Omega 000 (2018) 1–13

Contents lists available at ScienceDirect

Omega

journal homepage: www.elsevier.com/locate/omega

Review

Measuring the logistics performance of internal hospital supply chains – a literature study☆

Karen Moons[a,*], Geert Waeyenbergh[b], Liliane Pintelon[a]

[a] KU Leuven, Centre of Industrial Management/Traffic & Infrastructure, Celestijnenlaan 300C, 3001 Heverlee, Belgium
[b] KU Leuven, Group T, Research Group Sustainable Engineering, Andreas Vesaliusstraat 13, 3000 Leuven, Belgium

ARTICLE INFO

Article history:
Received 10 March 2017
Accepted 19 January 2018
Available online xxx

Keywords:
Healthcare logistics
Performance measurement
Inventory management
Internal distribution
Multi-criteria decision-making

ABSTRACT

The patient care processes in hospitals are supported by a range of operational activities including inventory management and distribution of supplies to point-of-care locations. Hospitals carry large amounts and a great variety of items, and the issues of storing and distributing these items throughout the hospital supply chain are of great importance to providing high-quality patient service. Healthcare logistics encompasses the process of handling physical goods (e.g. pharmaceuticals, surgical medical products, medical equipment, sterile items, linen, food, etc.) and the associated information flows, from the reception of the goods within a hospital to their delivery at patient care locations. The medical supply costs constitute the second largest expenditure in hospitals, after personnel costs. A high-performing supply chain may realize improved outcomes (e.g. safe and quality patient service) and greater efficiency. Logistics managers need to identify opportunities to improve the logistics processes in order to lower costs and to improve patient care quality. However, in order to improve the logistics processes, you must understand how the healthcare supply chain is currently performing. Measuring the performance of the supply chain is fundamental to identify and address deficiencies in the logistics activities, and it serves as a good input for managerial decision-making. The purpose of this article is to present existing research on performance measurement at the internal hospital supply chain (e.g. inventory management, distribution activities), and more specifically in the operating theatre since it is among the most critical resources for a hospital. At the operating theatre, the requested items should be available at the right time at the right place, in the right condition, at the lowest cost possible. Furthermore, we will also discuss literature on multi-criteria decision-making techniques. It enables researchers to build a performance measurement framework and to prioritize between multiple performance indicators since a diverse group of stakeholders with conflicting interests is involved in the internal operating room supply chain.

1. Introduction

The internal supply chain in hospitals is characterized by its complexity, uniqueness and operational challenges, such as extremely expensive products and medical devices used in operating rooms, difficult inventory tracking due to the urgency of treatments, and unpredictable demand for medical supplies [60]. Many different types of supplies are stored in multiple storage rooms within the hospital and many processes (clinical, logistics, administrative, etc.) interact to contribute to the achievement of high-quality patient care [82]. Therefore, it is beneficial to have effective logistics practices in a hospital for controlling and distributing the supplies to patient care units. In recent years, however, the cost of logistics operations (e.g. handling, moving and processing of materials) has increased, ranging between 20% up to 45% of the total hospital operating budgets, partly due to the considerable amount of wastes in healthcare supply chain processes [54,97]. The operating theatre, in particular, turned into a major cost driver for a hospital [63,71], with the medical supplies and equipment used in the operating rooms taking up 40% to 60% of the hospital supply expenditures. However, effectively managing these supplies have long been a challenge [15]. The healthcare sector exhibits special features that directly affect the quality of patient care. Non-availability of materials may postpone a surgical procedure and possibly results in planning trouble and/or hazard of patient's health, whereas hidden stocks or overstocking of supplies in patient care locations increase costs and cause supply chain inefficiencies [26,30].

Healthcare Supply Chain Management (SCM) refers to "the information, supplies and finances involved with the acquisition and movement of goods and services from the supplier to the end

☆ This manuscript was processed by Associate Editor Gel.

* Corresponding author.
E-mail address: karen.moons@kuleuven.be (K. Moons).

https://doi.org/10.1016/j.omega.2018.01.007
0305-0483/

user in order to enhance clinical outcomes while controlling costs" [27]. The companies that make up the supply chain need to interact and cooperate in order to fulfill the purposes of the logistics processes (i.e. supply, distribution and warehousing) [8]. Coordination and integration between the processes positively contributes to the performance of the healthcare supply chain. The fields of Industrial Engineering (IE), Operations Research (OR) or Operations Management (OM) provide (analytical) methodologies to support the supply chain or logistics operations of hospitals. Chase and Jacobs [20] define OM in healthcare as "the design, management and improvement of the systems that create and deliver healthcare services" . It is, however, a major challenge for operational researchers to ensure high-quality patient care by considering limited resources (e.g. healthcare professionals, operating rooms, supplies, etc.) and high process variability due to patient characteristics and physician preferences, and to engage multiple stakeholders with conflicting interests to cooperate. Stakeholders have different goals for efficiency management because there is no consensus on what constitutes efficiency and what actions to take to improve it [62]. The ultimate goal is to achieve "a well-coordinated system that delivers care with great efficiency and quality, at reasonable cost, matching the resources for care to where (and when) they are needed most" [40].

The scope of this article is limited to the internal hospital supply chain processes, and more specifically medical supply logistics in the operating room environment, with a focus on inventory control and distribution of medical supplies and equipment to ensure availability and cost containment. Rivard–Royer, Landry and Beaulieu [75] stated the internal supply chain as "the sore spot or weak link" in process integration and optimization. The internal supply chain processes are performed within the hospital and include product and information flows from receiving, replenishing, picking, etc. [80]. The functions of the internal supply chain include purchasing, inventory, distribution and consumption. In this article, the focus will be on inventory and distribution management in the operating theatre. Volland, Fügener, Schoenfelder and Brunner [95] review the relevant literature regarding the logistics activities of handling physical goods (e.g. pharmaceuticals, medical consumables, food, sterile items, etc.) in hospitals and investigate quantitative methods applied to hospital materials management (i.e. coordination of all activities related to material ordering, holding and administrating). The authors distinguish between four streams of literature across the hospital supply chain: supply and procurement, inventory management, distribution and scheduling, and holistic supply chain management to enable patient care. A streamlined process might lead to reduced costs, increased efficiency, materials traceability, information sharing, and patient safety, while simplifying the activities accomplishment by hospital personnel [82]. The Association for Healthcare Resource and Materials Management (AHRMM) presents valuable knowledge for materials management in healthcare as it helps realizing an efficient and effective functioning of the internal hospital supply chain.

1.1. Hospital supply chain strategy

The internal supply chain links the logistics processes and patient care services within the hospital. Today's hospital supply chains face several issues, including fragmented supplier base, supply chain inefficiencies, excessive administrative expenses, poor management, inappropriate care, waste, etc. Hence, an effective supply chain management can positively impact the hospital's bottom line [88]. With supply chain operations taking up to 40% of the hospital's budget, implementing a successful hospital supply chain strategy is important. Hospitals that take a holistic view of their supply chain and focus on strategic issues may realize significant benefits, such as improved employee satisfaction, patient safety and outcomes [45]. The key steps to strategic healthcare SCM include improved collaboration with vendors, align with physicians, focus on integration, automate the supply chain, adopt more and better standards and use process improvement methodologies (e.g. Lean). Dittmann [29] presents guidelines for planning an effective supply chain strategy by taking into account customer needs, internal assessment of supply chain capabilities (e.g. benchmarking), industry trends, evolving technologies, risks and competition. Hospitals can gain competitive advantage by effectively managing their supply chain and hence, achieve supply chain excellence. Finally, the right supply chain key performance indicators (KPIs) should be defined to track performance and evaluate the implementation of the supply chain strategy.

Unlike other industries, where SCM techniques are already successfully applied, the healthcare sector is lagging behind in adopting the logistics concepts due to several factors, including regulatory issues, outdated information technology (IT) systems, poor inventory and distribution management, lack of executive involvement, no process improvement culture, etc. [14,65]. Researchers should look beyond the healthcare sector when assessing the internal hospital supply chain capabilities [29]. They can learn a lot by looking at best-in-class practices from manufacturing or retail industry as a way to maintain a high level of efficiency (i.e. control costs) and effectiveness (i.e. high quality of patient care). For example, the Wal-Mart retail chain adopts Collaborative Planning, Forecasting and Replenishment (CPFR) and information is shared through Enterprise Resource Planning (ERP). Such concepts are key to get an integrated supply chain [19]. However, the unique characteristics in the healthcare setting, a diverse group of stakeholders, complex technologies and a dynamic internal and external environment make it difficult to transfer logistics concepts from the manufacturing or retail sector to the healthcare sector [27]. Toba et al. [88] discuss four areas as potential improvement opportunities in the hospital supply chain. A first opportunity for supply chain savings is in the area of physician preference cards and physician buy-in. The most cost-effective products are purchased by team consensus between clinical experts and sourcing staff. A successful partnership with a Group Purchasing Organization (GPO) provides another cost saving opportunity because they have a global network of suppliers and benefit from economies of scale. Furthermore, hospitals should improve on supply data management technology (e.g. Global Data Synchronization Network (GDSN)) and the integration with their purchasing systems in order to have faster and more valuable information in the supply ordering process. Finally, significant cost savings can be achieved by effectively managing inventory and distribution, which will be elaborated in Section 2 and 3.

