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Pulling Drugs Along the Supply Chain: Centralization of Hospitals' Inventory

Regular Paper

Raffaele Iannone[1], Alfredo Lambiase[1], Salvatore Miranda[1], Stefano Riemma[1]and Debora Sarno[1,*]

1 Department of Industrial Engineering, University of Salerno, Fisciano, Italy
* Corresponding author E-mail: desarno@unisa.it

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Abstract Due to the economic crisis and the predominance of drug expenditure in healthcare costs, the cooperation of groups of hospitals to negotiate with suppliers and centralize warehouses has been a recent trend in the pharmaceutical supply chain.
This paper shows the economic convenience of centralizing the hospitals' inventory decisions (how much/when to order) based on the sharing of medical prescriptions of patients along the supply chain.
The logistic network under investigation (TO BE model) integrates: a central pharmacy negotiating with suppliers, collecting hospital orders, storing and distributing materials; a number of hospitals feeding their medical units with materials; and a number of medical units taking care of their patients.
The study is carried out comparing the cost performances of the proposed model with a non-cooperative one(in which hospitals manage their stocks individually) by means of simulation.

Keywords Pharmaceutical SCM – Drug Inventory Management – GPO – Electronic Medical Records – Material Requirement Planning

1. Introduction

Drug expenditure accounts for more than a sixth of the health spending in OECD countries, second only to inpatient and outpatient care costs [1].

Furthermore, due to the economic crisis, countries and organizations are adopting demand-side and supply-side management measures to cope with the issue [2]. The first actions arefocused on prescribers and patients, mainly through introducing prescription guidelines, administrationmonitoring and patient co-payment; the supply-side measures include, for example, negotiation with suppliers, reference pricing, expenditure ceilings and pooled procurements, also by means of groups of purchasing organizations (GPOs).

Looking at the hospital supply chain, the huge impact of the logistic costs on the hospital's operating budget (around 35% according to [3]) has led many researchers to improve inventory control policies [4] and several structures belonging to the same geographical areahave resorted to shared services or third-party logistics (3PL) providers [3].

With regard to the drugs' information flow, many technological advances have been introduced (for example, collection of electronic prescriptions in the field of electronic medical records – EMR - or drug and medical device tracking for reduction of the risk of wrong administration [5]). Despite this,Vila-Parrish and Simmons [6] state that data provided by these innovations are often not exploited to obtain supply chain cost savings.

This paper aims at covering the gap found in the literature, proposing a new approach to hospital materials management (HMM), in which purchasing negotiation and inventory management are carried out integrating the supply chain by means of real-time patient information sharing.

The paper is organized as follows: in section 2, the literature review is analysed; section 3 deals with the description of the investigated logistic models; in section 4, the notation is reported; section 5 shows the cost function used as a performance measure for the logistic configurations; section 6 describes the case study; section 7 presents the design and analysis of experiments. The conclusions are drawn in section 8.

2. Literature review

New trends towards healthcare supply chain integration can be classified in three logistic strategies [7]:

- GPOs;
- partial/total centralization of medical supplies;
- outsourcing to a 3PL.

In the following, the three approaches and the level of information sharing they use at the state-of-the-art are discussed.

2.1 GPO

The advantages and disadvantages of GPO have been described [8]: the main advantages are price-quantity discount and other purchasing-related costs (transaction and administrative costs), focus on core activities and, in the public sector, prevention of corruption; the principal disadvantage is indicated as the coordination cost.

Rego et al. [8] proposed a method to find the least expensive GPO (in terms of number, size and composition of the group) for a set of hospitals willing to cooperate, starting from the assumption that there is no direct relationship between a larger size of GPO and lower prices.

As an example, the introduction of GPO allowed a saving of about 8% of the total purchasing cost in New Zealand [2].

2.2Partial/total centralization of medical supplies

Centralization of storage has been a topic of interest of logisticssince distribution networks began to be diffused, as a way to minimize the holding and penalty costs of inventory and shared supply chain risks [9].

Humbel and Tshudi in [7] reported the example of a group of Swiss hospitals that centralized purchasing and reception of merchandise, obtaining a saving of 5% of the cost of logistic activities.

Studies by Eppen [10] and, later, by Chen and Lin [11] demonstrated the statistical economies of scale achievable by means of inventory centralization. In particular, they showed the economic convenience in the case of normally distributed demand (the first author), or concave inventory cost functions (the second authors), adding that the saving depends on the correlation of demands. In the case of demands identically distributed and uncorrelated, Eppen [10] provedthat the total cost of the decentralized system is proportional to the number of warehouses while, in the centralized system, it is proportional to its square root.

Obviously, another research question in the centralization of inventories is the distribution policy, because it implies intensification of transportations.

