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# A COLLABORATIVE SUPPLY CHAIN NETWORK DESIGN WITHIN A TERRITORY HOSPITAL GROUP

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**ABSTRACT :** *The management of logistics functions is essential for the overall good functioning of a health-care establishment to meet the efficiency and the effectiveness requirements that hospitals are increasingly faced with. Minimizing spending is currently leading health-care establishments to reason and optimize the physical flows in terms of the overall performance of their supply chains. Therefore, logistics pooling could be seen as a solution for hospitals to reduce costs and enhance the quality of service. In this work, linear programming (LP) model was proposed to design a shared hospital supply chain among various establishments of a "Territory Hospital Group" based on a horizontal collaborative logistic strategy. The objective is to rationalize, pool, and optimize the storage and the distribution of products between suppliers, warehouses, and cross-docks. Instances with small and medium sizes were generated based on a real situation and several tests were developed on different hypotheses to reveal the impact of the proposed logistics collaboration on economic costs.*

**KEYWORDS :** *Optimization, horizontal collaboration, hospital supply chain, logistics pooling*

## 1 INTRODUCTION

In recent decades, the grouping of establishments or communities (university communities, etc.) is becoming of great importance, and several research studies aimed at promoting new models of territorial organization in different areas of real life. Since July 2016, hospitals in France were also affected by this grouping, cause medical sector has been faced new challenges and issues that obliges to re-organize the activity of its different functional units. Encountered with these deep changes, it is essential to revise the structure of the health-care system in order to optimize the resources mobilized and control spending Pillay (2008).

Therefore, in the interest of enhancing hospital logistics (managing products and material flows and distribution circuits), France hospitals have met to form Territorial Hospital Groups (THG) that vary mainly according to their establishment's parties, their budget, and the territories served. This reform aimed at pooling progressively certain support functions provided by the establishment such as logistic management and increasing cooperation between hospitals. Following other sectors, collaboration strategy will be advantageous through an overall cost reduction, a supplier integration, and an optimization of processes such as storage of products in warehouses and pharmacies and their distribution to care units. Hence, to model this collaboration, mastery of logistics functions is essential for the overall good functioning of the

hospital supply chain.

Generally, in a classic supply chain, every single hospital must review, release, treat, and monitor its supply cycle individually. The supplier's organization responds to this operation and must meet the unit care specifications. In this work, a linear programming model was proposed, at the strategic level of decision making, to design a pooled hospital supply chain among various establishments of a territory hospital group based on a horizontal collaborative logistic strategy.

The remainder of this paper is organized as follows: Section 2 reviews the literature on collaborative logistics network design problems with different real-word applications domains and methodologies. Section 3 presents a description of the proposed problem and its mathematical formulation. In the fourth section, several instances were generated to demonstrate the pooling performance. Finally, Section 5 presents a conclusion with some future research studies.

## 2 Literature review

According to Moutaoukil et al. (2013), collaboration strategy consists to share logistics means and resources in order to minimize costs and increase profits, it could be either on a vertical or horizontal level. The first type concerns partners who belong to the same logistics chain that operates at different levels of the supply network. Unlike the second

type, that concerns partners of the same level who do not belong to the same logistics chain. Several collaborative supply chain design problems and models have been developed in the literature dealt with the design of a shared logistics network Mrabti et al. (2019) to increase the efficiency of the supply chain and achieve economies of scale in a different real-world domain (agronomy, automobile, etc.) and for all decision-making levels. In this section, we identified different research studies belonging to the strategic level of decision making that can be classified according to their field of application and their resolution approach.

