Blood Products Inventory Pickup and Delivery Problem under Time Windows Constraints

Imane Hssini[1], Nadine Meskens[1] and Fouad Riane[2]
[1]*Louvain School of Management, Catholic University of Louvain, Mons, Belgium*
[2]*Ecole Centrale Casablanca, Casablanca, Morocco*

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Abstract: The inventory pickup and delivery problem with time windows (IPDPTW) addressed in this paper is a variant of the well known inventory routing problem (IRP). It consists in combining the inventory management problem and the problem of delivery and collection under the constraints of time window. In our study, we apply this approach to model a blood products distribution system over a certain horizon. The objective is to determine for each period of the planning horizon, the quantities of products to deliver and collect as well as the routing to be performed by each vehicle in order to minimize the total transportation and storage cost without allowing shortages. We present a brief review of literature related to our problem and we provide a mathematical model that takes into account the constraint of perishability.

1 INTRODUCTION

Blood is a critical commodity for human race. The demand for blood products is stochastic while the supply is irregular. The management in such context consists on matching supply and demand in an efficient manner. This task becomes complicated when one considers the fact that blood products are perishable. Shortages can cause increase mortality rates while outdates products are not accepted (Beliën and Forcé, 2012).

An efficient manner to handle the problem of concern is to integrate the all supply chain processes. In this context, the Inventory Routing Problem (IRP) method can achieve this purpose by managing simultaneously the distribution and the storage. Indeed, the IRP objective is to determine the optimal distribution circuit according to the topology adopted: from a central warehouse to a set of clients ("one to many" typology) or to a single customer ("one to one" typology), or from several warehouses to a single client ("many to one"), or from several warehouses to several customers (" many to many"). This circuit (or these circuits) must jointly optimize the costs of transportation and storage without causing any shortage. It thus consists to answer three questions: when each customer should be supplied? How much should we deliver to each customer every visit? And which route(s) should be used?

The IRP problem has been addressed by different authors in several studies. We cite among them the work of (Coelho et al., 2014) and (Bertazzi and Speranza, 2012). They have featured very interesting literature reviews where they classified the IRP according to several variants such as:

- The nature of demand: deterministic or stochastic.
- The planning horizon: Finite or infinite.
- The size of the fleet: A single vehicle, multiple or unconstrained.
- The nature of the fleet: Homogeneous or Heterogeneous.
- The routing: direct or multiple.
- The inventory decision: nonnegative, back-orders or lost sales.
- The number and the type of products: one or multi-products, homogeneous or heterogeneous.
- Periodicity: one or multi-periods.

In addition to the variants mentioned above, the formulation of an IRP problem requires the definition of an objective function. Generally the aim of this function is to minimize simultaneously the inventory and the transportation costs. Since the IRP problem is an extension of vehicle routing problem (VRP), it is considered as NP-hard problem (Coelho et al., 2014).

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In our research, we aim at optimizing the supply chain of blood products by ensuring the availability of the right product in the right quantity at the right time while reducing the inventory and transport costs. This study will focus on the Belgian blood supply chain.

For the French-speaking part of Belgium, the management of the supply chain of blood is at 95% guaranteed by the Red Cross (Croix Rouge, 2012). This ensures the smooth running of the blood collection process from blood donation until the delivery of various blood products to hospitals, passing through storage.

The blood service of the Red Cross is responsible for the organization and the planning of blood collection which is done in fixed collection sites and also through mobile collection 'bloodmobiles'. Every day, the Red Cross distribution service organizes shuttles to pick up the blood bags collected at blood centers and route them to the Red Cross blood central service (central and unique geographical location) where they will be decomposed, qualified biologically and then stored in the form of three perishable products called blood products (plasma, red cells, platelets) before being distributed. Theses shuttles carry also the bags of plasma and platelets collected by Apheresis in order to be qualified biologically and then stored before being distributed. The Apheresis is a blood sampling technique for taking a single blood component (plasma, platelets, red blood cells) using a cell separator Thus, during an apheresis donation, the required component is collected in a sample bag, and other components are returned to the donor.