In a multi-echelon inventory system, Baboli et al. [12] analysed the replenishment problem from a central warehouse to hospital pharmacies, incorporating the transportation cost in the inventory optimization problem. A distinction was made between decentralized and centralized replenishments: in the first case, companies tend to minimize their own costs, while in the second, the partners try to find a global optimum for the whole system. In conditions of constant demand rate and lead time and hindered shortage, the authors proposed a method to identify the best quantity and period of replenishment, taking into account warehousing costs and penalty costs for orders consigned in advance, in order to exploit the capacity of vehicles used for transportations.

Essoussi and Ladet [7]suggested a cooperative scheme for centralization of medical supplies, where the purchasing group was provided by a common logistical platform that performs the cross-docking of materials and a number of local depots, each one allocated to a cluster of hospitals. Then, in the case of a singleitem/single vendor problem, they developed a heuristic procedure to find the number and location of depots, the allocation of hospitals to each depot and the inventory policy to adopt in order to reduce shortages and outdating.

2.3 Outsourcing to a 3PL

The main reason to outsource healthcare inventory management is the expected increase in the service level that the new operator, thanks to its expertise, can provide to the system, together with the complete freeing of hospitals' facilities and staff from non-clinical activities, while many evaluation criteria can be used to choose the best supplier [13]. Nicholson et al. [14] investigated the savings obtainable in a single review period model of non-critical items (the minimum service level has to be 90 %) with zero lead times (including transportation times). The cost savings ranged from 2-3% of the total holding and penalty costs, and the higher echelon was able to provide a higher service level.

Another literature contribution to outsourcing is the "extended VMI" presented by Danese [15]. The vendor managed inventory (VMI) is an inventory management strategy in which suppliers decide the inventory level and the orders' quantities and timing on the basis of information communicated by customers, sometimes also retaining the financial responsibility of buyers [16]. Danese [15] reporteda case study of the adoption of the VMI in the upstream/downstream pharmaceutical supply network, from raw materials' suppliers to drugs' distribution centres. The downstream members shared data about sales forecast and inventory levels. A central function elaborated the distribution requirement planning (DRP), which was shared with manufacturers in order to elaborate their material requirement planning (MRP) and generate production and purchasing plans. According to the VMI approach, finally, manufacturers and suppliers could confirm or modify the orders proposed by the DRP-MRP system. The author concludedby stating that future researches should address an extension of this model to a collaborative planning, forecasting and replenishment (CPFR) problem.

2.4 Information sharing in the pharmaceutical supply chain

The presented logistic strategies imply information sharing about inventory levels among supply chain actors, but no inventory management study examines this aspect in depth along the supply chain.

Two groups of information are considered in literature [17]: downstream information (demand forecasts) and upstream information (supplier capacity and lead time).

In the field of downstream information sharing, Dobson et al. [18] proposed a data-driven waste reduction project in a hospital pharmacy, using the pharmacy information system to collect cancellation of orders from the medical unit in realtime, avoiding the preparation, at the hospital pharmacy level, of useless compounded sterile products (for intravenous drips) delivered daily. The authors estimated the savings in terms of employees' time and number of wasted doses. They evaluated the possibility of rescheduling the preparation of daily batches in order to minimize the impact of cancellations, to schedule multiple production batches or prepare the less expensive compounds first, according to the cancellation probability distribution function during a day.

In the case of upstream information sharing, Mehrabi et al.[19] assessed the economic impact of lead time information sharing on safety stocks in a two-echelon pharmaceutical supply chain (central pharmacy and hospital pharmacy), quantifying the reduction of uncertainty in terms of reduction in the total cost of the inventory system.

2.5 Research gap and study aims

Apart from the logistic strategies of the supply chain, the data provided by the technological advances introduced in healthcare inventory management (from computer physician order entry systems to radio-frequency identification tags – RFID - for traceability of materials [20]) have never been exploited in a whole supply chain from patient to suppliers, to obtain cost savings [6].

This kind of supply chain integration – achievable by means of real-time data sharing about requirement forecasts (based on patient information) and inventory positions – is considered the open research challenge for hospital inventory management [6].

This study aims at investigating the performance improvements achievable by means of the sharing of patients' requirements data collected in the hospital's electronic medical records (EMR) along the supply chain.

Because only by integrating the internal supply chain can the benefits of integration with the external one be enjoyed[21], we investigated in a previous paper [22] the convenience of adopting the new system in a hospital with three medical units.

In this study, instead, we assessthe performance of a wider supply chain network of three echelons. A number of medical units and hospital pharmacies are considered, and a central pharmacy is added, in charge of pooling requirements, receiving incoming materials from suppliers, cross-docking and distributing them in the nearby hospitals. The possibility of obtaining price-quantity discounts is evaluated. A significant cluster of drugs and the stochastic behaviour of their demand is taken into account by means of simulation.

3. Description of models

This section describes the proposed model (TO BE logistic system) as compared to a non-cooperative one (AS IS). See Figure 1 for a graphical representation.