Simulation is the most cited techniques in the literature to solve this problem. As it was presented in Giso (2008), authors used simulation to compare traditional supply chain against vertical and horizontal collaborative strategies and confirmed that horizontal collaboration is the best strategy for reducing logistics costs. In Pooley and Stenger (1992), authors proposed a simulation approach to evaluate a logistic transportation consolidation strategy within a food manufacturing business to reduce costs by combining several types of logistical pooling; (1) pooling of warehouses, (2) pooling of platforms, and (3) pooling of means of transport. Wanke and Saliby (2009) developed a simulation tool to determine the impact of inventory centralization and regular transshipment inventory-pooling models, on logistic costs and indicated the best pooling scenario. Leitner et al. (2011) used simulation techniques to evaluate pooling strategy on two projects in the automobile sector in Romania and Spain and optimize cost structures. Also, Moutaoukil et al. (2013) uses several scenarios to compare the performance of a traditional logistics network against a pooling supply chain with a horizontal collaborative strategy and they used simulation technique to manage the agri-food SMEs flows. In 2017, Makaci et al. (2017) developed a generic simulation model to solve a multiple case study approach that dealt with the management of shared warehouses, a list of indicators was presented to assess the performance of logistical pooling. Recently, in health-care domain, a simulation tool was developed by Nicolas et al. (2018), the decision-maker can create, choose and compare different pooling scenarios in order to measure their impact on the local maintenance and/or pooling of product flows among hospitals.

Other studies proposed heuristic optimization approaches and exact methods to solve the collaborative supply chain design problem. Authors in Groothedde et al. (2005) used heuristics to search the best combination of hubs in a pooled logistics chain in order to minimize costs. Nataraj et al. (2019) proposed a meta-heuristic approach to solve different horizontal collaboration scenarios in the

transport domain in order to increase the vehicle filling rate and decrease economic cost. In Cheong et al. (2007), a LP model was proposed to solve collaborative network design problem and decide the number, location, and operation of consolidation hubs by minimizing upstream and downstream costs of warehouses. Tuzkaya and Öniüt (2009) proposed a LP model to solve a two-echelon supply chain problem for distributing automotive industry products from the suppliers to the warehouse and from the warehouse to the manufacturers to maximize profit.

For the best of our knowledge, in the operational research field, none of the existing research works has modeled or studied the impact of horizontal collaboration and pooling strategy in hospital sector and notably within territorial hospital groups, which provides us a strong motivation to study. This paper could be an extension of the work presented by Nicolas et al. (2018) where authors allow decision-makers to choose and compare the pooling scenarios of products below a THG based on a set of criteria chosen by hospital partners. However, an optimal product pooling scenario could not be generated. In this paper, we propose an optimization linear programming model that offers an optimal product pooling scenario for the decision-maker within a THG to optimize the economic performance of hospital sector among the management of several logistics costs. Therefore, a multi-supplier, multi-warehouse, and multi-product network is considered as a collaborative pooled warehousing structure. The problem is designed as a minimum-cost flow graph generalized to several products.

### 3 PROBLEM DESCRIPTION

In our study, the hospital logistics chain could be designed as a layered network with  $|S|$  suppliers,  $|W|$  warehouses, and  $|P|$  products sub-family (food, cleaning materials, textiles, medicines, etc.). Knowing that every warehouse has its managing strategy that characterizes its purchasing, procurement, and storage activities and it is dedicated for serving only one establishment. The process flow consists of three steps: (1) making a procurement order from suppliers, (2) shipment of products to the warehouse of the considered hospital, and (3) the distribution of these products to the unit care. Knowing that each care unit can only be supplied by its warehouse and that each warehouse manages its procurement, warehousing, and transportation activity independently. Such a supply chain problem can generate several logistics costs such as transportation costs, inventory holding costs, and ordering costs, etc. Which explains the request to migrate for a horizontal collaborative

pooling strategy and to form a territorial hospital groups.

Therefore, our work consists in designing a pooled supply chain within various establishments of the THG. The objective is to find an optimal allocation of product flows, that are distributed from suppliers to warehouses and from warehouses to establishment, and to set up a pooling scenario that groups one or more sub-families (materials, food, etc.) of products in the suitable stores. Thus, in the present hospital logistics network, there are storage warehouses that hold the stock of one or more sub-families of products, and cross-dock stores that represent a point of material handling and distribution, where products are not stored for an extended time period. Knowing that a store can be, simultaneously, as a storage warehouse for one or more subfamilies and as a cross-dock for other subfamilies.

