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A SURVEY OF THE VEHICLE ROUTING PROBLEM IN-HOME HEALTH CARE SERVICES

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A B S T R A C T

In a transport Logistics problem, there can be a multitude of constraints that come into play such as vehicle/depot capacity constraints, time constraints… in this paper we will see first the works which relate mainly to the context of logistics in the home care and services. then we will details the main works existing related to routing problems that have similarities to the field we are interested in. in third, we will see the various and several resolution approaches such as exact, approximate or even hybrids resulting from these of methods from combinatorial optimization and operational research whose effectiveness has been proven on the logistics problem of transport in general. This study allows us to have a general overview of research opportunities not still explored. Therefore, we expose and investigate the problems addressed in the literature, to identify new emerging research perspectives in this context.

1. INTRODUCTION

Operations research (RO) goal is to solve decisions or optimization problems using mathematical and computer science tools. In this article, we are going to illustrate and study combinatorial optimization problems which are part of the transporting problem category. These problems are wide spread in logistics and there are numerous variants, usually designed by acronyms to distinguish between them. The motivation of studying such problems is the large field of practical applications and the economic and environmental implication. The transport fees represent for about 10 to 20% of merchandise financial prices by Toth & Vigo (2014). Optimization techniques usually allow developing efficient and flexible transportation systems responding to the life quality and economy preoccupations and to save 5 to 20% of transport costs. So, these techniques deemed to be very essential.

The origin of logistics work in Health Systems can be linked to proposed door to door transportation service for the elderly or the disabled persons (Bodin & Sexton, 1986; Desrosiers et al, 1986, 1995). In many countries, the reason why local authorities have thought of setting up Dial-A-Ride services DARP can be partly attributed to the aging population, which has led to an increase in the number of patients suffering from functional disability, but also to a trend towards the development of ambulatory healthcare services. Later, Rousseau et al (2003, 2013) proposed a particular variant of the DARP where a special team offering specific Services is sent to the patient's residence before the arrival of the vehicle responsible for transporting them. This type of patients

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usually needs help before being transported (being helped to dress, wash …). This requires the coordination between visits by nursing assistants and transporters. For this, the authors discuss the value of introducing synchronization constraints that will allow managing priorities between visits. More recently Coppi et al (2013) introduced a new variant of DARP with time windows, in which the objective is to plan care for hospital. However, patients are transported from their homes to the hospital in non-emergency conditions. The criterion to optimize concerns the minimization of costs generated by patient transport. The elderly and/or disabled people have more and more new needs requiring special care. Indeed, DARP has been extended to HHCP (Home Health Care Problem) by Cheng & Rich (1998) where healthcare workers are assigned to patient's homes in order to provide the care requested on site. They have developed a mathematical model with integer mixed variables (MILP) and have developed a heuristic approach to solve the HHCP. At this point, the numerical results are given only for 4 nurses and 10 patients. Since then, the number of publications dealing with this theme is constantly increasing and the optimization tools used are diverse.

In the context of Home Health Care (HHC), the logistical issues considered touch various fields. We distinguish two categories, detailed in this paper, allocation and planning issues as well as pickup and delivery issues. At first we will present the vehicle routing problem in general and the main resolution methods dealing with the VRP.

2. VEHICLE ROUTING PROBLEM

The traveling salesman problem (TSP) is certainly the most famous problem in combinatorial optimization. It consists of a salesman traveler whose mission is to visit many cities; each city must be visited only once. The objective is to find the tour with the minimum total traveling distance made by the salesman. The vehicle routing problem is defined as an extension of the TSP with travelers in which K vehicles of capacity W must visit and/or serve a set of n customers from a common depot (initial start). Firstly proposed by Dantzig & Ramser (1959a), the problem consists of visiting customers from an initial depot using a fleet of vehicles with a minimal cost. The VRP is considered as a NP-hard problem. Many mathematical formulations were proposed in order to model this problem. We present in this section a formulation known by simplicity proposed by Fisher & Jaikumar (1981). This modsel is defined on an oriented graph $G = (V, E)$ where $V = \{0,1,2, \dots, n\}$the set of nodes and E the set of arcs. The Node o represents the depot and each $i \in V\{0\}$ is a customer to whom it would be necessary to deliver a certain quantity q_i of goods. Each of the arcs $(i, j)\epsilon E$ possesses a weight C_{ij} that represent the cost of moving vehicles from customer i to j. This modeling requires n^2K binary decision variables x_{ijk} and nK variablesy_{ik}, such as:

