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Human Resource Scheduling and Routing Problems in Home Health Care Context: A Literature Review

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Human Resource Scheduling and Routing Problems in Home Health Care Context: A Literature Review

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Abstract

Home Health Care (HHC) service is an alternative to the conventional hospitalization. The goal is to deliver medical, paramedical and social services to patients at their homes, which help them to improve and keep their best clinical, psychological and social conditions. As a large number of resources (i.e., material and human) contribute to delivering the HHC service, there are many issues that should be considered. Among these, the resource scheduling and/or routing problems (i.e., deciding in which sequence each operator will visit patients assigned to him/her) are the most important issues to be addressed while planning HHC resources. In this paper, we review studies in the literature that address the scheduling and/or routing problems as a Traveling Salesman Problem (TSP) or Vehicle Routing Problem (VRP) in the HHC context. We analyze each study according to four main categories: i) general characteristics, ii) modeling characteristics, iii) network characteristics, and iv) data characteristics. The objective of this review is to highlight the unexplored issues in researches dealing with the resource scheduling and/or routing problems, formulated as either TSP or VRP in the HHC context.

Keywords: literature review, home health care, routing, travelling salesman problem, vehicle routing problem.
1. Introduction

The Home Health Care (HHC) concept emerged more than fifty years ago. Although this concept has been present for a long time, recently it has been attracting more attention. The first HHC structure was used in France in 1951 (Chahed, 2008). Although the provided care type differs from one country to another (see Table 1), all seem to find this way of organizing care as developing and promising. The development of the HHC concept can be attributed to the ageing of populations, the increase in the number of people with chronic diseases, the improvements in medical technologies, the advent of new drugs and the governmental pressures to contain health care costs. This concept was developed as an alternative to conventional hospitalization in an effort to address problems regarding the capacity of hospitals and rising health care costs (Asquer et al., 2007; Chahed et al., 2006). In most of the existing works, it has been shown that the HHC system has the potential to provide care more cheaply than admission to hospital. Jones et al. (1999) show that the HHC can be a viable and cheaper alternative to acute hospital when viewed in the long term. They design a cost minimization analysis for 18 months. The provided analysis is based on 199 patients with the median age of 84. Campell et al. (2001) present cost analysis method for the HHC initiative. They examined 51 patients, thirty of which received medical care at home and the rest received care at hospital up to two weeks. They entered all incurred costs and clinical event data on a discrete event simulation model to obtain a baseline results. Then, they performed the baseline simulation with 1000 patients in each group. As a result, they claim that for especially elderly patients who need no more than two weeks of medical care, HHC system is a cost saving alternative. Frick et al. (2009) compare the costs of the HHC system and the traditional hospitalization for old patients with certain diseases. As a result they suggest that high-quality hospital-level care can be
provided to them at their homes as a cost efficient substitute to the traditional hospitalization.

HHC service provides the delivery of medical, paramedical and social services to patients at their homes to help them to improve and to keep their best clinical, psychological and social conditions. However, since a range of human resources (e.g., nurses, physicians, physiotherapists, social workers, psychologists, home support workers, etc.) and material resources (consumable and non-consumable) are involved in the HHC delivery service, there are many issues that should be considered in details. Human resource planning is one of those and can be classified as follows: the resource dimensioning which is used to determine the number of resources, partitioning of a territory into districts in which small geographical areas are grouped to form larger districts, allocation of resources to districts where resources are distributed, assignment of care providers to patients or visits which is used to determine which care provider will take care which patient, and the resource scheduling and/or routing in which the time table and routes of visits are identified.

Another important issue is the material resource planning. Material resources can be divided into consumable and non-consumable material resources. Non-consumable material resources are usually delivered at the beginning of the medical treatment process of the patient. These are all the equipments to be installed in the patient's house throughout his/her care and that will be delivered by a provider according to the availability of the patient. These resources include hospital beds, wheelchairs, life-support systems, drugs pump, etc. Although it seems that deliveries of these material resources do not require planning as long as they are delivered once to the patient's house, planning should still be carried out by the provider to deliver them at right time and to the right place. Another
planning operation that is necessary during the whole HHC process is planning of the maintenance operation of the materials. Moreover, consumable material resources include all consumable supplies and drugs that are delivered by the employees of the HHC provider, pharmacists, family members, etc. The delivery must be carried out according to the availability of the patient and it must usually precede the arrival of human resources (Ben Bachouch, 2010). It is also possible that the HHC providers can bring the necessary materials with them.