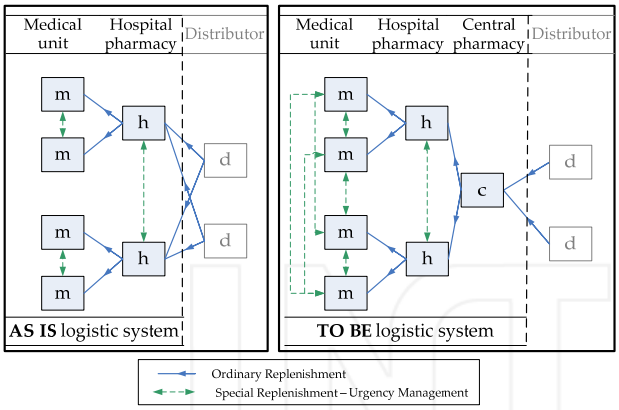

Figure 1. Representation of AS IS and TO BE logistic systems

3.1 AS IS logistic system

The AS IS logistic system is constituted by a number of hospitals that manage their stocks individually. Two echelonscan be identified [23, 24]:

- hospital pharmacies (one for each hospital), in charge of negotiating prices with suppliers (for a medium period of time), ordering from suppliers, performing the quality control and handling of the incoming materials, holding and distributing materials to medical units after having evaluated the medical units' requests in clinical and financial terms. This echelon manages medical unit urgencies (when a drug is not available for administrations) inside the hospital, accessing the medical unit information system (which is not always updated) and activating urgent transport procedures;
- medical units, where patients are hospitalized. The medical unit's nurse manager delivers drug orders to the hospital pharmacy. Nurses place incoming materials in a local warehouse or closet and administer them to patients according to medical prescriptions.

The inventory management policy adopted at both echelons to release orders is the common periodic review par level servicing approach, whereby orders are placed each review period (RP) as the difference between a predetermined maximum quantity to keep in stock at each warehouse (par level, S) and the available inventory on hand (AV) [14].

3.2 TO BE logistic system

The TO BE logistic system is an integrated supply chain of three echelons where at the medical unit level, for clinical and traceability reasons, medical prescriptions and drug administrations to patients are recorded in the EMR. The prescriptions and the inventory levels(derived by delivery and consumption information) are shared in real time along the supply chain, and used to decide order quantities at each echelon (a detailed description of the information records and the hospital information system is reported in [5]).

The logistic activities at each echelon are the following:

- central pharmacy echelon:
  - negotiation of prices with suppliers, relying on bigger purchasing quantities than a single hospital (configured as a GPO);
  - periodic aggregation of orders coming from hospitals by means of a shared information platform;
  - transmission of orders to the selected supplier, which can refer to a single actor for any problem;
  - inventory centralization (which ensures that penalty and holding costs are minimized according to [10-11]). This level receives the incoming materials, controls their quality (avoiding the repetition of activity at each hospital pharmacy) and temporarily stores them;
  - materials distribution. This level is equipped with means of transport to serve the hospitals (which have a single contact point) by delivering the requested materials. This feature allows suppliers to avoid replenishing each single hospital pharmacy, and is another reason for GPO bargaining power;
  - urgency management. In case of urgency, knowing the inventory level at each warehouse, the downstream supply chain can be considered as a virtual warehouse, and the request can be managed with urgent transport procedures;
- hospital pharmacy echelon. Receipt and distribution of materials to medical units;
- medical unit echelon. Storage of incoming materials and administration to patients.

The collaborative purchasing and replenishment model is grounded ina requirements-based inventory management policy, the MRP method, with a fixed order period (FOP) lot sizing approach (for technical issues, see [25-26]).

Prescriptions are evaluated each review period (RP) and, if a requirement for a medical unit exists, order quantities to be provided by the hospital pharmacy are computed by aggregating the needs of a specific period of time (FOP). Finally, the replenishment is planned at the latest time, according to the hospital pharmacy's lead time. The same applies for the hospital pharmacy's orders from the central pharmacy, and when the central pharmacy requires materials from distributors.

4. Notation

Both models' behaviours are analysed for a period of time $T = \{t_1, \dots, t_j, \dots, t_J\}$, where the time base unit is the time bucket (t_j) (according to the MRP slang [27]).

The following notation is defined for a geographical area:

- c: central pharmacy;
- h:hospital pharmacy, with $h \in H$ being the set of hospital pharmacies;
- m: medical unit, with $m \in M$ being the set of medical units belonging to hospitals;
- d: distributor, with $d \in D$ being the set of distributors of drugs.

There are four echelons considered (M, H, c, D). The logistic costs are evaluated for the first three, while the fourth is the system's feeder (it provides the materials to the supply chain).

