HAL
open science

Positioning and Innovations from the Champagne Sud Hospitals in the World of Hospital Logistics

Moïse Noumbissi Tchoupo, Alice Yalaoui, Lionel Amodeo, Farouk Yalaoui

To cite this version:

Moïse Noumbissi Tchoupo, Alice Yalaoui, Lionel Amodeo, Farouk Yalaoui. Positioning and Innovations from the Champagne Sud Hospitals in the World of Hospital Logistics. Hospital Logistics and e-Management: Digital Transition and Revolution, 145-169, Wiley, 2019, 9781119670537. 10.1002/9781119670537.ch6 . hal-03260799

HAL Id: hal-03260799

https://utt.hal.science/hal-03260799

Submitted on 25 Jan 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Positioning and Innovations from the Champagne Sud Hospitals in the World of Hospital Logistics

Moïse NOUMBISSI TCHOUPO, Alice YALAOUI, Lionel AMODEO and Farouk YALAOUI

6.1. Introduction

The hospital logistics commission of the ASLOG (*Association française pour la logistique*, French Logistics Association) defines hospital logistics as "the management of the flow of patients, products, materials, services and information relating to them in order to ensure that quality and safety meet a defined standard of performance and efficiency, from the supplier to the patient and, depending on the case, the final user". Hospital logistics, therefore, is a field of study and optimization of two types of physical hospital flows: the flow of people (which consists of the movements of patients from their arrival until they leave the establishment, as well as the staff and visitors) and the flow of material. This material is very varied and is at the center of a care unit with incoming flows as follows: patient files, labile blood products, medication, sterile and non-sterile medical equipment, meals, clean linen, general consumables, mail and parcels. The outgoing flows are as follows: samples, equipment to be sterilized, used cutlery, crockery and linen, waste, mail and parcels.

Around the world, the hospital world comes up against scaling and organization challenges in order to satisfy patient needs. These needs may often be urgent and require high quality and safety. In this context, we find complex systems, which are increasingly being studied by operational research, with the aim of bringing in optimized solutions while respecting a pre-established set of rules.

From 1980 to 2001, research conducted on the evaluation of logistics activity in the hospital world estimated that in France, this total represents approximately 31–34% of a hospital's activity (Bourgeon *et al.* 2001; Henning 1980; Kowalski 1991). Other, more recent, studies have concluded that it would be possible to reduce costs associated with hospital logistics by 15% (Davis 2004). From these studies, we can conclude that hospital logistics are a crucial area for economizing in hospitals and that this would require reorganization and the implementation of smarter systems.

The Champagne Sud hospitals are currently carrying out a review to improve the management of processes and procedures within their logistics network. This is being done through smart digitization, brought about through techniques tried and tested through operational research. However, the hospital has also clearly demonstrated its ambition of bringing about innovations in techniques by funding studies and the creation of tools. This is the framework within which our project has taken place. Within the framework of a CIFRE study[1], a collaborative project between the University of Technology of Troyes and the Troyes hospital center (THC), we work on optimizing logistics in the case of the flow of materials. These studies are part of a CIFRE project in partnership with THC.

THC is the largest employer in Aube, with an operating budget of 232.4 million euros, including 11.2 million euros of investment. It is made up of:

– the Hauts-Clos hospital;

– the Comte Henri residence;

– the retirement home in the Nazareth estate.

1 Industrial agreements for training through research, a program that funds companies that take in a doctoral student who is at the center of a collaborative project between the company and a public laboratory.

In France, the application of operational research has made contributions at all levels of decision making (strategic, tactical and operational). The resources made available and the time necessary to bring about solutions to such complex problems are calculated over a period of months. However, as we will see in this chapter, operational research with much lower resources allows us to propose solutions in terms of minutes or even seconds.

In the University of Tours, the doctoral work of Kergosien *et al.* (2011) was carried out in collaboration with the François Rabelais University of Tours focused on the problem of the transport of product flows and patient flows (allocation of transport to patients in real time through ambulances). To resolve the problems faced in this field, several methods inspired by operational research techniques were proposed: exact methods (linear programming models with whole numbers) and heuristic methods (greedy algorithms, tabu search with and without adaptative memory, genetic algorithms, mimetic algorithms). In the context of this project, the underlying problem of pickup and delivery was framed in a very specific way: indeed, the journeys made by vehicles are either for delivery or for pickup. Further, changing a vehicle is not allowed, which leaves scope for improvement in the quality of the solutions put in place. In fact, changing vehicles would make it possible to increase the utilization rate for the vehicles and thus maintain a fleet of optimal size.

In 2011, Virginie (André 2011) worked on the organization of flows of different products circulating in a hospital. There is a partnership between the Clermont-Ferrand teaching hospital and partner universities, such as the LIMOS research laboratory (*laboratoire d'informatique en modélisation et optimisation des systèmes*, Laboratory of Information Sciences for Modeling and Optimizing Systems) in Clermont-Ferrand. This partnership also enabled the study of other problems such as the scheduling of the surgical unit and the optimization of the medication circuit. Another example of a study that highlighted the scientific aspect of the problem of pickup and delivery, with considerations closer to reality, is the study carried out by Xu *et al.* (2003). However, this study worked on the fixed rule that "the delivery demands must be carried out in reverse order compared to the corresponding pickup demands".

Our studies follow these studies, while considering aspects that these studies did not approach. In our case study, we take into account the journeys

made by good drivers and also consider the welfare of the drivers on these journeys. This involves ensuring that rules regarding working hours, driving hours and rest times are respected. Thus, in our construction of the journeys, we work on the general case, without restricting ourselves to the problem of pickup or delivery. In other words, the only restriction we have taken into account is that it is not possible to deliver something that was not first collected. To the best of our knowledge, this problem has not been approached in previous studies. Further, in practice, the different flows (meals, linen, pharmacy, etc.) are transported in trolleys of different dimensions (length, width and height) in trucks that are also of different dimensions. This aspect, which has not been approached in literature so far, has been integrated into our work.