Differences may be observed in the HHC system when different countries are considered. These differences are usually the type of home care services provided and the factors which promoted their development. In particular, the difference may also occur as a result of internal (family) and external (care provider) participants and the population etc. Another point of comparison can be the objectives to be achieved. In Table 1, we provide examples from five different countries such as United Kingdom, Canada, Australia, France and Italy to illustrate these differences (Chevreul et al., 2004).

In this study, we focus on the human resource scheduling and routing problems where, the route specifies the sequence in which the patients are to be visited, and the schedule identifies when each patient is to be visited. If the visits for the patients have no time limitations and no precedence relationships, then the problem is named as routing problem. If there is a time specification on the visit, then it turns out to be a scheduling problem. It is also possible to combine both cases (Haksever et al, 2000). We review studies in the literature that address the scheduling and/or routing problems as a Travelling Salesman Problem (TSP) or Vehicle Routing Problem (VRP) in the HHC context. It is important to focus on these aspects because modeling the scheduling and routing aspects of the HHC
problem as a TSP or VRP is beneficial to decrease the total time/cost spent in the system and to increase the number of patients visited in a given period.

<table>
<thead>
<tr>
<th>Country</th>
<th>Main Reasons for Switching to the HHC System</th>
<th>Provided Care type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Italy</td>
<td>Drastic hospital bed closure</td>
<td>High technicality¹ care, care continuity</td>
</tr>
<tr>
<td>France</td>
<td>Overload of certain services in the hospitals</td>
<td>High technicality care, acute or limited treatment, care continuity, follow-up care, rehabilitation care</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>Clogging up of acute beds in the hospitals</td>
<td>Low technicality care, care continuity, to return the chronically ill or elderly patients to home</td>
</tr>
<tr>
<td>Canada</td>
<td>Drastic hospital bed closure</td>
<td>Low technicality care, long-term care as a substitute for hospital care</td>
</tr>
<tr>
<td>Australia</td>
<td>Inadequate supply of hospitals</td>
<td>High technicality care</td>
</tr>
</tbody>
</table>

Table 1: Examples of the HHC structure from different countries

We analyze papers according to the general characteristics, the modeling characteristics, the network characteristics, and the data characteristics. The objective of this analysis is to show unexplored issues in the existing studies and to point out the possible future research opportunities.

¹ High technicality consists of detailed care provided to all kind of patients like the hospitals do.
The reminder of this paper is organized as follows. Section 2, details the TSP and VRP. Section 3 presents the human resource planning process in details. Section 4 makes a survey on the existing literature for the resource scheduling and/or routing problems in the HHC. Based on this survey, in Section 5 we analyze each work. The concluding remarks are presented in Section 6.

2. The Travelling Salesman and Vehicle Routing Problems

In this section we briefly describe the TSP, VRP and connections between these problems. We also provide details about the static, dynamic, deterministic and probabilistic/stochastic cases of these problems. Table 2 presents the four possible combinations for these problems. We first discuss the static problems (indicated in the Table 2 as 2.1.1 and 2.1.2). Then, we provide a general discussion about the dynamic cases.

<table>
<thead>
<tr>
<th></th>
<th>Static</th>
<th>Dynamic</th>
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<tbody>
<tr>
<td>Deterministic</td>
<td>2.1.1</td>
<td>2.2.1</td>
</tr>
<tr>
<td>Probabilistic/ Stochastic</td>
<td>2.1.2</td>
<td>2.2.2</td>
</tr>
</tbody>
</table>

Table 2: The TSP and VRP model classification

2.1. Basics for the TSP and VRP

The Travelling Salesman Problem (TSP) is one of the most studied combinatorial optimization problems in the literature. The general form of the TSP was first studied by Karl Menger (1932). Then, Dantzig et al. (1954) provided notable contributions by introducing a new solution method for this problem. The goal of this problem is to determine a set of routes for a salesman when a specific number of nodes are given. The salesman starts and returns back to a depot node such that all the remaining nodes are visited exactly once and the total cost of visiting all
nodes is minimized. Depending on the formulated problem, the cost can be defined in terms of time, distance, etc. If the average speed is constant then using time or distance term does not change anything in the formulated problem. A generalization of the TSP is the multiple travelling salesman problem (MTSP) in which routes are determined for $M$ salesmen instead of one. Clarke and Wright (1964) were the first that incorporated more than one vehicle in the problem formulation. Since the TSP is a special case of the MTSP, all the formulations and algorithms developed in the literature for the TSP are valid for the MTSP and vice versa. In the studies of Bektas (2005), Kara and Bektas (2006) and Laporte (1992), they review the MTSP and TSP explicitly. They present model formulations and solution procedures for the related problems.

The VRP can be considered as a variant of the MTSP, where the capacity restrictions on the vehicles (salesmen) are imposed. In other words, MTSP is a special kind of the VRP.