Our pooling scenario is carried out in two stages, (1) the placement of certain sub-families of products on one or more warehouses and (2) their distribution from these warehouses to one or more cross-docks. The proposed model allows to specify optimally for each product sub-family, its source (which supplier), its storage locations (warehouse), and its distribution to cross-docks stores. The objective is to minimize the overall economic costs defined as follows:

- Full-Time Equivalent cost (FTE): represents the workload of employees.
- Transportation cost: denotes expenses related to the distribution of products from storage warehouses to cross-docks.
- Purchasing cost: concerning product prices set by suppliers.
- Ordering cost: generated during the management of orders which vary according to their annual number (administrative and logistical monitoring, reception and handling charges, etc.).
- Holding cost: related to the inventory storage (insurance, depreciation of facilities, rental, and maintenance of premises, etc.).

Different constraints should be respected; each facility's demand for a product must be satisfied and the maximum storage capacity of warehouses should not be exceeded. In this setting, we make the following assumptions:

- Suppliers have unlimited delivery capacity.
- The supply strategy (i.e. procurement periods, unit costs, etc.) of the warehouse where the pooling of products takes place is maintained.

- The number and locations of warehouses and cross-docks are assumed to be fixed and known.
- A given product could be distributed for warehouses by one or more suppliers at different prices.
- The product price proposed by a given supplier is fixed for all warehouses.

The notation sets, parameters, and decision variables used in the model are presented below.

#### **Decision variables**

$x_{p,s,w}$ : quantity of product  $p$  transported from supplier  $s$  to warehouse  $w$ .

$y_{p,w,c}$ : quantity of product  $p$  transported from warehouse  $w$  to cross-dock  $c$ .

#### **Sets**

$S$ : set of suppliers,  $|S| = 1..s$ ;

$W$ : set of warehouses,  $|W| = 1..w$ ;

$C$ : set of cross-docks,  $|C| = 1..c$ ;

$P$ : set of products,  $|P| = 1..p$ ;

#### **Variables / expression**

$PC$ : Total purchasing cost;

$OC$ : Total ordering cost;

$TC$ : Total transportation cost;

$HC$ : Total holding cost;

$FC$ : Total Full-time equivalent cost;

$PC_{p,w,s}$ : Unit purchasing cost of products  $p$  by the warehouse  $w$  from the supplier  $s$ ;

$HC_{p,w}$ : Possession rate of product  $p$  in a warehouse  $w$ ;

$OC_{p,w}$ : Unit ordering cost of product  $p$  for a warehouse  $w$ ;

$FC1_{p,w}$ : Full-time equivalent unit cost of product  $p$  in warehouse  $w$ ;

$FC2_{p,c}$ : Full-time equivalent unit cost of product  $p$  in cross-dock store  $c$ ;

$TC_{p,w,c}$ : Unit transportation cost of product  $p$  from warehouse  $w$  to cross-docks  $c$ ;

$C_w$ : maximum storage capacity of warehouse  $w$ ;

$d_{p,c}$ : demand of product  $p$  by cross-dock  $c$ ;

$a_{p,w}$ : Unit surface occupied by product  $p$  in the warehouse  $w$  ( $m^2$ );

$t$ : calendar days;

$PP_{p,w}$ : procurement period of product  $p$  for warehouse  $w$  ( $PP_{p,w} \neq 0$ );

$I_{p,w}$ : Average inventory level of product  $p$  in a warehouse  $w$ :

$$I_{p,w} = \frac{x_{p,s,w}}{2 * (\frac{t}{PP_{p,w}})} \quad (1)$$

$IL_{p,w}$ : Inventory value of products  $p$  in warehouse  $w$ :

$$IL_{p,w} = \frac{PC_{s,w,p}x_{p,s,w}}{2 * (\frac{t}{PP_{p,w}})} \quad (2)$$

### 3.1 Objective function

In the economic objective function, we introduced the different costs that affect the pooling performance. It is represented by the following formula:

