by hospital wards, without returning them to the warehouse, and consumable products either do not have an expiration date or their useful life period is quite long. Additionally, these are not retail warehouses where return flows of goods not matching customer requirements are relevant. For such reasons reverse logistics was not taken into account in the proposed approach. Then, the selected warehouses share a very low level of technology, relying on traditional storage and material handling systems (e.g. transpallets and traditional counterbalanced forklifts) and implementing manual picking operations. Therefore, technology cannot be used to differentiate the performances of these warehouses.

~~-~~Data collection was performed by means of on field analyses and semi-structured interviews to both hospital and warehouse managers over a period of one year. To be more precise, the ~~table~~ columns ~~shows~~of Table 2 show the sample size, the mean, the standard deviation, the minimum, the first quartile (Q1), the median, the third quartile (Q3~~)~~), and the maximum for every variable.

Table 2. Description of the Dataset

Primary data collection was carried out. Coherently with the variables part of the developed approach, the gathered data can be broadly divided into three groups associated with warehouse general characteristics, stock, and flows. The information about the general characteristics includes the hospitals served by each warehouse, together with their number of beds, the warehouse usable floor area, the clearance below truss, the number of operators, and the associated working hours. The stock data comprise the number of SKUs managed by each warehouse and the average inventory level over one year per SKU. This last value was recorded as both number of units and the related economic amount expressed in Euros, although only the latter is considered in the analysis~~ because of the very different physical sizes of products.~~. Finally, the flow information keeps track of the quantity of products delivered by each warehouse to points of use over one year, for both stock and direct delivery items. Similarly to the inventory level, both the number of units and the associated economic value ~~are~~were assessed~~ by~~, although only the latter is included in the analysis. Additionally, the yearly number of incoming and outgoing order lines of stock and direct delivered products was gathered.

3.2 Empirical Approach Development

For every warehouse sample a Cluster Analysis is conducted for identifying common patterns (Mora et al., 2019). In particular, this method aims at grouping data into a few cohesive clusters, so that the objects within a cluster have high similarity. On the contrary, they are very dissimilar to the objects in other cluster (Everitt et al., 2011). In other terms, the aim of the Cluster Analysis is to classify the observations of a sample into homogeneous groups. A group can be called homogenous if ~~the~~its members are close to each other, but ~~the members of that group~~they differ considerably from those of the another groups (Mardia et al., 1979). ~~The aim of the Cluster Analysis is to group the observation of a sample into homogeneous classes. The related similarities~~ Similarities and dissimilarities are evaluated according to the different attributed values that describe the objects of the sample and are related to distance measures. In particular, the Pearson coefficient is used for evaluating the distance between the correlation coefficients and in turn to measure the proximity between the objects (Jung and Chang, 2016). The Ward linkage method is adopted since it is the one that ensures the smallest internal deviance (Rampado et al., 2019). When applying Cluster Analysis, the sample size is an important issue, since it might affect the statistical confidence. In particular, it should be large enough for including the possible patterns related to the process phenomena. The analysis can be conducted with a sample size N equal to 25, even if with more than 50 observations an improvement of the reliability of results can be observed (Wärmefjord et al., 2010). In the proposed research two samples show a size larger than 50 and two equal to or greater than 25.