The materials that flow throughout the supply chain are drugs, characterized by:

- f:drug code (pharmaceutical), with $f \in F$;
- ρ_f: stock decay rate, expressing the deterioration of drugs during the time;
- PT_m: time between two physician rounds to prescribe drugs in the medical unit m.

The cost parameters of the echelons (i) are:

- dp_i: disposal cost per unit of package (for reverse logistics);
- hr_i: holding cost rate, for financial and insurance costs;
- pc_i: handling costs per unit of package;
- ps_i: physical system cost (housing cost), related to the physical storage of a package (including the cost for energy, space, amortization, security, etc.).

The cost parameters of the interaction between echelons (i,k) are:

- $or_{i,k}$: ordering cost at echelon i to order a drug code from k (independently of quantities);
- $sto_{i,k}$: cost of urgent stockout repair at echelon i thanks to the availability at echelon k(independentof quantity);
- $tr_{i,k}$: cost of transportation from k to i.

The inventory decisions' variables and data are:

- AV_{i,f,t_j}: quantity of drug available;
- $FOP_{i,f}$: fixedorder period. This is the lot sizing policy chosen in the application of the MRP;
- $LT_{i,k}$: replenishment lead time that passes from the order request by echelon i to k till the consignment by echelon $k$to i;
- $Q_{ST\,i,k,f,t_j}$: stockout quantity at i to be released from k;
- $RP_{i,f}$: reviewperiod. This is the period between two consecutive controls of the inventory level;
- $Q_{O\,i,k,f,t_j}$: quantity ordered by I from k;
- $Q_{C\,i,k,f,t_j}$: quantity consigned by k to i;
- $TT_{i,k}$: transportation time that passes from the departure of a delivery from echelon k till the consignment to i;
- $v_{f,i}$: service factor. Multiplied by the standard deviation of the demand for an item, it allows determination of the safety stock for the item, which is the quantity to keep in stock at warehouses to manage the variability in drug demand during the period of time without new orders.

5. Models'performances

Having defined the two logistic systems, the research question to answer is how far the TO BE model is economical in comparison with the AS IS one, taking into account tangible and intangible aspects.

The HMM costs are:

- $C_{HA_{i,f,t_j}}$: handling cost, associated with the handling of drug packages in the warehouse to prepare an order delivery

$$\boldsymbol{C_{HA_{i,f,t_j}} = pc_i * Q_{C_{i,k,f,t_j}}} \quad (1)$$

- $C_{O\,i,kf,t_j}$: ordering cost, cost related to the issue of an order from i to k

$$C_{O\,i,k,f,t_j} = or_{i,k} * \delta_{O_{i,k,f}}(t_j) \quad (2)$$

  - $\delta_{O_{i,k,f}}(t_j)$: Dirac delta, taking into account the presence of an order during the time bucket

$$\delta_{O_{i,k,f}}(t_j) = \begin{cases} 1 \;\; if \; Q_{O\,i,k,f,t_j} > 0 \\ 0 \;\; else \end{cases} \quad (3)$$

- $C_{P\,if,t_j}$: purchasing cost, subjected to quantity discount. It is attributed to the last echelon interacting with the distributors, and it is a continuous linear function of the order size

$$C_{P\,i,f,t_j} = Q_{C\,i,k,f,t_j} * P_f * (1 - \alpha_f) \quad (4)$$

  - P_f:unit price for a drug package.
  - α_f: percentage of discount per unit of drug package.

- $C_{W\,i,f,t_j}$: warehousing cost, characterized by three components [28]: physical system cost (or housing cost), holding cost (proportional to the interest rate) and wasting cost (which occurs when items are no longer fit for use)

$$C_{W_{i,f,t_j}} = AV_{i,f,t_j} * \left[ps_i + hr * P_f + \rho_f * (dp_i + P_f)\right] \quad (5)$$

- $C_{T_{i,k,t_j}}$: transportation cost, independent of the quantity transported from *k* to *i*

$$C_{T_{i,k,t_j}} = tr_{i,k} * \delta_{T_{i,k}}(t_j) \quad (6)$$

  - $\delta_{T_{i,k}}(t_j)$: Dirac delta taking into account the transportation cost only if at least one drug replenishment is planned

$$\delta_{T_{i,k}}(t_j) = \begin{cases} 1 \;\; if \;\; \exists f: Q_{O_{i,k,f,t_j}} > 0 \\ 0 \;\; else \end{cases} \quad (7)$$

- $C_{ST_{i,k,f,t_j}}$: stockout cost, independent of the stockout quantity at the echelon *i*

$$C_{ST_{i,k,f,t_j}} = \left[sto_{i,k} + Q_{ST_{i,k,f,t_j}} * P_f * \varepsilon_{ST_{i,k,f}}(t_j)\right] * \\ * \delta_{ST_{i,k,f}}(t_j) \quad (8)$$

where:

$$\delta_{ST_{i,k,f}}(t_j) = \begin{cases} 1 \;\; if \; Q_{ST_{i,k,f,t_j}} > 0 \\ 0 \;\; else \end{cases} \quad (9)$$

$$\varepsilon_{ST_{i,k,f}}(t_j) = \begin{cases} 1 \;\; if \; Q_{ST_{i,k,f,t_j}} > 0 \; and \; k = d \\ 0 \;\; else \end{cases} \quad (10)$$