The NP-hard nature has already been demonstrated for the subproblems of the problem that we are working on. Indeed, earlier studies have demonstrated the level of difficulty of the problem of pickup and delivery within specific time windows (Dumas *et al.* 1991; Cordeau and Laporte 2003). To propose an efficient method for solving this problem, we have first worked on a tiered approach to the problem. At every step, this gave us proven methods to build on further. Our solutions at each step have been tested against instances in literature (when the problem was not new) or against instances taken from the THC's daily experiences. As we will see further on, the approaches we developed are efficient, not only in terms of the quality of the solution but also in terms of the computation time.

In the following sections, we will discuss hospital logistics and the links it has with operational research. We will then present the approach that we propose to solve this problem. Finally, we will present some optimization methods and techniques that we proposed and tested on real-life instances, as well as those taken from literature. These techniques focus on the problem of optimizing the journeys made by the vehicle for pickups and deliveries, while respecting the time windows for each visit and the capacity of the vehicle being used.

6.2. The hospital logistics problem

According to (Chow *et al.* 1994), hospital logistics activities can be divided into three categories:

– supplies: the process of buying and managing stocks of different products;

– production: transformative processes such as the washing of linen, the preparation of meals or the sterilization of equipment;

– distribution (or resupplying): the transport of transformed products in containers from the production units to the storage areas, before being used for patients.

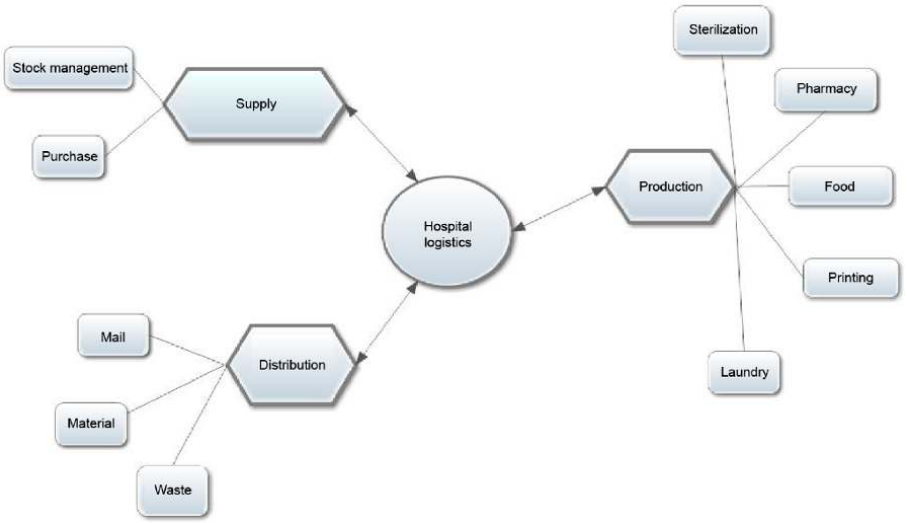

Figure 6.1. *The different logistics functions, from Chow et al. (1994)*

To the logistics functions given in Figure 6.1, we can also add the components of distribution: the distribution of food, laundry and pharmaceutical products flows.

6.2.1. *Operational research and the hospital world*

There are diverse applications of techniques developed in operational research in the hospital world. For a comprehensive view of this field, there are several general state-of-the-art discussions. One of the first studies to approach this problem was by Fries (1976); we then had projects proposed by researchers (Boldy 1987; Boldy and O'Kane 1982; Rosenhead 1978; Wiers 1997), who carried out literature reviews and offered propositions for

classifying problems encountered in the hospital world and that had been studied through operational research. There are also other reviews dedicated to recurrent problems in the hospital world, such as the organization of the surgical units (Cardoen *et al.* 2010), planning working hours for nurses (Burke *et al.* 2004), the criteria for measuring the performance of a health system (Li and Benton 1996), or the process of hierarchical analysis for decision-making in the medical field (Liberatore and Nydick 2008). More recently, (Castillo-Salazar *et al.* 2016) proposed a literature review on the subject of planning patient transport. The problems tackled by operational reviews are related to the patient's pathway from the time they are taken into care in their residence (ambulance journeys) to their discharge and return to their residence, with, in between, the care administered in emergency services, putting in place care teams, and organizing medication, meals and clean linen. All these components that contribute to the patient care and to the patient's well-being are brought in so they may be ready at the right time and the right place: techniques for planning under constraint, sequencing, journeys made by vehicles and stock management.

Table 6.1 lists the most recent work on problems of pickup and delivery in a fixed time frame and with a heterogeneous fleet of vehicles. It can be seen that no study on pickup and delivery studies the size of the fleet.

6.2.2. *Description, formalization and solution approach*

The goal of the research carried out in the context of optimizing logistics within the THC was to propose an efficient solution in order to re-size the team of drivers and the fleet of trucks. The chosen time horizons for planning was a weekly timeframe, as the requirements are periodical on a weekly basis. The costs we retained for our study are:

– the cost incurred by the number of drivers;

– the fixed cost incurred by the acquisition of the fleet of vehicles;

– the fuel costs used to cover all requirements.

The scaling of the team of drivers is subject to regulations on driving time and the break time for drivers operating vehicles larger than 3.5T and the regulations on working hours for an employee of a public hospital in France. When setting up the timetable for a driver, it may be that the driver changes vehicles and, in this case, the changeover time must also be considered.

