
Centralised healthcare supply networks for efficient and sustainable drug management: an Italian case study

Daria Battini, Ilenia Zennaro and
Riccardo Aldrighetti

Department of Management and Engineering,
University of Padova,
Stradella San Nicola, 3, 36100, Vicenza, Italy
Email: daria.battini@unipd.it
Email: ilenia.zennaro@unipd.it
Email: riccardo.aldrighetti@phd.unipd.it

Fabio Sgarbossa*

Department of Mechanical and Industrial Engineering,
NTNU – Norwegian University of Science and Technology,
Valgrinda, SP Andersens, V 37031, Trondheim, Norway
Email: fabio.sgarbossa@ntnu.no
*Corresponding author

Abstract: This study aims at investigating the logistic performance of centralised healthcare supply chains and quantifies consequent benefits on the entire system sustainability. The focus is on drug inventory management and distribution inside a network of hospitals, re-designed and optimised by applying a hub and spoke perspective coupled with logistics outsourcing. An Italian HSC is analysed by a multi-method simulation modelling in order to understand the overall sustainability of the new integrated supply chain. The findings provide a comprehensive analysis of the total savings obtained: increased opportunity for healthcare professionals to focus on patient care, financial savings in terms of a reduction in annual public expenditure (–25.8%) and transportation emissions reduction inside cities (–32%). The paper suggests to managers and logisticians that more attention needs to be paid to measuring the actual sustainability of HSCs, suggesting new logistics improvements. The work is might be easily extendable to similar cases.

Keywords: healthcare supply chain; hospital materials; drugs management; efficiency; supply network; logistic centralisation; sustainability; discrete event simulation.

Reference to this paper should be made as follows: Battini, D., Zennaro, I., Aldrighetti, R. and Sgarbossa, F. (xxxx) ‘Centralised healthcare supply networks for efficient and sustainable drug management: an Italian case study’, *Int. J. Integrated Supply Management*, Vol. X, No. Y, pp.xxx–xxx.

Biographical notes: Daria Battini is a Full Professor of Industrial Logistics at the University of Padua, Italy and she is the Coordinator of the Doctoral Course in Mechatronics and Product Innovation Engineering. She investigates supply chain design and management, industrial system optimisation, manufacturing

system management for sustainability. She is author and co-author of about 100 publications in relevant international journals, about industrial logistics, material handling, materials management, supply chain. She is a member of the Editorial Review and Advisory Board of the *International Journal of Production Economics* and guest editors of several special issues in relevant international journals.

Ilenia Zennaro is an Assistant Professor and Researcher in the Department of Management and Engineering at the University of Padua. Her research interests include industrial and logistics systems design and management. In particular, she investigates the design of warehousing and assembly systems through the mathematical modelling of both economic and ergonomics aspects and industrial plants maintenance management. She is currently teaching in courses, lectures and workshops, at the University of Padua and in other Italian institutes. She is usually also involved in various practical interdisciplinary research projects with important Italian companies.

Riccardo Aldrighetti is a PhD student at the University of Padua in the Doctoral School of Mechatronics and Product Innovation Engineering with the curricula of Logistics and Industrial Plants. He earned a BSc and MSc in Management and Engineering. His research interests explore supply chain simulation and structure dynamics, with a particular emphasis on global supply network design with disruption consideration.

Fabio Sgarbossa is a Full Professor of Industrial Logistics at the Department of Mechanical and Industrial Engineering at NTNU, Norway from October 2018. He was an Associate Professor at the University of Padua, Italy, where he also received his PhD in Industrial Engineering in 2010. He is working within the Production Management Group at MTP and he is responsible of the Logistics 4.0 Lab at NTNU. He has been and he is involved in several European and National Projects. He is author and co-author of about 100 publications in relevant international journals, about industrial logistics, material handling, materials management, supply chain. He is a member of organising and scientific committees of several international conferences, and he served as guest editor of several special issues in relevant international journals.

1 Introduction

The sustainability topic in healthcare is of course an urgent paradigm in all the world and the need of sustainable, efficient, and resilient healthcare supply chains is still urgent (Battini et al., 2013; Varabyova and Müller, 2016; Aldrighetti et al., 2019a, 2019b). The third EU Health Programme (2014–2020) has set out priority areas for achieving an improvement of the European Healthcare System. It stresses the need to create innovative, efficient and sustainable health systems. It is well known that spending on healthcare normally increases with

- 1 the number of persons in the population
- 2 the proportion of elderly persons
- 3 the average income per person

4 the cost of healthcare services.

Thus, a growing economy with an ageing population will spend more on healthcare.

Several studies have already demonstrated how excess costs and waste within the healthcare supply chain are largely a result of inefficient and redundant processes (Brennan, 1998; Chandra, 2008; Battini et al., 2009; Lee et al., 2011; Azzi et al., 2013; Landry et al., 2016; Beaulieu et al., 2018; Aldrighetti et al., 2019b). Supply chain, in general, addresses three flows as physical product, information and financial flow; typically supply chain design is driven by the first one, as the requirements of the physical product with related constraints and opportunities. In the healthcare sector instead also the other two flows, information and financial ones, have a critical role in the supply network management (Singh et al., 2006). In order to achieve improved performance, the healthcare supply chain need to be significantly re-engineered, by improving and integrating supply chain management practices with the aim of achieving substantial savings and sustainability goals. It must be also recognised that there is no one single best practice that can be adopted by all healthcare organisations. It is up to each organisation to determine the most appropriate strategy and target areas for improvement, coping with the peculiar characteristics of the specific healthcare setting: i.e., the criticality of the services provided to customers, regulation-orientation versus efficiency-orientation, breadth of products and services purchased, the power of suppliers, and the supply network capillarity. Public healthcare organisations, that represent a significant part of OECD (2011) countries, have been involved in a series of innovative projects related to two key supply chain processes as purchasing and logistics (Lega et al., 2013). In particular, more than 30% of hospital annual costs are today linked to logistics activities, making logistics costs the second largest cost after personnel cost (Volland et al., 2017). Moreover, Kelle et al. (2012) estimate that 10% to 18% of hospitals' net revenues are spent on inventory costs. Compared to other sectors, material management and logistics have not been given high priority in hospital management; this is due to the complexity of the healthcare supply chains and their hospital principal goal as effective patients' treatment. Recent studies estimates that through efficient logistics management, around half of the logistics costs in hospitals can be eliminated (Beier, 1995).

Several international leading practices show that the implementation of integrated supply chain management approaches by public healthcare organisations would yield significant savings (i.e., the elimination of inefficient and redundant processes) and hence enabling better focus on the core business: the patient care mission. Public healthcare organisations tend to behave like 'individual companies' with their own pharmacies, purchasing offices and internal and external distribution systems (Pinna et al., 2015); as consequence, many transactions sent to different vendors and orders of large quantities of drugs from different departments generate a high inventory, transport and storage cost. Recently, some organisations are applying innovative transformations starting from the traditional healthcare supply chain management in order to achieve economic savings and sustainability goals; in fact they are looking to the centralisation of the healthcare network, that is the aggregation under a single organisational unit of all the business function involved in the overall process of drugs purchasing and logistics (Parker and DeLay, 2008; Pinna et al., 2014).

The present research provides the results of an in-depth case study of an Italian healthcare supply chain showing benefits, costs saving and CO2 emission reduction due

to the supply network centralisation and integration, by reducing redundant and individual practices of drugs' procurement. The case study is firstly analysed with a simulation model created by anyLogistix, a multimethod simulation tool for supply chain optimisation. Successively, an Emissions Analysis of drug transportation inside urban areas is performed in order to show impacts in terms CO2 emission reduction due to the new configuration of the healthcare network.

The paper is divided into six paragraphs: firstly a brief background is presented in Section 2; then in Section 3 the method used to analyse the case study is described. Section 4 and Section 5 describe respectively the economic sustainability and the environmental and social sustainability results. Finally key findings and managerial implications are presented in Section 6.

2 Background

The healthcare sector is in continuous evolution due to the increased competition, the demographic and economic growing, and the need to deliver health services in an efficient and effective way. Supply chain management in the healthcare sector hardly reach in adopting supply chain practices following an industrial approach (De Vries and Huijsman, 2011). In fact, this sector is characterised by unique features as the complexity of the technologies being used and the coexistence of multiple stakeholders. The application of supply chain management practices not only concern physical flows of medical materials as drugs, pharmaceuticals, medical devices and health aids but also the patients flows, and consequently building relationships, authorities allocations and responsibilities and organising interface processes (Hussain et al., 2018). Healthcare supply chain includes two main chains as the internal one (patients, hospital storages, etc.) and the external one (distributors, manufacturers, etc.); it combines activities of different nature as business activities and operations that integrate materials and services flows for healthcare (Rivard-Royer et al., 2002).