The HMM total cost (*C*) in the observation time *T*, which can be evaluated in both the TO BE ($C^{TO\ BE}$) and the AS IS logistic configurations ($C^{AS\ IS}$) is thus:

$$C = \sum_f \sum_{t_j} \left[\sum_i \left(C_{HA_{i,f,t_j}} * \beta_{HA_i} + C_{P_{i,f,t_j}} * \beta_{P_i} + C_{W_{i,f,t_j}} ** \beta_{W_i}\right) + \sum_{i,k} \left(C_{O_{i,k,f,t_j}} * \gamma_{O_{i,k}} + C_{ST_{i,k,f,t_j}} * \gamma_{ST_{i,k}} + C_{T_{i,k,f,t_j}} ** \gamma_{T_{i,k}}\right)\right] \quad (11)$$

		Point of consumption			
Variable	Model	*m*	*h*	*c*	*d*
β_{HA_i}	AS IS	0	1	0	0
	TO BE	0	1	1	0
β_{P_i}	AS IS	0	1	0	0
	TO BE	0	0	1	0
β_{W_i}	AS IS	1	1	0	0
	TO BE	1	1	1	0

Table 1. Values of the binary variables β_{x_i} at the points of consumption

		Couple of adjacent points of consumption			
Variable	Model	*m, h*	*h, c*	*h, d*	*c, d*
$\gamma_{O_{i,k}}$ and $\gamma_{ST_{i,k}}$	AS IS	1	0	1	0
	TO BE	1	1	0	1
$\gamma_{T_{i,k}}$	AS IS	1	0	0	0
	TO BE	1	1	0	0

Table 2. Values of the binary variables $\gamma_{x_{i,k}}$ for each connection between points of consumption

The binary variables β_{x_i} and $\gamma_{x_{i,k}}$ used in the cost formula have the values reported in Table 1 and 2, depending on the logistic system and the connections of the supply chain network.

6. Case study

With the objective of carrying out the comparison of the performances of the two configurations (AS IS and TO BE), we collected, for a one-year period, the drug demand, time and cost data from a group of medium-sized acute hospitals belonging to the same Italian region, accounting for a fifth of the regional drug expense.

Quantitative data from hospital information systems, time and method studies, technical evaluations, budgets and profit and loss accounts were analysed, together with qualitative information coming from semi-structured interviews.

Finally, the following supply chainhas been analysed:

- Six drugs used: $|F| = 6$ (the drugs responsible for 30 % of the expenses of the supply chain – Pareto analysis);
- Three hospitals: $|H| = 3$ (hospitals belonging to the same geographic area);
- Three medical units for each hospital: $|M| = 9$ (the hospital locations where the chosen drugs are mainly used – Pareto analysis).

Moreover, we consider the introduction of a central pharmacy with the tasks described in section 3.

6.1 Data collection

6.1.1 Demand data

Drug daily demand for one year for each medical unit (9*6=54) has been collected. Mean and standard deviation of the Gaussian probability distribution functions are reported in Table 3.

6.1.2 Cost and time parameters

The time-driven activity base costing [29] has been performed to compute the standard unit cost for each logistic activity of the supply chain, obtaining the cost parameters considered in the performance function of the model. Particular attention has been given to the central pharmacy cost parameters' assessment. Where possible, the standard unit cost of the hospital pharmacy has been taken into account (see dp_i, pc_i, hr, v_{f,i_i} in Table 4).

The physical system component of the warehousing cost

(ps_i) has been fixed at half that of the hospital pharmacy due to economies of scale in the central pharmacy warehousing system.

The case $or_{i,k}$ is specific because it changes from the AS IS to the TO BE logistic organization due to the different use level of the hospitals' information system, and, then, the automation of the computations involved. In this case, each activity related to the ordering task (and the correspondent duration) has been accurately addressed to each echelon in each logistic system (Table 5). The stockout cost ($sto_{i,k}$) from the hospital to the distributor is broken into two parts: from hospital to central and from central to distributor. A transportation cost ($tr_{i,k}$) of €40.00 per trip from the central pharmacy to a hospital has been assumed, leaving aside cost and time savings obtainable with routing optimization algorithms.