Characteristics	*Publications*	(*Noumbissi Tchoupo* et al. *2016*)	(*Dumas* et al. *1991*)	(*Xu* et al. *2003*)	(*Qu and Bard 2013*)	(*Bettinelli* et al. *2014*)	(*Irnich 2000*)
Contexts	Vehicle with an adjustable capacity				x		
	Heterogeneous fleet of vehicles	x	x	x		x	x
	Scaling the fleet of vehicles				x		
	Different types of products			x			
	Possibility of overshooting the time window					x	
	Multiple windows			x			
Constraints	Parity constraints	x	x	x	x	x	x
	Respecting the transit window	x	x	x	x	x	
	Constraints around capacity of the vehicle	x	x	x		x	
	Constraints regarding precedence between a pickup request and an associated delivery request	x	x	x	x	x	x
	Duration of the journey			x			
Performance indicators	Fixed cost of the vehicles	x			x		
	Fuel costs	x	x	x	x	x	x
	Cost of not adhering to the timeframe					x	
	Time spent in the vehicle				x		
Resolution methods	Branch and price method					x	
	Column generation method		x	x			
	Benders' decomposition method	x					
	Two phase heuristics				x		

Table 6.1. *Pickup and delivery problems with a heterogeneous fleet of vehicles*

Publications	*Problems*	*Characteristics*	*Objectives*	*Types of products*
(Kergosien et al. *2013)*	Transport of products between hospitals; scaling teams	Meta heuristics, genetic algorithm (Mitchell *et al.* 1996) and tabu search (Glover 1989)	Minimizing the sum of the hours of the arrivals and the number of employees required	Pharma-ceutical consumables
(Medaglia et al. *2009)*	Search for the best site to process hospital waste	Problem with dual goals of positioning the installations (MIP), heuristics	Multiple-objectives: minimizing the transport costs, minimizing the number of employees assigned	Waste
(Shih and Chang 2001)	Planning of routes for periodic collection of waste in a logistics network	PVRP and MIP to assign routes for days of the week	Minimizing the transport costs, minimizing the number of kilometers traveled on a daily basis	Waste
(Swaminathan 2003)	Allocation of rare medicines to hospitals	Resolved with a heuristic	Minimizing the total value of the budget for medicines, leave/maximize the total value of the budget allocated for medications	Pharmaceutical products
Studied problem	Designing transport flows between hospitals and suppliers; scaling the team of drivers; scaling the fleet of vehicles	Linear program, ant colony algorithm	Minimizing the total cost (cost of the number of drivers used, fixed cost of the use of vehicles and the total fuel costs)	Linen, medication, meals and shop products

Table 6.2. *Publications on the problems of external hospital logistics coupled with the problem of assigning drivers (Volland et al. 2017)*

A requirement (or request) is defined as a request for collecting a quantity (number of trolleys) of a type of product from one site and a request for delivery of whatever has been collected to another site. Each request is characterized by the data: regarding the product type, a trolley number for this product type, a timeframe within which this operation must be carried out and the duration required for the operation to be carried out (loading, unloading and cleaning the vehicle). Each request is fulfilled by a driver by carrying out the pickup request before the associated delivery request using the same vehicle. In our case study, there are two types of flows: the supply flow and the removal flow. The supply flow corresponds to the pickup from the suppliers for delivery to the care service. The removal flow corresponds to pickup from the care service for delivery to the processing centers. The removal flow for meals or linen involves collecting meal trolleys or used linen trolleys that are sent to the central kitchen or the laundry, respectively. For medicines (or equipment), this involves returning empty trolleys to be used again for future deliveries.

Each type of product (food, linen, medicine and equipment) is delivered in a specific type of trolley. Consequently, four types of trolleys are considered and each has specific dimensions. The trolleys cannot be piled one atop the other, thus the chosen dimensions for the trolleys are length and width. The fact that the products are transported on trolleys poses the problem of arranging this across two dimensions during each pickup round in order to respect the constraints regarding the capacity of the truck. Our case study also presents constraints related to compatibility:

– product/product compatibility (certain products cannot be transported together);

– product/truck compatibility (certain products must be transported in specific vehicles, and this is the case with meal trolleys, for example, which must be transported in refrigerated trucks to conserve the cold chain);

– truck/request site compatibility (certain requests emanate from sites with specific access constraints).

Figure 6.2 presents an example of a solution to a problem consisting of five requests (hence, 10 requirements: five pickups and five deliveries), three vehicles and five types of flow (clean linen, used linen, equipment, meals and medication) The proposed solution consists of two drivers using three trucks

and the objective is to satisfy all demands. Each request made up of a pickup/delivery pair is carried out by the same driver and the same truck. Further, each pickup is made before its corresponding delivery. It is assumed that constraints relating to the time frame, capacity, compatibility and various regulations are respected. The first driver uses only one kind of vehicle and the second driver changes vehicles during his break.

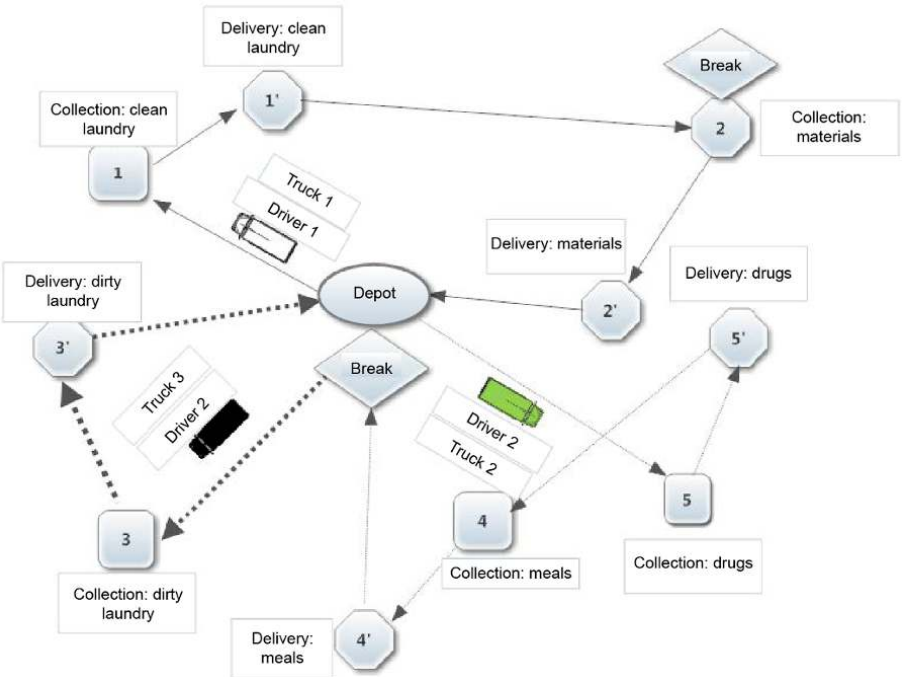

Figure 6.2. *Example of a problem*

The problem approached here is difficult as it is an extension of problem of pickup and delivery within a time frame, which is an NP-hard problem (Xu *et al.* 2003). In literature, research has been carried out on problems close to the one we pose (André 2011; Kergosien *et al.* 2011; Xu *et al.* 2003). However, these studies have not simultaneously considered all the aspects of the problem explored in our study. To propose efficient algorithms to resolve this problem, rich in the diversity of the problems that constitute it, we present a sequential resolution approach in order to use the different solutions proposed to resolve the subproblems.