Coordination and integration between the processes positively contributes to the performance of the healthcare supply chain [27]. In order to achieve internal coordination, the logistics processes such as supply, warehousing and distribution must be aligned with the organization's business strategy as well as with the supply chain strategy [21]. Healthcare supply chain management is concerned with five domains in order to get integrated supply chain processes [19]. First, demand can be managed by using forecasting techniques and by standardizing supplies. Effective order management practices should be in place by consolidating purchases. Third, supply chain actors should participate in GPO agreements to reduce the number of suppliers. A fourth area is related to logistics management by consolidating shipments. Finally, adopting automated point-of-use distribution, minimizing Stock-Keeping Units (SKUs), maximizing inventory turnover rates, increasing non-stock items, etc. all contribute to integrated management savings. Hence, hospital supply chains can become operationally efficient by adopting technologies, standards and best practices, and methodologies applied in other industries for managing supply chains. Balcazar–

Please cite this article as: K. Moons et al., Measuring the logistics performance of internal hospital supply chains – a literature study, Omega (2018), https://doi.org/10.1016/j.omega.2018.01.007

Camacho et al. [8] also suggest a set of guidelines for coordinating the supply chain planning in a healthcare setting as it positively impacts some performance indicators, such as delivery times, production costs and customer service perception [93]. Supply chain coordination can be achieved by purchasing policies, inventory management, use of information technology (e.g. ERP systems, Warehouse Management Systems (WMS)), high levels of standardization, joint planning processes, synchronized forecasts, information sharing and aligned interests and management styles between all agents. The tactical and operational planning is facilitated by using real-time information on inventory levels and resource availability. A coordinated supply chain planning reduces the overall supply chain costs and results in an integrated hospital supply chain management [73].

1.2. Methodology

The methodology used in this study was an extensive search of the journal articles that describe the internal supply chain of a hospital. Various English language sources are included in the search at online databases, such as PubMed, ScienceDirect, Limo and Google Scholar. The following keywords were used in this search: “Hospital materials management”, “Hospital supply chain management”, “Operations research/management healthcare”, “Operating theatre logistics”, “Medical supplies operating theatre”, “Hospital inventory management”, “Internal distribution hospital”, “Integrated hospital supply chain”, “MCDM healthcare”, and “Performance indicators hospital supply chain” . The abstract of the articles were screened to determine (1) if it concerned internal supply chain management, (2) whether the application or literature fits in the hospital environment, (3) and if it was related to performance measurement of the logistics activities in a hospital. In addition, some best-practice healthcare solutions, such as Cardinal Health, were included. A total of 99 articles were assessed in this review. The majority of the articles were published after 2000, with 56 articles being published between 2010 and 2016. Tables 1 and 2 in Section 2.3 and 3.2 respectively, include the articles that address performance measurement in inventory and distribution management. The articles are ordered in descending order with respect to the year of publication. The largest number of articles in the operating theatre context was found in the domain of surgical planning and scheduling, and operating room utilization. Our search excluded these papers and focused on inventory and distribution management, and operational performance in the operating room supply chain.

The objective of this article is to present existing research on performance measurement in the internal hospital supply chain (e.g. inventory management, distribution activities), and more specifically in the operating room since it is critical to the patient care process and it has become a major cost center of the hospital. Logistics managers need to identify opportunities to improve the logistics processes in order to lower costs and to improve patient care quality. However, in order to improve the logistics processes, you must understand how the internal supply chain is currently performing in order to identify and address inefficiencies in the logistics activities. Performance indicators will help monitor management policies such that logistics managers can take evidence-based decisions that can optimize the inventory and distribution system. Currently, there is a lack of clear and measurable cost and quality metrics for measuring hospital logistics performance [66]. The literature review by Volland et al. [95] points to investigating performance metrics in healthcare logistics as an interesting research opportunity. Kucukaltan, Irani and Aktas [52] recognize the need for a performance measurement framework in the logistics industry. Aronovich, Tien, Collins, Sommerlatte and Alain [4] present a guide with KPIs for public health managers and they distinguish between four types of indicators – quality, time, financial and productivity – for each supply chain function (e.g. product procurement, inventory management, distribution, etc.). Moreover, it is also important to determine the relationships among performance indicators and to identify trade-offs required to improve the overall supply chain performance [4,52,85].

The remainder of this article will focus on performance indicators that are used in internal hospital logistics and operating room supply chain processes. Section 2 provides an overview of inventory management models and indicators to measure its performance. Distribution and scheduling activities are addressed in section 3. Section 4 presents literature on Multi-Criteria Decision-Making (MCDM) to account for the multitude of involved stakeholders. Finally, we present a conclusion and opportunities for further research in Section 5.

2. Inventory management

Inventory management constitutes the key lever to realize efficiency improvements (e.g. reduce costs, waste and the risk of product obsolescence) while satisfying healthcare service levels [95]. It impacts your bottom line as it ensures cost containment, supply chain efficiencies and customer satisfaction [16]. However, logistics managers lack quantifiable data regarding supply consumption, inventory levels, product duplication and procedure costs to notify the key stakeholders of the financial, clinical and operational impact of supply chain practices [15].

In a hospital, the consequence of a stock-out is far more severe (e.g. endanger patient’s life) compared to other industries where a stock-out typically results in lost revenue [88]. One of the biggest challenges in healthcare supply chain management is balancing costs with the right amount of inventory to sustain quality and timely patient care [1]. The hospital decision makers must consider many elements such as costs, service levels, storage space, product availability, product expiration dates, etc. in order to control stocking levels at all times both in the central warehouse and at point-of-care locations (e.g. operating rooms, wards, etc.). Current practices in healthcare organizations rely on surplus planning of resources to deal with complex and last-minute changes in the operating room planning and hence, produce stock wastages due to poor planning, not understanding appropriate inventory levels and not monitoring budgetary guidelines [1]. Forecasting techniques, inventory management, simulation and optimization algorithms provide solution approaches to control inventory in hospital warehouses. New technologies and automation (e.g. RFID, barcoding) can point to new supply chain capabilities and help healthcare providers overcome the biggest inventory and distribution management barriers of product variability, charge capture inaccuracies, complicated workflows, etc. [17]. Furthermore, there is a growing need for technologies that provide end-to-end supply chain visibility, resulting in lower inventory and cost, improved patient service, improved tracking, shorter delivery times, and lean and proactive supply chain partners [29]. Camp et al. [15] provide several strategies to improve the healthcare supply chain performance, such as the degree of standardization, inventory control, waste reduction, data analysis and improved physician preference card management. However, there is a lack of cost and quality metrics to measure healthcare logistics performance. “You can’t manage what you don’t measure” [66].

2.1. Inventory management in hospitals

High capital is tied up in inventory due to the growing volumes and variety of physical goods carried by hospitals, and thus an increasing number of SKUs. In particular, in the operating room, four types of materials are used [53]. The medical consumables

Please cite this article as: K. Moons et al., Measuring the logistics performance of internal hospital supply chains – a literature study, Omega (2018), https://doi.org/10.1016/j.omega.2018.01.007

Table 1
Overview of performance indicators for inventory management.

	Quality				Time		Financial		Productivity		
	Availability (service level, stock-out)	Inventory visibility (on-hand, safety stock)	Criticality of inventory items	Patient safety (delays, errors)	Replenishment time	Clinical staff involvement	Inventory cost	Value of stock, stock wastage	Inventory turnover	Utilization rate	Standardization
Fong et al. [36]	X			X			X			X	X
Supeekit et al. [86]	X			X	X		X	X	X	X	
Carrus et al. [18]				X			X	X	X		X
Hoeur et al. [44]	X	X		X			X				
Rosales et al. [78]		X			X						
Supeekit et al. [85]	X			X			X	X	X		
Abukhousa et al. [1]	X	X						X		X	
Camp et al. [15]	X									X	X
Gebicki et al. [37]	X		X	X			X	X	X		
Sarno [82]	X	X		X			X		X		
Beaulieu et al. [10]	X					X				X	
Landry et al. [55]		X		X	X	X					
Bijvank et al. [12]	X	X								X	X
Kelle et al. [51]	X	X								X	
Rossetti et al. [80]	X	X		X		X	X				
Al-Qatawnez et al. [12]	X	X	X				X				
Baboli et al. [7]	X	X			X		X		X		
De Vries [26]	X			X			X				
Aronovich et al. [4]	X	X		X	X		X	X	X		
Lanckzweirt et al. [53]				X			X			X	X
Augusto et al. [5]	X				X	X					
Di Martinelly [30]	X	X		X		X	X				
Nachtmann et al. [66]	X	X						X		X	X
Park et al. [70]		X		X							
Little et al. [61]	X		X							X	
Lapierre et al. [56]		X				X	X				
Danas et al. [24]		X	X	X						X	
Baboli et al. [6]							X		X		
Epstein et al. [33]							X				

Table 2
Overview of performance indicators for distribution activities.