$$\text{Minimize } PC + HC + TC + FC + OC \quad (3)$$

$$PC = \sum_P \sum_S \sum_W PC_{p,w,s}x_{p,s,w} \quad (4)$$

$$HC = \sum_P \sum_W HC_{p,w}IL_{p,w} \quad (5)$$

$$TC = \sum_P \sum_W \sum_C TC_{p,w,c}y_{p,w,c} \quad (6)$$

$$FC = \sum_P \sum_S \sum_W (FC1_{p,w}x_{p,s,w} + FC2_{p,c}y_{p,w,c}) \quad (7)$$

$$OC = \sum_P \sum_S \sum_W x_{p,s,w}OC_{p,w}(\frac{t}{PP_{p,w}}) \quad (8)$$

The economic function aims to minimize the summation of five types of costs; the purchasing cost, inventory holding costs at the warehouse, transportation cost, FTE cost and finally total ordering cost.

### 3.2 Constraints

The constraints of our model are as follows:

$$\sum_W y_{p,w,c} \geq d_{p,c} \quad \forall c \in C, p \in P \quad (9)$$

$$\sum_P 2I_{p,w}a_{p,w} \leq C_w, \quad \forall w \in W \quad (10)$$

$$\sum_S x_{p,s,w} - \sum_C y_{p,w,c} = 0, \quad \forall w \in W, p \in P \quad (11)$$

$$x_{p,s,w} \geq 0, \quad \forall w \in W, p \in P, s \in S \quad (12)$$

$$y_{p,w,c} \geq 0, \quad \forall w \in W, p \in P, c \in C \quad (13)$$

Constraints 9 ensures that the demand of the unit care for each subfamily of product is satisfied. Equation 10 ensure that the total products quantity at each warehouse should not exceed its storage capacity. Constraint 11 represents the balance among supplying, inventory and deliveries at each warehouse. Constraints 13 and 12 represent the types of decision variables and guarantee the positivity of the flows.

## 4 EXPERIMENTAL RESULTS

In this section, we present computational tests and analysis results to validate the computational efficiency and effectiveness of the model and to see the impact of the horizontal collaboration on our economic objective function. Two different configurations are used, firstly we considered the pre-pooling scenario where products are delivered directly from supplier to unit care, then we considered the polling scenario, where collaboration between functional units of the THG is authorized (i.e. products can be stored in the warehouse of another unit care before being shipped). The experiments have been complimented on Intel(R) Core(TM) Duo i3-5005U 2.00 GHz and 4 Gb RAM. They have been solved using IBM ILOG CPLEX solver.

### 4.1 Data generation

For lack of real data, we performed computational experiments on a set of randomly generated test instances based on realistic parameter value obtained partially from a real situation of an existing territory hospital group. We considered a set of 8 instances that vary according their size and their cost structure. According to the number of warehouses, we can form two groups of instances (small and medium). Table 1 summarizes the parameters of each instances.

Tableau 1: Instances parameters

Instance	W	P
S1		4
S2		12
S3	5	20
S4		28
M1		4
M2		12
M3	20	20
M4		28

The size of an instance is given by the number of potential warehouses (|W|) and the number of products (|P|). Continuous uniform distributions,

independent from each other, were considered in the random number generation of all variables. The number of suppliers is fixed and it is equal to two, the warehouse storage capacity and the demand of the care unit are generated randomly. The unit costs structure is determined as follows; the unit ordering cost has been supposed fixed (20€) for all warehouses and all types of products. Next, for each product  $p \in P$ , a purchasing unit cost is chosen randomly in the interval  $[1, 20]$ . Also, for each warehouse  $m \in M$ , a fixed unit holding cost is set between  $[20,30]$  for all products of this warehouse.

## 4.2 Results and discussion

A comparison between the pre-pooling and the pooling scenarios will be considered to evaluate the effect of collaboration (is it advantageous for hospitals?). The pre-pooling scenario (SC1) presents the direct shipment of products from the supplier to the distribution center, and the pooling scenario (SC2) is obtained by solving the model presented previously with the objective economic function. Table 2 summarized the optimal solutions of different instances for the two scenarios.