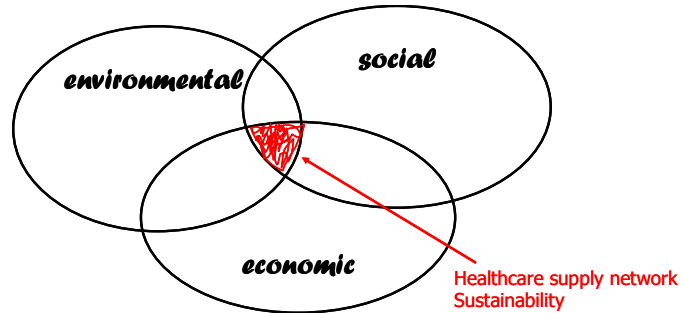
2.1 Sustainability issues in the healthcare sector

The large-scale literary review offered by Carter and Rogers (2008) demonstrates that organisational sustainability, at a broader level, consists of three components:

- 1 the natural environment
- 2 society
- 3 economic performance (see Figure 1).

The 'triple bottom line' allows an organisation to achieve long-term economic viability. Unfortunately, either too much emphasis is put on the economic aspects, with not enough focus placed on social and environmental concerns, or traditional social and environmental initiatives fail to address long-term economic impacts, including the effects on businesses and the availability of future funding sources. There are many kinds of sustainable development opportunities available depending upon the type of organisation. In this work, we are interested in sustainable healthcare supply chain development.

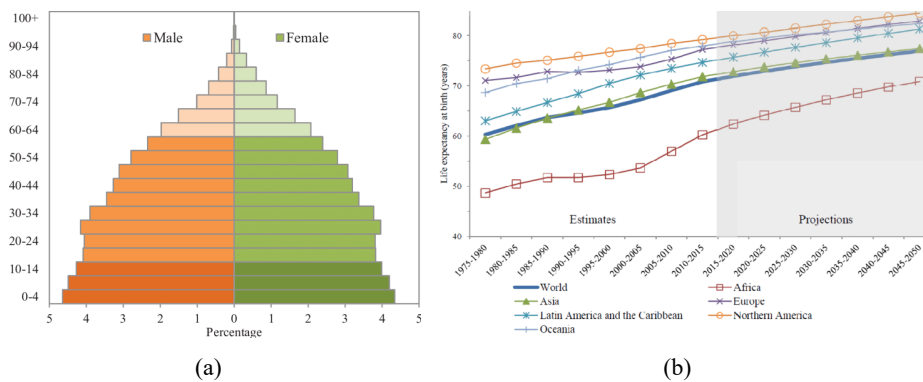
Figure 1 Traditional sustainable development: balance of social, environmental and economic ‘three pillars’ (see online version for colours)



‘Sustainability’ is a word widely used within healthcare. Many public documents underline the great importance of this topic in the face of challenges [i.e., European Commission 739 final (EC, COM, 2016)]. However, sustainability is widely seen as meaning the economic use of available resources. The urgency to also consider social and economic sustainability can be better understood by thinking about the demographic situation of occidental countries. According to the projections of the major international institutions, public health spending for the EU countries could increase between 40% and 60% by 2050, depending on the assumptions made.

The Statistical Office of the European Communities (Eurostat) estimates that by 2060, 30% of the population of the 27 EU countries will be over 65 years of age. This means that the ratio of productive individuals to retired people will be 2:1, versus the current ratio of 4:1. Moreover, from a comparative study of the expenditures per age bracket in various European countries, it is apparent how healthcare expenses increase exponentially as individuals grow older and the population in all the world is becoming older very fast (see Figure 2).

Figure 2 (a) Distribution of the world’s population by age and sex (b) Life expectancy at birth (years) by region (see online version for colours)



Source: United Nations, Department of Economic and Social Affairs, Population Division (2017)

Baskaran et al. (2009) point out how factors other than aging, such as technological advances and general economic growth, contribute to increased expenditure.

The need for healthcare to ensure a joined-up approach to economical, social and environmental sustainability has become a key driver. Traditionally, hospitals and healthcare organisations have paid surprisingly little attention to the relationship between hospitals and their impact on sustainable development (Ulhøi and Ulhøi, 2009). This has created a growing international interest in the efforts being made and the research being generated world-wide to develop more sustainable healthcare systems. Evidence of this growing interest is shown in the emergence of inter-organisational initiatives such as Healthcare Without Harm (<http://www.noharm.org>), Practice Greenhealth (<http://www.practicegreenhealth.org>), the Collaborative on Health and the Environment (<http://www.healthandenvironment.org>), the Green Guide for Healthcare (<http://www.gghc.org>), the ISDE, International Society of Doctors for the Environment (<http://www.isde.org>) and some national units, e.g. the English National Health Service's Sustainable Development Unit (<http://www.sdu.nhs.uk>). Evidence of this growing interest has been found also in the Baskaran et al. (2009) scientific study which for the first time approaches the problem of healthcare sustainability from a holistic point of view, proposing a theoretical framework.

Kjaer et al. (2015) carry out the increasing interest in sustainability of healthcare sector, as it presents an input-output analysis applied three hospital realities in Denmark to study the carbon footprint accounts. Moreover, to reach positive patient outcomes, healthcare facilities should move beyond the notion of merely treating disease towards prevention and wellness, which is a major component of social sustainability (Hussain et al., 2018). A health service is sustainable when operated through an organisational system that aims to meet individual and public health needs (Olsen, 1998). As the human element is involved at every stage of the process, social sustainability is part of the whole process. Finally supporting sustainability practices in the supply chain network requires a strong integration between hospitals and stakeholders; in particular integration should be focused not only on processes, but also on information flows, planning processes, inter-organisational processes, market approach and development (Rivard-Royer et al., 2002). Kotavaara et al. (2017) present a study about a centralised warehousing system, including the optimal location of the warehouse, the delivery network and routes and the accessibility of health centres and hospitals.

The present study, as a first step in a wider area of research, aims to explore the sustainability of a healthcare supply chain from a holistic point of view. To reach this purpose, we develop a healthcare supply chain simulation model applying system dynamics tools: we demonstrate how the aggregation of different healthcare structures and partners into a single centralised logistic network brings many benefits. As far as the authors know, this is the first time such a healthcare topic has been assessed from a holistic, sustainable point of view, providing both qualitative and quantitative results.

2.2 International leading practices in healthcare supply chain management

The ever-escalating pressures to simultaneously increase service efficiency and effectiveness while decreasing associated costs, largely explains the growing concern with healthcare network logistic modelling in countries such as the USA, Canada, the Netherlands and Spain. International leading practices demonstrate that one of the most important steps that hospitals can take to become more efficient and gain better control of costs is to stop thinking like 'hospitals' (Friesen, 2005; Baltaxe et al., 2008; Rossetti, 2008). Recent changes in international healthcare supply chains structure include:

centralised and/or outsourced control of logistics [to a third-party logistics provider like in El Mokrin et al. (2015), and Beaulieu et al. (2018)]; shared healthcare supply services (Abdallah et al., 2017); advanced electronic tools and automated processes implemented into key hospital supply chain functions (i.e., RFID technology, including requisitioning, ordering, invoicing, payment, contract management and reporting like in Bijvank and Vis (2012) and Rosales et al. (2015); materials inventory centralisation and distribution (Nicholson et al., 2004; Persona et al., 2008) and group purchasing organisations (Nollet and Beaulieu, 2003; Rego et al., 2014).

As discussed by Battini et al. (2013), Cagliano et al. (2016, 2017) and Iannone et al. (2014), “the leading approach is the adoption of a centralised healthcare logistic network in a ‘hub and spoke’ perspective, improving efficiency and effectiveness by scale and scope economies and achieving an integrated and collaborative structure pursuing service sharing, such as (1) purchasing, (2) service operation management (e.g., medical equipment maintenance) and (3) warehousing and distribution”.

Much has been written with regards to purchasing. Spending on healthcare materials procurement in the European Union (EU) has been estimated to be approximately €1,800 billion a year, which is about 16% of the EU’s GDP. However, this percentage varies from country to country; in Italy, for instance, it is about 12%. Many scientific contributions demonstrate the benefits of new centralised purchasing strategies (Nollet and Beaulieu, 2003; Mazzola and Perrone, 2009). Dal Bosco (2010) shows how collaborative purchasing provided consistent savings to the Veneto Region in Northern Italy (where the present research takes place), thanks to resource productivity increases and contractual empowerment. The adoption of competitive tendering returned a saving of €125,476,232 (26% of the estimated value) during a three-year period (2007, 2008, 2009).

The present case study focuses mainly on the third aspect (drug warehousing and distribution), since, with few exceptions (De Vries, 2010) it seems to be the one most lacking in proper study.