6.3. Innovative methods and techniques

In this section, we propose a hierarchization of the problem in order to construct a complete solution to it using the solutions to the subproblems. We will also discuss some methods that we proposed and which were proven to be effective regarding the subproblem of journeys made by vehicle. In this section, since the research has not yet been published, we will not discuss the approaches that lead to a solution which integrate other tiers apart from that of vehicle journeys.

We proposed a hierarchization into four steps:

1) proposing a solution method to the pickup and delivery problem with a given time frame;

2) integrating the problems of compatibility between flows, between trucks and the flow being transported, and between trucks and the delivery or pickup site;

3) integrating the multiple dimension aspect (two dimensions) of the capacity of the vehicles, as the flows are transported in specific trolleys, in trucks whose containers are of different sizes;

4) integrating rules on breaks, rest time and driving time for the drivers.

The proposed approach is presented diagrammatically in Figure 6.3. This approach made it possible to carry out reorganization in 6 months, with considerable gains in the order of 10.8% (tens of thousands of euros/year). Further, we observed a decrease of over 71% (hundreds of hours per year) in waiting time before the requests were taken up by drivers.

In the following sections, we present the different work we carried out in order to integrate the subproblems and we propose a comprehensive solution method to the problem.

6.3.1. *The problem of pickups and deliveries within a time frame and with a homogeneous fleet of vehicles*

Several recent studies have explored the problem of pickups and deliveries with using a homogeneous fleet. For one of the definitions of this problem, see the article by Dumas *et al*. (1991). In this variant, we proposed an efficient

meta-heuristic, which is a hybridization of the ant colony algorithm with dedicated local search algorithms. We chose the ant colony algorithm because it constructed actionable solutions, unlike some other algorithms (for instance, the genetic algorithm), which often require a reconstruction in order to obtain actionable solutions.

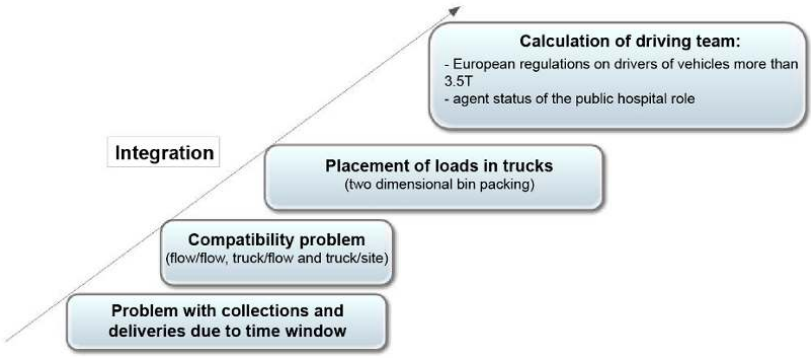

Figure 6.3. *Approach to the solution*

The heuristics for the ant colony were first proposed by Dorigo and Gambardella (1997) for research on the optimal pathways in a graph. It was inspired by the work of Goss *et al*. (1989), who studied the behavior of ants finding a path between their colonies and a food source. This technique led to several successes when used with combinatorial optimization problems. This was the case with the research carried out by Belmecheri *et al*. (2009) to resolve a problem with vehicular journeys within a certain time frame and using a heterogeneous fleet of vehicles.

An ant constructs a solution made up of a set of routes and each route is traveled by a vehicle. The routes are constructed in a sequential manner. A new route is added if all the demands are not satisfied and no routes can be inserted into the route under construction. Local searches have been proposed for each aspect of the goal to be achieved:

– reducing the cost of each route constructed (H1 algorithms);

– reducing the total cost of a solution due to the number of vehicles (H2 algorithms);

– reducing the fuel consumption in a solution (H3 algorithms).

The pseudopod of the proposed algorithm is given by:

```
Constructing an initial solution
while the best solution is not improved after a given number of
iterations do
    for each ant in the population do
        Construct a new solution that satisfies all demands
        while we can delete one route do
            Applying, respectively, the algorithms H2, H1 and H3
        end
        if The current solution has the same number of vehicles as the
        best solution that was found then
            while the total distance decreases do
                Applying, respectively, the algorithms: H2 and H3
            end
        end
        Carrying out a local update of the pheromones
    end
    Carrying out an overall update of the pheromones
end
```

Algorithm 6.1. *Pseudopod for the ACO hybrid*

For more details on this solution method, see (Noumbissi Tchoupo *et al.* 2017).

The experimental results for 56 instances of 100 requests in *Benchmark* by Li and Lim (2003) showed that the proposed hybrid meta-heuristic is better than existing algorithms, up to then, to resolve this kind of a problem. Indeed, in 98.2% (55/56) of the cases, a best solution or a solution equal to the best-known solution was found and it found a better solution than the best-known solution in 44.6% (25/56) of cases.

6.3.2. *Pickup and delivery problems with a time frame and a heterogeneous fleet of vehicles of finite size*

Work carried out on the $P2$ problem (Noumbissi Tchoupo *et al.* 2016) made it possible to determine efficient techniques to reduce the search space

for solutions. Valid inequalities were proposed for this problem. This problem was modeled by generalizing the formulation proposed by Grandinetti *et al.* (2014) for the case of a homogeneous fleet of vehicles. And to solve this problem we proposed an algorithm based on Benders decomposition.