Table 3. Results of Cluster Analysis

Table 3 shows the results of the four cluster analyses carried out for every kind of warehouse. For each category, three clusters are identified. One of the ~~keys~~key aspects of cluster analyses is to determine an appropriate number of groups. Researchers typically face the need to balance the parsimony, in the sense that~~, with~~ a small number of clusters ~~it is easier~~allows to easily carry out comparisons and trace consistent conclusions, and the accuracy that it is expected to increase with the number of groups (Diaz et al., 2003). In general terms, the number of appropriate clusters is unknown (Sahmer et al., 2006) and it is a very challenging and difficult issue in Cluster Analysis (Yao et al., 2019). In fact, there is ~~not one~~no commonly accepted method to establish the number of ~~cluster~~clusters in a ~~study~~studied population (Nylund et al., 2007) and the exact number of clusters can be difficult to be determined (Park and Kim, 2020). Lehmann (1979), indicates as a K number of ~~cluster,~~clusters a value included in this interval (N/60)< K< (N/30), where N is the number of objects of the sample. However, this method has been considered to be very restrictive especially if N is small. At the same time, with very large values of N, K could be too great for carrying out consistent analysis (Diaz et al., 2003; Chrstiansen et al., 2003; Brusco et al., 2017). Therefore, the common approach is to repeatedly run the clustering algorithm several times until a satisfactory result is obtained (Zhu et al., 2019). The number of objects of every cluster is similar for three out of the four samples under study, meaning that the observations of each sample are homogeneously distributed. In addition, a one-way Analysis of Variance (ANOVA) is completed as an internal consistency procedure, in order to check if the differences come up from the Cluster Analysis are significant and in turn confirmed. ~~Thus as~~As suggested by Milligan (1996~~)~~), ANOVA can be useful to ~~validated~~validate clustering solutions.

Table 4. Cluster Mean Values

Table 4 reports the values of the means of each cluster for all the variables taken into account in the Cluster Analysis. Three variables affecting the stocks and the main logistics flows managed in a warehouse, selected according to the KPI literature framework presented in Table 1, are here added in order to deeply investigate the Cluster Analysis results and identify possible different patterns for the warehouses at issue that represent their current situation. This in turn might suggest decision-makers appropriate strategies for each warehouse cluster, according to the guidance perspective of performance management (Smith, 2002) adopted in the present work. The specific variables are chosen since they are recognized by literature as key determinants of warehouse performance. First, the Number of Beds available in a hospital is selected because it can be considered a proxy of the hospital size and in turn of the demand for both drugs and consumable products faced by the warehouses serving it (Atumanya et al., 2020; De Marco and Mangano, 2013). In other terms, the number of beds measures the capacity to hospitalize patients (Best et al., 2015; Nguyen et al., 2005) in a given time span and contributes to define the quantity of needed healthcare materials (Aptel and Pourjalali, 2001) that warehouses will have to deliver in the same period. Thus, the number of beds significantly influences the warehouse activities and its performance: this is the reason why such a variable is included in the study. Also, the usable floor area is another relevant factor for assessing warehouse operations (Gu et al., 2010; Lega et al., 2013; De Marco et al., 2010). It is part of the analysis because the warehouse physical size drives the value of its storage capacity and, consequently, the ability to make products available in order to timely satisfy the demand. In fact, the warehouse storage capacity is the amount of space to accommodate products so that a desired service level is met (Lee and Elsayed, 2005). Storage capacity, together with workforce staffing, impact the responsiveness and effectiveness of product movements (De La Fuente et al., 2019). Therefore, ~~as a third variable, the~~ Full Time Equivalent (FTE) is introduced as a third variable. It is expressed by the ratio of total paid hours in a certain period over the number of working hours in that period (Kyyrä et al., 2019) and measures the actual personnel working in a warehouse. This variable is important in order to understand whether the workforce is aligned with the total warehouse workload required by receiving, storage, and delivery activities according to the healthcare material demand level.

The average values for each cluster of the variables Number of Beds, Usable Floor Area, and FTE will be compared with the mean values of the five variables involved in Cluster Analysis as discussed in Section 4.