We discuss the variants of the VRP as follows:

- **VRP with Capacity Restrictions (CVRP):**
  We name the MTSP with capacity restrictions as CVRP. This is the basic model for the VRP.

- **VRP with Single and Multiple Depots:**
  In the single depot case, all of the salesmen start and end their routes at a single depot, whereas in the multiple depots case each salesman can start or end his/her routes at one of the common depots. For example, managers of a distribution company may need to construct routes where some of the salesmen may be away from the central depot for more than one day. Thus,
suitable locations for salesmen should be provided for parking over the night so that they can have rest before they continue their routes in the following day.

- **Open VRP (OVRP):**
  If each of the salesmen does not have to return back to the depot after visiting the final customer then the problem is named as OVRP. This formulation can be applied when vehicles (salesmen) are hired from outside sources and the cost of the hire is based on the distance travelled (Fu et al., 2005).

- **VRP with Distance Constraints (DCVRP):**
  The capacity constraint is replaced by a maximum route length (time) constraint and named as DCVRP (Desrochers et al., 1988). This variant can be used when there is a distinction between the driving times (only includes travelling time) and the total times (includes both the load time and service time of each customer on the route).

- **VRP with Backhauls (VRPB):**
  The node set is partitioned into two subsets: linehaul and backhaul. In the linehaul set, each node requires the delivery of a certain amount of products from the depot. In the backhaul set, each one requires the collection of a certain amount of products to the depot (Casco et al., 1988).

- **VRP with Picks and Deliveries (VRPPD):**
  A set of customer orders are considered where a single commodity is to be picked up from one location and delivered to a second location (Desaulniers et al., 2001). The salesmen routes, starting and finishing times should be
constructed properly. Hence, the visit in a pick-up location should proceed the corresponding delivery location.

- **VRP with Time Windows (VRPTW):**
  Time window constraints restrict the times at which a customer is available to receive a delivery and they are usually expressed in terms of time intervals. Time window concept can be applied to all the previously described variants as shown in the Figure 1 (Toth and Vigo, 2002).

Note that all of these models can also be considered as variations of the TSP. Thus, we do not distinguish between them again in this section. In Figure 1, the relationship between TSP, VRP, and their variants is presented. For more details please refer to the book of Toth and Vigo (2002). In particular, there are also several survey papers on this subject. For example, Desrochers et al. (1990) give a similar classification scheme like we do, Laporte and Nobert (1987) present an extensive survey on exact methods, Christofides et al. (1979) and Toth and Vigo (1998) provide a survey on heuristic methods.

The following parts present further details on the static and dynamic versions.

### 2.2 Static Case

In the static TSP or VRP, all relevant information for planning routes is assumed to be known before the routing process begins and this information does not change once the routes have been constructed. Details of different variants of the static problem are as follows:
2.1.1 Deterministic Case

Here the number of nodes, the number of vehicles, the demand of each node, and the travel time between each node, etc. are known in advance.

2.1.2 Probabilistic and Stochastic Cases

There can be some uncertain elements in the system such as the level, the time and the location of the demand. For example, the customer demand in many cases is known before the route planning process. However in some situations, the size of the demand from a customer may be unknown until the vehicle arrives at the customer. This is an example of uncertainty where routes must be planned based on the probability distribution of the demand. In particular, the availability of resources may also vary as a result of service times etc.

In the following part, we discuss the Probabilistic Travelling Salesman Problem (PTSP), the Probabilistic Vehicle Routing Problem (PVRP) and the Stochastic Vehicle Routing Problems (SVRP).

2.1.2.1 Probabilistic Travelling Salesman Problem (PTSP)

The PTSP can be considered as the variant of TSP where the total distance of a priori tour is a random variable parameterized by the node probabilities. The problem consists of $n$ nodes. On any instance only $k$ out of $n$ nodes must be visited where $k$ is determined according to a known probability distribution. The aim in this problem is to find a priori tour through $n$ nodes and then $k$ nodes should also be visited in the same order as they appear in the priori tour where objective is finding the tour whose expected length is minimal. One typical example for PTSP
can be the case of a postman. Generally, a postman delivers mail according to a fixed assigned route. On any day, postman checks addresses to be visited from the regular route. Although there are \( n \) customers in the list, some of them may not require a delivery thus the postman can skip that address on that day and continue through the priori route. Jaillet (1985) was the first who introduced this problem and extended by Bertsimas (1988).