Tableau 2: Optimal total cost for pre-pooling and pooling scenarios

Inst	SC1	CPU	SC2	CPU	Gain
S1	2160 $10^3$	2.5	1780 $10^3$	4.2	17.6%
S2	3200 $10^3$	2.8	2647 $10^3$	7.0	17.2%
S3	3876 $10^3$	112.4	3356 $10^3$	135.2	15.5%
S4	4652 $10^3$	94.0	4111 $10^3$	162.4	13.1%
M1	1316 $10^4$	0.3	1166 $10^4$	0.9	11.3%
M2	1744 $10^4$	0.7	1238 $10^4$	1.4	29.0%
M3	2226 $10^4$	124.0	1732 $10^4$	342.0	22.2%
M4	2447 $10^4$	114.6	2174 $10^4$	562.0	11.2%

For all instances, the optimal logistic cost of the pre-pooling scenario is usually lower than the pooling scenario, which can confirm that the pooling strategy within the THG is advantageous and provides a remarkable improvement at the economic level. Indeed, there is a significant reduction of the total cost that varies, depending on the instance, between 13% and 17% for small ones and between 11% and 29% for medium instances. This is reflected by an improvement in FTE cost, purchasing cost, ordering cost, and inventory holding cost. The CPU time (s) required by CPLEX for each scenario SC1 and SC2 is given in the third and fifth column, respectively. It can be seen that the CPU time increases with the number of warehouses and products, and the pooling scenario is always time-consuming than the pre-pooling configuration, e.g. the CPU time of SC1 is 80% lower than SC2 in M4.

Figure 1 and Figure 2 demonstrate economically the details of costs saving realized, they represent the average of each cost among all instances. Despite the appearance of an additional transportation cost, we note that we make gains in terms of other costs; 13% for the FTE cost since the solver will choose warehouses with lowest labor costs, and 29% for purchasing cost. In addition, a reduction in inventory holding cost and ordering cost with respectively 19% and 14%. This gain results generally from the optimal pooling of multiple products between warehouses according to better flow allocation.

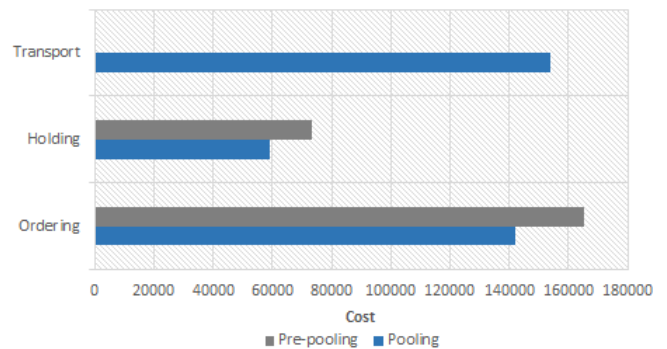


Figure 1: Transportation, holding and ordering costs variation

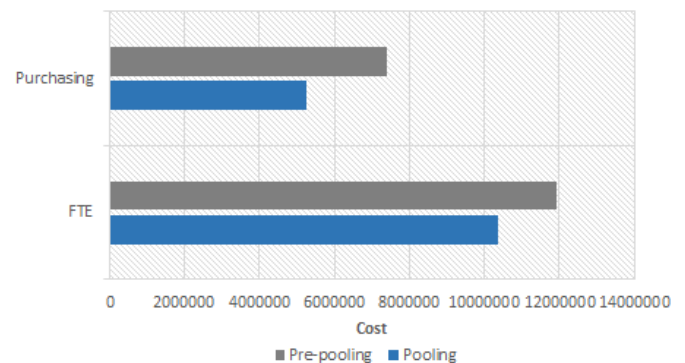


Figure 2: FTE and purchasing costs variation

Horizontal collaboration does not only have an impact on logistics costs, but also it could generate additional added value on other factors. Therefore, the resulting analysis may be projected on different important dimensions such as the warehouse filling rate. This makes it possible to quantitatively evaluate the initial situation comparing by the collaborative configuration. Furthermore, it is possible to deduct the amount of products exchanged and grouped after collaboration for each instances by presenting the percentage of pooling products (Table 3).