	Quality			Time			Financial	Productivity		
	Delivery accuracy	Centralization degree	Disruption of distribution activities	Preparation time	Responsiveness (on-time delivery)	Workload distribution	Distribution cost	Case cart capacity/ availability	Delivery frequency	Standardization
Supeekit et al. [86]	X				X		X			
Carrus et al. [18]	X			X	X	X	X			X
Hoeur et al. [44]	X				X		X			
Pinna et al. [72]		X				X	X		X	X
Robinson et al. [76]						X				X
Supeekit et al. [85]	X			X	X			X		
Iannone et al. [47]		X								
Sarno [82]		X				X	X		X	
Landry et al. [55]		X								X
Rossetti et al. [80]										X
Baboli et al. [7]		X					X			
De Vries [26]	X								X	
Aronovich et al. [4]					X		X	X		
Bett et al. [11]					X					X
Lanckzweirt et al. [53]	X			X				X		X
Augusto et al. [5]				X		X		X	X	
Di Martinelly [30]	X		X	X	X	X		X	X	
Essoussi et al. [34]		X								
Lebeer et al. [57]	X				X		X	X		
Miller [63]		X	X		X					
Park et al. [70]			X							
Little et al. [61]							X		X	
Lapierre et al. [56]			X	X		X			X	
Hassan et al. [42]	X			X						
Baboli et al. [6]				X	X					

or disposables (e.g. surgical drapes, gloves, suture, syringes, bandage, etc.), often combined into custom procedure trays (CPTs), are the most frequently used items taking up the majority of the storage space. Second, procedure-specific surgical supplies are often stored at point-of-care locations (e.g. operating rooms). A third type of materials are the sterile, reusable supplies which are organized into surgical instrument trays (e.g. suture tray, hernia tray). A reverse logistics flow describes the sterilization process, which can be outsourced or performed in-house depending on the interaction between transportation, storage and instrument unit costs [90]. Finally, the high-cost, slow-moving materials are often held in consignment with the vendor or supplier (i.e. the supplier is the owner of the materials until the material is effectively consumed in a care process). These four types of materials are duplicated in many storage locations and high availability rates are achieved through stocking according to a “nice-to-have” rather than “need-to-have” principle [15]. It is important to identify and consolidate the locations of the materials in the hospital storage space [16]. The inventory system is characterized by centralized and decentralized storage areas, whereby the hospital central storage room replenishes the lower-level (decentral) point-of-use locations (e.g. operating rooms) [12,26]. A general rule of thumb states that maximum 20% of the supplies should be stored in the operating room, with the remaining inventory in the central storage room [70].

The operational efficiency of hospital supply chain processes can be improved by focusing on replenishment of inventories based on product consumption and independent of the level of product variability. However, controlling the materials flow is not straightforward due to a lack of information (e.g. no registrations of the consumed materials). Given the number of items and storerooms in each facility, it is desirable to adopt replenishment policies that are both simple and efficient [78]. In order to understand how to use inventory models, many terms should be understood such as Periodic Automatic Replenishment (PAR) level, inventory turnover, Economic Order Quantity (EOQ), safety stock, etc. [3]. Traditional inventory replenishment models at medical units determine when to order (i.e. reorder point) and how much to order (i.e. reorder quantity). The reorder quantity is determined based on the state of the inventory system (i.e. inventory on-hand plus pending orders minus backorders), demand forecasts, internal replenishment lead times, the review period and the safety stock, which takes into account the drug demand uncertainty [82]. The review period has to be set based on the demand variability and the cost of ordering, holding and delivering the supplies. Improving demand forecasts is beneficial for the logistics operations, as it lower costs for case preparation, improves fill rates and service levels and reduces inventory [80].

Rossetti et al. [80] list a number of periodic and continuous inventory policies, such as reorder point/reorder quantity policy or two-bin Kanban system, reorder point/order-up-to policy, PAR level system, etc. PAR-level balancing (i.e. matching stock levels to actual demand) is commonly used to control inventory [16,87]. However, PAR levels tend to reflect experience-based inventory levels rather than data-driven actual inventory levels, which leads to overstocking of some products while others are short in supply [74]. Furthermore, a continuous inventory system may be superior to a periodic inventory management system as it allows to continually update the inventory on-hand according to utilization data and to capture details that can improve patient billing [46,50,70]. Using data standards (e.g. GS1 product identification standards) in barcodes allows for automatically updated inventory replenishment systems upon scanning, increased inventory accuracy and increased visibility throughout the supply chain, with major cost and inventory savings [28]. A hybrid inventory policy combines periodic and continuous replenishments and it will result in a reduction in cost, inventory and number of replenishments at point-of-use locations [78]. Another way to control inventory in the operating room is to apply lean management tools and conduct a waste analysis [70]. Lean principles can streamline processes, reduce costs, reduce waste, improve quality and increase satisfaction among patients, healthcare providers and staff [96].

Information technology and technological innovations enable decision-making throughout the supply chain, improve productivity, lower costs and improve patient safety [80]. The Materials

Please cite this article as: K. Moons et al., Measuring the logistics performance of internal hospital supply chains – a literature study, Omega (2018), https://doi.org/10.1016/j.omega.2018.01.007

Management Information System (MMIS) typically supports inventory management (e.g. inventory on hand, order quantity, storage locations, etc.). Automatic identification and data capture technologies, such as barcoding and RFID, help systems identify products, and capture and store information. The use of barcodes is widespread among hospitals, but it has limitations since it requires personnel time for scanning with manual cycle counts to match supply usage and inventory levels, and hence human accuracy. RFID tags and readers can replace barcoding technologies in order to improve productivity and efficiency, but the current level of existing technology in healthcare limits the benefits compared with the high cost of adopting and implementing RFID systems [22]. Data standards (e.g. GS1) ensure interoperability of systems across the supply chain and it increases internal supply chain visibility, which streamlines inventory management processes. The medical supply chain has been slow in adopting these technologies [80]. Hospitals should evaluate the medical effectiveness of the new technologies as well as the cost before adoption. In addition, the logistical performance (e.g. fill rate, supply chain cost) should be evaluated for various levels of cost in order to take advantage of technological advances.

2.2. Inventory classification

The function of holding surgical-medical supplies in inventory is supporting the patient care processes. Different inventory control and distribution policies may be required depending on the type of physical goods stored. For frequently used, general supplies a two-bin Kanban system can be implemented, whereas other types of supplies may require individual tracking with RFID technology either for cost purposes or due to clinical requirements [10]. Rosales et al. [78] propose a periodic two-bin inventory system and optimize the review cycle length to control point-of-care locations which contain low-cost, non-critical supplies, whereas a change to a continuous review two-bin policy with the use of RFID is recommended for storage rooms with critical supplies. Adopting RFID technology in a hospital is good solution to reduce supply costs by tracking supplies as well as monitoring distribution management and patient billing. The benefits of applying RFID to medical supplies tracking are apparent, including improved efficiency, productivity, and cost performance, increased inventory visibility throughout the supply chain, reduced stock-outs, increased patient safety through error reductions, etc. [22,83]. A hospital, however, should make a trade-off between the cost of implementing RFID infrastructure and the potential benefits. Other barriers to adopt this technology include unclear return on investment, technological limitations, lack of standards, privacy concerns and competition with other strategic imperatives. Furthermore, RFID systems may be too complex in some healthcare settings because tracking each SKU could be a challenge [88,98].

Several classification methods exist to control the multitude of supplies, since these differ strongly in terms of stock-out effects, item value and demand patterns [64]. The ABC analysis is a traditional approach to classify items in a hospital inventory based on Pareto's principle of "vital few and trivial many" (i.e. select items with largest impact), typically based on cost criteria [39]. However, this method classifies items in terms of one single criterion and does not consider other attributes of each item, such as size, consumption, obsolescence characteristics, order frequency, functionality, etc. As a result, inventory management policies are adjusted by only taking into account this single criterion [24]. Typically, in hospitals the majority of the items are in the B and C categories for unit cost and demand, so the hospital inventory system is challenged with carrying a wide variety of item types. This SKU proliferation problem is mainly caused by physician preference items [80]. Another important distinction should be made between critical and non-critical items in the healthcare sector. The non-availability of critical items could have dramatic consequences for a patient's life. Because the ABC method mainly focuses on costs, some low-cost critical items may not receive sufficient management attention. This limitation is overruled by the VED analysis which classifies items into three categories – Vital, Essential, and Desirable - based on their criticality for the operation. Vital items are those items that drastically affect the operational processes, essential items carry high stock-out costs or consequences for the process, and items categorized as desirable cause only a minor disruption to the process [39]. Molenaers et al. [64] develop a classification scheme based on item criticality to rationalize the efficiency of the inventory policy of spare parts for maintenance purposes. They combine a decision diagram and Analytical Hierarchy Planning (AHP) to determine the criticality level of a spare part based on relevant criticality criteria (e.g. equipment criticality, logistics characteristics and probability of failure). The criticality level can be used as a justified basis for holding these items in stock and to determine service level requirements. Nicholson, Vakharia and Erenguc [69] suggest to use the criticality of items as a starting point to determine the desired service levels for each item. Danas et al. [24] adopt the multi-attribute spare tree analysis (MASTA) approach for spare parts inventory for production machines from Braglia, Grassi and Montanari [13] and apply it to a hospital pharmacy environment. They identify four major categories – patient treatment criticality, supply characteristics, inventory problems and usage rate – and their corresponding characteristics (e.g. danger of loss of life, lead time, price, frequency of use, etc.). The drugs are classified into four classes, ranging from very important drugs to not important drugs, which then determine the inventory strategy for each drug in order to optimize hospital pharmacy inventory. Al-Qatawneh and Hafeez [2] develop a multi-criteria classification system depending on the criticality, cost and usage value of items to assign different service level percentages to items and hence to optimize the overall inventory cost and to ensure the availability of items that are critical for patient care. For instance, high-cost orthopedic materials are characterized by high demand uncertainty and high service requirements, which will drive a large amount of safety stock for that item [30].