Time parameters have been collected. Lead times ($LT_{i,k}$) and transportation times ($TT_{i,k}$) of the AS IS model are repeated in the TO BE model for the medical unit-hospital pharmacy link.

f	m	$\mu_{f,m}$	$\sigma_{f,m}$	m	$\mu_{f,m}$	$\sigma_{f,m}$	m	$\mu_{f,m}$	$\sigma_{f,m}$
1	1	5.8	4.4	4	-	-	7	-	-
2		6.5	4.8		-	-		-	-
3		426.0	288.7		73.5	69.5		313.6	315.8
4		4.0	4.9		-	-		5.2	4.4
5		11.1	9.1		-	-		7.3	7.3
6		35.0	28.0		12.0	7.7		42.0	38.5
1	2	3.5	2.3	5	-	-	8	-	-
2		6.7	7.3		3.7	8.6		-	-
3		243.0	214.1		384.0	323.4		153.6	137.5
4		6.0	5.9		6.2	8.0		-	-
5		4.3	5.0		8.4	4.7		6.4	3.8
6		62.1	62.8		59.2	55.7		12.3	9.3
1	3	-	-	6	-	-	9	-	-
2		-	-		-	-		6.0	2.3
3		79.2	104.6		61.0	64.6		197.2	201.1
4		-	-		-	-		7.2	3.6
5		-	-		-	-		5.3	4.3
6		-	-		-	-		17.9	16.1

Table 3. Mean ($\mu_{f,m}$) and standard deviation ($\sigma_{f,m}$) of the drugs' demand [packages/day]. Gaussian distribution functions.

In the rest of the TO BE supply chain, the distributors' times are kept. Finally, in order to allow not only "real-time" data sharing but also "just in time" replenishments, the TO BE review period $RP_{i,f}$ for all medical units and the hospital pharmacy is one day, while for the central pharmacy it is three days, equal to the upstream echelon (h) of the AS IS model (Table 6).

	Point of consumption		
Cost Param.	m	h	c
dp_i [€/package]	1	0.50	0.50
pc_i [€/package]	0	0.105	0.073
ps_i [€/package/day]	0.0355	0.0028	0.0014
hr_i [price rate/€/year]	6%		
$v_{f,i}$ $\forall f$	3		

Table 4. Values of the cost parameters at each echelon

		Couple of adjacent points of consumption			
Cost/ Time Param.	Mod.	m, h	h, c	h, d	c, d
$or_{i,k}$[€/code]	AS IS	1.70	0	7.45	0
	TO BE	0.08	1.14	0	4.64
$sto_{i,k}$[€/code]	AS IS	150.00	0	2500.00	0
	TO BE	150.00	800.00	0	1700.00
$tr_{i,k}$[€/trip]	AS IS	10.00	0	0	0
	TO BE	10.00	40.00	0	0
$LT_{i,k}$ [h]	AS IS	1	0	24	0
	TO BE	1	24	0	24
$TT_{i,k}$ [h/trip]	AS IS	0.5	0	6	0
	TO BE	0.5	6	0	6

Table 5. Values of the cost and time parameters in the interaction between points of consumption for the AS IS and TO BE model

		Point of consumption		
Time Param.	Mod.	m	h	c
$RP_{i,f}$ [d]$\forall f$	AS IS	3	3	0
	TO BE	1	3	1
$FOP_{i,f}$ [d]$\forall f$	AS IS	0	0	0
	TO BE	1	3	3

Table 6. Values of the time parameters at the points of consumption for the AS IS and TO BE model

6.2 Model development

The performances of the two logistic configurations have been tested in a simulation environment in order to reproduce the variability of medical prescriptions and to evaluate the dynamic of ordering, storing and consuming drugs along the supply chain, according to the chosen inventory policies.

6.2.1 Assumptions

Some non-limiting assumptions have been made in order to develop the models:

- both models are arborescent multi-echelon distribution systems, in which the lower echelon receives items from only one source belonging to the higher echelon (that is, urgencies are managed by only looking at the availability of the higher echelon);
- replenishment lead times ($TT_{i,k}$) are constant;
- the time between two physicians' rounds in a medical unit (PT_m) is one day (that is, prescriptions change daily);
- drug demand is stochastically independent among days;
- the maximum time horizon of prescriptions is eight days;
- the stock decay rate (ρ_f) is50%/year$\forall$ f.

6.2.2 Simulation

A discrete event simulation model has been developed using Arena Rockwell software. Drug packages are the entities flowing throughout the system. The time-driven occurring events are:

- medical prescription recording (each PT_m), which defines the needs of drugs at medical units;
- drug administrations (distributed during the day), which determines the consumption of drugs;
- end of the review period ($RP_{i,f}$), which calls into action inventory management policies to decide the time and quantity of orders;
- order planning($Q_{O\,i,k,f,t_j}$), which implies that the related picking and order preparation activities take place and transportations are activated;
- stockout, which involves urgent procedures to transfer the quantities from the nearest available storage location at a high cost ($C_{ST\,i,k,f,t_j}$).