2.3 *Multimethod simulation modelling*

Discrete event simulation is a well-known and diffused instrument in supply chain network studies (Ivanov et al., 2019; Aldrighetti et al., 2019a). In the healthcare literature, simulation-based methods have been previously used to optimise patient paths inside hospitals, by solving queueing problems and optimising activity scheduling and job sequencing (Battini et al., 2013). Most business processes can be described as a sequence of separate, discrete, events. For example, a truck arrives at a warehouse, goes to an unloading gate, unloads, and then departs. To simulate this, discrete event simulation is often chosen. Also, system dynamics is a well-known technique for studying and solving complex problems, with a focus on policy analysis and design. The basic idea lays in trying to model a system and analyse its dynamic behaviour. Considering aggregated variables, it encourages both a systemic view of the resource interactions and information flows, and a more strategic perspective in system management. The methodology involves development of causal diagrams and policy-oriented computer simulation models that are unique to each problem. Thus it is applied in many sectors, such as supply chain design, reengineering and management (Hafeez et al., 1996; Reiner, 2005; Langroodi and Amiri, 2016; Ivanov, 2017a, 2018). Ivanov (2017b) proposed an interesting analysis of supply chain disruption management

using simulation, focusing on single vs. dual sourcing, considering demand and inventory patterns. System dynamics theory and modelling is well-suited to address the dynamic complexity that characterises many public health issues (Sterman, 2000; Homer and Hirsch, 2006; Diez Roux, 2011; Mielczarek and Uziółko-Mydlikowska, 2012; Pavlov et al., 2019) and coupled with a discrete event simulation approach by the software anyLogistix, it permits to consider the process of planning and monitoring healthcare from the perspective of the ‘whole system’ (Wolstenholme, 1993). In this work we applied to a real case the multi-method simulation approach offered by the Anylogic technology and in particular by the software anylogistix to seamlessly integrate different methods of modelling and simulation to overcome the drawbacks of individual approaches and get the most from each one. Combining different methods leads to efficient and manageable models without using workarounds (<http://www.anylogic.com>). In particular, a real network of 15 hospitals and supply chain partners has been modelled and analysed by anyLogistix as described in the following paragraph.

3 Methodology

In order to analyse how the healthcare supply chain achieve a sustainable development through its supply network centralisation, we adopted a single case study design enabling to capture into details the transformations operated by the supply chain. As previously underlined in the literature, a single case study design is an appropriate method under five main circumstances and five rationales (Yin, 2003):

- 1 the critical case to test a well-formulated theory
- 2 the extreme or unique case
- 3 the representative or typical case
- 4 the revelatory case when the “investigator has the opportunity to observe and analyse a phenomenon previously inaccessible to scientific investigation” even if the phenomenon under scrutiny is common;
- 5 the case carried out over a long period specifying how certain conditions change over time.

The present research corresponds to the fourth rationale above. The study has been carried out in 2010, in a period in which the sustainable management of hospital materials through a re-design of the supply chain structure was rather novel in Italy and considered strategic to obtain a transformational change of the national healthcare system. Moreover, the presence of similar case studies in published literature is minimal, due to the great difficulty to collect and analyse hospitals’ consumption data and obtain healthcare managers’ collaboration and trust.

The Italian National Health Service (INHS) was established in the late 1970s and modelled on the British NHS. In the 1990s, it underwent a major reform that introduced regionalisation. Legislative Decrees and several other legislative measures approved between 1997 and 2000, initiated and gradually enabled the regionalisation of the INHS, concentrating the powers of organisation and management of the healthcare services in the regions, and giving them the opportunity to implement quite divergent policies.

Due to the stress placed on cost reduction, a great deal of pressure was put on new healthcare supply chain modelling, in the perspective previously described. Thus, the regionalisation of the INHS has been both a decentralisation process from State to Regions and a centralisation process from municipalities to an intermediate level named after the 'Area Vasta' consortia, in a 'hub and spoke' perspective (centralising services and processes such as consumption analysis, market research, materials/services purchasing and management, assets distribution and resource planning). Following these concepts, Italian regions have recently been working towards the creation of new centralised supply chains with priority given to purchasing and logistics processes such as hospital materials handling (i.e., drugs), warehousing and distribution. Discussions about the optimum dimensions of such Area Vasta networks and the hospital clustering following economic, cultural and geographical criteria have already been provided in Battini et al. (2013). It was estimated that in Veneto (a north-eastern Italian region), municipal hospitals and other health structures linked and grouped in different clusters, would achieve a reduction from about 90 fragmented drug and medical supplies warehouses to only five centralised hubs, providing a saving of about €15 million per year (Assologistica Conference, Verona 2011).

The present study is focused on a specific healthcare network of hospitals located in Veneto region. This network has the following features that make it an appropriate case study for the present research:

- 1 it is a well-representative network, easily comparable with others Italian Area Vasta systems: 15 hospitals involved and a total amount of 3,400 beds.
- 2 the geographical distribution of the hospitals in the network reach an action distance of maximum 180 km, in accordance with other Italian consortia.
- 3 a consistent set of data related to historical drug consumptions inside hospitals' wards is available and a sufficient number of healthcare managers are available to collaborate in the right development of this study.

3.1 Input data

A series of one-to-one discussions and two main working groups with local healthcare stakeholders helped us to explore people's 'mental models' of the centralised healthcare network system, including anticipated system behaviour and anticipated impact on different parts of a hospital (Battini et al., 2013). The two working groups were made up by 7 and 8 pharmacy managers respectively, representing the 15 hospitals involved in this project, together with the healthcare managers of the local sanitary units (LSU) involved in the project. In a traditional healthcare supply chain, suppliers transport their products, through intermediate distributors, to each hospital warehouse (i.e., pharmacy or other structures). The hospital warehouse then receives the pallets, breaks them down into smaller quantities, and stores the products until they are needed by the hospital. In this traditional model there is a large amount of inventory in the system (which means a high cost in holding inventory and handling materials). Moreover, the absence of efficient and automated procedures leads to last-in first-out policies instead of a first-in first-out approach in materials consumption with consequently a large amount of out-of-date inventories stored in warehouses. In the newer network structure, a centralised warehouse system replaces the distributors and the need for hospital warehouses is eliminated.

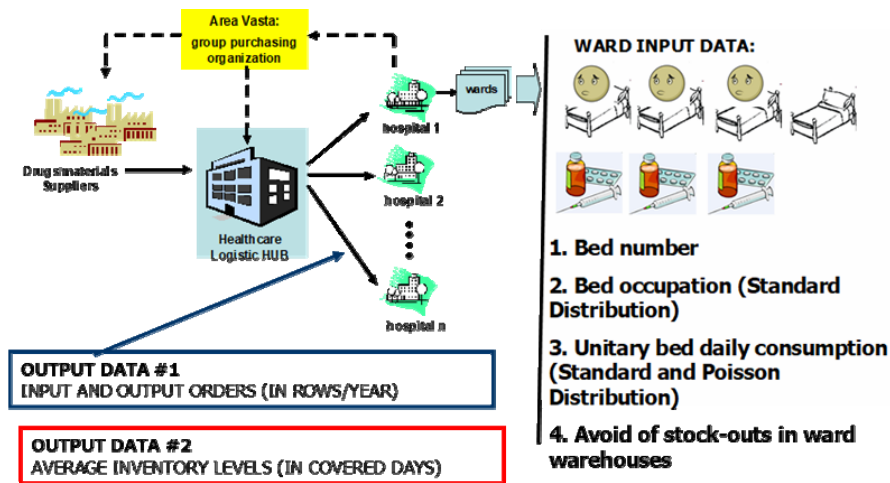
Suppliers transport directly to the hub, which is coordinated by the leading hospital of the consortium. It breaks down the shipments into smaller units and repackages, bar-codes and stores them. The materials are then transported (using pallets and different kinds of reusable stock keeping units) directly to the hospital, cross-docked at a pre-defined hospital transit point and immediately sent to wards.

The objectives of this work can be briefly summarised as follows:

- providing a dynamic simulation of the future system configuration from a logistic viewpoint
- identifying network requirements in terms of number of prepared orders per year, number of stored orders per year, materials and drug shortages, and average current inventory
- applying the network requirements data (which are the simulation outcomes) to estimate the total supply chain cost, and to quantify the economic sustainability and annual standard cost of the whole healthcare supply network.
- applying the same simulation outcomes, as second phase, to evaluate and discuss social and environmental sustainability issues linked with the new healthcare supply network.

Figure 3 shows in a qualitative way how the developed system dynamic model will seek to reflect the new centralised logistic system.

Figure 3 Logistic flow schema of the new centralised healthcare supply chain under study and input data used in the model at ward level (see online version for colours)



Whilst increased economies of scale provided by the Group Purchasing Organization bring greater reduction in the total annual public expenditure for product purchasing (medical materials, drugs, devices, supplies), there remains the need to properly assess total annual logistic costs and system sustainability at different levels of the supply network. This is therefore a key element in modelling the logistics of the centralised healthcare system by applying a multi-method simulation, an approach that seeks to represent the system schematically rather than precisely in order to provide an

approximation of the key elements of the future system and permit its comparison with the actual logistic system (called for simplicity the ‘traditional system’).