2.1.2.2 Probabilistic Vehicle Routing Problem (PVRP)

The probabilistic nature was added to the standard VRP by Golden and Stewart (1978). This problem is the probabilistic variation of the standard VRP, in which demands are probabilistic (i.e. subject to uncertainty with some probability distribution). The goal is to determine a fixed route of minimum expected total length, which represents the expected total length of the fixed set of routes plus the expected value of the extra distance that might be required because demand on the route may exceed the vehicle’s capacity and force the vehicle to visit the depot before continuing its route.

2.1.2.3 Stochastic Vehicle Routing Problem (SVRP)

The SVRP is another variant of the classical VRP where more than one element of the problem is stochastic. The stochasticity can appear as a result of uncertain travel times, unknown demands and/or the set of customers to be visited.
2.2 Dynamic Case

In the dynamic TSP and VRP, we do not know all the information for planning the routes when the routing process begins. In particular, after constructing the initial routes, the information can be updated due to various external factors. For example, after constructing a certain road plan for a food delivery system, new customer orders may appear so that the new routes must be planned while executing the current ones. As a result, re-routing the vehicles in the light of this information is important to reduce costs and to meet customer service time windows. The first dynamic VRP study was provided by Powell (1986). Then, Psaraftis (1995) introduce a high level classification scheme for the general dynamic transportation models.
Note that, all the previously described static cases (deterministic and probabilistic/stochastic) are also applicable to the dynamic case. But the dynamic problem is much more complex since the time dimension is essential, the process is not bounded, the future information is not certain etc.

It is also important to present solution approaches used to solve the TSP and VRP. There are exact and heuristic approaches to solve both the deterministic and probabilistic/stochastic cases. Mostly applied exact methods for both cases are Branch and bound (Laporte & Nobert 1983; Fischetti et al. 1994; Toth & Vigo 2001), Branch and cut (Bard et al. 2002; Lysgaard et al. 2004), Branch and cut and price (Fukasawa et al. 2004; 2006). In particular, many heuristic algorithms are also applied such as simulated annealing (Gendreau et al. 1998), genetic algorithm (Potvin and Bengio) (1996), tabu search algorithm (Cordeau et al. (2001)) etc. The main difference between the deterministic and probabilistic/stochastic problem cases exist in the modeling part instead of the solution part. The probabilistic/stochastic approaches are based on three main streams such as the chance constraint models, stochastic programming with recourse models and Markov decision models. Thus, in addition to the solutions approaches applicable to the deterministic case there are additional exact algorithms for the probabilistic/stochastic models. One of them is the L-shaped method that is given by Gendreau et al. (1995).

Some of the widely used application areas of TSP and VRP are as follows: the emergency management (Wang et al., 2009), the waste collection (Nuortio et al., 2006), the print press scheduling (Gorenstein, 1970), the crew scheduling (Lenstra and Rinnooy Kan, 1975), the school bus routing (Angel et al., 1972), the interview scheduling (Gilbert and Hofstra, 1992) and the nurse scheduling and/or routing problems.
The following section provides the details of the human resource planning process in the HHC structure.

3. Human Resource Planning Process in the HHC context

There are several issues that should be considered in the human resource planning of the HHC, such as the resource dimensioning, partitioning of a territory into districts, allocation of resources to districts, assignments of care providers to patients or the visits and the resource scheduling and/or routing. There are some important points to be mentioned about these issues. For example, they can be classified as long run or short term decisions. Among them, partitioning of a territory into districts can be considered as a long run decision whereas assignment of care providers can be considered as a short term decision. Furthermore, partitioning of a territory into districts turns out to be an important process to reduce complexity when there are many patients in the geographical area. Moreover, the routing process may not be required, if the geographical area is small.

Although, we only focus on the resource scheduling and/or routing part in this study, it is also crucial to illustrate the flow of the human resource planning procedure to analyze what has to be done before the scheduling and/or routing process starts. The first step is the resource dimensioning issue. Here, the number of operators is determined to meet the predetermined care demand with the minimum cost and the adequate service quality. The second step is partitioning of a territory into districts. This consists of grouping small geographic areas into larger clusters, which are named as districts, according to relevant criteria where each district is under the responsibility of a multidisciplinary team. Once districts
are determined, resources are assigned to districts and then to patients equitably. After that the successive step is the scheduling and/or routing processes.

We have discussed the human resource planning procedure where each step has been considered independently. It is also possible to carry out some of the processes simultaneously. For example, depending on the size of the territory, it is possible to carry out both assignment and routing processes together. Since both of these processes are short term decisions, combining them might be efficient. Similarly, the assignment procedure can be held together with the allocation issue. Alternatively, all assignment, allocation and routing processes can also be held simultaneously.