A Monte Carlo simulation (MCS) has been used to simulate the stochasticity of daily medical prescriptions on the basis of collected drugs' daily demands. Both logistic configurations have been subjected to the same medical units' demand.

Inventory management decisions have been implemented in VBA (Visual Basic for Application) code.

At the end of each simulation, the time series of prescriptions, stocks, orders and stockouts are provided, together with the value of each cost item.

The simulation length has been one year. A number of replications have been provided to compensate for the effects of extractions over the time of the MCS, and thus accurately reproduce the drug demand distributions.

7. Design and analysis of experiments

The cost performances of the two logistic systems have been investigated in three different experiments:

1. under the case study;
2. under the variation of the fixed order period of the central pharmacy;
3. in the case of pure GPO.

No quantity discount α_f(due both to the GPO's bargaining power and the distribution task transfer to the central pharmacy) has been implemented in the basic simulation model, because it is strictly dependent on the GPO dimension, drug type and volume, suppliers' competition, location and hospitals' accessibility. This sure saving has to be added to the one found in the simulation comparisons, and it affects not only the purchasing cost but also the warehousing cost, because of the holding cost (hr_i) variation.

For the same reason, no experiment has been carried out assessing the convenience of the introduction of a 3PL.

The cost comparison between the systems is carried out by means of the synthetic performance indicator (mean total cost saving):

$$\%C\_T_{sav} = \frac{C^{AS\,IS} - C^{TO\,BE}}{C^{AS\,IS}} \tag{12}$$

Moreover, the distinction between purchasing costs savings ($\%C\_P_{sav}$)and logistic cost savings ($\%C\_L_{sav}$)is made.

A summary of the results of the experiments is shown in Figure 2.

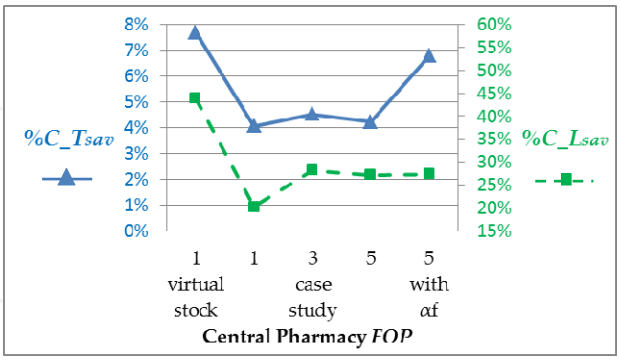

Figure 2. Summary of the experimental results. Mean total cost saving ($\%C\_T_{sav}$) and logistic costs savings (dotted line,$\%C\_L_{sav}$) in the simulated scenarios (discussed later).

7.1 The case study experiment

In this first experiment, the economic saving of the centralization of purchasing, warehousing and decisions is evaluated by the case study contest.

Generally, a three-day review period inventory policy in the absence of communication in a two-echelonnetwork (AS IS) is opposed to a one-day review period with

prescription data sharing in a three-echelon supply chain, where the central pharmacy rules the system on the basis of requirements, andit is in charge of daily transportations and ordering to cover requirements for three days forward.

The simulation length, along with the number of repetitions, ensures that the real demand variability over time has been accurately reproduced during the simulation runs. The standard errorof$\%C_T_{sav}$, with a confidence level of 95%, is 0.0044 [30].

The experiment shows that the TO BE logistic system is much more convenient than the AS IS one: while assuring the same service level to patients (proportional to $v_{f,i}$), the mean total cost saving ($\%C\_T_{sav}$) of the supply chain is4.53 %.Moreover, both the purchasing and logistic costs can be reduced with the TO BE model:

- $\%C\_P_{sav}$ = 1.02%;
- $\%C\_L_{sav}$ = 28.21%.

It is not surprising that there is a saving in the purchasing costs C_P even if the consumed quantities are the same in both models. Indeed, in the AS IS model, the materials are purchased to restore the par level (S), but part of them is not used because it is notprescribed to patients. By contrast, in the TO BE model,only what is really needed is bought (given the adoption of the MRP method).

The logistic cost savings are due to a number of reasons, so it is worth examining the cost distribution among the cost items in the AS IS and the TO BE configurations (Table 7).

	Logistic cost items				
	C_{HA}	C_O	C_{ST}	C_T	C_W
AS IS cost composit.	21%	5%	14%	2%	58%
$\%C_{sav}$(TO BE on AS IS models)	-69%	54%	64%	-586%	80%

Table 7. AS IS expenditure distribution for the logistic costs items and percentage of savings thanks to the TO BE model adoption

The handling cost $C_{HA}$is a significant component of the AS IS logistic costs (21%) due to the labour-intensive tasks. It increases in the TO BE model because the distribution from a new echelon (the central pharmacy) has to be managed. For the same reason, the transportation costs $C_T$rise. On the other hand, the ordering cost $C_O$records a decrease due to the automation introduced by the information system. Theevident re-ordination logic and the shorter $RP_{i,f}$of the TO BE model are the reasons for the reduction instockout costs $C_{ST}$and warehousing costs C_W, whichaccount for more than half of the total logistic costs of the AS IS supply chain.