3.2 Model construction

The model created has been simulated in anyLogistix. The model is made-up of two sub-models: one representing the traditional healthcare supply chain (‘as is’ configuration), and one representing the future supply network with a centralised distribution hub (‘to be’ configuration). The two models refer to an Italian healthcare district, with three different LSU and one healthcare enterprise, accounting for a total of 15 different hospitals, 4 healthcare managerial structures and about 3,400 bed places. Both models contain a range of independent stochastic variables, dependent variables and feedback dynamics that capture the overall system behaviour and the logistic performance over time. Our research interest is in the supply chain’s actions regarding materials/drugs storage, consumption, handling and distribution from a set of suppliers to the future hub and then from the hub to each single hospital ward.

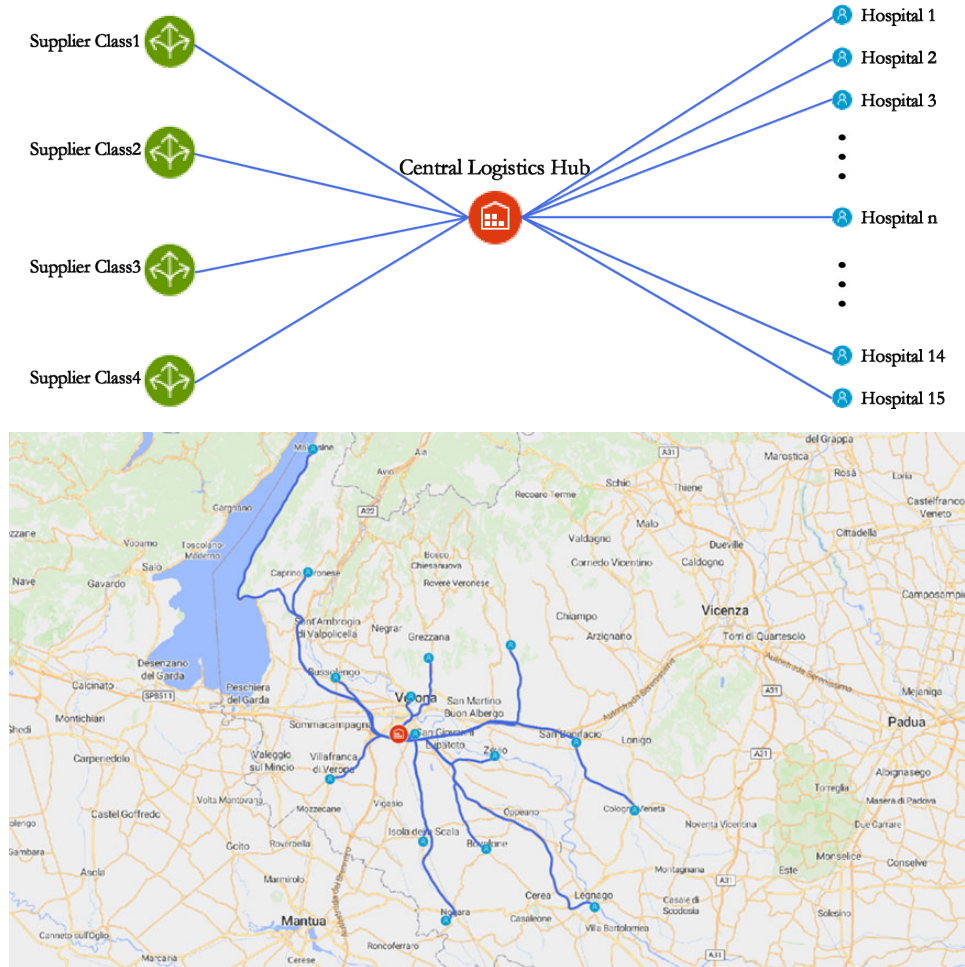
The main difference between the traditional model and the future one consists, in the first part, of the graphical scheme: in the traditional model the ‘supplier order process’ is completely decentralised and independent for each one of the 15 hospitals. In the same way also the pharmacy drug stocks (and their specific parameters, as safety stock and order levels) are managed independently. Conceptually, the traditional model is a set of 15 parallel inventory systems, one for each hospital. This is very straightforward by a modelling point of view and, for this reason, all the supply chain variables depicted in the traditional model are expressed as arrays into arrayed variables with several dimensions (in particular 15 different hospitals, each of them with a number of wards – between 22 to 30 wards). On the other hand, in the future centralised model the group of 15 hospitals with fluctuating drug demand associated to each hospital ward, banded together by buying, storing, and distributing their drug inventory jointly. Thus, in the future model, the first two entities (the ‘supplier order process’ and the ‘HUB inventory stock’) are shared by all the hospitals belonging to the network and for this reason they are simple and not arrayed variables. The other two entities (‘delivering process’ and ‘ward stocks’) are modelled as arrayed variables in both the models. Thus, it’s important to highlight that in the future model, all inventory parameters (levels of reorder, safety stocks, order quantities) are largely influenced by the correlation between the individual drug demands of hospitals’ wards.

The baseline scenario developed for the ‘traditional’ model aims to reflect the current situation of the healthcare system under study:

- the current rate of prepared orders, from hospital pharmacies to each hospital ward (i.e., 1,500,000 order rows per year)
- the current rate of incoming orders, from drugs/materials suppliers to pharmacies (i.e., 200,000 orders stored per year)
- existing bed numbers and average occupancy levels (the daily occupancy of beds in each ward deviates from the mean value with a percentage standard deviation)
- average inventory level in pharmacies’ warehouses (about 49 days of consumption)
- average inventory level in ward warehouses (about 28 days of consumption)

- percentage of materials orders managed with an OP-EOQ (order point and economic order quantity) inventory policy (about 80% of the items)
- percentage of materials orders managed with direct requests from wards to suppliers (about 20%).

Figure 4 The conceptual healthcare supply network model and the supply network simulated in anyLogistix (see online version for colours)



The future centralised healthcare network model develops a challenging set of assumptions due to the centralised logistic structure, as discussed before. The following criteria have been considered:

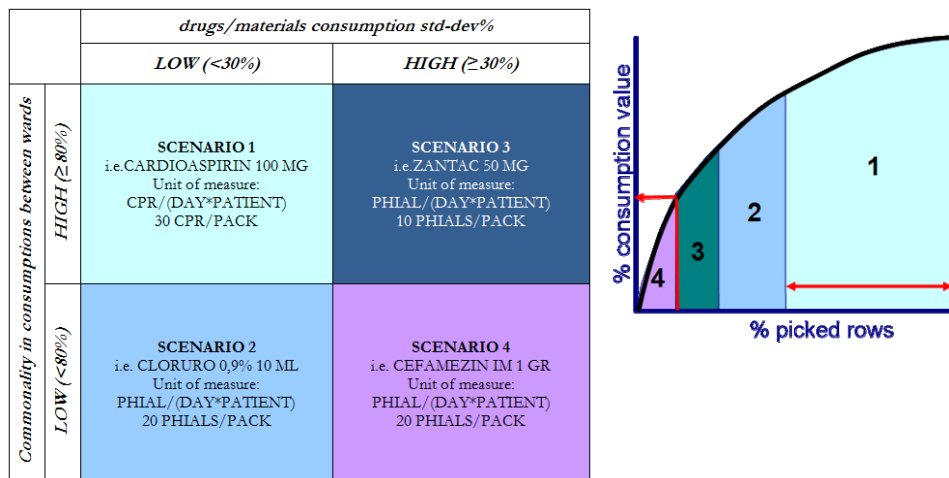
- The implications of drugs/materials daily transportation are modelled: euro-cargo deliveries from the logistic hub to hospitals are planned with four routine trips and milk runs involving between four and five different stops at different hospital. The hub is optimally located near the highway with a range of between 85 and 180 km per trip.

- Stochastic transportation lead times are considered and modelled, taking into account different delivery time windows and road traffic conditions.
- Drugs are shipped (using pallets and different kinds of reusable stock keeping units) from the hub directly to each hospital, cross-docked at a pre-defined hospital transit point inside or closed to the hospital pharmacy and sent to wards after a stochastic cross-docking time.
- The total avoidance of stock-outs in wards' warehouses is required to assure a patient service level of 99.9%.
- The drastic reduction in wards' stocks is quantified in the model and economies of scale at the hub level are estimated by a quantitative point of view.
- The handling lead times in each stage of the network are modelled with stochastic distribution.