In order to check the consistency of the results obtained with the Cluster Analysis, an ~~Analysis of Variance (~~ANOVA~~)~~ is also conducted. It is statistical methods largely applied in order to explore the differences in terms of impacts of categorical factors on a dependent variable (Aristizabal et al., 2019). ~~In this analysis, the categorical factors are the three identified clusters of the Cluster Analysis and its~~Therefore, it has been selected as a suitable approach for the aim of this research. Other methods might be taken into account, such as the Kruskal-Wallis test. Even though, this no-parametric test considers the effects of categorical factors, it is focused on the value of medians, often associated with ordinal scales such as the Likert scale (Panchal et al, 2020; Mangano et al, 2021; Arditi et al., 2015). Thus, this method has been not considered as the most suitable one. Sample size is a critical issue in carrying out an ANOVA. As for many statistical approaches, the larger the sample, the more reliable are the results that are obtained. However, ANOVA could be completed even with a sample size equal to 20, with no noteworthy potential bias (Meyners and Hasted, 2021). In this analysis, the categorical factors are the three identified clusters of the Cluster Analysis and the variables used for tracing the healthcare warehouses' characteristics are the dependent ones. The null hypothesis of the ANOVA is that no significant differences exist among the different ~~group~~groups under study. If the p-value obtained running the test is lower that a critical threshold that is typically equal to 5%, the null hypothesis has to be rejected, and it turn it is possible to affirm a difference among the ~~group~~groups considered (Rezaei et al., 2018). In this paper, the final aim of the ANOVA is to check if the different clusters obtained, are actually different for every variable taken into account. Thus, the test is carried out for every kind of warehouse~~,~~ and for each variable of the study. A first statistical analysis checks if the response ~~variable~~variables for the ANOVAs are approximately normally distributed (Kozak and Piepho, 2018) by using the normal probability plot (De Marco et al., 2012). When data show a non-normality of records, a logarithmic transformation is applied to the response variables at issue, so that the transformed variables result to be normal distributed~~, so that they~~ and can be used as response factors (De Marco and Mangano, 2011). Figure 1 shows an example of variable that becomes normal after the logarithm transformation.

Figure 1. Example of Normal Probability Plot before and after the logarithm transformation

18 ANOVAs are completed overall. The cases of tests carried out with the logarithm of the response variable are shown in italics font. Table 5 shows the results obtained.

Table 5. Results of the ANOVA

Through the ANOVA it can be demonstrated the consistency of the Cluster Analysis carried out. As a matter of fact, all the tests prove to be significant, meaning that the Cluster Analysis has been able to properly group the warehouses ~~of~~in the samples. In addition, ~~as~~the R-Squared is considered as a measure of the explanatory power of the model ~~the R-Squared is considered~~ (De Marco et al., 2017). It represents the percentage of the variability that an empirical model is able to capture (Everitt and Skrondal, 2002). An appropriate R-Squared value depends on the application fields and the values derived from the present study ~~is~~are in most of the cases higher than 50%, that can be considered as acceptable (Newbold et al., 2012).

4. Analysis of Results

As a preliminary statement, it is worth highlighting that the aim of the developed approach is comparing and contrasting the outcomes obtained for the three clusters in each of the four samples under investigation. As a matter of fact, based on what discussed in Section 2~~.1~~ and Section 3~~.1~~, clusters in different warehouse samples cannot be compared because of the heterogeneous characteristics of the managed products (drugs vs consumables) and the different material management policies (stock vs direct delivery).

