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Abstract: Healthcare (HC) warehouses play a pivotal role in providing a satisfactory service level for hospitals. In fact, the warehouse performance significantly affects the treatment of patients by supplying drugs and other medical products in the right place at the right time with the right quantity and quality. Therefore, performance assessment of HC warehouses leads to making the right strategy for improving them. Current literature highlights a lack of approaches comparing and contrasting logistics performance in different HC warehouses. However, recognizing and categorizing warehouses based on their performance similarities offers the advantage of better managing them with the selection of proper fitting strategies. In this manner, the decisions would be made according to the specific characteristics of each warehouse group to improve efficiency. In the present study, key performance indicators for HC warehouses are extracted from literature and semi-structured interviews with HC logistics professionals. Using an empirical approach, the data related to the performance of several warehouse are collected from a set of Italian HC institutions. Afterwards, the statistical tool named cluster analysis is applied for the classification of the investigated warehouses based on their logistics behaviour. This results in a specific analysis of the current state of each cluster. The cluster analysis outcomes are verified based on some demand and flow indicators. The proposed approach may stimulate further research about comprehensive performance assessments of HC logistics systems. Additionally, it provides HC decision-makers with a methodology giving valuable insights for the development of integrated strategies based on the actual logistics characteristics of warehouses. Future research could be conducted by considering a more complete set of variables with different levels of contribution to the overall logistics performance. Finally, the presented approach will be further tested in multiple HC settings.

Keywords: Healthcare supply chain management, warehouse, key performance indicators, cluster analysis.

1. Introduction

Policy-makers all over the world face the serious challenge of making the most desirable decisions on healthcare (HC) systems. Also, the community expectations for HC system improvements are growing. On the other hand, many HC systems are funded by public sectors, and their budgets are often limited for satisfying the community need for receiving high-quality services.

The current literature on HC systems has studied such a problem significantly from the general performance point of view. Authors often consider criteria such as financial and operational ones (Otay et al., 2017; Pasqualini Blass et al., 2017; Silva & Ferreira, 2010). However, few researches examine HC systems from the Supply Chain Management (SCM) and logistics aspects (Gonul Kochan et al., 2018; Leksono et al., 2019; Moons et al., 2019). In fact, at the first step hospitals must obtain the drugs and consumable materials they need at the right moment with the right quality and quantity. Therefore, SCM corresponds to a huge part of the hospital budget. To be precise, 30% of the total expenditures in hospitals are related to logistics activity, which makes it the second-largest cost after human resources costs (Volland et al., 2017). It implies that policy-makers should pay special attention to the performance measurement of HC SCs. As a matter of fact, decision-makers need this information to recognize the inefficiencies and improve the HC SCM practices (Moons et al., 2019). The assessment of each single HC supply chain (e.g. the supply chain of each single hospital or local HC agency) is not so useful because HC decisions mainly are made by central committees. Therefore, decision-makers need to have a big picture to improve the HC strategies for the macro scale in a country or region. However, there is a significant lack of methodologies to assess SCM performance in HC by considering a set of institutions together. By investigating several HC supply chains policy-makers can have a more reliable perception of the current state of the HC system in a given geographical area.

Additionally, HC warehouses play an important role as a bridge between patients and previous supply chain stages. Thus, warehouses need to receive more attention from policy-makers to increase their efficiency and effectiveness. This clarifies the importance of measuring and assessing the performance of such a part of HC supply chains.

Hence, the present work develops a new approach to classify HC warehouses in different groups based on their logistics performance similarities. To this end a consolidated statistical method is applied. The final aim is providing decision-makers with a tool able to help them making the best fitting policies for each warehouse group.

The rest of this paper is organized as follows. Section 2 discusses literature about HC SCM and especially HC warehouses performance assessment. Section 3 dedicates to introduce the Descriptive Parameters to clarify the methodology of the work. Additionally, in Section 4 the results of the study are discussed by a real application in HC system of Italy. Finally, in the last section, some implications on the results and conclusions of the work are indicated.

2. Literature Review

Healthcare Logistics and Supply Chain

SCM contributes to controlling and optimizing all the activities and flows among the different logistics partners. The main SCM concepts originated from the manufacturing system but they spread to the HC sector and brought about the great impacts on the hospital performance, not only in terms of reducing waste and medical errors but also increasing productivity, improving quality of care, service and operational efficiency. In this regard, addressing the role of the different players within supply chain activities could provide an integrated view on logistics (Cagliano, Grimaldi, and Rafele 2011).