3.3 Inventory control policy and inventory cost computation

The drugs/materials demand of ward beds reflects an average patient consumption during a period of six hours (the minimum time unit considered in the model) and four different demand scenarios have been simulated. Scenarios 1–4 reflect four kinds of demand pattern according to the cross matrix reported in Figure 5, in which variations in 'item demand standard deviation' and 'item demand commonality' inside the whole network of hospitals are considered (in other words we classified drugs according to their consumption variability and their diffusion into the healthcare network). As shown in the Pareto curve reported in Figure 5, drugs/materials with a uneven demand pattern and low diffusion (scenario 4) make up about 10% of materials orders and about 40% of total annual consumption value, while drugs/items with a regular consumption and a high diffusion (scenario 1) represent only 30% of total annual consumption value but cover about half of total material flows.

Figure 5 Four different demand scenarios coupled with four different supplier classes have been simulated in anyLogistix and their Pareto curve distribution is reported on the right (see online version for colours)



To define the inventory levels in each hospital ward, we model a (s,S) policy with Safety Stock also known as Min-Max policy with Safety Stock, as previously done also by Aldrighetti et al. 2019b. This type of policy assumes that both the time between orders and the order quantity are variable, where the latter varies between the order level S and the Re-Order Point (ROP) s. Thus, the parameters that need to be defined are the safety stock (SS), the minimum value of the inventory (s) and the maximum level (S):

$$SS = z \cdot \sigma \cdot \sqrt{LT} \quad (1)$$

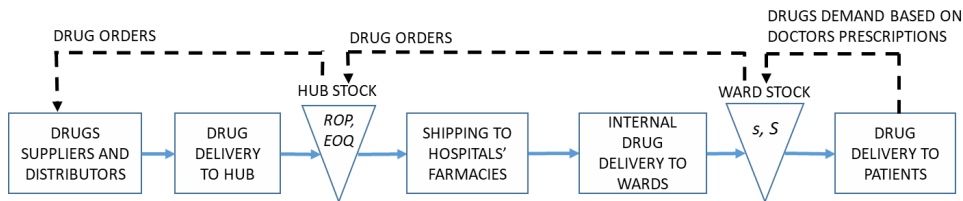
$$s = d \cdot (LT) + SS \quad (2)$$

$$S = 2 \cdot s \quad (3)$$

where z is the z -value obtained from the tables of the normal distribution, σ is the standard deviation of the demand, LT is the supply lead time and d is the demand. For calculating the inventory parameters, weekly consumption has been considered. Due to the nature of the supply chain, a service level equal to 99.9% has been set for all classes of products; thus, z is set equal to 3.5. Finally, the supply lead time has been set equal to 3 days for the central logistics hub to the hospital wards (this is a conservative assumption to be used in the first year of implementation) and to 1.5 days for the hospitals' warehouses in the traditional configuration. The value of s and S have been calculated in each of the four demand scenarios reported in Figure 5 and varies between a minimum of 5 stock cover days for level s to a maximum of 20 stock cover days for level S , according to the drug consumption behaviour and the demand standard deviation. Initial stock when the simulation starts has been set equal to the maximum value (S).

The suppliers are assumed to have enough capacity to always satisfy the demand and their inventory levels are modelled to be infinite. Inventory costs can be divided into ordering, carrying and shortage costs. The focus of this work is on carrying or holding costs, which represent the costs that emerge as a consequence of having an inventory. These costs are usually divided in capital, storage space, inventory services and inventory risks costs: they include the cost of the building, the facility maintenance (lighting, air conditioning, heating, etc.), purchasing, depreciation, or the lease, the property taxes, insurance, IT services, inventory control. According to Azzi et al. (2014), the average unitary holding cost rate of an item is equal or superior to 25% of the inventory value. In Figure 6, the flow chart of the drug flows and drug orders is reported for the new centralised healthcare supply chain configuration.

Figure 6 Drug flows and drug orders in the new centralised supply chain structure according to a (s, S) inventory control strategy inside wards and a (ROP, EOQ) strategy inside the logistic hub (see online version for colours)



3.4 Model outputs

On the basis of the four demand scenarios and planning assumptions described above, the model is able to indicate an approximation of the future logistic flows required between all the echelons of the centralised supply network in order to avoid stock-out risk at the ward level (that in the healthcare sector signifies an adverse event for patients). A final assumption built into the model is represented by changes in the inventory management and replenishment policies in respect of each different simulated demand scenario. The optimisation of the inventory policies adopted has an impact on the logistic performances of the centralised healthcare network model compared to the traditional one. Model outcomes are summarised in Table 1.

Table 1 Output data from the simulation model: the future scenario with logistic centralisation compared with the traditional decentralised scenario

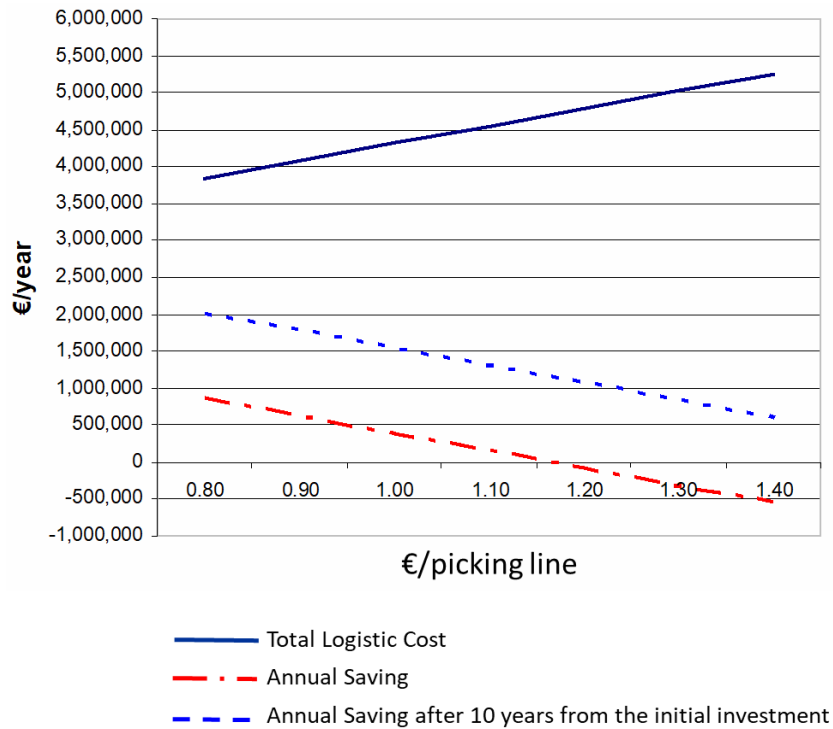
| | <i>AS IS scenario: decentralised supply network</i> | <i>TO BE scenario: centralised supply network</i> | <i>Difference</i> |
|--|---|---|-------------------|
| Outbound flow (picked handling units/year) | 1,424,566 | 2,435,665 | +71.0% |
| Inbound flow (putaway orders/year) | 171,232 | 27,675 | -83.8% |
| Average inventory level in pharmacies' warehouses compared with the new hub (stock cover days) | 48.3 | 23.8 | -50.7% |
| Average inventory level inside wards (stock cover days) | 32.5 | 16.2 | -50.2% |
| Mean inventory value on hand (€) | 18,254,045 | 9,467,243 | -48.1% |

4 Economic sustainability: results and discussion

Table 1 suggests a challenging future supply network that would require careful planning and cost control (difficulties arise due to the relevant increment in picking lines per year from the hub to the wards), and at the same time a drastic reduction in stock level and consequent floor space occupation inside hospital wards (-50.2%) and inside the new hub (-50.7% if compared with actual hospitals' pharmacy warehouses). Within the healthcare supply chain, material and logistic costs (inventory, picking, storing and distribution) are rising at a significant rate and may even comprise a large percentage of total annual healthcare public expenditure, leading, in other words, to social costs. This motivates the need for focused research on reducing inventory, distribution and shortage costs within the healthcare supply chain through a new and improved logistic structure. A reduction in total annual healthcare expenditure consequently improves the whole system sustainability from an economic point of view through public financial savings. Figure 6 below summarises the main results obtained from simulation that proposes the complete outsourcing of the control of logistic activities in the central hub to a service provider. The total annual logistic cost calculated in Figure 7 consider the sum of the storage space rental cost, inventory holding costs and the cost of the logistics activities performed by the service provider in accordance with the data reported in Azzi et al. (2013) and storage

cost parameters provided in Azzi et al. (2014) and plant maintenance cost parameters provided in Sgarbossa et al. (2018).

Figure 7 Total annual logistic cost of the new centralised healthcare network and forecasted savings over the traditional system when the hub management is out-sourced to a third party logistic provider (see online version for colours)



In Figure 7, the total annual logistic cost is calculated according to variation in the logistic provider quotation of the picked handling unit (also called €/picking line, Figure 7). As shown in the graph the annual saving with the new system configuration after an amortisation schedule of 10 years (for plant and equipment initial investments) is always positive and means a percentage saving between 10% and 33% over the traditional system cost. So, if we draw a line on the graph for a picking line rate of 1€ per row (which is currently considered by the healthcare management a really conservative one) we obtain a saving of 1,500,000 euro/year, that means a 25.8% of saving. Annual standard cost of the future network will be around 4 to 4.5 million euro per year.