In order to address the results obtained by the proposed methodology, and in particular explain the outcomes of the Cluster Analysis, the following ratios have been computed with the average cluster values of the warehouse variables previously presented, both the five ones involved in the Cluster Analysis and the additional variables presented in Section 3.2 (Table 6). The main purpose of calculating these ratios is confirming the behavior of each of them is aligned with that of the variables used to identify the three clusters resulting from the Cluster Analysis. The first ratio compares the number of yearly outgoing order lines with the FTE value, thus assessing the operators' productivity. It has been included in the analysis because it is one of the key factors of global warehouse productivity (Karim et al., 2018) and is useful to assess whether the current warehouse workforce is consistent with the amount of logistics flows they have to support (Klodawski et al., 2018). Such flows are measured as the number of order lines picked and prepared for delivery because, as already mentioned, the warehouses at issue are usually equipped with traditional storage racks accommodating entire unit loads. This makes the workload required by receiving and putting away incoming products significantly lower than that related to picking and packaging single outgoing boxes (Cagliano et al., 2016). The ratio of the number of SKUs to the usable storage floor area has been then considered because it gives an idea of the item storage density and in turn of how adequate the warehouse space is compared to the amount of products to be stocked (Faber et al., 2013). The present ratio has been taken into account because an optimal utilization of the storage space is crucial for undersized warehouses or expensive storage areas like the ones associated with refrigerated systems (Gamberini et al., 2008). The total yearly economic value of delivered products over the inventory economic value, namely the Inventory Turnover ratio, is a reliable measure of how fast the inventory is replenished. A high value means products spend a short time in stock and thus it proves a good inventory management (Silver, EA, Pyke, DF, Peterson, 1998). The Inventory Turnover ratio is a performance indicator that can guide strategic decisions (Wan et al., 2020) and show how successful are organizations in reducing inventory waste (Demeter and Matyusz, 2011). The last two ratios have been assessed just for stock products, while for direct delivery products onlythey have been replaced by the Total Value of Delivery divided by the number of SKUs has been computed. This indicator shows in economic terms the amount of products delivered for each SKU over one-year period and is useful because it allows to make considerations on the appropriateness of managing such items by applying the direct delivery strategy. In fact, the inventory policy of each SKU is also influenced by the yearly sale volume (van Kampen et al., 2012). Finally, all the four warehouse samples have been compared through the ratio Total Value of Delivery over Number of Beds in order to obtain a normalized value estimating the level of demand of the hospitals served by each warehouse (Aptel and Pourjalali, 2001).

Table 6. Variable Ratios

For the Stock Consumable Products, the first cluster includes the largest warehouses, with many SKUs managed and a lot of inventory stored, together with a large amount of orders delivered. This result is reflected by the average number of beds and by the FTE value that are the highest ones in this cluster. On the contrary Cluster 3 is made up by small warehouses with a limited number of SKUs and, as a consequence, fewer logistics activities that need to be carried out. Cluster 2 presents intermediate values for the variables considered meaning that for the Stock Consumable Products warehouses, the Cluster Analysis has been able to clearly group the observations of the sample.

Looking at the same warehouse sample, the results of the ratio between the number of orders lines processed and the FTE are not coherent with the outcomes of the Cluster Analysis. In particular, both Cluster 1 and Cluster 2 show values more than 100% greater compared with Cluster 3. This means that there is not a proper balance of the workload among the warehouses of the sample and a more effective organization of the human resources should be addressed. This results might also depend on the fact that the warehouses of the analysis are managed by different local healthcare agencies with different inventory policies and more in general different approaches for carrying out logistics processes.

On the contrary, the warehouse floor area exploitation is aligned with the outcomes of the Cluster Analysis. This means that warehouses managing a large number of SKUs also tend to have a relevant number of items stocked per each square meter. Similarly, fewer SKUs per square meter might show that the available storage floor area is not consistent with the total number of items handled. Such an outcome reflects a utilization of the warehouse area that might not be coherent with the number of items that need to be stored, due to a high level of product heterogeneity in terms of both type and size. Also, the availability of new storage floor areas does not always keep the pace with the current logistics needs. Although the Inventory Turnover does not fully reflect the Cluster Analysis results, it proves to be of the same order of magnitude in each cluster. Its values show an acceptable performance that could be the result of the recent public budget cuts that have forced more careful inventory policies (Malovecka I et al., 2015). On the contrary, the values of the ratio between the Total Value of Delivery and the Number of Beds are completely coherent with the outcomes of the Cluster Analysis and reflect an appropriate demand level based on the size of the served hospitals.