Due to the heterogeneity of these products in terms of shelf life and storage temperature, the conditions of storage and distribution must be appropriate to each product. The blood service uses the same vehicle (with limited capacity) pick up the collected products (Whole blood, non qualified plasma and platelets) from the blood centers and at the same time to deliver the blood products to hospitals (figure 1).

The hospitals served by the Red Cross are divided into four regions (clusters), each hospital has a time window during which it should be visited and has a frequency of visits that is based on its consumption.

The plasma is transported separately from other products, as it is distributed in a frozen state and under a temperature of -25 ° C. Therefore, a specific vehicle should be used to transport this product. Our study will then cover only the distribution of platelets and red blood cells.

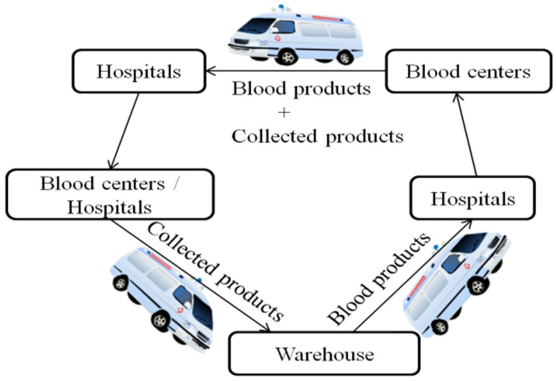

Figure 1: The route for Pickup and Delivery of blood products.

The stochastic nature of the demand, either in the number of patients who need blood products or in number of blood units required by each patient, may imply shortages which are not authorized because blood products are vital.

To improve the performance of blood products distribution process, it is necessary to optimize both the inventory management problem and the vehicle routing problem with pickup and delivery and time windows (VRPPDTW). This problem is referred to as an inventory pickup and delivery problem with time windows (IPDPTW).

Furthermore, in the VRPPDTW, the vehicles must ensure during the same tour a dual service: pickup and delivery of products to customers during specific periods of time called time windows. This temporal constraint can be divided into two types: tight time windows and wide time windows.

In the case of the tight time windows, the customer cannot be visited outside the time window i.e. if a vehicle arrives to customer location before the start of the time window, then it must wait until the beginning of the time window to deliver, and if it arrives late (after the end of the time window), it cannot serve the customer. While in the case of the wide windows, the time windows cannot be respected: the customer can be visited outside the time window; however, the penalties can be applied to the supplier. In this paper, we study the IPDPTW problem as part of a two stage blood product supply chain (a single supplier with multiple hospitals and blood centers). In reality, the demand of blood products is stochastic; however, to simplify our model we assume that the demand is deterministic. Referring to the classification of the IRP problem presented by (Coelho et al., 2014), the problem of concern is a deterministic, multi-period, multi-product, multi-vehicle, multi-routing problem over finite planning horizon.

The objective function is the minimization of the inventory and the transportation costs. This paper is organized as follows. We start reviewing related studies encountered in the literature. We then suggest a mathematical formulation for the problem that we solved to optimality for small size instances. We finally analyze the relevant computational results.

2 RELATED LITERATURE

During the last two decades, the literature on the IRP problem has increased exponentially. Despite the abundant literature on the IRP problem, we did not find any papers that address the problem of Inventory Pickup and Delivery Problem with Time Windows for Perishable Products (IPDPTWPP). To this end, we have introduced in this state of the art the articles dealing the IRP problem applied to perishable products since blood products share this relevant characteristic.

Indeed, the IRP problem researches related to perishable products are very rare. Of these, we include those performed by (Federgruen et al., 1986) ; (Coelho and Laporte, 2014) ; (Jia et al., 2014) ; (Chen and Lin, 2009) ; (Hemmelmayr et al., 2010) ; (Hemmelmayr et al., 2009); (Rusdiansyah and Tsao, 2005) ; (Zanoni and Zavanella, 2007) ; (Le et al., 2013) ; (Niakan and Rahimi, 2015) ; (Mirzaei and Seifi, 2015) ; (Diabat et al., 2014); (Soysal et al., 2015); (Al Shamsi et al., 2014); (Kande et al., 2014).