2.3. Performance measurement for inventory systems

Within healthcare organizations, the main goal of inventory management is to reduce the costs associated with supplies without sacrificing the quality of patient care [80]. The financial performance indicators (e.g. inventory holding cost, value of stock, average response cost, etc.) identify the supply chain cost drivers and help move toward a more efficiently managed supply chain [4]. The inventory costs are estimated to be between 10% and 18% of net revenues [48]. Epstein and Dexter [33] categorize the inventory costs into five types of costs: ordering, shipping, purchasing, storage and opportunity costs. In addition, one should also consider the cost of not having the items in stock when needed (i.e. stock-out cost). Stock-out costs are difficult to measure given its high variability. Therefore prevention of stock-out is handled via a service level constraint that is dependent on the item criticality, which is a measure of the consequences of a stock-out [37,38]. The reordering and storage costs as well as the risks of stock-outs should be taken into account when determining the inventory turnover rate. In case of a stock-out, more time is spent by the logistics team who need to make extra visits to care units, and by the clinical personnel who waste their time making extra calls to the supply department or chasing the products at other care units [56].

Moving toward product standardization (e.g. reduce the number of different items that have to be stored, reducing volatility

Please cite this article as: K. Moons et al., Measuring the logistics performance of internal hospital supply chains – a literature study, Omega (2018), https://doi.org/10.1016/j.omega.2018.01.007

of demand) in clinical practices is one way to cut costs and to reveal opportunities for time savings because standardized instrument trays use the storage space more efficiently and reduce material movements to the point-of-care locations [36,41]. In the operating theatre, however, surgeons have specific preferences for supplies and there exists considerable variability in supplies and processes to ensure quality of care [83]. Hence, it is not straightforward to align the material preferences of surgeons, who want to use the best materials in order to offer qualitative patient care, with the logistics management team, whose objective is to reduce the operational costs and inefficiencies. The physician preference cards typically contain 20% to 40% more items than what is actually consumed, which increases costs in terms of waste, returned supplies and unnecessary labor . The efficiency of the logistics flow can be increased by updating the physician preference cards to actual utilization patterns by using automated inventory systems [10]. Important cost savings could be realized by tagging and tracking medical supplies. Leveraging technology (e.g. barcode scanning, RFID) to automate material management systems enables logistics managers to monitor performance of operating rooms as it creates databases with real-time information on consumption of materials, case costing, etc. rather than having to rely on static inventory data [53]. These data can support decision-making in supply chain processes and may convince a surgeon to engage in effectively managing their supplies [67]. “If you don’t have data, it’s hard to get physicians on board and aware of the expenses associated with stocking many similar products” [17]. Potential (financial) benefits of an efficient supply management include [70]: (a) timely providing medical supplies reduces delays in the operating room, (b) reduced labor cost in picking and restocking unused supplies, (c) automated information sharing between operating room scheduling, central sterilization, billing, accounting, materials management and purchasing departments, and (d) reduced inventory on-hand.

The majority of literature is devoted to inventory management systems that reduce inventory levels in order to achieve the main objective of cost reduction. Sole cost cutting objectives, however, do not suffice since patient’s satisfaction is influenced by the perceived quality of care and prices. Hospital managers need to balance inventory levels by trading-off between quality metrics (e.g. service level, timely treatment, meeting professional standards, etc.) and costs [26]. Nachtmann and Pohl [66], Aronovich et al. [4] and Hoeur and Kritchanchai [44] develop a set of performance measures to monitor the quality of its inventory activities, including inventory visibility, inventory availability, stock-out rates, inventory accuracy rate, stock wastage due to expiration or damage, etc. Supply availability is a crucial factor in a healthcare logistics system’s ability to support patient care processes [94]. An interesting indicator to measure the performance of an operating room is the percentage of unplanned operating room closures due to non-availability of supplies [35]. Understanding the relationship between logistics processes and clinical care processes is important to manage the utilization of supplies and services. For hospital logistics managers, knowing what is used in a surgical case and how often is more effective than knowing the supply cost per case [66].

Supeekit et al. [85] and Supeekit, Somboonwiwat and Kritchanchai [86] explore four supply chain performance criteria of cost, time, reliability and productivity to evaluate internal hospital supply chain performance. Typical performance criteria to evaluate inventory management include value of buffer stock, inventory days of supply, stock-out at point of use, preparation time, picking accuracy, etc. Bijvank and Vis [12] list the characteristics of relevant literature on inventory management for point-of-use locations in hospitals, such as demand process, lead time, number of items, capacity restriction, etc. They redirect the focus of controlling inventory from a cost objective function [25,56,69] to a service level objective [12,61]. The service level is defined as the fraction of demand that can be satisfied directly from inventory on-hand (i.e. item fill rate) [12]. They introduce a capacity model and a service model in order to determine the reorder level that maximizes the fill rate and minimizes the required capacity, respectively. Little and Coughlan [61] propose an optimal inventory policy that maximizes the average and minimum service level by taking into account restrictions on space, delivery and criticality of items, in order to achieve a solution that has many products of high importance at high service level. Gebicki et al. [37] propose medication inventory policies that combine three drug characteristics – drug availability (i.e. probability that a drug is available from the supplier when ordered), criticality (i.e. based on the criticality of the treatment for which the drugs is used) and expiration dates – that influence the performance of the system with respect to total cost and total number of stock-outs with the aim to minimize the trade-off between costs and patient safety. Kelle, Woosley and Schneider [51] propose reorder point policies and discuss the key performance indicators for inventory management in the pharmaceutical supply chain, including the expected number of daily refills, the service level and storage space utilization. In the operating room environment, Beaulieu et al. [10] describes four objectives to effectively manage supplies: supply availability for scheduled surgical procedures, up-to-date inventory management information, minimal clinical personnel involvement and automating inventory management. An optimized inventory management system will result in an improved workflow of all employees, improved control of both inventory and waste, significant cost savings, increased traceability, data collection and accurate case costing. Table 1 presents an overview of the four types of performance indicators – quality, time, financial and productivity – for inventory management activities which are retrieved from literature.

3. Distribution and scheduling

Medical supply logistics activities ensure the proper functioning of the healthcare system, and the performance of the healthcare delivery system strongly influences the hospital’s service quality. A mismatch between demand (e.g. the need for care) and supply (e.g. human resources, materials, equipment, etc.) often results in hospital waiting times, due to the lack of planning, coordination and communication in delivering healthcare services. Coordination of the healthcare resources, effective delivery strategies and measurement of the delivery services are crucial for creating high-value outcomes [77]. Therefore, the hospital supply chain management is faced with developing distribution strategies (e.g. direct shipment, cross-docking, etc.) to deal with movements of goods in the supply chain, while minimizing storage and transportation costs. Carrus, Marras and Pinna [18] define the quality of the logistics processes as the internal customer satisfaction, since the quality of the healthcare provider’s internal processes determines how well the processes meet the needs of the patients, in terms of response time, workload distribution, delivery accuracy, etc. The hospital material managers are responsible for having medicines and other medical supplies available at the health facility, while being aware of the distribution costs (including the handling and transportation costs, e.g. in terms of frequency of delivery) [61]. The supply availability depends on the performance of the healthcare supply chain. Measuring this performance will provide information on deficiencies in internal distribution operations [4].

3.1. Internal distribution and scheduling activities

The healthcare supply chain is very fragmented with many different parties at various supply chain stages. Three key players are identified and they typically operate in silos, independently from one another, resulting in badly coordinated supply chain processes.

Please cite this article as: K. Moons et al., Measuring the logistics performance of internal hospital supply chains – a literature study, Omega (2018), https://doi.org/10.1016/j.omega.2018.01.007

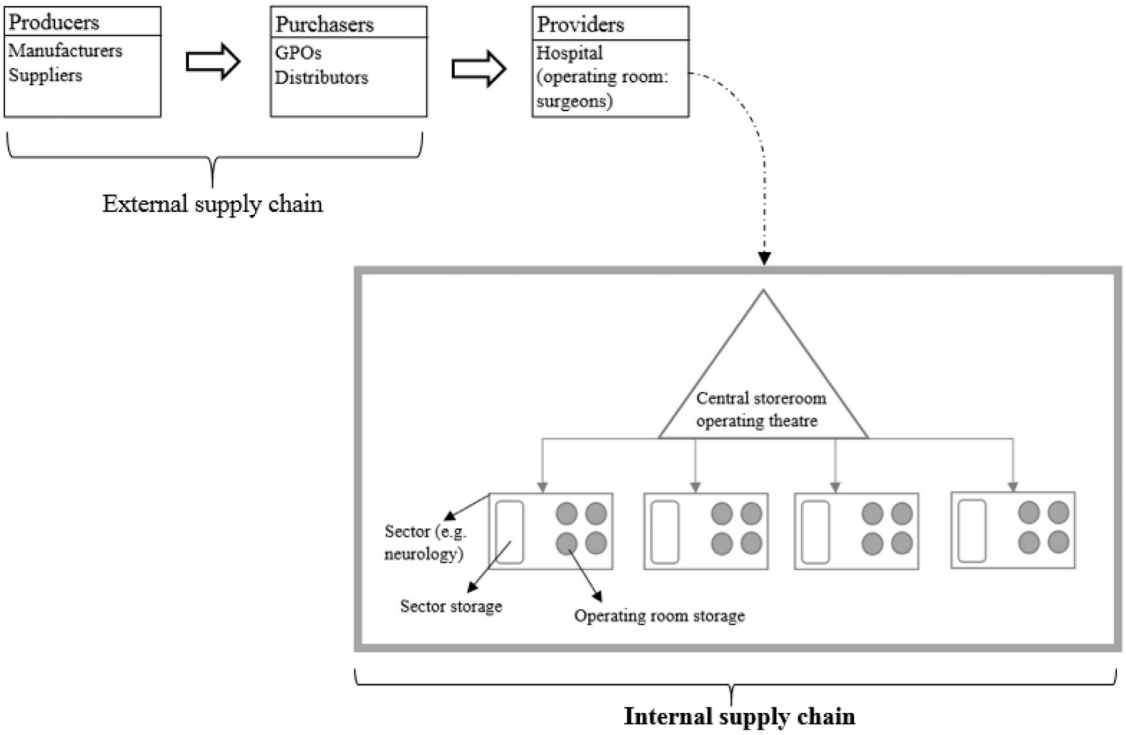

Fig. 1. External and internal hospital supply chain.