By observing the Direct Delivery Consumable Products, Cluster 3 includes the largest warehouses. However, this group is made up of only two observations that can be considered as outliers. The number of SKUs is not much higher compared with Cluster 2, even if the value of the delivered goods and the number of order lines managed is significantly greater. Also the human workload appears to be larger. In Cluster 1 there are smaller warehouses although the value of FTE is quite similar to the Cluster 2 one. This might be due to the fact that the workforce required by some organizational activities associated with logistics, such as the administrative ones, is independent from the number of handled products (Krajnc et al., 2012). The dissimilar economic values of yearly deliveries among the three clusters, caused by the heterogeneous types of consumable products that are usually managed as direct deliveries based on hospital needs, are reaffirmed by the delivery values per each hospital bed. This result is also stressed by the fact that the difference in the average number of beds served in each cluster is not so high. A more detailed analysis of this product category is not feasible since the quantity and type of items not stocked but directly delivered to points of use are extremely volatile among different healthcare agencies and sometimes even among warehouses of the same institution. In fact, the products at issue are associated with specific therapeutic requirements and might not be used on a regular basis. Such an organizational structure is reflected by the outcomes of the Cluster Analysis that has assigned only two observations to a cluster, meaning that it could be difficult to clearly identify evident patterns.

In the sample of Stock Drug warehouses, Cluster 1 presents the highest values in all the analyzed variables, especially regarding to the Total Value of Delivery. Cluster 2 shows intermediate values, and in Cluster 3 smallest warehouses can be observed. As already highlighted in the previous sample, the FTE value for Cluster 2 and 3 is almost the same. Considering the ratio of Stock Out Order Lines to FTE, it can be stated that the differences in its values among the clusters are not significant. This might be due to the fact that different warehouses, dealing with a different amount of yearly order lines, have coherent workloads assigned. Similarly, the behavior just outlined can be observed in the values of the number of SKUs managed per each square meter that are quite similar for every cluster. As matter of fact, the size of drug product packages is quite standardized, enabling an appropriate planning and management of the storage area.

The Inventory Turnover confirms the results of the empirical analysis. The related values are higher than the stock consumable products ones because drugs typically have shorter expiration dates that stimulate a frequent stock replacement (Leaven et al., 2017). In addition, drugs are usually more expensive than consumable products, thus the effects of reduced public budgets are even stronger for the warehouses managing such a kind of products. In fact, in order to avoid waste of money, they tend to always keep in stock an amount of goods able to cover the demand over a limited time period. On the contrary, the yearly economic value of deliveries per each hospital bed is only partially consistent with the Cluster Analysis outcomes due to the very small average number of beds served by the warehouses in Cluster 3.

Finally, for the Direct Delivery Drug sample the values associated with the 32 warehouses in Cluster 3 are the lowest ones, followed by Cluster 1 and then Cluster 2. As in the Cluster Analysis, for the warehouses in Cluster 3 the ratio between Stock Out Order Lines and FTE is significantly low. Such an evidence can be explained by the relevant number of local drug warehouses grouped together in this cluster that, due to their nature, have a smaller number of order lines delivered per year than hospital warehouses. In fact, according to the Italian public healthcare system, local drug warehouses are smaller logistics units located throughout a geographical area in charge of distributing products to patients affected by particular pathologies or who have specific therapies. This causes a small level of logistics flows that in turn requires a low amount of workforce. The yearly economic value delivered for each SKU is coherent with the Cluster Analysis. It is important to highlight that these values are higher than the corresponding consumable products ones because the present item category includes very specific and often expensive drugs that would not be efficiently managed with a stock strategy. Finally, the ratio of the delivery value over the number of beds is consistent with the Cluster

Analysis results. Cluster 3, which includes many local drug warehouses, shows the lowest value for this indicator due to the low value of deliveries and the reduced number of beds. In fact, local drug warehouses do not serve hospital beds and usually manage more stock products than direct delivery ones. Direct delivery products are more typical of hospital pharmacies, which may need particular drugs only in certain situations.