It is also important to discuss the Nurse Scheduling (rostering) Problem (NSP) that is usually applied in the traditional hospital environment. Similar to the HHC scheduling and routing problem, the NSP also involves in the scheduling of health care staff, subject to a variety of soft/hard constraints (Cheang et al. 2003). These constraints include nurses’ preferences, personnel policies and also some hospital-specific requirements. The difference between the HHC scheduling and routing problem with the NSP is the route construction issue which is usually not applied in the NSP. Other than this all other concepts in both problems are similar.

The classification of routing and scheduling problems depends on certain characteristics of the HHC system, such as the number of health care provider, location of health care providers, restrictions on working times of health care providers, and objectives etc. In the basic case, we can consider a set of patients to be visited by a single health care provider. The patients can be visited in any order with no precedence relationships, the travel costs between two patients are the same regardless of the direction traveled, and there are no delivery-time
restrictions and no working time limitations for the health care providers. Thus, the output for this problem is a route where each patient is visited only once and the route begins and ends at the HHC center. The tour is formed under the objective of minimizing the total tour cost. This simplest case is referred as the TSP. The extension of the TSP is the MTSP where more than one health care provider is available. The aim is to generate a set of routes for each health care provider under the same objective and same constraints of the TSP. Furthermore, if we restrict the health care provider’s working times then this problem is classified as the VRP. It is also possible that the health care providers can start and finish their routes at their houses. Thus, this case is referred as the Multi Depot VRP. Similarly, the health care providers can start their routes at a general depot but they may not have to go back to the depot at the end of the day so this case is referred as the Open VRP. Moreover, if the time window restrictions are imposed on all of these problems then they are named as the VRPTW (see Figure 1 for all these variants).

Most of the existing works in the HHC literature are devoted to the resource scheduling and individual route construction problems. Hence, in the following section we provide a general overview for each existing paper on this topic. The main aim of this part is to explain the details and the contributions achieved by each work.

4. Resource Scheduling and/or Routing Problems as the TSP and VRP in the HHC context
In this part, we discuss articles\textsuperscript{2} devoted to resource scheduling and/or routing problems in the HHC context.

Begur et al. (1997) propose a spatial decision support system (SDSS) that contains a special module for the daily scheduling of care providers' activities. This module assigns simultaneously care providers to visits and generates the sequence in which the visits would be carried out. It is based on a heuristic approach that combines a set of procedures for building and improving the daily routes of care providers. The objective of this heuristic is to minimize the total travelling time while respecting the constraints related to the route construction, care providers time windows, and skills requirements. In the work of Cheng and Rich (1998), a daily scheduling problem is developed as a multi-depot VRPTW and the compatibility information. The problem is formulated as a mixed integer linear program. The objective is to minimize the total cost associated with the amount of overtime hours of full-time nurses and the amount of hours assigned to part-time nurses. Meanwhile this objective is obtained with respect to visiting each patient exactly once, assigning each nurse at least one patient, starting and ending at his/her home, taking a lunch break within the given time interval and respecting the maximum nurse shift length constraints. The problem is solved by a two-phase heuristic: the first phase falls into the parallel tour-building procedure category and the second phase attempts to make an improvement on tours identified in the first phase.

Eveborn et al. (2006) develop a decision support system for the local authorities in Sweden, called Laps Care. In this system, they formulate the scheduling problem as a VRPTW with the set partitioning model and solved by a repeated matching

\textsuperscript{2} All papers presented in this part were found using the Web of Science and Google search engines with the following keywords: home health care, resource scheduling, routing, travelling salesman problem and vehicle routing problem. We also examine literature review parts of all papers to increase the depth of our review.
algorithm. The objective is to minimize a total cost related to the travel time, scheduled hours, preferences, etc., while respecting the following constraints: time windows for visits, operators’ skill requirements, and accomplishment of each visit by one operator.

Bertels and Fahle (2006) propose a weekly plan by using the VRPTW which combines linear programming, constraint programming, and heuristics in order to assign operators to visits and sort visits assigned to each operator optimally. The objective is to minimize the total transportation cost while maximizing the satisfaction level of patients and operators with respect to a variety of soft constraints. These soft constraints include affinities between the patients and care providers, preferences for certain visits and soft visits' and care providers' time windows. Besides, there are also some hard constraints that must be satisfied: skill requirements, work time limitations, time window constraints for visits, and the assignment of each visit exactly once.

Thomsen (2006) addresses the daily scheduling problem as a VRPTW and shared visits (visits by two operators). The objective of this model is to minimize the total travelling cost, the number of unshared (visit is carried out by a non-reference operator) and unlocked visits and the number of shared (visit is carried out by two non-reference operators) and unlocked visits. The constraints of the model are as follows: respecting the visits' and operators' time windows, assignment of at least one visit to each operator and starting, ending a shared visit at the same time. The model is solved by using an insertion heuristic and Tabu search technique.