Among the researchers interested in the IRP problem with a single perishable product we quote: (Coelho and Laporte, 2014) ; (Hemmelmayr et al., 2009); (Rusdiansyah and Tsao, 2005) ; (Diabat et al., 2014); (Soysal et al., 2015); (Jia et al., 2014). Each of them analyzed the problem in a different way according to the used variants (number and nature of product, nature of demand, size of fleet...) or the proposed solution. For example, (Rusdiansyah and Tsao, 2005) ; (Diabat et al., 2014); (Jia et al., 2014); (Mirzaei and Seifi, 2015) have studied the IRP problem in the case of a deterministic demand, others such as (Soysal et al., 2015); (Coelho and Laporte, 2014) are interested in the case of a stochastic demand. In these articles, the authors have used several homogeneous vehicles to transport products; they targeted the minimization of costs (transport, storage and shortages) as the main objective function. In the case of multiple perishable products, (Al Shamsi et al., 2014); (Zanoni and Zavanella, 2007) ; (Le et al., 2013) studied the IRP with deterministic demand. In addition to the multiplicity of products, the stochasticity of demand was considered by researchers as (Federgruen et al., 1986) ; (Chen and Lin, 2009); (Hemmelmayr et al., 2010) and (Niakan and Rahimi, 2015).

Blood products have been the subject of some works such as those of (Federgruen et al., 1986) ; (Hemmelmayr et al., 2010) ; (Hemmelmayr et al., 2009). Indeed, (Hemmelmayr et al., 2009) studied the impact of the adoption of the VMI policy by the Austrian Red Cross blood service. The objective of this study was to minimize the distribution cost. They have developed a flexible vehicle routing system to deliver one blood product with deterministic demand. This study has been extended by (Hemmelmayr et al., 2010) to cover the case of several blood products with a stochastic demand.

Certainly the optimization of inventory management and distribution of blood products is complex given the perishable nature of these products and their heterogeneity. In fact, each blood product has its own shelf life, storage temperature, temperature to be maintained during transport, storage conditions: in the case of blood platelets (must be stored under continuous agitation), so each product should be stored separately from other products and transported separately in insulated containers. All these constraints further complicate the management of the distribution process and storage of blood products.

According to this state of art we noticed that the articles on the IRP problem applied to perishable products are few in number especially in the case of blood products (three papers), and, the only paper that has searched the almost similar characteristics to ours is that of (Niakan and Rahimi, 2015). However, our research is distinguished by taking into account constraints such as the respect time windows and treatment of problems of delivery and pickup at the same time. To our knowledge no research has focused on optimizing inventory management problems of perishable products and vehicle routing problems with pickup and delivery with time window simultaneously. In the following, we present the mathematical model.

3 PROBLEM DESCRIPTION

In our problem, a single warehouse receives from the laboratory during each period three heterogeneous perishable products (red cells, plasma and platelets) (indexed $r \in P$ each with a quantity N_{rt}. Each product has an age a_{rt} at period t. In this study, we will be limited to the case of distribution of platelets and red blood cells seen as plasma are distributed separately from the other blood components. The warehouse uses a fleet of heterogeneous vehicles V (indexed by $v \in V$), with a charge capacity Cap_v of insulated containers K and a travel cost per km of CT_v to distribute these products to a set of geographically dispersed hospitals denoted H (indexed by i or j Є H) and at the same time to collect the bags of whole blood and plasma and platelets (indexed r' Є P') collected in blood centers and which are not yet qualified biologically. The quantity of qualified products is $Z_{r't}$. In the following we present the parameters, the sets and the decision variables that are used:

Table 1: The used sets.

H	The set of hospitals
H^+	The set of hospitals plus the warehouse (0 for warehouse, 1 and higher for hospitals).
B_c	The set of blood centers
HB_c	The set of blood centers plus hospitals (= $H+B_c$)
HB_c^+	The set HB_c plus the warehouse (= $H^+ + B_c$)
P	The set of blood products (delivered products)
P'	The set of collected products

Table 2: The used parameters.