5. Implications and Conclusions

The study proposes a quantitative approach for classifying healthcare warehouses according to several relevant logistics aspects, such as the number and type of products managed (Teunter et al., 2017), the demand faced by each warehouse (Johansson et al., 2020), and the inventory level (Lega et al., 2013). The addressed warehouses deal with drugs and consumable products, managed as both stock and direct delivery items. The purpose of the research is to identify common patterns in warehouse management by taking a guidance perspective as suggested by Smith (Smith, 2002). In fact, his approach is based on measuring performance in healthcare systems in order to capture how they currently behave. Thus, the methodology proposed in this work aims to facilitate policy-makers in understanding the logistics status of different groups of warehouses, so that they are able to develop more tailored strategies for each of them.

To this end, an empirical analysis is carried out. In particular, the selected method is the Cluster Analysis that is broadly used in many ~~field~~fields of applications (Anuşlu and Fırat, 2019). However, the use of this statistical approach appears to be quite limited in healthcare in order to address the behavior of logistics systems, and in particular warehouses. Through such a methodology, in the proposed analysis each warehouse is grouped with other similar ones by taking into account main stock and flow variables~~.~~, such as the inventory level and the incoming and outgoing order lines just to mention some of them. This avoids comparing warehouses with heterogeneous behaviors in terms of their logistics processes. In fact, a more precise comparison can be carried out among similar warehouses belonging to the same cluster. ~~The developed approach proves to be~~The similarity in warehouse behavior, supporting the clustering purpose of this work, is established through specific logistics KPIs that are numerically evaluated in order to provide quantitative and objective measures to base the comparison on. Thus, KPIs, together with Cluster Analysis, play an essential role in making the developed approach more coherent than other approaches comparing warehouses and their performance based on subjective criteria or less structured methodologies (Zhu et al., 2019). As a matter of fact, the comparison is completed among warehouses belonging to the same cluster, thus avoiding analyzing warehouses with significantly different sizes in terms of stocks and logistics flows. The outcomes appear reliable and coherent. In fact, the warehouses belonging to the same cluster show similar behaviors for all the indicators considered. The results of the empirical model have been evaluated by carrying out a confirmatory ANOVA, which showed the consistency of the developed Cluster Analysis. This has also been proved by observing other parameters that contribute to determine the demand for healthcare products, the warehouse storage capacity, and its ability to handle the current material flows.

In this context, theThe proposed work might be able to support a performance analysis including a plethora of warehouses belonging to different healthcare institutions. This is an important point since quantitative and structured approaches to performance management are often related to single organizations (Feibert and Jacobsen, 2019; Hassan et al., 2006) and mostly refers to single warehouses (Moons et al., 2019). On the contrary, the developed contribution takes a comprehensive perspective on multiple warehouses of different healthcare agencies and it identifies a number of clusters, each of them with homogeneous behavior. In this way, by observing the cluster features, it is possible to easily define the general performance level of a specific warehouse group. As mentioned before, such an objective has been achieved by proposing an approach integrating two main statistical approachestools, namely the Cluster Analysis, for grouping the sample observations, and the ANOVA for confirming the consistency of the obtained groups.

This work originates several both academic and practical implications. From an academic perspective, the present paper enlarges the body of knowledge on healthcare warehousing operations by highlighting the need for properly comparing their performance comprehensively to support the identification of any existing criticality (Dixit et al., 2020). Additionally, performances are here compared and contrasted according to their similarities and differences, which could be a first phase towards the development of a research stream aimed at an accurate warehouse system assessment based on a combined view of different logistics performance aspects. Finally, thisthe present study is likely to stimulate research exploiting statistical methods. In fact, statistics is still scarcely used in healthcare SCM although this sector might benefit from it through the implementation of consolidated methods providing objective results. In fact, the combination of the Cluster Analysis and the ANOVA has provided reliable outcomes, although, as highlighted by literature, their use is not completed established in logistics healthcare studies (Otay et al., 2017).

From a practical point of view, the proposed Cluster Analysis might support healthcare systems in comparing the performance of their warehouses more properly and accurately. In particular, thanks to a deep understanding of the logistics activities provided by the developed approach, it is possible to easily assign a warehouse to a specific cluster according to its performance features, in order to define appropriate management policies. Also, healthcare decision-makers might be supported in the design of guidelines tailored to the peculiar logistics processes of the different warehouse groups.