In the following section, we will consider a heterogeneous fleet of vehicles K. Each vehicle, k, with a capacity Q^k, a fixed cost δ^k and a cost v^k per kilometer traveled. Each vehicle's journey begins and ends at the depot. Let n be the number of requests. Each request consists of a pair: a pickup request and a delivery request. All requests must be satisfied. Let A be the set of arcs and V be the set of vertices. The graph for the transports is modeled by a direct graph $G =< V, A >$, where $V = \{0, 1, \cdots, n, n+1, \cdots, 2n, 2n+1\}$. The vertices 0 and $2n+1$ are the fictional requests modeling the departure from and return to the depot. An arc $(i, j) \in A$ if $max\{t_{0i}, a_i\} + s_i + t_{ij} \leq b_j$ and $i \neq j$. Let $P \subset V$ designate the subset of vertices representing the set of pickup requests and $D \subset V$ the set of delivery requests. For any request $i \in P$, $q_i > 0$ represents the quantity to be collected and for any request $i \in D$, $q_i < 0$ is the quantity to be delivered. The negativity of the quantities for the delivery requests is due to the fact that they correspond to a reduction in the number of trolleys present in the vehicle after a delivery request has been carried out. Each request $i \in V$ corresponds to a window for the visit $[a_i, b_i]$. For all $i \in P$, $n+i$ designates the associated delivery request and $|q_i| = |q_{n+i}|$. t_{ij} is the Euclidian distance between the requesting sites i and j, and s_i is the time required to carry out the service i. In practice, s_i is the time required for loading or unloading the request i and does not depend only on the number of trolleys but also on the characteristics of the site.

The variables in the decision are: $x^k_{i,j}$, which is a binary variable whose value is 1 if the vehicle k satisfies the demand i and then j, 0 if not; B^k_i, which is the continuous variable representing the date of commencement of the servicing of the request i by the vehicle k; $Q^k_{i,j}$, which represents the number of trolleys present in the vehicle k on the arc (i, j). For the next part, let us write:

$$c^k_{i,j} = v^k d_{ij} \qquad [6.1]$$

n	Number of requests
A	Set of arcs
V	Set of vertices (requests)
P	Set of pickup requests
D	Set of delivery requests
K	Set of vehicles
Q^k	Capacity of the vehicle k
δ^k	Fixed cost of the vehicle k
v^k	Cost per kilometer for the vehicle k
$\|q_i\|$	Quantity of i to be delivered or collected
a_i	Earliest start date for i
b_i	Latest start date for i
s_i	Service time for i
$t_{i,j}$	Journey time from i to j
$d_{i,j}$	Distance traveled from i to j
$n+i$	Delivery corresponding to the pickup i

Table 6.3. *Notations*

This is written in a linear mathematical program with mixed numbers as:

$$Min \sum_{i \in P} \sum_{k \in K} \delta_k x_{0i}^k + \sum_{(i,j) \in A} \sum_{k \in K} c_{ij}^k x_{ij}^k \qquad [6.2]$$

$$\forall i \in P, \sum_{k \in K} \sum_{(i,j) \in A} x_{ij}^k = 1 \qquad [6.3]$$

$$\forall (i,k) \in P \times K, \sum_{j|(i,j) \in A} x_{ij}^k = \sum_{j|(n+i,j) \in A} x_{n+ij} \qquad [6.4]$$

$$\forall k \in K, \sum_{i \in P} x_{0i}^k \leq 1 \qquad [6.5]$$

$$\forall k \in K, \sum_{i \in P} x_{0i}^k = \sum_{i \in D} x_{i(2n+1)}^k \qquad [6.6]$$

$$\forall (i,k) \in P \cup D \times K, \sum_{j|(i,j) \in A} x_{ij}^k \leq \sum_{j \in P} x_{0j}^k \qquad [6.7]$$

$$\forall (i,k) \in P \cup D \times K \qquad [6.8]$$

$$\sum_{j|(i,j)\in A} x_{ij}^k - \sum_{j|(j,i)\in A} x_{ji}^k = 0 \qquad [6.9]$$

$$\forall (i,j) \in A, \forall k \in K, \quad B_i^k - b_i + (b_i + s_i + t_{ij}) x_{ij}^k \leq B_j^k \qquad [6.10]$$

$$\forall (i,k) \in P \times K, \quad B_i^k - B_{n+i}^k + (s_i + t_{in+i}) \sum_{j\in V} x_{ij}^k \leq 0 \qquad [6.11]$$

$$\forall (i,k) \in V \times K, \quad a_i \sum_{j|(i,j)\in A} x_{ij}^k \leq B_i^k \leq b_i \sum_{j|(ij)\in A} x_{ij}^k \qquad [6.12]$$

$$\sum_{i\in P} \sum_{k\in K} Q_{0i}^k + \sum_{i\in D} \sum_{k\in K} Q_{i(2n+1)}^k = 0 \qquad [6.13]$$

$$\forall i \in N, \quad \sum_{k\in K} \sum_{j|(i,j)\in A} Q_{ij}^k - \sum_{k\in K} \sum_{j|(j,i)\in A} Q_{ji}^k = q_i \qquad [6.14]$$

$$\forall (i,j) \in A, \forall k \in K, \;\; Q_{ij}^k \leq Q_k x_{ij}^k \qquad [6.15]$$

$$\forall (i,j) \in A, \forall k \in K, \;\; x_{ij}^k \in \{0,1\}, \; Q_{ij}^k > 0 \qquad [6.16]$$

$$\forall (i,k) \in P \times K, \;\; B_i^k > 0 \qquad [6.17]$$

The objective [6.2] is the minimization of the fixed cost of use of the vehicles and the per kilometer cost of the journeys. The constraints [6.3] and [6.4] model the adherence to the time frame and the precedence in service between a pickup point and the corresponding delivery point. Constraint [6.5] obliges vehicles to leave the depot once at most, while constraint [6.6] ensures their return to the depot. Constraint [6.7] obliges the vehicles to leave the depot to service a request. Constraints [6.8], [6.9], [6.10] and [6.11] model the loading of the vehicles along the journey and ensure that the capacity of each vehicle is not violated. Constraint [6.12] ensures that all vehicles leave and return to the depot empty. Constraints [6.13] and [6.14] model the loading of the vehicles along the journey and ensure that the number of trolleys present in each vehicle does not exceed the capacity.