$$x_{ijk} = \begin{cases} 1, if\ the\ arc\ (i,j) is\ travelled\ by\ the\ vehicle\ k \\ 0, otherwise \end{cases}$$

And

$$y_{ik} = \begin{cases} 1, if\ the\ customer\ i\ si\ visited\ by\ the\ vehicle\ k \\ 0, otherwise \end{cases}$$

The linear program is as follows:

$$\min \sum_{(i,j)\epsilon E} \sum_{k\epsilon K} C_{ij} x_{ijk} \quad \textbf{(1)}$$

With constraints:

$$\forall k\epsilon K\ \sum_{i\varepsilon V} q_i . y_{ik} \le W \quad \textbf{(2)}$$

$$\forall k\epsilon K\ \sum_{k\varepsilon K} y_{0k} = K \quad \textbf{(3)}$$

$$\forall i\epsilon V\{0\}\ \sum_{k\varepsilon K} y_{ik} = 0 \quad \textbf{(4)}$$

$$\forall i\epsilon V\ ,\ \ \forall k\epsilon K\ , \sum_{j\varepsilon V} x_{ijk} = y_{ik} \quad \textbf{(5)}$$

$$\forall j\epsilon V\ ,\ \ \forall k\epsilon K\ , \sum_{i\varepsilon V} x_{ijk} = y_{ik} \quad \textbf{(6)}$$

$$\sum_{i,j\varepsilon S} x_{ij} \le |S| - 1\ ,\quad \forall k\epsilon K\ , \quad \forall S\epsilon V\{0\}: 2 \le |S| \le n-1 \quad \textbf{(7)}$$

$$\forall k\epsilon K, \forall (i,j)\epsilon E: i \ne j,\ x_{ijk}\epsilon\{0,1\} \quad \textbf{(8)}$$

$$\forall k\epsilon K\ ,\ \forall i\epsilon V\ ,\quad y_{ik}\epsilon\{0,1\} \quad \textbf{(9)}$$

The objective function (1) expresses the minimization of the cost of movements of vehicles on arcs. The vehicles capacity is respected using constraints (2). The number of vehicles used must not exceed the number of vehicles available in the repository (depot), this is managed by constraints (3). The constraints (4) ensure that each customer is visited exactly once. Constraints (5) and (6) guarantee that each vehicle visiting a customer leaves. Finally, the constraint (7) allows the elimination of sub-tours. The rest of the constraints set the nature of the variables.

There are many variations of the vehicle routing problem by adding more constraints and objectives to the original definition of the problem such as adding time windows constraints, pickup and delivery constraints… We will investigate them further in upcoming sections of this paper.

3. RESOLUTION METHODS

The vehicle routing problem is considered as a classic combinatorial optimization problem, was solved by exact methods and approached methods, in what follows, a general classification of these approaches is illustrated.

3.1 Exact methods

An integer linear program (ILP) goal is to minimize a mixed integer linear function respecting a set of constraints which are also linear. Most of vehicle routing problem are formulated as an integer linear program. Solve an ILP requires the use of dedicated methods such as Branch and Bound algorithm, column generation methods, dynamic programming, lagrangian relaxation…. These methods are also called exact methods.

The algorithm of branch and bound is based on tree-like method of searching for optimal solutions; it enumerates all the possible solutions in an intelligent way to find the best. This method is based on the separation (Branch) of the solution space in sub-sets more and more small. The exploration of these solutions uses an optimistic evaluation (Bound) to limit the sub-sets, which allows to only those (sub-sets) that are likely to potentially contain a solution better than the actual one.