Based on what was discussed above, it implies the importance of considering a method to compare logistics performance in HC supply chains to have a big picture and enable policy-makers to appropriately redesign these systems. Hence, this goal needs Descriptive Parameters that account for assessing important aspects in HC SCM. In this manner, Descriptive Parameters related to the status of operational, logistics, and purchasing processes can be evaluated. Identifying and measuring Descriptive Parameters could detect the inefficiencies in HC systems. Moreover, it can benefit decision-makers as input for choosing proper strategies in each HC supply chain (Moons et al., 2019).

Warehouse and inventory management in the healthcare sector

Recently HC systems figure out the need to optimize their process. In this regard, the efficient management of material flow (Landry & Philippe, 2004) and accordingly inventory policies are commonly discussed (de Vries & Huijsman, 2011). In fact, HC warehouses store a different range of items including drugs, medical products, and consumable goods to provide a more reliable and good quality of the services to the patients (Kumar et al., 2005). In order to achieve such a goal, several authors focus on HC warehouse centralization. Among them, Iannone et al. (2014) consider centralized inventory management as one larger warehouse which combines the operational activities of different warehouses by internal logistics employees or special service providers. The levels of centralization or outsourcing in HC warehouses are varied by the nature of processes and material flows (Pinna et al., 2015). Moreover, besides warehouse centralization, other policies do exist including collaborative inventory management (Mustaffa & Potter, 2009), vendor-managed inventory (Danese, 2006), and collaborative planning, forecast, and replenishment (Ho et al., 2014). As a result of the application of these strategies, warehouses in the HC systems can have a great impact on the satisfaction of patients by participating to make a proper service level at the optimal costs.

Assessing Healthcare Logistics Performance

Performance measurement has been introduced as one main area for future research in HC SCM (de Vries & Huijsman, 2011). To this end, it is necessary to apply a complete set of indicators so that each of them will be responsible to assess a specific and important part of process activities. Recently, Cagliano et al., (2016) by regression analysis perform a pairwise comparison among logistics descriptive parameters. To this end, similarities and differences for logistics management in a group of HC warehouses are identified as a preliminary step towards centralization.

By relying on the development of new technologies, such as those related to Industry 4.0, some studies investigate the possible improvements in information flow and traceability among the multi echelon hospitals SCs, with the ultimate aim to increase the logistics performance (Gonul Kochan et al., 2018). Finally, some authors are paying special attention to the sustainability concepts in HC SC performance assessment. Leksono and others (2019) investigated the impact of using the green materials and technologies by considering the Balanced Scorecard and the Analytical Network Process to evaluate a multi-dimensional performance assessment.

There is a lack of research to address both operational and strategical points of view in the assessment of HC supply chains. In this regard, aside from identifying supply chain inefficiencies, Moons, Waeyenbergh, and Pintelon (2019) discuss the importance of performance assessment to benefit decision-makers by paving their way to implement the right strategies to optimize inventory and distribution policies. However, in the public HC sector, very few researches addresses the effect of supply chain strategies in the public health to assist HC policy-makers in making strategic decisions (Nollet et al., 2008).

In recent years, performance measurement has been extensively used in the HC sector (Silva & Ferreira, 2010), but classifying multiple warehouses based on a logistics performance assessment has not been studied so far. Based on the literature, the common procedures for measuring the performance of HC systems are Discrete Event, System Dynamics simulation, and 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; Leksono et al., 2019; Otay et al., 2017). Statistical tools are seldom used in this field.

Therefore, there is a need to evaluate the HC SCM for several warehouses by considering the prominent aspects for representing their logistics performance. The aim of the present paper is using statistical data cluster analysis to develop a framework for comparing performances among different warehouses to drive better logistics decisions.

Table 1: Description of Dataset

Stock Consumable Products Descriptive Parameter	**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
Stock Drugs Descriptive Parameter	**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

3. Research Methodology and Approach Development

For conducting a cluster analysis to assist the policy makers following steps need to be completed.