6.3.2.1. *Some techniques to accelerate the solution*

To accelerate the procedure for solving problems in operational research, it is often usual to determine techniques to reduce the solution space before starting on the solution, strictly speaking, of the problem. Based on earlier work, we have proposed results that allow us to reduce the solution space.

Proposed for the first time by Desrochers and Laporte (1991) for TSP with a time frame, (Cordeau 2006) proposed the reinforcement of the limits of the variable B_i by:

$$B_i \geq a_i + \sum_{j \in N \setminus \{i\}} max\{0, a_j - a_i + s_j + t_{ij}\} x_{ij}$$

$$B_i \leq b_i - \sum_{j \in N \setminus \{i\}} max\{0, b_i - b_j + s_i + t_{ij}\} x_{ij}$$

We extend this proposition to the case of a heterogeneous fleet of vehicles through:

$$B_i^k \geq a_i + \sum_{j \in N \setminus \{i\}} max\{0, a_j - a_i + s_j + t_{ij}\} x_{ij}^k, \ \forall k \in K$$

$$B_i^k \leq b_i - \sum_{j \in N \setminus \{i\}} max\{0, b_i - b_j + s_i + t_{ij}\} x_{ij}^k, \ \forall k \in K$$

Let us assume that $Q^0 \leq Q_1 \leq \ldots \leq Q^{|K|}$. We can then see that:

– $(0, n+i)$ is unfeasible $\forall i \in P$;

– $(i, 2n+1)$ is unfeasible $\forall i \in P$.

For the VRPPDTW problem, $\forall i, j \in P$, Dumas *et al.* (1991) proposed eliminating the arcs:

– $(i, n+j)$, if the route $(j, i, n+j, n+i)$ is unfeasible;

– $(n+i, j)$, if the route $(i, n+i, j, n+j)$ is unfeasible;

– (i, j), if the routes $(i, j, n+i, n+j)$ and $(i, j, n+j, n+i)$ are unfeasible;

– $(n+i, n+j)$, if the routes $(i, j, n+i, n+j)$ and $(j, i, n+i, n+j)$ are unfeasible.

We propose adding:

– (i, i) is unfeasible $\forall i \in N$;

– (i, j) and $(j, n+i)$, are unfeasible, if $a_i + t_{ij} + t_{j,n+i} > b_{n+i}$ $\forall i \in P, j \in N \setminus \{0, i, n+i, 2n+1\}$;

– (i, j) is unfeasible, if $q_i + q_j > Q^{|K|}$ $\forall i, j \in P$.

6.3.2.2. *Benders' decomposition*

We propose resolving HVRPPDTW by using algorithms based on Benders' decomposition by decomposing the mixed variable linear program (PL). Benders' decomposition is a decomposition method that is used in operational research to resolve linear optimization problems that have a block structure. It is based on the principle of generating constraints as it progresses toward the solution. Proceeding through generation of lines, it may be perceived as the pair to the (Dantzig and Wolfe 1960) decomposition method based on the generation of columns.

The master program, still called the restricted linear program, is given by:

$$(Q) \quad min \sum_{i \in P} \sum_{k \in K} \delta^k x_{0i}^k + \sum_{(i,j) \in A} \sum_{k \in K} c_{ij}^k x_{ij}^k$$

subject to [6.2], [6.12], [6.16] and [6.17].

From now on, an optimal solution of (Q) will be denoted by x^*.

The idea in algorithm 6.2 is to not simultaneously consider the large number of constraints. The advantage that this method offers arises from the fact that it captures a part of the information on the restrictions around precedence in the graph using the results presented in section 6.3.2.1. The number of arcs in the graph is thus reduced and it then appears natural to generate, as we progress, the constraints for the precedences that have been violated.

The impact study on the reduction of the search space, in addition with valid inequalities, shows the efficiency of these techniques in reducing the computation time. Further, we have tested our algorithm on instances from literature (in the case of the fleet of homogeneous vehicles) and obtained optimal solutions for certain instances.

```
1) Solve (Q);
if x* is feasible then
  | 2) x* is optimal for (PL), stop.
else
  | while there exists a constraint capacity violated by x* do
  |   | 3) Adding in Q the violated constraints ;
  |   | 4) Solving (Q);
  | end
  | x* is an optimal solution for (PL), stop.
end
```

Algorithm 6.2. *Algorithm*

The logistics center of the THC includes a fleet of vehicles of different capacities. The pickup and delivery requests are periodic, over a period of 7 days and thus, we have seven instances, one per day. Using instances from the THC, the algorithm for the Benders' decomposition optimally solved all the instances (one instance/day), with a mean computation time of 10 min.

6.3.3. *Pickup and delivery problem with a time frame and a heterogeneous fleet of vehicles of infinite size*

In this section, we present the work we did on the new problem that we introduced and that was born out of a real-life problem. To the best of our knowledge, this problem has never been studied in literature and so we proposed a new set of instances that came out of the coupling of the instances from Li and Lim (for requests) and Liu and Shen (1999) for the different types of vehicles.

We propose a column-generation algorithm in which the subproblem of finding the variable for the negative reduced cost is subdivided into subproblems (a problem for each vehicle type). The type of subproblem has been identified as a restricted shortest route denoted by *ESPPTWCPD* (*Elementary Shortest Path Problem with Time Windows, Capacity, and Pickup and Delivery*).

Linear models with whole numbers have been proposed to model and resolve the subproblems. To accelerate the solution of the subproblems, certain heuristics have been proposed.