More details on this approach can be found in many books treating the combinatorial optimization problems, like Lacomme et al (2003) and Balas & Toth (1983).

Several applications of the vehicle routing problem can be found in the books of Wolsey & Nemhauser (2014), Wolsey (1998) and Lacomme et al (2003), and can be found in the literature such as Cordeau (2006) and Lysgaard et al (2004).

These approaches can have the advantage to be less costly in terms of memory space and computing time when an upper bound (for the problem of minimization like the VRP) of good quality are provided beforehand. Generally, this one is given using effective metaheuristics.

3.2 Approached methods

Heuristics are methods allowing to obtain workable solutions. The solution built generally results from a succession of elementary decision, usually selected by a greedy way. Heuristics are practically designed to be specific for a certain problems. For the vehicle routing problem, many types of heuristics can be found in the literature.

A constructive heuristic is a type of heuristic method, and the most popular one among them is the nearest neighbor which generates a workable solution by construction, adding in each iteration an element to the partial solution. When the insertion becomes impossible in a tour, the vehicle return to the depot and a new tour is open.

Solomon (1987) was inspired by the nearest neighbor to propose the best insertion heuristic, this heuristic proceed to the successive insertion of clients in a solution, in a position which optimize the chosen criteria.

Another approach was taken into consideration in order to obtain quickly feasible solutions is the touring merging. The most classic and the one giving better results for the VRP (Laporte et al (2000)) is the algorithm of Clarke and Wright (1964) which runs in an iterative way. It is about starting from the most expensive solution consisting of visiting each client on a dedicated tour then carrying out mergers routes to improve the overall cost.

Another interesting heuristic is the heuristic with two phases, the first heuristic included in this category of heuristics is the Cluster First Route Second heuristic, which starts by clustering all the clients, then decide on their sequencing, with a TSP resolution for each cluster. The simplest example is given by Gillet & Miller (1974) where scanning algorithm was proposed. The opposite of the first heuristic, is the Route First Cluster Second heuristic, which determine first the order and sequencing of the clients, then clustering them in tours. For the need to solve the TSP problem creating big tours, Beasly (1983) proposed this paradigm. In order to improve the results generated by a heuristic, several strategies can be considered:

- Apply a local search to the initial solution obtained by a constructive heuristic.
- Run several heuristics and keep the best solution.
- Randomize a heuristic component, apply it multiple times and keep the best solution obtained.
- Any combination of theses.

3.3 Metaheuristics

Metaheuristics are generic methods that use techniques to avoid local minima, which make them more effective and more efficient than heuristics. Metaheuristics can be classified into two large families:

- Those based on the use of a set of solution, generally called population. With each iteration, the approach evolves this population of solutions.
- Those based on neighboring exploration that manipulates one solution at a time.

A more detailed description of metaheuristics methods and their different applications in VRP problem can be found in the book of Labadie et al (2016).

In this paper, we will present some basics principles of some of the metaheuristics methods.

GRASP was introduced by Feo & Resende (1995) which the principle idea was to create at each iteration a new feasible solution and by doing that improving it by local search methods. This metaheuristic has two phases: a constructive phase which permits to generate an initial solution using a greedy randomized heuristic and an amelioration phase that consists on applying local search techniques. These two phases are repeated a predefined number of time and the best solution obtained during iterations is retained.

In the year 1989, Glover (1989) introduced a deterministic metaheuristic called Taboo Search (TS) that does not consider any random parameter. This metaheuristic consists on sweeping an entire predefined neighborhood of the current solution provided by a heuristic, then make the best possible transformation even there is a certain risk deteriorating the objective function. Solutions are stored in a queue (FIFO) of limited size, this list is called the taboo list. The method stops after a certain predefined number of iterations and the best solution encountered while execution is returned. More details about TS method can be found in the literature such as Glover & Laguna (2013 and applications of TS in the VRP problem can be found in Taillard et al (1997), Gendreau et al (1994) and Cordeau et al (2002).