For each instance, a total filling rate is measured among the overall warehouses before and after collaboration. We note that for all instances, the filling rate in SC2 decreases with an improvement ranging from 1% to 2%. Therefore, we can confirm

Tableau 3: Warehouse filling rate and percentage of pooled products

Inst	% Filling rate		#SW	% Pooled product
	SC1	SC2		
S1	35%	29%	2	100%
S2	56%	52%	3	100%
S3	64%	62%	5	85%
S4	72%	67%	5	78%
M1	19%	15%	3	75%
M2	25%	21%	8	100%
M3	42%	38%	14	100%
M4	56%	52%	17	68%

that horizontal collaboration ensures better stock management and allows to save more free space and hold even more products. The fourth column represents the number of storage warehouses (#SW) kept open after collaboration. Moreover, according to pooled product percentage, it is noticed that for the majority of instances, more than 50% of products have been pooled, which confirms that collaboration is usually more advantageous.

### 4.3 Sensitivity analysis

In this section, we determine how target variables are affected based on changes in input parameters. It is a way to predict how changes in coefficients of the model can affect the optimal solution. Considering the importance of transportation cost generated during pooling, we motivated the analysis by increasing the unit transportation cost and assuming that warehouses are far apart to show the sensitivity of the model to this parameter. This study was carried out only on instance S1. Figure 3 shows the changes in the overall costs following the unitary increase in transportation cost.

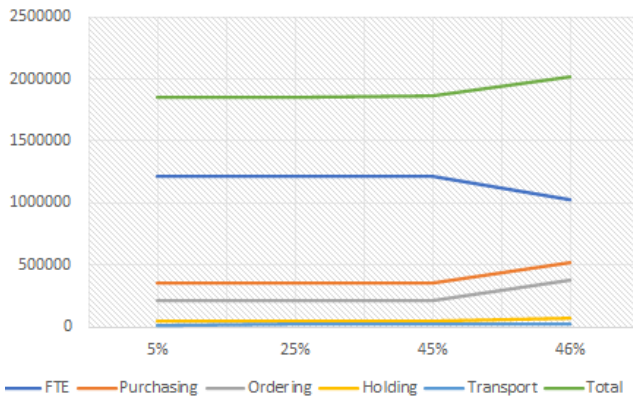


Figure 3: Sensitivity analysis when transportation cost is increasing

As it is clearly shown in Figure 3, when the unit transportation cost increases up to 45%, the total

cost (objective value) gradually increases, while the other logistics costs remain constant. Above 45%, not only the transportation cost is increased but also all other logistics costs are influenced. Therefore, we can note that if the unit transportation cost is raised to a maximum of 45%, the optimal procurement and distribution plan (optimal solution) remains unchanged, but among 46% the optimal solution is no longer maintained. On the other side, we evaluate if the decrease of transportation cost affects the optimal solution and it was revealed that the coefficient can be decreased without bound by influencing only the cost of the objective value and not the optimal solution.

## 5 Conclusions

In this paper, we consider a collaborative supply chain within a territory hospital group in a multi-product, multi-supplier, and multi-warehouse setting. Our main objective was to demonstrate the pooling performance and improve the economic level of the supply chain. A LP optimization model was designed to organize product pooling within hospitals in order to minimize the overall logistic costs, including ordering cost, transportation cost, inventory holding cost, FTE cost, and purchasing cost. The proposed linear programming model can help managers to decide not only which product sub-family to pool, but also the storage locations of those products and the quantity transported between facilities to satisfy demand. The network presented in this study deals with capacitated facilities (warehouses/cross-dock). We test our model on small and medium instances generated. Good results are obtained; as logistics cost and warehouse filling rate.

This study can be extended in several directions. It will be possible to incorporate other different aspects of sustainable development such as environmental objectives in the context of horizontal collaboration. Also, to specify the problem for a more realistic scenario, we should deal with uncertain demand over the decision horizon.

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