$c_{rjt}^{a_{rt}}$	Consumption rate of each product r whose age a_{rt} (at period t) at each hospital during each period time t
C_{ir}	The capacity of storage at each hospital i for each product r
$Cc_{r'}$	The capacity of storage at the warehouse for each collected product collected r'
$I_{rjt}^{0a_{rt}}$	The inventory level of the product r whose age a_{rt} (at period t) at each location j Є H^+ by the beginning of period t
$IC^0_{r't}$	The initial inventory of collected products r' at the warehouse at each period
N_{rt}	The quantity produced of products r at period t
$Z_{r't}$	The quantity of qualified products r' at period t
$Ic_{r't}$	The final inventory of collected product r' at the warehouse in period t
Cap_v	The capacity of vehicle v
a_{rt}	The age of product r at period t (in days)
sl_r	The shelf life of product r (in days)
k_r	The insulated container of delivered product r
$k_{r'}$	The insulated container of collected product r'
$Dist_{ij}$	The distance between locations i,j Є HB_c^+ (in Km)
φ_{ij}	The travel time between locations i,j Є HB_c^+ (in hours)
b_i	start of time window for location i Є HB_c
e_i	end of time window for location i Є HB_c
CS_{rjt}	The holding cost of product r at location j Є H^+ at period t
CT_v	Travel cost per Km
τ_t	Total working hours per driver per each period t
M	A big number

Table 3: The decision variables.

$Q_{irt}^{a_{rt}v}$	The quantity of product r whose age a_{rt} (at period t) delivered to hospital i Є H by vehicle v Є V in period $t \in T$
$CP_{r'zt}^{v}$	The quantity of product r' collected from blood center z Є B_c by vehicle v Є V in period $t \in T$
O_{rjt}	The amount of outdated product r at location j Є H^+ during the period t
$I_{rjt}^{sl_r+1}$	The inventory level of product r whose age sl_r+1 at location j Є H^+ by the end of period t
$I_{rjt}^{a_{rt}}$	The inventory level of product r whose age a_{rt} (at period t) at location j Є H^+ by the end of period t
x_{ijt}^{v}	A binary variable set to 1 if location j is visited immediately after location i by vehicle v at each period t, 0 otherwise
$q_{ijrk_rt}^{a_{rt}v}$	Total quantity of product r whose age a_{rt} (at period t) transported in insulated container k_r in vehicle v from a location $i \in HB_c^+$ to location $j \in HB_c^+$ at period t
$qc_{ijr'k_{r'}t}^{v}$	Total quantity of product r' transported in insulated container $k_{r'}$ in vehicle v from a location $i \in HB_c^+$ ($HB_c^+ = H^+ + B_c$) to location $j \in HB_c^+$ at period t
y_{it}^{v}	A binary variable set to 1 if vehicle v visits location i Є HB_c at period t, 0 otherwise
s_{vi}^{t}	The arriving time of vehicle v at hospital i at period t

Some assumptions are made in this study:

- Each tour must begin and end at the warehouse and each hospital and blood center must be served by a single vehicle.
- The storage capacity at each hospital cannot be exceeded.
- Given that the products concerned are perishable products, we assume that each product r is delivered only if its age a_{rt} is less than or equal to its shelf life sl_r, thus any outdated product is no longer appearing in the inventory and it cannot be used to satisfy the demand.
- Also we assume that no stock-out is allowed.
- Since each blood product has its own conditions of conservation, each product is transported in insulated container k_r Є K separately from other products. We assume that all insulated containers k_r and $k_{r'}$ have the same size.

The model is:

$$\text{Min} \sum_{i=0}^{HB_c^+-1} \sum_{j=i+1}^{HB_c^+} \sum_{t} \sum_{v} CT_v * Dist_{ij} * x_{ijt}^{v} + \sum_{j}^{H} \sum_{a_{rt} \leq sl_r} \sum_{t} \sum_{r} CS_{rjt} * I_{rjt}^{a_{rt}} \quad (1)$$