6.3.3.1. *Modeling*

In this section, we model the problem of pickups and deliveries using a heterogeneous fleet as a problem of partitioning of demands. Each partition is a route traveled by one type of vehicle. A route starts at ends at the depot, 0, while satisfying a series of requests and respecting the constraints of the time windows, the capacity of the vehicles and the constraints related to the coupling of the demands. The coupling constraints express the fact that any pickup request is coupled with a delivery request, such that the requests for pickup and delivery are carried out in the same journey and the pickup request must be satisfied before the associated delivery request.

Let K be the set of the types of vehicles. Let $\mathcal{R}^k$ denote the set of feasible routes for a type of vehicle $k \in K$ and let us posit $\mathcal{R} = \bigcup_{k \in K} \mathcal{R}^k$.

For each route $r \in \mathcal{R}^k$, the fuel cost is denoted by c_r^k. Let $\mathcal{R}_r^k$ be the subset of requests fulfilled by the route $r \in \mathcal{R}^k$. Let λ_s be a binary variable equal to 1 if the route $s \in \mathcal{R}$ is integrated into the solution and 0, if not. We can see that for all $s \in \mathcal{R}$, there exist a $k_s \in K$ and $r_s \in \mathcal{R}^{k_s}$ such that: $s = r_s$. We model the problem through:

$$(MP) \;\; Min \;\; \sum_{s \in \mathcal{R}} (f^{k_s} + c_{r_s}^{k_s}) \lambda_s \qquad [6.18]$$

$$\sum_{s \in \mathcal{R}/i \in s} \lambda_s = 1 \, ; \, \forall i \in P \qquad [6.19]$$

$$\lambda_s \in \{0, 1\} \, ; \, \forall s \in \mathcal{R} \qquad [6.20]$$

6.3.3.2. *Solution method and results*

We propose a column generation method to solve the relax version (RMP) of the master problem (MP). The problem of finding the column to insert is modeled by a linear model with mixed variables. Heuristics have been proposed to accelerate the search for columns with negative reduced cost. If the optimal solution of the RMP is not an integer, the integer version (IRMP) of this problem is resolved. In this case, it is not possible to know whether or not the solution obtained by the IRMP is optimal.

The proposed algorithm returns an actionable solution for all instances. It finds an optimal solution for 11% of instances. In 45% of instances, it makes

it possible to find a lower limit that makes it possible to judge the quality of an integer solution found. An interesting observation was made on instances with "small" time windows, for which the algorithm found a lower limit in 86% of instances. For the instances in this configuration, the integer solution found is with a mean gap of 1.9%. Thus, we can state that in this configuration, the solutions returned are close to optimal. The computation time remains reasonable. These results form an initial version of the best-known solutions, which will be used in the future as the base for testing of future algorithms.

6.4. Conclusion

In this chapter, we presented a complex logistics problem in the hospital world. We proposed a hierarchization, with the aim of using scientific research carried out on the subproblems of this problem. Following this proposal, we established a procedure for solving the problem and the initial solutions proposed resulted in the implementation, within the Troyes hospital center, of a new organization of the journeys made by the vehicles with significant savings in terms of time and money, and with unexpected positive consequences such as a drop in the number of hours spent as waiting time by the drivers. In this procedure for the solution, we contributed significantly to the formalization and solution of problems that have not yet been taken up in the scientific milieu. This resulted in publications and, consequently, a scientific recognition of this work. Because of the partnership agreement between THC, the University of Technology of Troyes and the start-up Opta-Lp, the proposed solutions have been implemented in the form of a software package.

6.5. References

André V. (2011). Problème de livraison-collecte dans un environnement hospitalier: méthodes d'optimisation, modèle de simulation et couplages. PhD Thesis, Université Blaise Pascal, Clermont-Ferrand.

Belmecheri, F., Prins, C., Yalaoui, F., Amodeo, L. (2009). An ant colony optimization algorithm for a vehicle routing problem with heterogeneous fleet, mixed backhauls, and time windows. *IFAC Proceedings Volumes*, 42(4), 1550–1555.

Bent, R., Van Hentenryck, P. (2006). A two-stage hybrid algorithm for pickup and delivery vehicle routing problems with time windows. *Computers & Operations Research*, 33(4), 875–893.

Bettinelli, A., Ceselli, A., Righini, G. (2014). A branch-and-price algorithm for the multi-depot heterogeneous-fleet pickup and delivery problem with soft time windows. *Mathematical Programming Computation*, 6(2), 171–197.

Boldy, D.P. (1987). The relationship between decision support systems and operational research: health care examples. *European Journal of Operational Research*, 29(2), 128–134.

Boldy, D.P., O'Kane, P.C. (1982). Health operational research, a selective overview. *European Journal of Operational Research*, 10(1), 1–9.

Bourgeon, B., Constantin, A., Karolszyk, G., Marquot, J.-F., Pedrini, S., Landry, S., Diaz, A., Estampe, D. (2001). Évaluation des coûts logistiques hospitaliers en France et aux Pays-Bas. *Logistique & Management*, 9(1), 81–87.

Burke, E.K., De Causmaecker, P., Berghe, G.V., Van Landeghem, H. (2004). The state of the art of nurse rostering. *Journal of Scheduling*, 7(6), 441–499.

Cardoen, B., Demeulemeester, E., Beliën, J. (2010). Operating room planning and scheduling: a literature review. *European Journal of Operational Research*, 201(3), 921–932.

Castillo-Salazar, J.-A., Landa-Silva, D., Qu, R. (2016). Workforce scheduling and routing problems: literature survey and computational study. *Annals of Operations Research*, 239(1), 39–67.

Chow, G., Heaver, T.D., Henriksson, L.E. (1994). Logistics performance: definition and measurement. *International Journal of Physical Distribution & Logistics Management*, 24(1), 17–28.

Cordeau, J.-F. (2006). A branch-and-cut algorithm for the dial-a-ride problem. *Operations Research*, 54(3), 573–586.

Cordeau, J.-F., Laporte, G. (2003). A tabu search heuristic for the static multi-vehicle dial-a-ride problem. *Transportation Research Part B: Methodological*, 37(6), 579–594.