Among the supply chain actors, there are producers (e.g. medical device manufacturers, pharmaceutical companies, etc.), purchasers (GPOs, medical-surgical distributors, etc.), and healthcare providers (e.g. hospitals) [14]. Hospital SCM is often faced with selecting warehouse locations and capacities in order to maximize production, transportation and inventory costs. These issues are typically related to the manufacturers or suppliers in the healthcare supply chain. The healthcare provider will be setting up supply contracts or relationships with a distributor or directly with the supplier [19]. To limit the scope, this article will focus on the healthcare providers.

The healthcare providers divide the supply chain in external, internal and bedside administration processes [80]. Figure 1 shows an overview of the external and internal supply chain with the associated actors [14]. The external supply chain processes include transactions with distributors, GPOs and manufacturers upstream in the supply chain in order to save money on procurement (e.g. reducing lead times, considering logistics when designing packaging, leveraging economies of scale, etc.) [28]. This study focuses on the internal supply chain processes including product and information flows from receiving, replenishing, picking, etc. within the hospital. The objective is to optimize the service delivery in terms of costs, quality, time and flexibility to increase patient's and personnel's satisfaction and the economical return [30]. The automation of the internal processes and the integration with the hospital materials management information system allows for significant improvements (e.g. cost savings, eliminate labor-intensive inventory counts, etc.) [80]. One of the most important issues is to look at the supply chain from an integrated perspective [31,58,80]. In order to achieve a high-performing supply chain, various departments in the internal supply chain (e.g. central sterilization, pharmacy, operating room, material management, etc.) must be efficient and integrated which requires a thorough operational planning and coordination. Integration results in streamlined, cost-effective processes characterized by optimal usage of space, reduced cost, standardization, and fewer cancellations or delayed interventions [53]. Uthayakumar and Priyan [89] optimizes inventory by modeling the integrated supply chain planning, while considering the patient service level. The third type of supply chain processes are related to the delivery of care to the patient (i.e. bedside administration). Applying barcode scanning or RFID technologies to identify the pharmaceuticals or medical supplies allows materials managers to speed the distribution, to efficiently control recalled products, notifications to patient billing, clinical record systems, and to improve the traceability of supplies.

Traditionally, suppliers ship their products to distributors, from where the products continue to the hospital's warehouse. This traditional distribution model holds a large amount of stock and keeps the number of deliveries relatively low, resulting in low transportation and ordering costs, but high holding costs and increased material handling. A newer model, used by the Mercy Health System replaces the distributor by setting up a centralized warehouse system for direct shipments from suppliers. The central service center is responsible for shipping to the hospitals. In this model, the holding costs and material handling costs are greatly reduced, efficiency increases and fill rates improve [80]. Integration of the healthcare supply chain can be achieved by centralization of medical supplies or by outsourcing to a third party logistics provider [34]. Operating rooms use different methods for the internal distribution of medical supplies and equipment. Typically, SCM distinguishes between a centralized and a non-centralized structure depending on the degree of control every agent in the supply chain has [8]. Recently, some hospitals adopt RFID technologies in their inventory and internal distribution system providing them with real-time information on inventory levels. RFID stimulates automatic inventory rotation and decreases the inventory on-hand. However, a balance should be made between inventory costs, ordering costs, and the costs of implementing the new technology. Surgical procedures require a great variety of medical supplies which are stored in multiple storage areas. Landry and Beaulieu [55] classify the methods of distributing the materials to the point-of-care locations by considering two aspects: the reorder quantities

Please cite this article as: K. Moons et al., Measuring the logistics performance of internal hospital supply chains – a literature study, Omega (2018), https://doi.org/10.1016/j.omega.2018.01.007

are set by the centralized materials management department or by the decentralized nursing units, and the supplies are managed according to a continuous or periodic inventory management system. By creating a centralized material management system, hospitals can improve efficiency and reduce costs associated with inventory, storage space, time and labor [63]. Essoussi and Ladet [34] pool their resources (e.g. medical supplies) in cooperative healthcare networks and choose the best configuration for the logistic cooperative scheme which minimizes the total costs while improving the responsiveness of the healthcare network. Baboli, Fondrevelle, Tavakkoli-Moghaddam and Mehrabi [7] find that it is more cost-effective to use a centralized model, rather than a decentralized model, to determine the EOQ and the review period for products replenishment, when jointly optimizing the inventory and transportation costs. Iannone, Lambiase, Miranda, Riemma and Sarno [47] also propose a centralization of the hospitals' inventory decisions based on real-time patient information sharing among supply chain actors and they find cost and time savings in comparison with the decentralized system. As an alternative, the replenishment activities can be outsourced resulting in direct deliveries to point-of-use locations by suppliers (e.g. stockless or just-in-time inventory systems) [12]. Rivard-Royer et al. [75] adopt a hybrid version of the stockless system in order to reduce hospital inventory and hospital resources devoted to inventory management and supply distribution.

The supply department also has to make scheduling decisions related to inventory (e.g. how often and when should each medical care unit be visited). Lapierre and Ruiz [56] develop a scheduling approach, rather than an inventory-oriented approach, for improving hospital logistics by coordinating the distribution activities while respecting inventory capacities. By adding a secondary objective of workload balancing to the supply model, they can produce schedules to decide at what time each care unit will be visited and which products will be delivered, as well as decide for employee management (e.g. work shift, task assignment). The schedules are evaluated on three criteria: the carrying costs, the uniformness of the workload distribution, and the required amount of worktime. The hospital logistics team controls the materials flow (e.g. linen, pharmaceuticals, surgical supplies, medical instruments, etc.) and performs activities associated with storage, transportation and disposal of supplies. The delivery frequency is important to hospital material managers as it influences the effort needed for material management activities. They should simplify or standardize the flows of materials, control the inventory and ensure safety and availability of medical supplies [53,80]. At point-of-care locations, automated dispensing machines (ADM), based on a hybrid inventory system, can be implemented to store and deliver pharmaceuticals. This system reduces the time spent by nurses to manage supplies, reduces dispensing errors (e.g. wrong dose, wrong product, non-dispensing), simplifies the dispensing process, increases material traceability, increases personnel satisfaction, etc. ([30]; Rosales et al., 2015 [78]).

Healthcare delivery processes often include unnecessary steps that do not contribute to serve the patient needs and may cause additional costs and risks of mistakes [68]. Taiichi Ohno identified seven types of non-value added activities or wastes which are to be eliminated to help achieve savings in costs and improve the workflow. One concept of lean management that supports the goals of high-quality patient care, easy and timely access, lowest cost, etc. involves level loading the work by redistributing workload or by optimizing the work itself. Standardized delivery processes will make the system more reliable and offer great opportunities to reduce waste. In addition, a continuous flow by using a reliable demand-pull system rather than a supply-push system, optimizes the logistics flow as it provides supplies based on customer demand [76].

Sarno [82] proposes a new holistic approach to the hospital material management by integrating the logistical and the clinical perspectives. By means of the material requirements planning (MRP) method, medical information is retrieved to pull medical unit replenishments and pharmacy orders with suppliers. This will result in a more frequent delivery schedule, exploiting the advantages of a central stock while assuring a high service level to patients. A streamlined hospital material management process (e.g. patient management, medical unit inventory management, centralized management) might lead to reduced costs (ordering, purchasing, warehousing, handling, transportation, distribution, stock-out costs), reduced stock points at patient care locations, improved efficiency, materials traceability, information sharing, and increased patient safety, while simplifying the activities accomplishment by hospital personnel. Pinna, Carrus and Marras [72] propose to standardize the logistics procedures related to supply, storage and distribution of medical supplies by improving the effectiveness, efficiency and safety through centralization of the common logistics activities. This centralized supply system will lower costs and inventory due to more frequent deliveries, reduce staff in terms of amount of work of both hospital pharmacies and patient care staff, and provide a higher service level.

3.2. Performance measurement of distribution system

By streamlining the supply chain, the costs of internal distribution can be reduced. Effective inventory control lowers the cost of internal distribution by improving inventory turnovers and hence, it reduces time and labor associated with inventory management (e.g. ordering, handling stock-outs, etc.) [16]. Little and Coughlan [61] propose to expand their inventory model to incorporate delivery resources and routing information to combine logistics and inventory decisions. Furthermore, the hospital delivery systems play a key role in the outcomes of patient care services [82]. Variables such as transportation costs, resources, the capacity restriction in warehouses determining the maximum quantity of supplies stored, and the lay-out of the hospital which influences the transportation time to reach the point-of-care locations, are taken into account when searching for optimized transportation or routing solutions. Typically, distribution problems aim at determining the routing, the number and type of carriers, and the working schedules of the transporters [30].

The performance of the internal hospital distribution activities can be evaluated on several factors, such as on-time delivery of supplies, response time to urgent requests, errors, waste, satisfaction of patient and personnel, streamlined organization, etc. [63]. The Supply Chain Operation Reference (SCOR) model addresses, improves and communicates SCM activities within and between all involved stakeholders [59]. It can be used to define the current logistics processes, get benchmarks or best-practices and define performance measures. Di Martinelly [30] apply the Porter-SCOR modeling approach to the hospital supply chain and define reliability, responsiveness, flexibility, costs and assets as five types of performance indicators. Rossetti and Selandari [79] use the AHP model to formulate the hospital delivery system and select three groups of performance indicators – technical, economic and qualitative – related to the distribution process to decide on the replacement of a human-based delivery system by mobile robots to distribute pharmaceuticals. Table 2 shows an overview of indicators identified in literature to measure the performance of distribution activities.