In addition to these results, from an economic point of view, an important annual saving is also expected in terms of purchasing costs thanks to a Group Purchasing Strategy, and as demonstrated by Mazzola and Perrone (2009), it accounts on the 26% of saving.

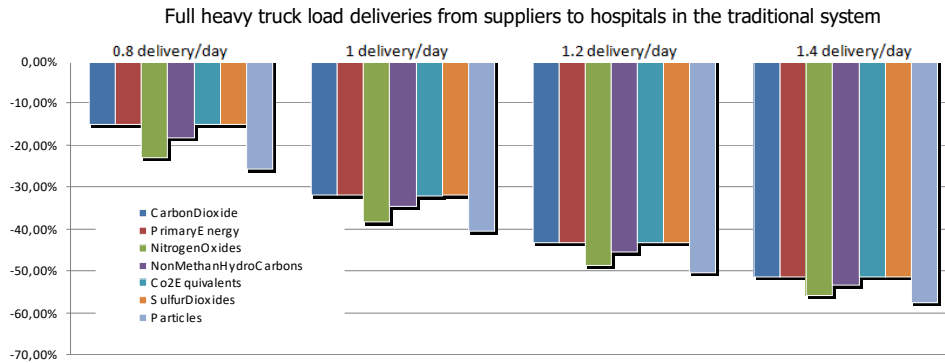
5 Environmental and social sustainability: results and discussion

A key strategic result, demonstrated in previous paragraphs, is that the new centralised supply network when coupled with outsourcing of hub logistic operations to a third-party supplier can achieve a competitive advantage in term of annual saving in the annual system expenditure. Anyway, other beneficial effects need to be considered and quantified in order to investigate the system sustainability.

Concerning the environmental impact of the new centralised healthcare network, we must recognise three main benefits:

- 1 The delocalisation of heavy truck load deliveries from hospital pharmacies (which are located inside the cities) to the new logistic hub plant (well-situated near main roads and far from urban districts). Only light forms of transport are used daily from the hub to the hospitals.
- 2 The reduction in drugs packaging consumption since reusable plastic stock-keeping units will be applied to transfer materials between hub and wards.
- 3 The reduction in out-of-date drugs waste thanks to a correct ‘first-in first-out’ drug consumption in the new central hub and advanced ICT equipment implementation.

In this case study, we provide a quantitative evaluation of point (1), by applying a life cycle assessment of the network transportation activity. The full explanation of the methodology is trivial to the purpose of this study and we cross-refer for a better comprehension of the methodology to a recent study in the field of transportation emissions computation (Harris et al., 2011). As pointed out by Piecyk and McKinnon (2010), hub and spoke systems typically have the effect of adding links to the supply chain and therefore generating additional tons-kms. In the industrial sector this problem could be resolved by applying haulage sharing in suppliers’ transportations (Andriolo et al., 2015). However it is worth underlining how industrial networks cannot be fully compared to healthcare networks since the capillary spread of hospitals in the urban fabric makes infrastructure critical when considering urban traffic and the need to reach every hospital with suppliers using heavy trucks full of drugs, paramedical materials and medical equipment. Thus, the question here is to understand how much transportation emissions will be reduced inside the urban district involved in this study after the implementation of the new system configuration. The positive environmental impact of changes in freight transport configuration and operation is here demonstrated by calculating the reduction in vehicle emissions using a well-known Life Cycle Assessment tool, the EcoTransIT software (<http://www.ecotransit.org>). The methodology embedded in the calculator follows the guidelines of the standard EN 16258 “Methodology for calculation and declaration of energy consumption and greenhouse gas emissions of transport services” and integrates latest research available for the air pollutants. Aggregate daily drug deliveries from the hub to hospitals with city trailers (max. 12 tons) instead several full heavy truck load deliveries from suppliers to each hospital warehouses are here considered. Interviews conducted by the authors with hospitals pharmacists estimate that one full heavy truck load arrives each day in each hospital of the Italian district analysed. Entering in Figure 8 with this value (1 delivery/day), the new centralised configuration of the network will lead to about 32% reduction in CO₂ emissions inside urban areas (as depicted in Figure 8).

Figure 8 Emissions reduction (%) in urban areas in the future centralised scenario when compared with the traditional system (see online version for colours)

Finally, from a social point of view the system sustainability evaluation is certainly more difficult, but required to fully complete this case study. The public healthcare annual expenditure is a fraction of social costs, in the form of direct costs for individuals. Thus, the annual saving in logistic costs computed for the new centralised network (and discussed in previous paragraph) might be a relevant quantitative measure of future social sustainability. Anyway, social costs also include other indirect costs linked with the new system configuration (e.g., the level of service perceived by the patient, quality and safety of drug administration to patients, the cost for the society of out-of-date drugs, etc.). It seems consensual, by analysing the literature (Colonna and McFaul, 2004; Kremic et al., 2006; Schneller and Smeltzer, 2006; Kumar et al., 2008; Roberts, 2011; Guimarães and Carvalho, 2011; Eroglu et al., 2017), that the new centralised logistic configuration coupled with the outsourcing of hub logistic operations, will benefit from more flexibility, access to world class expertise (the logistic provider managing the new hub) and increased focus on core activities (by reducing non-value adding activities for nurses and other healthcare professionals). These benefits will of course increase the social sustainability of the new system if compared with the traditional configuration. For instance, the increased opportunity for healthcare professionals to focus on patient care will lead to an increment in the patient service level. Moreover, the new centralised management of drug inventories will assure a seamless movement of information, a reductions in out-of-date drugs inventories together with the consequent reduction in Adverse Drugs Events; and more floor space being made available inside the hospitals. Moreover, the use of ergonomic and reusable plastic handling units between the hub and the hospital wards will permit to reduce the ergonomic work load for nurses inside the ward warehouse (i.e., Battini et al., 2018). Table 2 summarises both quantitative results obtained in the previous paragraphs (in particular numerical results reported in Figures 7 and 8) and qualitative considerations supported by the literature discussed in this paragraph. Data reported in Table 2 demonstrate that the new centralised healthcare logistic network will achieve a long-term sustainability in relation to the well-known triple bottom line.

Table 2 Quali-quantitative analysis of the future healthcare supply network sustainability

| <i>Healthcare logistic system improvements</i> | <i>1) Economic</i> | <i>2) Environmental</i> | <i>3) Social</i> |
|---|---|---|--|
| a Logistic cost reduction in the warehouse (hp: logistics outsourcing) | -25.8% | | ↓ public spending per capita |
| b Inventory level reduction | in wards: -50.2% in hub: -50.7% Elimination of intermediate stocks between the hub and hospital wards | ↓ floor space for inventories ↓ Co2 emissions for warehousing activities | ↑ floor space for new bed and equipment |
| c Urban transportation reduction | | -32% Co ₂ emissions | ↓ noise, congestion, traffic |
| d Materials purchasing costs reduction | -26% in total annual purchasing cost (Dal Bosco, 2010) | | ↓ public spending per capita |
| e Out-of-date drug inventory reduction | ↓ drug disposal costs | ↓ drug wasted | ↓ Adverse drug events |
| f Focus on healthcare professionals core competences rather than on logistic activities | ↓ labour costs for logistic operations ↓ non-value-added activities | | ↑ time spent by nurses at patient bedside ↑ patient service level |
| g Packaging consumption reduction | ↓ packaging waste disposal costs | ↓ packaging waste | ↓ ergonomic work load in hospital wards |

Note: Assuming a conservative order picking line cost rate of €1 charged by the logistic provider.

6 Key findings and managerial implications

Sustainability development is a crucial concept in healthcare sector management. A myopic approach needs to be avoided and economic, social and environmental aspects need to be explored in order to guarantee wellbeing together with fair and affordable healthcare services. This work is a first attempt to quantify the logistic challenges faced by the creation of new centralised healthcare supply networks in Italy. The case study proposed here demonstrates that the new centralised healthcare supply system will lead to consistent annual savings when compared with the traditional and fragmented logistic configuration. In addition, we demonstrate how the new centralised healthcare logistic network will achieve a long-term sustainability in relation to the well-known triple bottom line, applying a quali-quantitative approach. For these reasons, this case study seems to be first effort in the field.

Quantitative model outcomes of the case study provided here could be summarised as follows:

- A 50% reduction in drug inventory both in hospitals' wards and both in central warehouse.
- A 25.8% public expenditure annual saving over traditional system costs with a conservative cost rate of €1/picked handling unit (under the hypothesis to outsource the control of logistic activities in the hub to a service provider).
- Environmental impact reduction: 32% less CO2 emissions in urban areas thanks to a well-located logistic hub.