7.2 Variation of the central pharmacy fixed order period

This second experiment deals with the possibility of balancing the increase in transportation costs from the central pharmacy to hospitals with reducing the frequency of orders from distributors (low FOP) and, thus, the corresponding costs. In return, obviously, the central pharmacy warehousing costs will increase. The opposite strategy is to boost the central pharmacy FOP to drastically reduce the C_W while $C_O$isincreased.

Table 8 shows the experimental levels of $FOP_{c,f}$ and the savings results.

Factor	Level	$\%C\_T_{sav}$	$\%C\_L_{sav}$	$\%C\_P_{sav}$	$\%C\_T_{sav}$ $\alpha_f = 3\%$
$FOP_{c,f}$ [day]	1	4.06%	20.25%	1.66%	6.65%
	3 (case study)	4.53%	28.21%	1.02%	7.14%
	5	4.23%	27.18%	0.83%	6.77%

Table 8.TO BE mean cost savings depending on $FOP_{c,f}$ variations

The results clearly show that $FOP_{c,f}$has to be set according to the supply chain cost structure in order to achieve the maximum benefit.In any case, the sharing of patient information always assuresa total cost saving, and there is a procurement reduction the lower $FOP_{c,f}$ is, because frequent orders better follow the demand.

Moreover, if the central pharmacy is able to negotiate, for example, a 3% quantity discount (α_f) on the purchasing, the total savings are greater (last column of Table 8).

7.3 Pure GPO

The last experiment has been carried out to evaluate the economic convenience of centralizing bids and orders while keeping the reception and storage of materials at the individual hospitals. This last configuration is a pure GPO in which the central pharmacy has the role of demand aggregator provided by a virtual warehouse. Obviously, the ordering cost parameter ($or_{i,k}$) at each echelon has been recalculated accounting for the new task distributions among supply chain actors.The FOP setting and the experimental' results are reported in Table 9.

This logistic configuration shows higher savings than the other tested scenario. The savings in purchasing costs due to shorter $FOP_{c,f}$matchthe lower warehousing costs because of the elimination of the physical centralization of stocks. The ordering costs, which have a short weight on the total AS IS costs, rise due to the duplication of some tasks at the hospital pharmacy echelon.

Factor	Level	$\%C\_T_{sav}$
$FOP_{c,f}$ [day]	1	7.67%

Table 9.TO BE model setting andmean cost savings in case of pure GPO

8. Conclusions

Because the economic crisis and competition have led hospitals to faceincreasing financial pressures, healthcare supply chain integration has become a topic of interest for researchers and practitioners. Three main logistic strategies have emerged: GPO, centralization of inventory and outsourcing to a 3PL.The main demonstrated advantages have been price-quantity discount, savings in warehousing costs, focus on core activities and prevention of corruption, even if some other budget items have been identified as checkpoints, such as coordination and distribution costs.

As a worldwide trend, medical supply centralization has been implemented in many contexts, both growing out of bottom-up initiatives and imposed by governments, as in the case of the compulsory administration of healthcare in some Italian regions.

On the other hand, the pervasiveness of information and communication technologies – reflected in the introduction of electronic medical records, RFID for patients and medical devices, and hospital enterprise resource planning systems [31] – has not been fully exploited to improve operations management.

This research proposes an integration of both centralization and information technology trends in healthcare, to provide better and cheaper care to patients.

In particular, the economic convenience of cooperation in the pharmaceutical supply chain from the patient's bed to the drug distributor by means of sharing patients' prescriptions has been assessed. The logistic network under investigation (TO BE model) integrates: a central pharmacy negotiating with suppliers, collecting hospital orders, storing and distributing materials;a number of hospitals feeding their medical units with materials; and a number of medical units taking care of their patients.

The quantitative study has been carried out comparing the cost performances of this model with a non-cooperative supply chain, where hospitals manage their stocks individually (AS IS model).

Monte Carlo simulation has been used to reproduce the variability of prescription requirements over time in a discrete event simulation environment. Costs and time parameters to perform the comparison come from a case study.

The convenience of a centralization of inventory or of the introduction of a pure GPO has been evaluated. The results are impressive, showing that there is always a cost saving in adopting the cooperative model, including in situations without price-quantity discounts, when varying the period of central pharmacy order aggregation (FOP) or when completely avoiding the physical centralization of stocks.

Further studies should explore the effect of stochastic supplier leadtimes on the cost savings. Finally,logistic resources' capacities and their load conditions could be analysed to optimize the frequency and scheduling of HMM activities in the TO BE model.

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