Recently, the pharmaceutical industry is turning their focus to supply chain optimization in order to deliver added value, rather than only focusing on drugs development [84]. The hospital pharmacy activities are highly intertwined with the primary patient care activity and it is important to have a perfect coordination between these two flows [30]. Pharmaceutical SCM is faced with

Please cite this article as: K. Moons et al., Measuring the logistics performance of internal hospital supply chains – a literature study, Omega (2018), https://doi.org/10.1016/j.omega.2018.01.007

uncertain demand patterns and short life cycles of drugs. The organization of the internal transportation for pharmaceuticals in a hospital is complex, as different types of pharmaceuticals need to be delivered from different storage areas to various point-of-use locations, and different actors (e.g. warehouse employees, nurses, etc.) are involved [57]. The internal transportation system can be quantified by incorporating the hospital lay-out and corresponding distances, flow dimensions such as time and quantity, and resources (e.g. case carts and personnel along with their associated costs). Typical problems in the transportation system involve inflexibility, communication and time management issues and distribution inefficiencies, such as inefficient routing, long walking distances, excess transportation movements, elevator problems, etc. The performance of the distribution activities can be evaluated based on several criteria, such as cost, ergonomics for personnel, lead time, reliability of timely and correct deliveries, traceability of supplies, walking distances, etc. Hassan, Baboli, Guinet, Leboucher and Brandon [42] aim at high accessibility to the stored products, improvement of working conditions, reduction in preparation time and errors, etc. when reorganizing the pharmaceutical supply chain downstream. They evaluate the performance of the internal flow of pharmaceuticals products to care units by measuring the delivery performance, order fulfillment, lead time, supply chain response time, inventory days of supply, storage costs, distance covered, etc. [6]. An optimized pharmaceutical supply chain will result in decreased stock-out rates, reduced picking time, reduced storage costs and traceability of pharmaceuticals. Sarno [82] considers the logistics costs related to pharmacy management policies in terms of personnel and physical resources (transportation resources, inventory costs). The number and type of logistics resources depend on the frequency and quantity of transports from the pharmacy to point-of-use locations, characteristics of material handling equipment, etc. Personnel shift scheduling also influences internal transport frequency. Augusto and Xie [5] develop a supply and transportation planning in order to balance workloads for both pharmacy assistants and transporters, while respecting the availability constraint of having a mobile medicine closet at each medical unit. The supply planning determines the refilling of medicine closets at the central pharmacy based on the number of assistants available and the average time needed for inventory checking and refill, whereas the transportation planning is similar to a classical vehicle routing problem in which the number of pick-up routes for transporters are minimized. Banerjea–Brodeur, Cordeau, Laporte and Lasry [9] model the linen distribution as a periodic vehicle routing problem to determine the routing and frequency of linen delivery to care units by respecting the constraints of carts sizes and linen availability. Augusto and Xie [5] recommend reorganizing the medication classification (e.g. alphabetically in shelves, by medical family, etc.) in order to reduce the moves by the assistants during the supply process, and to decrease inventory checking times by adopting an automated inventory management system.

Lanckzweirt and Gemmel [53] present some methods to manage the materials flow in the operating theatre. As discussed above, inventory control can reduce inventory costs as well as handling costs. Second, standardization reduces the movements of materials to the point-of-care locations, decreases picking time and improves picking accuracy. Furthermore, CPTs combine procedure-specific, disposable medical supplies into a single sterile package, which leads to reduced inventory costs, fewer number of suppliers, improved efficiency of the materials flow and time savings. Finally, case cart systems are an efficient and organized method of supply distribution for the operating theatre. The physical constraints of the health facility determine the routing of the carts, as well as the type, size and number of carts in order to meet demand at peak capacity [63]. Benefits of such a case cart system include time savings, reduced travel distances, improved material flow, more standardized practices, better tracking of materials, reduced costs, improved care for patients, etc. [11].

4. Multi-criteria decision-making

Transferring knowledge or logistics concepts used in manufacturing or retail industry to a healthcare setting is complex because of the availability constraint of medical supplies, the different stakeholders involved with conflicting objectives, the fragmented logistics responsibility among several departments with coordination and integration problems, etc. [18,26]. Van Houdenhoven, Wullink, Hans and Kazemier [92] suggest a planning and control framework for a hospital setting which provides a common language for all stakeholders. They highlight the interaction between the different management areas (e.g. medical, resource capacity, material and financial planning) and the hierarchical levels of control (strategic, tactical, operational offline and operational online control). Since the hospital can be modeled as a complex system, policies and decisions at each level are needed to ensure supply availability while at the same time costs can be reduced. The four main stakeholders in the healthcare environment include medical staff, materials management staff, department managers and patients [61]. The existence of conflicting interests and power relationships among the stakeholders result in a multi-dimensional character of the inventory and internal distribution system in healthcare operations. Although the medical-oriented objectives (e.g. having medicines stored locally at care units, fast and reliable delivery, no stock-outs, etc.) seem to dominate the logistical objectives (e.g. minimize inventory costs, optimize trade-off between delivery and efficiency, avoid obsolete items, etc.), the interrelationship between patient care processes and the process of storing and distributing medical supplies from hospital storerooms to point-of-care locations significantly influences the outcomes of the inventory and internal distribution systems [26].

It is a difficult task to determine the contribution of supply chain activities to the cost and performance of the healthcare delivery system [66]. The different expectations and perceptions of the stakeholders complicate the performance definition in the healthcare sector. The performance indicators reflect the conflicting hospital objectives depending on the different stakeholders' perspectives [30]. This paper addresses the research question of identifying a list of performance indicators, used in literature, that can optimize the internal flow of logistics processes in the operating theatre. Sections 2.3 and 3.2 comprise the elements categorized under four objectives of quality, time, financial and productivity. In order to achieve consensus on which indicators are most important for measuring performance, input from all stakeholders is required to evaluate medical supplies for safety, function, clinical value to patients, cost-effectiveness, ease-of-use, necessity, etc. [43]. Di Martinelly [30] builds a knowledge model based on the ASDI – Analyze, Specification, Design, Implementation – methodology to assess the hospital supply chain, enriched with value and performance modeling to account for the different stakeholders' perspectives. The author proposes to reengineer the hospital supply chain by using an adapted value modeling and performance definition based on Porter's value chain model and the balanced scorecard (BSC) framework. The BSC model is a performance evaluation approach for decision problems which involve multiple criteria. It incorporates both financial and non-financial indicators from different perspectives (e.g. internal learning and growth, business processes, customer satisfaction, etc.) and allows for causal relationships between the indicators to evaluate and improve the supply chain performance [23,52]. Multi-criteria decision-making (MCDM) can be applied as a quantitative approach to assess a

Please cite this article as: K. Moons et al., Measuring the logistics performance of internal hospital supply chains – a literature study, Omega (2018), https://doi.org/10.1016/j.omega.2018.01.007

number of alternatives on multiple criteria in order to find the best choice. Relative weights are assigned to the criteria in order to represent their importance as a quantitative measure and to prioritize the indicators by using the Analytical Hierarchy Process (AHP) or the extended Analytical Network Process (ANP) method [49,81,91]. AHP/ANP is a popular method for solving MCDM problems in various industries, such as maintenance. Transferring this concept to the healthcare sector may help measuring the performance of the internal supply chain processes in a hospital. Rossetti and Selandari [79] perform a multi-objective analysis to improve the performance of hospital delivery systems. They use the AHP model to evaluate the replacement of a human-based delivery system by automation alternatives by selecting a set of performance measures, including the economic, technical and qualitative indicators. Hoeur and Kritchanchai [44] develop a framework to quantitatively measure healthcare logistics activities' effectiveness and efficiency, and they use the ANP model to determine interrelationships between and to prioritize the performance indicators. They identify inventory management and information and technology management to be the most critical components in healthcare logistics. However, they did not take into account the internal distribution processes within the hospital. Supeekit et al. [86] employ a combination of DEMATEL (i.e. Decision Making Trial and Evaluation Laboratory) and ANP to observe interrelationships between performance groups (i.e. patient safety, clinical care process efficiency and supporting process efficiency) by describing the causal relationships among the criteria and to determine relative weights of performance aspects. This way, the most important aspects of hospital supply chain performance can be derived in order to enhance performance improvement. Kucukaltan et al. [52] propose a decision support model for the identification and prioritization of key performance indicators in the logistics industry by considering various stakeholders. They use a combination of stakeholder-informed BSC and ANP method to identify, categorize into four perspectives (financial, internal process, stakeholders, learning and growth), and prioritize the performance indicators.

In the healthcare context, MCDM is a useful approach because it takes multiple, often conflicting, quantitative and qualitative criteria into account in order to make justifiable decisions [57]. However, a biased attitude of the decision maker results in subjectivity when identifying the alternatives, criteria and their weights. Group decision-making methods like consensus may be used to avoid this. Moreover, the ANP method allows for an inconsistency ratio of less than 10% in the pairwise comparisons [44].