Despite the limits inevitable in a single case application, the results obtained in this study offer some insight into the future Italian healthcare policies aimed at centralising hospital materials purchasing and management. Every Area Vasta consortium in Italy, in fact, has similar characteristics (in terms of distances between hub and hospitals, order lines to handle, dimensions etc), and the results here reported can be easily extended to the whole country and to other similar situations. If sustainability considerations are to be used in Italy in the near future, the centralisation and integration of different healthcare structure in a few highly efficient supply networks will become of course competitive and beneficial by an economical (resulting in a reduction of 26% both in logistics and purchasing costs), environmental (32% less CO2 emissions in urban areas) and social point of view (i.e., reduction in public spending per capita and in adverse drugs events).

Future investigations are now required to define the best transition process between the current logistic system and the new one. The inclusion and quantification of out-of-date drugs/materials in the simulation model is also necessary.

References

- Abdallah, A.B., Abdullah, M.I. and Mahmoud Saleh, F.I. (2017) 'The effect of trust with suppliers on hospital supply chain performance: the mediating role of supplier integration', *Benchmarking: An International Journal*, Vol. 3, Vol. 24, No. 3, pp.694–715.
- Aldrighetti, R., Battini, D., Persona, A. and Zennaro, I. (2019a) 'State of the art on disruption cost evaluation methods in supply chain network design', *Proceedings of the Summer School Francesco Turco*, 11–13 September 2019.
- Aldrighetti, R., Zennaro, I., Finco, S. and Battini, D. (2019b) 'Healthcare supply chain simulation with disruption considerations: a case study from northern Italy', *Global Journal of Flexible Systems Management*, Vol. 20, pp.81–102, DOI: 10.1007/s40171-019-00223-8.
- Andriolo, A., Battini, D., Persona, A. and Sgarbossa, F. (2015) 'Haulage sharing approach to achieve sustainability in material purchasing: new method and numerical applications', *International Journal of Production Economics*, Vol. 164, Nos. 164, pp.308–318.
- Assologistica Conference (2009) *Libro Bianco per la logistica nella Sanità*, January, Verona.
- Azzi, A., Battini, D., Faccio, M., Persona, A. and Sgarbossa, F. (2014) 'Inventory holding costs measurement: a multi-case study', *International Journal of Logistics Management*, Vol. 25, No. 1, pp.109–132.
- Azzi, A., Persona, A., Sgarbossa, F. and Bonin, M. (2013) 'Drug inventory management and distribution: outsourcing logistics to third-party providers', *Strategic Outsourcing: An International Journal*, Vol. 6, No. 1, pp.48–64.
- Baltaxe, E., Cano, I., Herranz, C. et al. (2019) 'Evaluation of integrated care services in Catalonia: population-based and service-based real-life deployment protocols', *BMC Health Serv Res.*, 11 June, Vol. 19, No. 1, p.370, doi:10.1186/s12913-019-4174-2.

- Baskaran, V., Shah, B. and Tiessen, A.J. (2009) 'Canada's healthcare sustainability: a holistic perspective on emerging challenges', *2009 IEEE International Conference on Systems, Man and Cybernetics*, 11 October, pp.1453–1457.
- Battini, D., Calzavara, M., Persona, A., Sgarbossa, F., Visentin, V. and Zennaro, I. (2018) 'Integrating mocap system and immersive reality for efficient human-centred workstation design', *IFAC-PapersOnLine*, Vol. 51, No. 11, pp.188–193.
- Battini, D., Faccio, M., Persona, A. and Sgarbossa, F. (2009) 'Healthcare supply chain modelling: a conceptual framework', *Proceedings of POMS Conference*, Orlando.
- Battini, D., Faccio, M., Persona, A. and Sgarbossa, F. (2013) 'Modelling the growing process of integrated healthcare supply networks', *International Journal of System Dynamics Applications*, Vol. 2, No. 1, pp.1–13.
- Beaulieu, M., Roy, J. and Landry, S. (2018) 'Logistics outsourcing in the healthcare sector: Lessons from a Canadian experience', *Canadian Journal of Administrative Sciences/Revue Canadienne des Sciences de l'Administration*, Vol. 35, No. 4, pp.635–48.
- Beier, F.J. (1995) 'The management of the supply chain for hospital pharmacies: a focus on inventory management practices', *Journal of Business Logistics*, Vol. 16, No. 2, p.153.
- Bijvank, M. and Vis, I.F. (2012) 'Inventory control for point-of-use locations in hospitals', *Journal of the Operational Research Society*, Vol. 63, No. 4, pp.497–510.
- Brennan, C.D. (1998) 'Integrating the healthcare supply chain', *Healthcare Financial Management*, Vol. 52, No. 1, pp.31–34.
- Cagliano, A.C., Grimaldi, S. and Rafele, C. (2016) 'Paving the way for warehouse centralization in healthcare: a preliminary assessment approach', *American Journal of Applied Sciences*, Vol. 13, pp.490–500, DOI: 10.3844/ajassp.2016.490.500.
- Cagliano, A.C., Grimaldi, S., Rafele, C. and Torino, P.D. (2017) 'Assessing warehouse centralization and outsourcing in the healthcare sector: an Italian case study', *Proceeding of the XXII Summer School 'Francesco Turco'*, September.
- Carter, C.R. and Rogers, D.S. (2008) 'A framework of sustainable supply chain management: moving toward new theory', *International Journal of Physical Distribution & Logistics Management*, Vol. 38, No. 5, pp.360–387.
- Chandra, C. (2008) 'The case for healthcare supply chain management: insights from problem-solving approaches', *International Journal of Procurement Management*, Vol. 1, No. 3, pp.261–279.
- Colonna, J. and McFaul, W. (2004) 'Hospitals reconsider outsourcing key support and clinical departments', *Healthcare Strategic Management*, Vol. 22, No. 7, pp.11–14.
- Dal Bosco, F. (2010) *La razionalizzazione e la omogeneizzazione degli acquisti*, Centro Regionale Acquisti per la Sanità, Venice, Italy.
- De Vries, J. (2010) 'The shaping of inventory systems in health services: a stakeholder analysis', *International Journal of Production Economics*, doi:10.1016/j.ijpe.2009.10.029.
- De Vries, J. and Huijsman, R. (2011) 'Supply chain management in health services: an overview', *Supply Chain Management: An International Journal*, Vol. 16, No. 3, pp.159–65.
- Diez Roux, A.V. (2011) 'Complex systems thinking and current impasses in health disparities research', *American Journal of Public Health*, Vol. 101, No. 9, pp.1627–34.
- EC, COM (2016) *Next Steps for a Sustainable European Future*, 739 Final, EU Commission, Strasbourg.
- El Mokrini, A., El Mhamedi, A. and Berrado, A. (2015) 'A decision framework for outsourcing logistics in the pharmaceutical supply chain', in *2015 International Conference on Industrial Engineering and Systems Management (IESM)*, 21 October, pp.748–756.
- Eroglu, D.Y., Cagliano, A.C. and Rafele, C. (2017) 'A multi-capacity integrated vehicle routing and loading model for pickup milk run', *International Journal of Mechanics and Control*, Vol. 18, No. 2, pp.107–122.