Subject to:

$$\sum_{\substack{i \in HB_c^+ \\ i \neq j}} x_{ijt}^v \leq 1 \qquad \forall\, j \in HB_c^+, v \in V, t \in T \qquad (2)$$

$$\sum_{v \in V} y_{it}^v \leq 1 \qquad \forall\, i \in HB_c, t \in T \qquad (3)$$

$$\sum_{\substack{i \in HB_c^+ \\ i \neq j}} x_{ijt}^v - \sum_{\substack{m \in HB_c^+ \\ m \neq j}} x_{jmt}^v = 0$$

$$\forall\, j \in HB_c, v \in V, t \in T \qquad (4)$$

$$\sum_{\substack{i \in H^+ \\ i \neq j}} q_{ijrk_rt}^{a_{rt}v} - \sum_{\substack{m \in H^+ \\ m \neq j}} q_{jmrk_rt}^{a_{rt}v} = Q_{jrt}^{a_{rt}v}$$

$$\forall\, j \in H, \forall\, k_r \in K,$$

$$\forall\, a_{rt} \leq sl_r, v \in V, r \in P, t \in T \qquad (5)$$

$$\sum_{\substack{i \in HB_c^+ \\ i \neq j}} qc_{jir'k_{r'}t}^v - \sum_{\substack{m \in HB_c^+ \\ m \neq j}} qc_{mjr'k_{r'}t}^v = CP_{r'jt}^v$$

$$\forall\, j \in B_c, \forall\, k_{r'} \in K, v \in V, r' \in P', t \in T \qquad (6)$$

$$\sum_{k_{r'} \in K} qc_{ijr'k_{r'}t}^v + \sum_{a_r \leq sl_r} \sum_{k_r \in K} q_{ijrk_rt}^{a_{rt}v} \leq Cap_v * x_{ijt}^v$$

$$\forall\, i, j \in HB_c^+, r \in P, r' \in P', v \in V, t \in T \qquad (7)$$

$$b_i * y_{it}^v \leq s_{vi}^t \leq e_i * y_{it}^v$$

$$\forall\, i \in HB_c, v \in V, t \in T \qquad (8)$$

$$s_{vi}^t + \varphi_{ij} \leq s_{vj}^t + M(1 - x_{ijt}^v)$$

$$\forall\, i, j \in HB_c^+, i \neq j, v \in V, t \in T \qquad (9)$$

$$\sum_{i}^{HB_c^+-1} \sum_{j}^{HB_c^+} x_{ijt}^v * \varphi_{ij} \leq \tau_t$$

$$\forall\, v \in V, t \in T \qquad (10)$$

$$\sum_{a_r \leq sl_r} I_{rjt}^{0a_{rt}} + \sum_{a_r \leq sl_r} Q_{jrt}^{a_{rt}v} \leq C_{jr}$$

$$\forall\, j \in H, \forall\, v \in V, r \in P, t \in T \qquad (11)$$

$$IC_{r't}^0 + CP_{r'jt}^v \leq Cc_{r'}$$

$$\forall\, j \in B_c, \forall\, v \in V, r' \in P', t \in T \qquad (12)$$

$$O_{rjt} = I_{rjt}^{sl_r+1} \qquad \forall\, j \in H^+, r \in P, t \in T \qquad (13)$$

$$I_{rjt}^{0a_{rt}} = I_{rjt-1}^{a_{rt-1}} - O_{rjt-1}$$

$$\forall\, j \in H^+, a_{rt} \leq sl_r, r \in P, t \in T \qquad (14)$$

$$I_{rjt}^{a_{rt}} = I_{rjt-1}^{a_{rt-1}} + Q_{jrt}^{a_{rt}v} - c_{rjt}^{a_{rt}}$$

$$\forall\, j \in H, \forall\, v \in V, a_{rt} \leq sl_r, r \in P, t \in T \qquad (15)$$

$$I_{r0t}^{a_{rt}} = I_{r0t-1}^{a_{rt-1}} + N_{rt} - \sum_{j \in H} Q_{jrt}^{a_{rt}v}$$