5. Conclusion

The literature study above is situated in the domain of supply chain management in healthcare, and more specifically at the internal hospital supply chain in the operating room environment. The internal supply chain is unique and differs from other industries. Interaction between clinical, material and information flows is essential for improving operational performance of the logistics processes and to obtain an integrated supply chain. Although patient care is the primary concern in hospitals, logistics-related activities are critical in ensuring safety, availability and affordability of supplies. The right supplies should be delivered in the right condition to the right patients at the right time. The operational functioning of the internal supply chain and the integration and coordination of the processes are vital to support patient care processes. Hospital materials management impacts clinical, financial and operational outcomes. With the supply costs accounting for as much as 40% of the average hospital operating budget, a well-defined supply chain strategy is needed to align the internal logistics processes and to efficiently control supply costs. In recent years, the costs associated with logistics activities, such as handling, storing and moving materials have increased and hidden stocks are held by clinical staff to avoid stock-outs [26]. Hospitals are forced to become operationally efficient in their operations. "Operational excellence is achieved through the use of best inventory management and distribution systems, combined with continuous supply chain process improvements and better integration with the patient care process" [55]. Integration and streamlining the supply chain is required to increase efficiency while guaranteeing high quality patient care. However, a lack of visibility of end-to-end performances of logistics processes, low product traceability, internal distribution problems, low ability to manage product utilization and a lack of data standardization make it challenging for logistics managers to achieve supply chain excellence [66]. Furthermore, a lack of coordination between several unit departments and little expertise in the operations research field complicate the efficient operation of healthcare logistics processes [62]. Coordination and integration between processes will positively contribute to the performance of the supply chain. Information technology and technological advances are essential tools to achieve an integrated supply chain [32].

This overview focuses on the elements that are determining an efficient and effective logistics flow within a hospital. It addresses the performance indicators (e.g. costs, time, inventory parameters, service level, criticality of items, etc.) identified from literature that impact the internal logistics flow in a hospital. Performance measurement is important to address inefficiencies in the logistics activities and it serves as a good input for decision makers in the healthcare supply chain. In hospitals, however, many parameters for inventory management are not up-to-date, which causes decreased performance of the internal supply chain. Several performance indicators are of interest to the different stakeholders when optimizing the inventory management and distribution activities. Therefore, MCDM techniques are useful to evaluate and combine these indicators while taking into account the stakeholders' preferences.

From the literature, it can be summarized there are several objectives and criteria for inventory and distribution management in hospitals. However, a methodological approach is missing for selecting relevant KPIs to measure the performance of the internal supply chain. Further research in this field will focus on the development of a general framework to measure the performance of the internal logistics flow in hospitals, and more specifically in the operating theatre, in terms of time and cost savings, etc. while guaranteeing a high service level to patients. In developing the framework, the AHP or ANP methodology can be used to simplify the complex multi-criteria decision problem by determining the relationship and prioritizing between the logistics performance indicators [44,91]. However, different performance indicators will be important depending on the hospitals' or stakeholders' preferences. The framework serves as a guideline when selecting relevant performance indicators aligned with the logistics and medical-oriented objectives. A case study in the operating room will be executed in order to illustrate and validate the performance measurement framework for inventory and distribution activities.

References

[1] Abukhousa E, Al-Jaroodi J, Lazarova-Molnar S, Mohamed N. Simulation and modeling efforts to support decision making in healthcare supply chain management. Sci World J 2014:10.
[2] Al-Qatawneh L, Hafeez K. Healthcare logistics cost optimization using a multi-criteria inventory classification. In: Proceedings of the 2011 International Conference on Industrial Engineering and Operations Management; 2011. p. 506–12.
[3] Amendolair D. Material management in the operating room. Infection Control Today; 2000. http://www.infectioncontroltoday.com/articles/2000/12/material-management-in-the-operating-room.aspx.

[4] Aronovich D, Tien M, Collins E, Sommerlatte A, Allain L. (2010). Measuring supply chain performance: guide to key performance indicators for public health managers. Arlington, Va.: USAID | DELIVER PROJECT, Task Order 1.
[5] Augusto V, Xie X. Redesigning pharmacy delivery processes of a health care complex. Health Care Manage Sci 2009;12:166–78.
[6] Baboli A, Hassan T, Guinet A, Leboucher G, Brandon MT. (2005). Modélisation de la chaîne logistique aval d'un établissement hospitalier par le modèle SCOR. 6e Congrès international de génie industriel – 7-10 juin 2005 – Besançon (France).
[7] Baboli A, Fondrevelle J, Tavakkoli-Moghaddam R, Mehrabi A. A replenishment policy based on joint optimization in a downstream pharmaceutical supply chain: centralized vs. decentralized replenishment. Int J Adv Manufact Technol 2011;57:367–78.
[8] Balcazar-Camacho DA, Lopez-Bello CA, Adarme-Jaimes W. Strategic guidelines for supply chain coordination in healthcare and a mathematical model as a proposed mechanism for the measurement of coordination effects. DYNA 2016;83(197):203–11.
[9] Banerjea-Brodeur M, Cordeau JF, Laporte G, Lasry A. Scheduling linen deliveries in a large hospital. J Oper Res Soc 1998;49(8):777–80.
[10] Beaulieu M, Quellette C, Bielen M, Costin M. Automating inventory management. Healthcare Purchasing News 2013;37(2):42–3.
[11] Bett K, Lawrence L, Van Oyen M, Claysen M, Duck M. Analysis of the instrument picking process in a case cart system at the university of Michigan hospital. University of Michigan Health System; 2010.
[12] Bijvank M, Vis E. Inventory control for point-of-use locations in hospitals. J Oper Res Soc 2012;63(4):497–510.
[13] Braglia M, Grassi A, Montanari R. Multi-attribute classification method for spare parts inventory management. J Quality Maint Eng 2004;10(1):55–65.
[14] Burns L, DeGraaf R, Danzon P, Kimberly J, Kissick W, Pauly M. The health care value chain: producers, purchasers and providers. NY: John Wiley; 2002.
[15] Camp M, Pfister J, Reeves D, Kneedler J. Effective operating room inventory management. Pfiedler Enterprises; 2014. p. 1–26.
[16] Cardinal health. (2012). Managing supplies in an operating room environment.
[17] Cardinal health. (2015). 10 barriers to effective inventory management.
[18] Carrus PP, Marras F, Pinna R. The performance measurement of changes in the logistics of health goods: a theoretical model. In: 18th Toulon-Verona International Conference; 2015. p. 85–100.
[19] Chandra C, Kachhal SK. Managing health care supply chain: trends, issues and solutions from a logistics perspective. In: Proceedings of the 16th annual society of health systems management engineering forum, Orlando; 2004.
[20] Chase RB, Jacobs FR. Operations and supply chain management. 13th ed. New York: McGraw-Hill; 2012.
[21] Chopra S, Meindl P. Supply chain management. Pearson Education; 2007.
[22] Coustasse A. Impact of Radio-Frequency Identification (RFID) Technologies on the Hospital Supply Chain: A Literature Review. Perspectives Health Inf Manage 2013:10.
[23] Curtright JW, Stolp-Smith SC, Edell ES. Strategic performance management: development of a performance measurement system at the Mayo Clinic. J Health Care Manage 2000;45(1):58-68.
[24] Danas K, Roudsari A, Ketikidis PH. The applicability of a multi-attribute classification framework in the healthcare industry. J Manufact Technol Manage 2006;17(6):772–85.
[25] Dellaert N, Van de Poel E. Global inventory control in an academic hospital. Int J Prod Econ 1996;46-47:277-284.
[26] De Vries J. The shaping of inventory systems in health services: A stakeholder analysis. Int J Prod Econ 2011;133(1):60–9.
[27] De Vries J, Huijsman R. Supply chain management in health services: an overview. Supply Chain Manage 2011;16(3):159–65.
[28] Dittmann JP. Best practices for managing cost in the healthcare supply chain. UPS; 2015. White paper.
[29] Dittmann JP. How to plan for supply chain success in the healthcare industry. UPS; 2015. White paper.
[30] Di Martinelly C. Proposition of a framework to reengineer and evaluate the hospital supply chain. Comput Sci, PhD, INSA de Lyon 2009:1–149.
[31] Dooley L. Make logistics the focus of your supply chain plan. Mater Manage Health Care 2009;18(5):26.
[32] Ebel T, George K, Larsen E, Neal E, Shah K, Shi D, ... Huijsman R. Supply chain management in health services: an overview. Supply Chain Manage 2011;16(3):159–65.
[33] Epstein RH, Dexter F. Economic analysis of linking operating room scheduling and hospital material management of information systems for just-in-time inventory control. Econ Health Syst Res 2000;91:337–43.
[34] Essoussi IE, Ladet P. Towards resource pooling in cooperative health care networks: case of medical supply centralization. Comput Industr Eng 2009:600–5.
[35] Fixler T, Wright J. Identification and use of operating room efficiency indicators: the problem of definition. Canadian J Surg 2012;56(4):224–7.
[36] Fong AJ, Smith M, Langerman A. Efficiency improvement in the operating room. J Surg Res 2016;204:371–83.
[37] Gebicki M, Mooney E, Chen S, Mazur LM. Evaluation of hospital medication inventory policies. Health Care Manage Sci 2014;17:215–29.
[38] Guerrero WJ, Yeung TG, Guéret C. Joint optimization of inventory policies on a multi-product multi-echelon pharmaceutical system with batching and ordering constraints. Euro J Oper Res 2013;231:98–108.
[39] Gupta R, Gupta K, Jain B, Garg R. ABC and VED analysis in medical stores inventory control. Medical J Armed Forces India 2007;63:325–7.
[40] Hall R. Handbook of health care system scheduling, 168. Springer International Series in Operations Research & Management Science; 2012.
[41] Hall BL, Campbell DA, Phillips LR, Hamilton BH. Evaluating individual surgeons based on total hospital costs: evidence for variation in both total costs and volatility of costs. J Am College of Surg 2006;202(4):565–76.
[42] Hassan T, Baboli A, Guinet A, Leboucher G, Brandon MT. Reorganizing the pharmaceutical supply chain downstream: implementation of a new pharmacy. IFAC Proceed Volumes 2006;39(3):727–32.
[43] Hoeksema J. Taking steps to control costs in the OR. AORN J 2011;64(6S):79–87.
[44] Hoeur S, Kritchanchai D. Key performance indicator framework for measuring healthcare logistics in ASEAN. Toward Sust Oper Supply Chain Logist Syst 2015:37–50.
[45] Hospitals & Health networks Strategic supply chain management. ProQuest Central 2011;41.
[46] Hostetler S. Comparing operating room inventory management models. IIE Annual Conference and Expo 2013; 2013.
[47] Iannone R, Lambiase A, Miranda S, Riemma S, Sarno D. Pulling drugs along the supply chain: centralization of hospitals' inventory. Int J Eng Bus Manage, Special Issue: Innovat Pharma Indust 2014:6–21.
[48] Jarett PG. Logistics in the health care industry. Int J Phys Distribut Logist Manage 1998;28(9/10):741–2.
[49] Jharkharia S, Shankar R. Selection of logistics service provider: an analytic network process (ANP) approach. Omega 2007;35(3):274–89.
[50] Kaczmarek D. Making a case for fully integrated case carts. Healthcare Purchasing News 2008.
[51] Kelle P, Woosley J, Schneider H. Pharmaceutical supply chain specifics and inventory solutions for a hospital case. Oper Res Health Care 2012;1(23):54–63.
[52] Kucukaltan B, Irani Z, Aktas E. A decision support model for identification and prioritization of key performance indicators in the logistics industry. Comput Human Behav 2016;65:346–58.
[53] Lanckzweirt J, Gemmel P. Een analyse van de materiaalstromen in het operatiekwartier. Masterproef universiteit Gent, Faculteit economie en bedrijfskunde 2010.
[54] Landry S, Beaulieu M. Logistique hospitalière: un remède aux maux du secteur de la santé? Groupe de recherche CHAINE 2000 rapport n° 01-01, ISSN: 1485-5496.
[55] Landry S, Beaulieu M. The challenges of hospital supply chain management, from central stores to nursing units. In: Handbook of Healthcare Operations Management: Methods and Applications. New York: Springer; 2013. p. 465–82.
[56] Lapierre SD, Ruiz AB. Scheduling logistic activities to improve hospital supply systems. Comput Oper Res 2007;34(3):624–41.
[57] Lebeer S, Koklu S. Analysis of the transportation system for pharmaceuticals in UZ Leuven Gasthuisberg Thesis. University of Leuven; 2009.
[58] Lee C, Kwon I, Severance C. Relationship between supply chain performance and degree of linkage among supplier, internal integration and customer. Supply Chain Manage 2007;12(6):444–52.
[59] Lenin K. Measuring supply chain performance in the healthcare industry. Sci J Bus Manage 2014;2(5):136–42.
[60] Lewis MO, Balaji S, Rai A. RFID-enabled capabilities and their impact on healthcare process performance. In: ICIS 2010 Proceedings; 2010.
[61] Little J, Coughlan B. Optimal inventory policy within hospital space constraints. Health Care Manage Sci 2008;11(2):177–83.
[62] Melo T. A note on challenges and opportunities for operations research in hospital logistics. Technical reports on Logistics of the Saarland Business school, 2; 2012. p. 1–13.
[63] Miller H. Making a case for case carts. Herman Miller Healthcare; 2009.
[64] Molenaers A, Baets H, Pintelon L, Waeyenbergh G. Critical classification of spare parts: a case study. Int J Prod Econ 2011;140:570–8.
[65] Moon S. Taking cost off supply shelf: healthcare turning to supply chain management techniques honed by retail, manufacturing to limit inventory, slash expenses. Modern Healthcare 2004;34(47).
[66] Nachtmann H, Pohl E. The state of healthcare logistics: cost and quality improvement opportunities. Center for Innovation in Healthcare Logistics, University of Arkansas; 2009.
[67] Neumann L. Streamlining the supply chain. Healthcare Financ Manage 2003;57(7):56–62.
[68] Nicholas JM. An integrated lean-methods approach to hospital facilities design. Hospital Topics 2012;90:47–55.
[69] Nicholson L, Vakharia AJ, Erenguc SS. Outsourcing inventory management decisions in healthcare: models and applications. Euro J Oper Res 2004;154:271–90.
[70] Park KW, Dickerson C. Can efficient supply management in the operating room save millions. Curr Opin Anaesthesiol 2009;22:242–8.
[71] Petrohoy G, Bleznak A, Toomey S. Value analysis: perioperative link in the supply chain. Poster presentation: AORN Congress; Philadelphia; 2011.
[72] Pinna R, Carrus PP, Marras F. Emerging trends in healthcare supply chain management – an Italian experience. In: Applications of Contemporary Management Approaches in Supply Chains; 2015. p. 117–37.
[73] Power D. Supply chain management integration and implementation: a literature review. Supply Chain Manage 2005;10(4):252–63.
[74] Prashant N. A systematic approach to optimization of inventory management functions. Hospital Mater Manage Q 1991;12(4):34–8.
[75] Rivard-Royer H, Landry S, Beaulieu M. Hybrid stockless : Lessons for health care supply chain integration. Int J Oper Prod Manage 2002;22(4):412–24.