In addition, each warehouse is not analyzed independently from the others but in a comparative way, which gives that level of detail about logistics processes that is necessary to healthcare policy-makers. The issue related to performance has been gaining a lot of importance especially in the case of public healthcare systems that have been facing significant cuts of public financial budget (De Marco and Mangano, 2013) and consequently have to address more carefully their expenses. Within such an operational environment, this work could support comprehensive investigations of the managerial similarities and differences that can be considered as a first step towards warehouse aggregation in homogeneous logistics units (Cagliano et al., 2016). Appropriately assessing healthcare warehouse performance has acquired a critical importance during pandemic periods, such as the current SARS-CoV-2, wherein inventory strategies tailored to specific warehouse characteristics are key levers for ensuring timely and accurate supply of drugs and individual protection devices (Cundell et al., 2020). In addition, the performance aspects of warehouses associated with the inventory management and the distribution of vaccines for SARS-CoV-2 are demonstrating to be crucial for ensuring a proper and diffused vaccination campaign among the population (Arnold, 2020).

Moreover, the offered warehouse categorization could be considered as a method to assist policy-makers in formulating SC strategies tailored to the peculiar characteristics of each set of warehouses. This appears to be crucial also in the facility design or renovation phase, when potentially expensive aspects, such as the warehouse size or the storage capacity, need to be defined.

Warehouses are a system of the healthcare SC that might be significantly improved in order to increase its efficiency, especially in the light of the current trends requiring higher service level to patients by reducing costs at the same time. To this end, it is crucial to be focused on a SC more integrated with no stock redoubling, with consequent cost redoubling. In order to achieve higher levels of integration, it is important to know in detail the performance of every warehouse, considering that different groups of warehouses can have different behaviours and in turn different performance. Thus, the performance benchmark should be carried out among warehouse structurally similar. Therefore, Cluster Analysis allows to group different warehouses in different clusters, and within every cluster it is possible to perform the benchmark. Through the benchmark, and after groups of homogenous warehouses are found, it is possible to undertake their centralization according to geographical and managerial conditions. In such a way operations efficiency might be more easily achieved. In this perspective, the present work is a preliminary contribution for more easily implementing the warehouse centralization strategy, which is actually already exploited in many industrial sectors, including new-born ones. As a matter of fact, the centralization of the warehouses for electric vehicle batteries is a phenomena that can be clearly observed (Rafele et al., 2020). To conclude, the proposed approach might be useful in those operations contexts requiring a unique control of many different healthcare warehouses in a specific geographical area.

However, the present work suffers from some limitations. In particular, the proposed approach is mainly focused on a limited number of variables associated with healthcare warehouses. For instance, the effects on performance of the layout or the material handling systems are not addressed, although they recognized role in determining the operational performance (Huertas et al., 2007; Ramli et al., 2017). Also, the application of the approach refers only to one regional healthcare system. A further limitation is related to the number of investigated warehouses. In fact, if on the one hand the number of drug warehouses looks appropriate, on the other hand the number of consumable product warehouses is actually limited. Such a sample characteristic, of course, impacts the empirical analysis performed and it is reflected by the size of the associated clusters. However, the number of consumable product warehouses in both the geographical area at issue and the entire Italian territory is quite reduced and this fact also dramatically emerged as one of the causes for the shortage of personal protective equipment (e.g. masks and gloves) and disinfectants experienced by Italian hospitals during the first phase of the Covid-19 pandemic (Veritti et al., 2020).

Thus, future research will be addressed towards enlarging the number of variables taken into account so that to include a more complete set of performance indicators in the Cluster Analysis, also related to warehouse design and equipment characteristics. Furthermore, the application of the developed approach will be extended to warehouses of other healthcare systems by also deepening the feedbacks from the associated healthcare practitioners about the results obtained by the proposed methodology. This will ultimately enable the comparison of the outcomes from the different healthcare systems studied.

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