In a more recent study, Akjiratikarl et al. (2007) generate daily schedules by using the VRPTW. Since this problem is a combinatorial optimization problem, they develop a heuristic based approach to solve it. They develop the Particle Swarm
Optimization Problem (PSO) and also incorporate the Local Improvement Procedure (LIP) into the PSO solution approach to improve their solutions. Finally, they combine their approach with the Earliest Start Time Priority with Minimum Distance Assignment technique to generate the initial solutions. Within this framework, they focus on the determination of routes for each operator while minimizing the total distance travelled with respect to visits' and operators' time windows and assignment of each visit to only one operator.

Ben Bachouch et al. (2008) develop the VRPTW as a mixed linear programming model with the objective of minimizing the total distance travelled by the operators. The model is subject to visits' and operators' time windows, nurses' meal breaks, care continuity and the restriction on the nurses' maximum distance travel limit constraints.

Bouazza et al. (2008) develop a model for determining routes for operators that incorporates constraints of the VRP with the medical and continuity of care constraints. Here, each patient is assigned to a region with respect to his/her home address. Similarly, each nurse is also assigned to a region but there can be more than one nurse in a specific region. They allow a nurse to visit a different region with a certain penalty. In this model, they add blood sample related constraints as a medical constraint and they consider the objective function as minimizing the total travelling cost of operators. As a final step, they solve this problem with a meta-heuristic approach based on Tabu search.

In a more recent work, Ben Bachouch et al. (2009) address the daily drug delivery problem in the French home care structure as a VRPTW. The objective of the model is to minimize the total distance travelled. In this model they assign carriers to specific regions so that each tour is realized by the same carrier. In addition,
they develop four different strategies as follows: starting deliveries when a specified number of deliveries is received, starting deliveries if a specified distance is reached regarding to the planned deliveries, starting deliveries on a fixed number of deliveries per carrier, and starting deliveries on fixed hours. They compare results for each strategy in order to identify which one is the most efficient to solve the drug delivery problem in the HHC context.

Chahed et al. (2009) couple the production and distribution of anti-cancer drugs within the context of the chemotherapy at home. They present six models based on three main criteria: time windows, objective function and distribution of drugs. The objective is either to minimize the delivery cost or maximize the number of visited patients.

Bredstöm and Rönnqvist (2008) develop a mathematical model that incorporates synchronization and precedence constraints between visits. The proposed model is based on the traditional VRP with the additional synchronization and precedence constraints. They use a heuristic approach based on the local branching heuristic to solve their model. In their previous study (see Bredstorm and Rönnqvist (2007)), they developed a branch-and-price algorithm to solve the same model without including the precedence constraints.

Kergosien et al. (2009) formulate the routing problem of the HHC operators as a MTSPTW. The objective of the proposed model is to minimize the total travelling cost while respecting visits' and operators' time windows constraints, the assignment of each service to one operator constraints, synchronized (some visits require more than one operator) and disjunctive (some operators cannot work together) services constraints, continuity of care and the assignment of all operator constraints.
More recently, Rasmussen et al. (2010) address the daily scheduling problem as a multi-depot VRPTW and connections between visits. They use a multi-criteria objective rather than only minimizing the total distance travelled. The proposed formulation is very similar to the one that is developed by Bredstörm and Rönqvist (2007) but here they allow also a visit to be uncovered (visit is not carried out). Thus, the proposed multi-criteria objective includes the minimization of uncovered visits, the maximization of operator-visit preference and the minimization of the total distance travelling costs. In particular, in the objective function they assign a higher priority to the uncovered visit part than the other parts. Finally, the constraints of this model include: each visit can be covered exactly once or left as uncovered, operators can only handle allowed visits, visits' and operators' time windows and precedence relations of visits.

Trautsamwieser et al. (2011) develop a model for the daily planning of the HHC services. The main aim of their work is securing the HHC services in times of natural disasters. They develop the daily scheduling model as a VRP with state-dependent breaks. The objective of the model is minimizing the sum of travel times and waiting times, and also the dissatisfaction levels of the patients and health care operators subject to the assignment constraints, working time restrictions, time windows and mandatory breaks. The proposed model is first solved for small data with a state of art solver. Then, they also solve the real life-sized data with a neighborhood search based heuristic.

In the upcoming section we provide some classification characteristics.
5. Classification of Papers

In the previous section, we presented general details of each paper. In this section, we will provide more details by proposing classification characteristics. We also present some modeling suggestions for the future works.

5.1. Classification Criteria

In this section, we present some classification criteria that are gathered according to the needs of the real care providers.