Please cite this article as: K. Moons et al., Measuring the logistics performance of internal hospital supply chains – a literature study, Omega (2018), https://doi.org/10.1016/j.omega.2018.01.007

[76] Robinson ST, Kirsch JR. Lean strategies in the operating room. Anesthesiology clinics 2015;33:713–30.
[77] Rohleder TR, Cooke D, Rogers P, Egginton J. Coordinating health services: an operations management perspective. In: Denton BT, editor. Handbook of healthcare operations Management: methods and applications. New York: Springer; 2013. p. 421–45.
[78] Rosales CR, Magazine M, Rao U. The 2bin system for controlling medical supplies at point-of-use. Eur J Oper Res 2015;243:271–80.
[79] Rossetti MD, Selandari F. Multi-objective analysis of hospital delivery systems. Comput Industr Eng 2001;41:309–33.
[80] Rossetti M, Buyurgan N, Pohl E, Hall R. Medical supply logistics. Handbook of Healthcare System Scheduling 2012:245–80.
[81] Saaty TL, Vargas LG. Decision making with the analytic network process. economics, political, social and technological applications with benefits, opportunities, costs, and risks. Berlin: Springer; 2013.
[82] Sarno D. A holistic approach to hospital material management process reengineering by means of the MRP algorithm. Engineering and Economics of Innovation, PhD. University of Salerno; 2014.
[83] Scalise D. Building an efficient supply chain. Hosp Health Networks 2005;79:47–52.
[84] Shah N. Pharmaceutical supply chains: key issues and strategies for optimization. Comput Chem Eng 2004;28(6-7):929–41.
[85] Supeekit T, Somboonwiwat T, Kritchanchai D. Linking hospital supply chain processes and performance to identify key performance indicator. In: Industrial engineering, Management science and Applications 2015; 2015. p. 927–38.
[86] Supeekit T, Somboonwiwat T, Kritchanchai D. DEMATEL-modified ANP to evaluate internal hospital supply chain performance. Comput Industr Eng 2016;102:318–30.
[87] Tefen Management Consulting. Optimizing healthcare supply management http://www.qualitydigest.com/inside/health-care-article/optimizing-healthcare-supply-management.html.
[88] Toba S, Tomasine M, Yang YH. Supply chain management in hospital: a case study. California J Oper Manage 2008;6(1):49–55.
[89] Uthayakumar R, Priyan S. Pharmaceutical supply chain and inventory management strategies: Optimization for a pharmaceutical company and a hospital. Oper Res Health Care 2013;2(3):52–64.
[90] Van de Klundert J, Muls P, Schadd M. Optimizing sterilization logistics in hospitals. Health Care Manage Sci 2008;11:23–33.
[91] Van Horenbeek A, Pintelon L. Development of a maintenance performance measurement framework – using the analytic network process (ANP) for maintenance performance indicator selection. Omega 2014;42:33–46.
[92] Van Houdenhoven M, Wullink G, Hans EW, Kazemier G. A framework for hospital planning and control. Healthcare logistics: the art of balance, PhD; 2007.
[93] Vickery S, Jayaram K, Droge J, Calantone R. The effects of an integrative supply chain strategy on customer service and financial performance: an analysis of direct versus indirect relationships. J Oper Manage 2003;21(5):523–39.
[94] Vila-Parrish AR, Ivy JS. Managing supply critical to patient care: an introduction to hospital inventory management for pharmaceuticals. In: Denton BT, editor. Handbook of healthcare operations Management: methods and applications. New York: Springer; 2013. p. 447–63.
[95] Volland J, Fügener A, Schoenfelder J, Brunner JO. Material logistics in hospitals: a literature review. Omega 2016.
[96] Womack J, Miller D. Going lean in health care. Institute for Healthcare Improvement; 2005.
[97] World Health Organization. Health systems financing: the path to universal coverage. WHO; 2010.
[98] Yao W, Chu CH, Li Z. The use of RFID in healthcare: benefits and barriers. In: IEEE International Conference on RFID Technology and Applications; 2010. p. 128–34.

Please cite this article as: K. Moons et al., Measuring the logistics performance of internal hospital supply chains – a literature study, Omega (2018), https://doi.org/10.1016/j.omega.2018.01.007