Cornuéjols, G. (2008). Valid inequalities for mixed integer linear programs. *Mathematical Programming*, 112(1), 3–44.

Dantzig, G.B., Wolfe, P. (1960). Decomposition principle for linear programs. *Operations Research*, 8(1), 101–111.

Davis, R.N. (2004). No more chances for supply-chain savings? Look again! Many hospitals assume they have exhausted opportunities to reduce supply-chain costs. but a well-coordinated, interdisciplinary effort may still yield substantial savings. *Healthcare Financial Management*, 58(1), 68–76.

Desrochers, M., Laporte, G. (1991). Improvements and extensions to the Miller-Tucker-Zemlin subtour elimination constraints. *Operations Research Letters*, 10(1), 27–36.

Dorigo, M., Gambardella, L.M. (1997). Ant colony system: a cooperative learning approach to the traveling salesman problem. *IEEE Transactions on Evolutionary Computation*, 1(1), 53–66.

Dumas, Y., Desrosiers, J., Soumis, F. (1991). The pickup and delivery problem with time windows. *European Journal of Operational Research*, 54(1), 7–22.

Fries, B.E. (1976). Bibliography of operations research in health-care systems. *Operations Research*, 24(5), 801–814.

Glover, F. (1989). Tabu search—part I. *ORSA Journal on Computing*, 1(3), 190–206.

Goss, S., Aron, S., Deneubourg, J.-L., Pasteels, J.-M. (1989). Self-organized shortcuts in the argentine ant. *Naturwissenschaften*, 76(12), 579–581.

Grandinetti, L., Guerriero, F., Pezzella, F., Pisacane, O. (2014). The multi-objective multi-vehicle pickup and delivery problem with time windows. *Procedia – Social and Behavioral Sciences*, 111, 203–212.

Henning, W.K. (1980). The financial impact of materials management. *Hospital Financial Management*, 34(2), 36–42.

Irnich, S. (2000). A multi-depot pickup and delivery problem with a single hub and heterogeneous vehicles. *European Journal of Operational Research*, 122(2), 310–328.

Kergosien, Y., Lenté, C., Piton, D., Billaut, J.C. (2011). A tabu search heuristic for a dynamic transportation problem of patients between care units. *HAL*, hal-00488270.

Kergosien, Y., Lenté, C., Billaut, J-C., Perrin, S. (2013). Metaheuristic algorithms for solving two interconnected vehicle routing problems in a hospital complex. *Computers & Operations Research*, 40(10), 2508–2518.

Kowalski, J.C. (1991). Materials management crucial to overall efficiency. *Healthcare Financial Management: Journal of the Healthcare Financial Management Association*, 45(1), 40–42.

Li, H., Lim, A. (2003). A metaheuristic for the pickup and delivery problem with time windows. *International Journal on Artificial Intelligence Tools*, 12(02), 173–186.

Li, L.X., Benton, W.C. (1996). Performance measurement criteria in health care organizations: review and future research directions. *European Journal of Operational Research*, 93(3), 449–468.

Liberatore, M.J., Nydick, R.L. (2008). The analytic hierarchy process in medical and health care decision making: A literature review. *European Journal of Operational Research*, 189(1), 194–207.

Liu, F.-H., Shen, S.-Y. (1999). The fleet size and mix vehicle routing problem with time windows. *Journal of the Operational Research Society*, 50(7), 721–732.

Medaglia, A.L., Villegas, J.-G., Rodríguez-Coca, D.-M. (2009). Hybrid bi-objective evolutionary algorithms for the design of a hospital waste management network. *Journal of Heuristics*, 15(2), 153.

Mitchell, M., Crutchfield, J.P., Das, R. (1996). Evolving cellular automata with genetic algorithms: a review of recent work. *Proceedings of the First International Conference on Evolutionary Computation and Its Applications (EvCA'96)*. Russian Academy of Sciences, Moscow.

Nagata, Y., Kobayashi, S. (2010). *Guided Ejection Search for the Pickup and Delivery Problem with Time Windows*. Springer, Berlin.

Nalepa, J., Blocho, M. (2016). Enhanced guided ejection search for the pickup and delivery problem with time windows. *Lecture Notes in Computer Science*, 9621, 388–398.

Noumbissi Tchoupo, M.N., Yalaoui, A., Amodeo, L., Yaloui, F., Lutz, F. (2016). Problème de collectes et livraisons avec fenêtres de temps et flotte homogène. University assignment, Université de Technologie de Troyes, Troyes.

Noumbissi Tchoupo, M.N., Yalaoui, A., Amodeo, L., Yalaoui, F., Lutz, F. (2017). Ant colony optimization algorithm for pickup and delivery problem with time windows. In *Methodologies and Applications Optimization and Decision Science*, Sforza, A., Sterle, C. (eds), Springer, Berlin, 181–191.

Qu, Y., Bard, J.F. (2013). The heterogeneous pickup and delivery problem with configurable vehicle capacity. *Transportation Research Part C: Emerging Technologies*, 32, 1–20.

Ropke, S., Pisinger, D. (2006). An adaptive large neighborhood search heuristic for the pickup and delivery problem with time windows. *Transportation Science*, 40(4), 455–472.

Rosenhead, J. (1978). Operational research in health services planning. *European Journal of Operational Research*, 2(2), 75–85.

Shih, L.-H., Chang, H.-C. (2001). A routing and scheduling system for infectious waste pickup. *Environmental Modeling & Assessment*, 6(4), 261–269.

Swaminathan, J.M. (2003). Decision support for allocating scarce drugs. *Interfaces*, 33(2), 1–11.

Volland, J., Fügener, A., Schoenfelder, J., Brunner, J.O. (2017). Material logistics in hospitals: a literature review. *Omega*, 69, 82–101.

Wiers, V.C.S. (1997). A review of the applicability of OR and AI scheduling techniques in practice. *Omega*, 25(2), 145–153.

Xu, H., Chen, Z.-L., Rajagopal, S., Arunapuram, S. (2003). Solving a practical pickup and delivery problem. *Transportation Science*, 37(3), 347–364.