Step1: Relevant Descriptive Parameters for the evaluation of the HC warehouses performance are identified from reviewing the current literature. The first one is the number of Stock Keeping Units (SKUs) stored in the warehouse. Measuring this indicator can assist policy-makers to have a better perception of some important information about warehouses such as the inventory safety stock, inventory expenditures, and service level (Teunter et al., 2017). Similarly, the Total Value of Delivery is measured in order to indicate the annual total economic value from each warehouse to the demand points (e.g. hospital wards, laboratories, etc.). This Descriptive Parameter can be a representative of the inventory costs that are a key operational parameter to have a better warehouse control (Johansson et al., 2020). Additionally, the average inventory level of the stock products at the end of each month are included as another Descriptive Parameter in the HC warehouses. HC products are usually characterized by a great variety of different physical sizes. Therefore, aiming at assessing performance comparisons, the average inventory levels must be expressed in the term of economic values (Inventory Value) instead of the number of product units.

Finally, the annual numbers of incoming and outgoing order lines are calculated as relevant Descriptive Parameters. As a matter of fact, they can show the workload required for managing stocks and fulfilling orders (Cagliano et al. 2012). In other words, typically each order can engage more than one order line (van der Gaast et al., 2019). Therefore, measurement the number of orders that are processed by the order lines can benefit warehouses, similarly HC warehouses (Saha & Ray, 2019).

Step2: A geographical area with a homogenous HC system is selected by consulting with HC stakeholders. In the first application of this approach, the HC warehouses of a regional area of Italy have been considered, which cannot be disclosed for confidentiality reasons.

Step3: Conducting semi-structured interviews with the managers of the selected HC warehouses as experts for the evaluation of Descriptive Parameters. Such interviews

Table 2. Results of Cluster Analysis

Stock Consumable Products	**Cluster 1_{SCP}**	**Cluster 2_{SCP}**	**Cluster 3_{SCP}**
	10	7	11
Stock Drugs	**Cluster 1_{SD}**	**Cluster 2_{SD}**	**Cluster 3_{SD}**
	26	31	38

also allow to choose the most important items in the HC warehouses to focus on. In the application discussed in this paper, based on experts' advice, two types of warehouse products have been selected due to their very high frequency of use by hospitals. The first one deals with Stock Consumable Products and the second one with Stock Drugs. Also, both of these product types are stored in warehouses and not directly delivered to hospital wards when are received from suppliers. Moreover, all of the Descriptive Parameters extracted from literature have been confirmed by the experts.

Step4: Relevant data about the selected Descriptive Parameters shown in Table1are gathered according to the scope of study. In the discussed real application, the data were collected on a yearly basis and they are basically related to the number of product codes managed in each warehouse, the economic value of the products delivered to points of use, the average level of inventory, and the incoming and outgoing order lines

Step5: Descriptive statistics of each parameter for the HC warehouses considered are computed. Table 1 includes the preliminary analysis and significant statistical characteristics of each parameter for the warehouses involved in the first application of the approach. Therefore, the columns of Table 1 show the sample size of HC warehouses for each type of products, the mean, the standard deviation, the minimum, the first quartile (Q1), the median, the third quartile (Q3), and the maximum for each Descriptive Parameter.

Step6: At the next step, the objective is to find out a proper classification of warehouses in each of the warehouse samples. To this end, a cluster analysis is performed (Mora et al., 2019). The main concept of this procedure is that observations included in to each cluster have maximum similarity within the cluster. On the other hand, the members of each cluster should have the maximum dissimilarity with the members of the other clusters (Everitt Brian, 2011). In particular, this means that the selected statistical method aims to minimize the variance among the observations belonging to a cluster and maximize the variance of the observations of the different clusters of the analysis. The Cluster Analysis is here carried out using the Ward linkage method (Rampado et al., 2019) and the Pearson correlation coefficient as measure of the distance (Jung & Chang, 2016). In this regard, one of the critical issues in each clustering method is the sample size. By choosing an appropriate sample size it is guaranteed to recognize all the possible patterns for clustering. In this context, (Wärmefjord et al., 2010) mention that for applying cluster analysis a minimum sample size equal to 25 is enough, although a sample size greater than 50 can give more reliable results. In the application of the proposed approach the size of the Stock Drugs sample equals to 95 and the size of the Stock Consumable Products sample is equal to 28.

The results of the cluster analysis for both Stock Consumable Products and Stock Drugs samples are presented in Table 2. The optimized number of clusters cannot be determined decisively, which leads to become as one of the tough decisions in cluster analysis (Yao et al., 2019) . For this reason, to achieve more reliable results for cluster analysis the best method is performing the procedure many times to have a reasonable solution (Zhu et al., 2019).