$$\forall\, v \in V, a_{rt} \leq sl_r, r \in P, t \in T \qquad (16)$$

$$Ic_{r't} = Ic_{r't-1} + CP_{r'jt}^v - Z_{r't}$$

$$\forall\, j \in B_c, \forall\, v \in V, r' \in P', t \in T \qquad (17)$$

$$\sum_{i}^{HB_c^+} x_{ijt}^v = y_{jt}^v$$

$$\forall\, j \in HB_c, i \neq j, \forall\, v \in V, t \in T \qquad (18)$$

$$y_{it}^v, \; x_{ijt}^v \in \{0,1\}$$

$$\forall\, i, j \in HB_c^+, i \neq j, \forall\, v \in V, t \in T \qquad (19)$$

$$CP_{r'zt}^v; Q_{jrt}^{a_{rt}v}; I_{rjt}^{a_{rt}}; I_{rjt}^{0a_{rt}} \geq 0$$

$$\forall\, i, j \in H^+, i \neq j, \forall\, v \in V, \forall a_{rt} \leq sl_r,$$

$$r \in P, r' \in P', z \in B_c, t \in T \qquad (20)$$

Objective function of the proposed model is defined by (1), it includes the total transportation cost and the total inventory holding cost at the end of each period. Constraints (2) ensure that each location (hospital or blood center) is visited at most once in period t. Constraints (3) define that each location (hospital or blood center) can be visited by one vehicle maximum per period. Constraints (4) ensure the continuity of a tour, so that if a vehicle arrives at a location (hospital or blood center), it must leave after it has served it to a next location or to the warehouse. Constraints (5) determine the quantity of delivered product r Є P to a hospital and eliminate sub-tours. Constraints (6) determine the quantity of collected product r’ Є P’ from a blood center and also eliminate sub-tours. Constraints (7) ensure that the quantity transported is less than or equal to the vehicle's capacity. Vehicles arriving time at location (hospital or blood center) must be in given time windows for each location (hospital or blood center), constraints (8) ensure that these time windows are respected for each location (hospital or blood center) and constraints (9) define the time arriving. Constraints (10) ensure that the total travel time of a vehicle should not exceed the planned total working hours in period. Constraints (11) ensure the respect of storage capacity at each hospital. Constraints (12) ensure the respect of storage capacity of collected product at the warehouse. Constraints (13) define the amount of outdated product. Constraints (14) ensure that the inventory at the beginning of a period is equal to the inventory at the end of the previous period minus the quantity of outdated products during this period. Constraints (15), (16) and (17) define the inventory conservation conditions for the warehouse and the hospitals. Constraints (18) indicate that a vehicle cannot be used to serve any hospital or blood center unless it is selected. Constraints (19) and (20) require that inventory levels at hospitals and warehouse, quantity of products delivered to hospitals, and quantity of products collected from blood centers are non-negative and define the binary nature of decision variables.

4 COMPUTATIONAL RESULTS

In order to validate the proposed mathematical model we tested it on small size fictitious instances. We have randomly generated seven test instances with the following parameters: one warehouse delivers two products to a set of hospitals, varying from 3 to 14 and picks up three products from a set of blood centers, varying from 2 to 4, two heterogeneous vehicles are used. The capacity of each vehicle is [Cap_{v1}=60, Cap_{v2}=140]; Hospital consumption by product is integer value randomly generated within the interval [1, 90]. We consider a planning horizon of three days (T=3). The travel distance between locations i and j is given in kilometer. The inventory level at location i Є H^+ at the beginning of planning horizon is randomly generated as an integer between [7, 65]; the inventory level of each collected product at the warehouse at the beginning of planning horizon is randomly generated as an integer between [2, 40]; the maximum working hours is set to 8 hours per day (b_i=0 min, e_i=480 min); The big number in constraints is set to M=100, the travel cost is 1.2 euros per km and the storage cost at each location i Є H^+ is [r_1=20, r_2=10] in euro. The IPDPTWPP was tested by the Cplex 12.5 on the Intel(R) Core(TM) i5-2450M CPU 2.50 GHz with 4 GB RAM. The results for the seven test instances are presented in Table 4. The table indicates the objective function values, the transportation cost, the storage cost and the CPU computing time. Given the small size of the first four instances, we have chosen to present the delivery routes, the quantities of products (r_1, r_2) to be delivered and of products [r'_1, r'_2, r'_3] to be collected during the fifth instance (figure 2).