Genetic algorithms were introduced by Goldberg & Holland (1988) and inspired by genetics and natural species evolution. It is about of going from a population which is solutions obtained by a heuristic and in each iteration making crosses of two chromosomes (individuals). Individuals are selected by favoring those being the most promising according to a selection criterion called *fitness*. A new individual is then created by combining the characteristics of the two parents and is called a child.

It was necessary to present some major resolution methods of the VRP problem in general, so to conclude this section, last metaheuristic to be presented will be the one introduced by Colorni et al (1991) and is called Ants Colonies. They are based on ants' behaviors while searching for food sources from their nest. When some ants find food, they mark the path leading to the food by leaving behind a certain quantity of pheromones dependent on the quality of the source of the food. By doing so, the other ants will be averted and attracted to the food source. Overtime, paths leading to the best food sources will be more frequented and the pheromones levels will get higher by the passing of ants. On the other hand, the pheromones levels of the less frequented paths will decrease little by little. This metaheuristic incorporate the journeys made by the ants on tours, and the quality of the food source to the value of the objective function.

More existing metaheuristics and other variants and hybrids can be found in the literature and next below a classification tree figure showing all metaheuristic algorithms that exist till now (Figure 1, see appendix).

4. ALLOCATION AND PLANNING

In general, this family had addressed the issues of attributing visits to personal care and planning of visits schedules. In this context, Bertels & Stefan (2006) presented the problem of assigning nurses to the home of the patients. Thus, so-called hard constraints relating to the qualifications requirement and time windows of nurses must be respected because each nurse has a certain skills and a specific work time. The aim of their study is to minimize the total nurses movement cost and to maximize the satisfaction of patients\nurses. In order to resolve this problem, the authors have developed a constraint programming method combined with a taboo search method which produces good quality solutions in a reasonable amount of time. Eveborn et al (2006) expressed this problem as a partitioning problem. This problem is the same as the last one except that the authors added periodicity constraint, regularity constraints of caregivers and time windows on service.
Planning problems of home health care are generally defined as a variant of VRPTW (Vehicle Routing Problem with Time Windows). Trautsamwieser & Hitch (2011) proposed a mathematical formulation and a metaheuristic approach based on variable neighboring search in order to optimize the daily planning of home health care services and to minimize the time related to nurses movements and the non-satisfaction ratio of patients/nurses.

Akjiratikarl et al (2007) proposed an approach based on population (Particle Swarm Optimization) to resolve the VRPTW problem applied in home health care. The objective was to minimize the total distance travelled by each caregiver with respect to the vehicles capacities and to the visit time windows. The location/routing problem in care planning was addressed by Doerner et al (2007) who proposed a multi-objective mathematical formulation. The visits are estimated according to a cost standard relied to the duration of visits and duration of caregivers movements. Two metaheuristics population based such as ACO (Ant Colony Optimization) and a multi-objective genetic algorithm were proposed and compared.

Another particular variant of the VRPTW for home care issues is when and old and senile person requires simultaneously two or more caregivers for a care service like the need of two caregivers to assist a client (patient) to perform his bath. In this case, coordination visits constraints have been looked at in Bredström & Rönnqvist (2007, 2008). Each patient (respectively, care staff) requires a time windows pinpointing its availability at home (respectively at the hospital establishment (depot)). In order to manage the fact that a service is performed by several caregivers simultaneously, so-called synchronization constraints have been taken into consideration, allowing to coordinate the time visit affected to the patient. The goal is to minimize the travel cost of caregivers and non-preferences of patients towards caregivers. A mono-objective method of type Branch and Bound has been proposed by the authors.

A linear programming with mixed variables (MILP) was proposed by Redjem et al (2012) in which an important optimization criterion in the improvement of home care structures has been introduced. In addition to minimizing the cost travelling, authors were attracted in minimizing and shortening the patients waiting time, especially those who requested multiple synchronized visits.

The same authors (Redjem & Marcon (In press)) recently proposed a heuristic in two stages where a set of routes were firstly generated by ignoring coordination constraints, then theses coordinating constraints are introduced to achieve feasible solutions. In the same flow, Afifi et al (2013) proposed a simulated annealing algorithm.