In table 3 the mean values of each cluster for described Descriptive Parameters in each sample are reported. They are calculated by considering all the variables previously mentioned in Table 1. Moreover, in table 4, in order to confirm the cluster analysis results, three further Descriptive Parameters are studied, again based on both literature review (Marino & Alvino, 2020) and the knowledge of the experts from the studied warehouses. They are related to stock and important logistics activities in HC warehouses. In this regard, the Number of available

Table 3: Means in the clusters for Descriptive Parameters

Stock Consumable Products	**Mean Cluster 1** $_{SCP}$	**Mean Cluster 2** $_{SCP}$	**Mean Cluster 3** $_{SCP}$
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
Stock Drugs	**Mean Cluster 1** $_{SD}$	**Mean Cluster 2** $_{SD}$	**Mean Cluster 3** $_{SD}$
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

Table 4: Means in the clusters for additional Descriptive Parameters

Stock Consumable Products	**Mean Cluster 1** $_{SCP}$	**Mean Cluster 2** $_{SCP}$	**Mean Cluster 3** $_{SCP}$
Number of Beds	395	321	268
Usable Floor Area [m2]	1,255	1,165	612
Full Time Equivalent [units]	19	8	5
Stock Drugs	**Mean Cluster 1** $_{SD}$	**Mean Cluster 2** $_{SD}$	**Mean Cluster 3** $_{SD}$
Number of Beds [units]	212	110	87
Usable Floor Area [m2]	467	202	248
Full Time Equivalent [units]	9	4	5

hospital Beds is considered so that to have a more precise perception of the hospital size and the real demand by points of use faced by HC warehouses (Atumanya et al., 2020; De Marco & Mangano, 2013). One of the other important issues in warehousing is the Useable Floor Area (De Marco et al., 2010) since it is able to highlight the storage capacity that might have great influence on satisfying orders in the right time.

Finally, the ratio of total real work hours with respect to the available work hours in the same period is introduced as Full Time Equivalent (FTE) index (Kyyrä et al., 2019). In particular, this Descriptive Parameter is able to capture the performance of the warehouse staff and the evaluation the workload for both incoming and outgoing logistics activities.

4. Analysis of Results

In Table 5 some Key Performance Indicators (KPIs) are calculated based on the Descriptive Parameters that have been introduced in Section 3. These KPIs were selected based on the experience of the managers of the studied warehouses and are applied for interpreting and providing a complete overview of the results of the methodology. Cluster analysis identifies three different clusters for the Stock Consumable Products sample. Based on Table 3, the first cluster (Cluster 1_{SCP}) includes the largest warehouses with respect to the number of SKUs and a very huge amount of incoming and outgoing order lines. Similarly, based on Table 4, this result is verified by analysing the other factors related to the number of beds and the FTE due to the fact that both of these factors are the highest one in this category. On the other hand, Cluster 3_{SCP} consists of the warehouses managing a small number of SKUs. This gives rise to the limited logistics flow that are performed by the HC warehouses in this cluster. Moreover, Cluster 2_{SCP} has a median position for this type of warehouse in all the Descriptive Parameters listed in Table 3 and Table 4.

A further interpretation of results is obtained by the analysis of the KPIs based on Table 5. This indicates that for the first index, which is related to the ratio of the stock out order lines to the FTE, the results are not consistent with the cluster analysis for the Stock Consumable Products sample. As a matter of fact, there is considerable discrepancy between the values for cluster 1_{SCP} and cluster 2_{SCP} compared with the cluster 3_{SCP}. Such a result can stem from the lack of proper workloads organization. Therefore, there is a need to have a more effective human resource management in Stock Consumable Products warehouses. On the other hand, the second KPI in table 5, which relates to the utilization of the floor area for each SKU, attests the cluster analysis results. Warehouses with many SKUs show a relevant number of items stocked per each square meter. Similarly, fewer SKUs per square meter might indicate that the available storage floor area is not consistent with the total number of items handled. The warehouse area utilization 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 is not always aligned with the current logistics needs.

However, the Inventory Turnover, which is introduced by the ratio between the Value of Delivery to the Inventory Value, is not fully complied with the results of the cluster analysis. The new inventory policies adopted by the HC warehouses to cut public budgets can explain this result (Malovecka et al., 2015). Finally, in Table 5, the results of KPI related to the ratio of the Total Value of Delivery and the Number of Beds are in the same way with the cluster analysis results. This KPI implies that the demand level for each hospital complies with the magnitude of hospitals that are assigned to the HC warehouses.