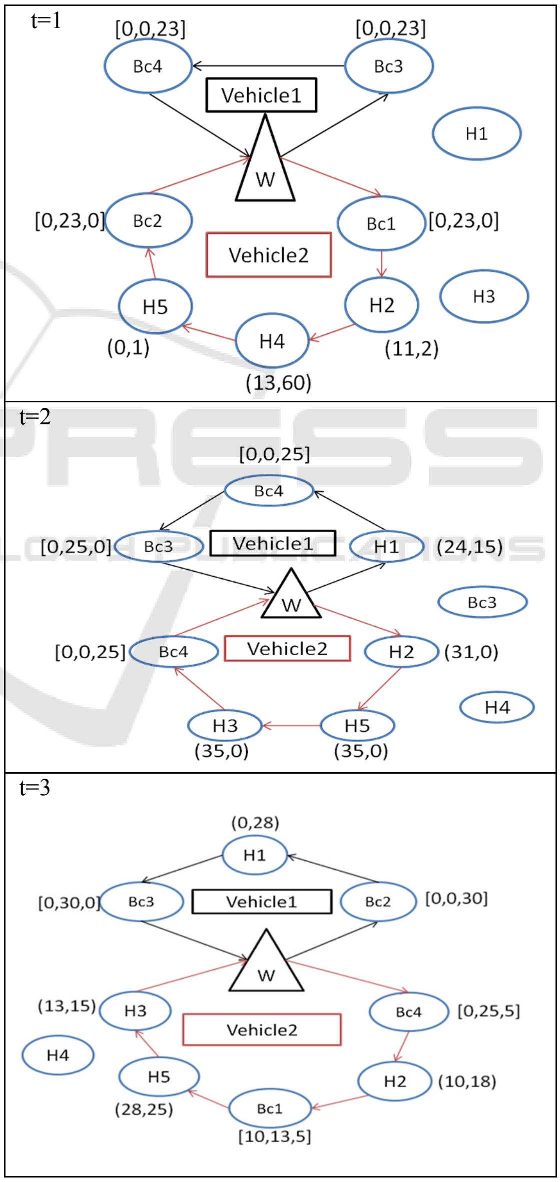

Figure 2: Delivery routes in each day for the instance5.

Table 4: Results for the seven test instances.

Inst	Nb of blood centers	Nb of hospitals	Storage cost (in €)	Transport cost (in €)	Total cost (in €)	CPU time (in sec)
1	2	3	9190	1944	11134	2.90
2	2	5	8860	2693	11553	2.37
3	2	7	9080	4490	13570	12.06
4	4	3	9080	2208	11288	3.24
5	4	5	7570	2952	10522	14.26
6	4	7	9470	5054	14524	38.41
7	4	14	17470	5611	23081	900

The obtained results show that by increasing the number of hospitals, the distribution cost increases. This can be explained by the fact that by increasing the number of the served hospitals, the distance traveled during the deliveries increases, and consequently the related cost also increases. As for the change in the storage cost, it is considered as a consequence of the variation in the final level of stock in the warehouse and in the hospitals. This is due to the variation in the level of consumption from one period to another. Also, it should be noted that for very small size instances, the model presented in Section 3 can be solved by using Cplex solver in very small CPU time.

However, the instance 7 cannot be solved in maximum allowed CPU time of 900 sec. This implies that the resolution of the presented model is affected by any change in instance input parameters. Additionally, CPU time for solving the small instances shows that the instances of realistic sizes cannot be solved to optimality in a reasonable time.

5 CONCLUSIONS

In this paper, we have modeled the optimization problem of the blood products supply chain as an IPDPTWPP problem with the objective of determining the quantities to be delivered and collected and fixing the optimal routes while respecting the constraints of storage and transportation related to the perishable nature of the products as well as the time windows during which each location must be visited. The studied products are heterogeneous and perishable, each with its own characteristics in terms of shelf life and storage conditions. Hence, the need to respect some constraints in the storage and distribution such as the separation of products and delivery in specific insulated containers. Also, no shortage will be permitted because of the criticality of these products. We conducted an experimental analysis of the model on seven instances of small size. Since the IRP problem is NP-difficult, we are now looking for a heuristic approach to solve this problem for real life instances of realistic sizes. Also we plan include additional constraints such as the possibility to visit hospitals more than once per period and the stochastic nature of the demand.

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