We try to identify each study according to four main aspects: i) general characterization of the study, ii) modeling characteristics, iii) network characteristics, and iv) data characteristics.

In the first category, general characterization, we analyze each study according to the model used, the solution approach applied, and whether the implementation of the model exists or not. It is important to note that while classifying each paper according to the model used, we group them as either TSP or VRP. Although both TSP and VRP have different variants, for simplicity we do not specify each variant in this classification. For example, if a paper is modeled by using the TSP or MTSP we consider this work under the TSP group. Similarly, all variants of the VRP such as CVRP, VRPB, DCVRP and VRPPD are considered under the VRP group.
The second category is the modeling characteristics. Here, we group each work according to the time horizon, visiting structure, patient covering, service providing, provider type, objective and time window structure.

The ‘time horizon’ characteristic is used to define for how long the model creates the routing structure. ‘Visiting structure’ is used to identify whether the visit is held by a single operator (unshared visit), multiple operators (shared visit) or operators with material resources (shared visit). Moreover, ‘patient covering’ characteristic is defined to represent the main properties of the visits. Numbers of services provided by operators (single or multiple) are classified under the ‘service providing’ characteristic. In particular, the service can be a drug delivery operation or doctor/nurse visit operation, so we classify them under the group of the ‘provider type’. The ‘objective’ characteristic is used to identify if the objective function is composed of a single criterion or multiple criteria. These criteria include the minimization of the total distance travelled, visiting outside regions, maximization of the satisfaction level of patients, and operators etc. ‘Time windows structures’ characteristic is used to identify either soft (can be violated with a penalty), hard (no violation is allowed) or both types of time windows are considered.

Some of these categories can also be identified differently. For example, ‘visiting structure’ includes shared and unshared visits and it can also be considered under the ‘patient covering’ group. But we rather choose to specify it separately, as it is one of the main contributions in the HHC context.

The third category is based on the network characteristics. Here the geography, operators’ center, time window type, contract type of operator, operator type, quality of the system, travel times, demand and service times are considered. The
‘geography’ characteristic is proposed to identify the number of districts used. To point out the number of depots (one or multiple) where operators start their daily tours, ‘operators’ center’ characteristic is considered. Since the visiting time of a patient depends on the availability of the patient, operator or both, the ‘time window’ group is defined. Moreover, a health care provider might employ an operator with a full time contract, half time contract or from external sources. Thus, the ‘contract type of operator’ characteristic is defined to show which one is applied. In the HHC structure, operators can be identical or can have different qualifications; therefore ‘operators’ skill type’ is used to distinguish them. ‘Quality of the system’ aspect is used to identify either the study includes the quality for patients’ satisfactions or operators’ satisfactions. The ‘travel time’ and the ‘demand’ characteristics are defined to present either papers use these issues deterministically or stochastically. Furthermore, service times of visits can be equal or variable thus, the ‘service time’ group is defined to show this issue.

The last category of our analysis is based on the data characteristic. The data can be a real life instance, randomly generated instance or widely applied state of the art instance.

There are many important criteria that require detailed explanation. The first one is the exclusion that is used to specify exclusion of a patient from the HHC structure. Although this aspect is important, it can only be considered when some uncertainty is available in the structure for example the demand uncertainty. The other important one is the precedence and coupling criterion because some of the services might be needed just after the completion of another service. For example, medication service might be needed before or after food delivery service. Another important criterion is the disjunctive events. This aspect is necessary when some of the events cannot take place simultaneously. For example, a speech
therapy and a regular medical check cannot be done at the same time thus one of them should be held before. Care continuity is also one of the main aspects in the HHC structure for providing a good service level and high patient satisfaction level. Another necessary criterion is the qualification requirements because some medical services may require specific types of operator qualifications.

We use all the characteristics to analyze previously mentioned papers to find the non-studied or rarely studied points that might be included in future works.

5.2. Discussion

Modeling the problem with the stochastic versions of the TSP and VRP, incorporating a shared visit with a material resource, excluding a patient from the system when needed, providing an operator from an outside source when required, adding stochasticity on travel time, demand and service time are the most important attributes according to our interests and according to the needs of health care providers. Existing works have not incorporated these attributes because of the complexity reasons. For example, although modeling the problem with the stochastic versions of the TSP and VRP are more realistic, this makes the problem really complex. Thus solving these problems might be hard.