Table 5: KPIs

Stock Consumable Products	**Cluster 1 SCP**	**Cluster 2 SCP**	**Cluster 3 SCP**
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 €
Stock Drug	**Cluster 1 SD**	**Cluster 2 SD**	**Cluster 3 SD**
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 €

In analysing the results of cluster analysis for the Stock Drug warehouses 3 clusters are identified. A clear and reasonable distinction between the different clusters can be observed. In this regard, the highest value in table 3 belongs to cluster 1_{SD}, particularly in Total Value of Delivery. Additionally, clusters 2_{SD} and 3_{SD} have the intermediate and smallest values respectively. Moreover, the last two clusters have the same values in Table 4 for FTE analysis, although, in Table 3 cluster 2_{SD} includes smaller warehouses compared with cluster 3_{SD}. It implies that regardless of the number of SKUs in each warehouse there is same amount of organizational activities associated with logistics management in both clusters. Based on the KPIs of Table 5 for Stock Drug warehouses and considering the ratio between the Stock Out Order Lines and the FTE, there is no strong variation between the three clusters. The proper balance between the number of yearly order lines and the assigned workload for each specific warehouse can bring about this result. In the same way, the number of SKUs with respect to the FTE are similar for the three clusters. Additionally, the inventory turnover endorses the cluster analysis classification and it is higher than the turnover for Stock Consumable Products. In fact, due to their shorter expiration dates, stocks of drugs might be replenished with shorter cycles (Leaven & Ahmmad, 2017). In this context, it is worth mentioning that the effect of cutting public budget is more visible in managing and ordering policy of Stock Drug warehouses. Finally, the annual results of the economic value of deliveries per each hospital bed do not reflect the results of cluster analysis. To be precise, the inconsistency stems from the limited number of beds assigned to cluster 3_{SD} compared with the two other clusters.

5. Implications and Conclusions

This research develops a statistical method for the classification of a set of HC warehouses based on assessing their logistics performance. To this end, an empirical approach is performed to recognize general patterns and provide a guidance perspective in warehouse management for policy-makers. Then, by applying cluster analysis as one of the well-known methods in many fields (Anuşlu & Firat, 2019), the warehouses are grouped based on pre-defined logistics Descriptive Parameters for identifying the similarities between them. The main benefit of such a classification compared to other existing methods is that each cluster includes similar warehouses and it leads to have more consistent strategies for each group. As a further step, the outputs from cluster analysis are also confirmed by comparing them with the KPIs related to hospital demand, material flows, and warehouse capacity. The present study promotes the current state of the subject in both academic and practical sides. From the academic point of view, the proposed statistical method develops a new way for performance assessment of a number of warehouses beyond the typical subjective procedures. Also, the performed statistical method classifies the warehouses based on their similarities and differences, which can lead to more research for having accurate and systematic performance evaluations of warehouses. In fact, the application of statistical methods in HC SCM to provide objective results is scantily discussed. Therefore, the present research might be an insight into this direction. On the other hand, for practitioners, this study can assist policy-makers to make more reliable decisions based on the clear position of the HC warehouses in a specific category. The importance of problems related to the performance assessment in public health gets great attention since it is constraint by the limited public financial budgets (De Marco & Mangano, 2013). Therefore, the proposed clustering method can pave the way for possible integration among the warehouses in the similar groups (Cagliano et al., 2016). To be precise, the classification by this method gives policy-makers the advantage to assign the merit budget and time to provide the strategies of each cluster. Also, the inefficiencies are detected and the opportunity to improve them leads to a decrease in costs. Finally, the limitation of this research can be addressed in the twofold. First of all, the Descriptive Parameters and KPIs provided for the implementation of this study are limited. Additionally, the results come from the implementation of the mentioned method only in one regional HC system of Italy.

For future research, a larger set of Descriptive Parameters and KPIs can be considered. Therefore, the cluster analysis will be conducted to obtain more precise clustering and have more details for comparison. Moreover, for structuring the total logistics performance, the possibility of different levels of contribution for different variables could be explored. Finally, the application of the proposed method might be studied in different countries to reflect various HC systems and provide comprehensive feedbacks to compare with the results of this work.

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