- Friesen, S. (2005) *Rattling the Supply Chain: The Opportunity for Supply Chain Management in Healthcare*, 23 March, University of Waterloo Smarter Health Seminar Series, Waterloo, Canada.
- Guimarães, C. and Carvalho, J.C. (2011) 'Outsourcing in health care sector – a state of the art review', *Supply Chain Forum- An International Journal*, Vol. 12, No. 2, pp.140–148.
- Hafeez, K., Griffiths, M., Griffiths, J. and Naim, M.M. (1996) 'Systems design of a two-echelon steel industry supply chain', *International Journal of Production Economics*, Vol. 45, Nos. 1–3, pp.121–130.
- Harris, I., Naim, M., Palmer, A., Potter, A. and Mumford, C. (2011) 'Assessing the impact of cost optimization based on infrastructure modeling on CO² emissions', *Int. J. Production Economics*, Vol. 131, pp.313–321.
- Homer, J. and Hirsch, G. (2006) 'System dynamics modeling for public health: background and opportunities', *American Journal of Public Health*, Vol. 96, No. 3, pp.452–458.
- Hussain, M., Ajmal, M.M., Gunasekaran, A. and Khan, M. (2018) 'Exploration of social sustainability in healthcare supply chain', *Journal of Cleaner Production*, Vol. 203, pp.977–989.
- Iannone, R., Lambiase, A., Miranda, S., Riemma, S. and Sarno, D. (2014) 'Pulling drugs along the supply chain: centralization of hospitals' inventory', *International Journal of Engineering, Business Management*, DOI: 10.5772/58939.
- Ivanov, D. (2017a) 'Simulation-based ripple effect modelling in the supply chain', *International Journal of Production Research*, Vol. 55, No. 7, pp.2083–2101.
- Ivanov, D. (2017b) 'Simulation-based single vs dual sourcing analysis in the supply chain with consideration of capacity disruptions, Big Data and demand patterns', *International Journal of Integrated Supply Management*, Vol. 11, No. 1, pp.24–43.
- Ivanov, D. (2018) 'Revealing interfaces of supply chain resilience and sustainability: a simulation study', *International Journal of Production Research*, Vol. 56, No. 10, pp.3507–3523.
- Ivanov, D., Tsipoulanidis, A. and Schönberger, J. (2019) 'Global supply chain and operations management: a decision-oriented introduction into the creation of value', *Springer Nature*, 2nd ed., Cham., ISBN 978-3-319-94312-1.
- Kelle, P., Woosley, J. and Schneider, H. (2012) 'Pharmaceutical supply chain specifics and inventory solutions for a hospital case', *Operations Research for Health Care*, Vol. 1, No. 1, pp.54–63.
- Kjaer, L., Høst-Madsen, N., Schmidt, J. and McAloone, T. (2015) 'Application of environmental input-output analysis for corporate and product environmental footprints – learnings from three cases', *Sustainability*, Vol. 7, No. 9, pp.11438–61.
- Kotavaara, O., Pohjosenperä, T., Juga, J. and Rusanen, J. (2017) 'Accessibility in designing centralised warehousing: case of health care logistics in Northern Finland', *Applied Geography*, Vol. 84, pp.83–92.
- Kremic, T., Tuckel, O.I. and Rom, W.O. (2006) 'Outsourcing decision support: a survey of benefits, risks, and decision factors', *Supply Chain Management: An International Journal*, Vol. 11, No. 6, pp.467–482.
- Kumar, A., Ozdamar, L. and Zhang, C.N. (2008) 'Supply chain redesign in the healthcare industry of Singapore', *Supply Chain Management: An International Journal*, Vol. 13, No. 2, pp.95–103.
- Landry, S., Beaulieu, M. and Roy, J. (2016) 'Strategy deployment in healthcare services: a case study approach', *Technological Forecasting and Social Change*, Vol. 1, No. 113, pp.429–37.
- Langroodi, R.R. and Amiri, M. (2016) 'A system dynamics modeling approach for a multi-level, multi-product, multi-region supply chain under demand uncertainty', *Expert Systems with Application*, Vol. 51, pp.231–44.
- Lee, S.M., Lee, D. and Schniederjans, M.J. (2011) 'Supply chain innovation and organizational performance in the healthcare industry', *International Journal of Operations & Production Management*, October, Vol. 31, No. 11, pp.1193–214.

- Lega, F., Marsilio, M. and Villa, S. (2013) 'An evaluation framework for measuring supply chain performance in the public healthcare sector: evidence from the Italian NHS', *Production Planning & Control*, Vol. 24, Nos. 10–11, pp.931–47.
- Mazzola, E. and Perrone, G. (2009) 'A framework for public purchasing under a decentralized organization: an empirical study in the healthcare sector in Italy', *Proceedings of the 16th International Annual EurOMA Conference*, 14–17 June, Göteborg, Sweden.
- Mielczarek, B. and Uziako-Mydlikowska, J. (2012) 'Application of computer simulation modeling in the health care sector: a survey', *Simulation*, Vol. 88, No. 2, pp.197–216.
- Nicholson, L., Vakharia, A.J. and Erenguc, S.S. (2004) 'Outsourcing inventory management decisions in healthcare: models and application', *European Journal of Operational Research*, Vol. 154, pp.271–290.
- Nollet, J. and Beaulieu, M. (2003) 'The development of group purchasing: an empirical study in the healthcare sector', *Journal of Purchasing and Supply Management*, Vol. 9, No. 1, pp.3–10.
- OECD (2011) *Health Data* [online] <https://www.oecd-ilibrary.org/> (accessed October 2019).
- Olsen, I.T. (1998) 'Sustainability of health care: a framework for analysis', *Health Policy and Planning*, Vol. 13, No. 3, pp.287–295.
- Parker, J. and DeLay, D. (2008) 'The future of the healthcare supply chain: suppliers wield considerable power, but healthcare organizations can benefit from virtual centralization of the supply chain', *Healthcare Financial Management*, Vol. 62, No. 4, pp.66–70.
- Pavlov, A., Ivanov, D., Pavlov, D. and Slinko, A. (2019) 'Optimization of network redundancy and contingency planning in sustainable and resilient supply chain resource management under conditions of structural dynamics', *Annals of Operations Research*, <https://doi.org/10.1007/s10479-019-03182-6>.
- Persona, A., Battini, D. and Rafele, C. (2008) 'Hospital efficiency management: the just in time and Kanban technique', *International Journal of Healthcare Technology and Management*, Vol. 9, No. 4, pp.373–391.
- Piecyk, M.I. and McKinnon, A.C. (2010) 'Forecasting the carbon footprint of road freight transport in 2020', *International Journal of Production Economics*, Vol. 128, pp.31–42.
- Pinna, R., Carrus, P. and Marras, F. (2015) 'Emerging trends in healthcare supply chain management: an Italian experience', *Applications of Contemporary Management Approaches in Supply Chains*, pp.117–137, DOI: 10.5772/59748.
- Pinna, R., Carrus, P.P. and Marras, F. (2014) 'The drug logistics between efficiency and safety for patients: The experience of an Italian region', in *Liverpool (2014): 17th Toulon-Verona Conference 'Excellence in Services'*, 18 August.
- Rego, N., Claro, J. and de Sousa, J.P. (2014) 'A hybrid approach for integrated healthcare cooperative purchasing and supply chain configuration', *Health Care Management Science*, Vol. 17, No. 4, pp.303–20.
- Reiner, G. (2005) 'Customer-oriented improvement and evaluation of supply chain processes supported by simulation models', *International Journal of Production Economics*, Vol. 96, No. 3, pp.381–395.
- Rivard-Royer, H., Landry, S. and Beaulieu, M. (2002) 'Hybrid stockless: a case study: lessons for health-care supply chain integration', *International Journal of Operations & Production Management*, Vol. 22, No. 4, pp.412–24.
- Roberts, V. (2001) 'Managing strategic outsourcing in the healthcare industry', *Journal of Healthcare Management*, Vol. 46, No. 4, pp.239–49.
- Rosales, C.R., Magazine, M. and Rao, U. (2015) 'The 2B in system for controlling medical supplies at point-of-use', *European Journal of Operational Research*, Vol. 243, No. 1, pp.271–80.
- Rossetti, M.D. (2008) *Inventory Management Issues in Health Care Supply Chains* [online] http://cihl.uark.edu/Inventory_Management_Issues_in_Health_Care_Final.pdf (accessed 30 October 2009).

- Schneller, E.S. and Smeltzer, L.R. (2006) *Strategic Management of the Health Care Supply Chain*, Jossey-Bass, San Francisco.
- Sgarbossa, F., Zennaro, I., Florian, E. and Persona, A. (2018) 'Impacts of Weibull parameters estimation on preventive maintenance cost', *IFAC-PapersOnLine*, Vol. 51, No. 11, pp.508–513.
- Singh, M., Rice, J. and Riquier, D. (Eds.) (2006) *Transforming the Global Health Care Supply Chain*, MIT Center for Transportation and Logistics, Cambridge, MA.
- Sterman, J.D. (2000) *Business Dynamics: Systems Thinking and Modelling for a Complex World*, p.982, McGraw-Hill Higher Education.
- Ulhøi, J. and Ulhøi, B. (2009) 'Beyond climate focus and disciplinary myopia. The roles and responsibilities of hospitals and healthcare professionals', *International Journal of Environmental Research and Public Health*, Vol. 6, No. 3, pp.1204–14.
- United Nations, Department of Economic and Social Affairs, Population Division (2017) *World Population Ageing 2017(ST/ESA/SER.A/390)*.
- Varabyova, Y. and Müller, J-M. (2016) 'The efficiency of health care production in OECD countries: a systematic review and meta-analysis of cross-country comparisons', *Health Policy*, Vol. 120, pp.252–263.
- Volland, J., Fügener, A., Schoenfelder, J. and Brunner, J.O. (2017) 'Material logistics in hospitals: a literature review', *Omega*, Vol. 69, pp.82–101.
- Wolstenholme, E.F. (1993) 'A case study in community care using systems thinking', *Journal of the Operational Research Society*, Vol. 44, pp.925–934.
- Yin, R.K. (2003) *Case Study Research: Design and Methods*, 3rd ed., Sage, Thousand Oaks, CA.

Websites

- <http://www.ecotransit.org>
- http://www.ec.europa.eu/health/programme/policy/index_en.htm
- <http://www.gghc.org>
- <http://www.healthandenvironment.org>
- <http://www.isde.org>
- <http://www.noharm.org>
- <http://www.practicegreenhealth.org>
- <http://www.sdu.nhs.uk>
- <http://www.simplan.de/en/software-2/anylogistix/>