In particular, the material resources are also needed in most of the medical visits so incorporating a shared visit with a material resource perfectly reflects the real life needs. But, adding this aspect can make the problem more complex. Remember that there are two types of material resources named as consumable and non-consumable material resources. In most of the cases, the consumable material resources are brought by the operator so we do not need to consider them separately and this does not make the problem more complex. However, in the
non-consumable case, there can be two different situations. In the first case, the non-consumable material should be brought before the arrival of the health care provider (this action is usually done for once before the first visit) and in the second case, the material should be brought at the same time or just after the care provider’s arrival (within service time limit). Thus, incorporating the last two cases can make the problem more complex and also hard to solve.

Another important criterion is the provision of an operator from an outside source when required. This is the case that is usually applied by the real health care providers. Sometimes the number of operators may not be sufficient to satisfy the required demand so the health care providers hire new operators from external sources. In particular, some of the existing health care providers prefer only hiring health care operators instead of having the contracted ones. Although this aspect is realistic, adding this can also makes problem more complex.

Excluding a patient from the system when needed can also be seen as a real life aspect because in reality when the situation of the patients gets better, he/she may not need any more service or when his/her situations gets worse, he/she may need to be transferred to the hospital thus in these cases the patient should be excluded from the HHC system. Although exclusion aspect is realistic, adding this makes the model more complex because some of the model parameters turn out to be stochastic.

The remaining excluded attributes such as soft time windows, monthly time horizon, and equal service times have not been considered in any study because they do not reflect the requirements of the real life applications.
There are also other important attributes that are not incorporated extensively in the existing literature: care continuity, multiple service provision and visiting multiple districts. Care continuity issue is considered in some papers but they are added as soft constraints thus, incorporating them as a hard constraint will be a significant contribution. It has not been added as a hard constraint due to complexity reasons.

Similarly, almost all works that we have discussed focus only on one service provision. They have generalized all services and named them as health care services and they have not distinguished services from each other. However, distinguishing services and imposing constraints on these aspects are important. In this case it is also important to consider the different operator skills since there can be various services that require different skills. Only in the work of Elbenani et al. (2008), they consider two different services. They impose constraints for blood sample collection as well as for general care services.

In addition to these attributes, dividing a region into districts and visiting more than one district are other important aspects. All in all, adding these attributes in future studies will be a significant contribution to the field.

5.3. Some Modeling Suggestions for the Future Works

Here we present some new modeling ideas that might be useful and contributing for the upcoming works.

We have discussed that assignment and routing processes can be carried out simultaneously. It might also be interesting to compare this idea with another one where firstly the assignment process is held and then with the corresponding
output the individual routes for the health care providers are determined. By comparing the results of these two cases, we can analyze in what circumstances which one of these models is more efficient.

Another interesting model can be developed by assuming that one of the previously assigned health care providers will be available in the upcoming day (it is also assumed that normally routes are generated at the beginning of the week for each working day on that week). Thus, the re-routing process should be done with the rest of the available health care providers by considering the availabilities of the patients on that day.

Moreover, we have also mentioned that there are no papers that have incorporated stochasticity yet. Hence, models with stochastic nature will be useful. To this end, we suggest two stage stochastic models. In real life, the demand may not be available at the beginning of the routing process so in this case routes should be constructed according to the average demand in the first stage of the model. Then once the demand become available, re-construction of the routes can be done at the second stage of the model in order to satisfy the newly available demand. In addition to this, we also suggest another two stage stochastic model where in the first stage the assignment of the health care providers can be determined and with this the output, individual routes for operators can be constructed in the second stage of the model.

6. Conclusion

The HHC domain has started to grow significantly in the past few years and it has become a real alternative to traditional hospitalization. In this study, we discussed that there are a large number of resources that participate in delivering the HHC
service and we focused on the resource scheduling and/or routing problems. We reviewed studies that address the routing and scheduling problems as a TSP or VRP in the HHC context. Although there are also other alternatives for modeling the routing and scheduling aspects, we do not include them in this study.

Note that there are only fifteen articles that present the routing and scheduling problems as a TSP or VRP in the HHC context. The main objective of our study is to compare the main characteristics of these articles and to find possible research directions as well. Thus, we analyze each study according to different characteristics and, as a result, we determined that imposing qualification constraints into the TSP and VRP structure will not only be an application on the HHC topic, will also be the extension of the TSP, VRP and HHC field (Cappanera et. al, 2011). We also revealed that although stochasticity reflects the real life needs, there is no previous study that incorporates any kind of stochasticity into the resource scheduling and/or routing problem in the HHC context. Thus, including stochastic nature will be a significant contribution to the literature. Other possible important research directions are adding multiple service provision concept and operator hiring concept from external sources. The first one is important because in real life a patient may require more than one type of medical treatment at one time. In particular, the second one is also crucial since a health care provider company may require additional operators due to increase in the demand so they can hire additional recourses from external sources to satisfy the customer demand.
References


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