From past available literature, metaheuristics reach optimal solutions and improve most of the best solutions found in the literature. In the above, the synchronization of the patients was modeled by duplicating the corresponding node, and in doing that increase the size of the initial path.

A new mathematical modeling was proposed by Labadi et al (2014) to avoid nodes duplication. An approximated Iterated Local Search (ILS) was proposed and tested on small available instances. In the same context, Issaoui et al (2015) proposed an iterative metaheuristic based on Variable Neighborhood Search (VNS), maximizing patient satisfaction and minimizing the travel cost.

Bazirha et al (2020) addresses the HHCRSP (Home Health Care Routing and Scheduling Problem) which is an extension of the VRPTW with multiple availability periods of patients considered as soft/flexible time windows. The authors proposed a mathematical model to minimize the total penalized earliness and tardiness of services operations and minimize the total waiting time of caregivers.

In the same order, a HHCRSP problem was addressed by Shahnejat-Bushehri et al (2019) which consider temporal synchronization and precedence constraints. The authors made a new formulation in order to discover the qualification of each caregiver based on the services requested by patients. Two metaheuristics were proposed to solve the problem, simulated annealing (SA) and taboo search (TS) and were applied in two phases. The objective was to minimize the cost related to the transportation and the unproductive time of caregivers by adjusting the needs of the patients to the correct caregiver with required service qualification.
Another variant of the VRPTW problem for Home Health Care Routing and Scheduling Problem with Time Windows and Synchronized visits (VRPTWSyn) was proposed by Borchani et al (2019) to optimize the sequence visits execution and visits to homes by caregiver's assignments. The objective is to minimize the difference in service time between different vehicles to optimize the workload balance. The approach was developed by a genetic algorithm and a hybrid genetic algorithm.

Ait Haddadene et al. (2016) proposed a variant of the VRP problem with time windows and timing constraints, where patients can demand for more than one visit either simultaneously or in a given order (precedence). A mixed integer linear program, a greedy heuristic, three metaheuristics was applied to find feasible solutions of the problem. The objective was to minimize the travels costs of the caregivers and the non-preferences towards caregivers.

5. PICKUP AND DELIVERY

Pickup and delivery in the home care service considers the problems in which patients are to be picked up and/or dropped off from an initial place to a final destination (Coppi et al (2013)). On the same level, Bräysy et al (2009) combined many variants of common problems detected in the health system such as home care planning and the transportation of the elderly and also the delivery of meals to patients' homes. In this particular context, care staff have different levels of skills and a maximum amount of working hours per day to perform the various services required by patients. Customers (patients) are grouped by zones and staff by team. In fact, each customer (patient) in a specific area is visited by a staff member of the corresponding team. The aim is to maximize the hours of visits performed and staff preferences (taking into consideration the regulation of breaks, daily load…). The authors split the problem in two:

- The problem of transporting the elderly.
- The problem of meal delivery in which time windows are considered.

A similar problem for which two main services were introduced by Lin et al (2013), delivery of medication and medical devices from pharmacies to patients' homes and the picking up of biological samples and/or medical devices not used anymore by patients. These two services are dependent on time windows constraints and are planned simultaneously.

To finish this section, we can cite the paper of Ceselli et al (2014) who worked on the distribution of medications and vaccines through the use of distribution centers and coordinated vehicles. Two approaches were considered to reach a patient:

- Creation of distribution centers where people go on their own to claim for example medication.

- Delivery to the patient via a fleet of heterogeneous vehicles.

The aim of this study is to minimize unsatisfied requests. An exact algorithm based on columns generation was developed in order to resolve this problem.

6. CLASSIFICATION OF ROUTING PROBLEMS IN HOME HEALTH CARE

In the previous sections, works on touring problems applied to the sector of home care have been detailed. We focus in this literature review on several articles that we are going to classify giving three essentials characteristics: (a) Optimization criteria, (b) Constraints, (c) The proposed resolution methods. In this section, we will strive to show the first criteria of comparison presented in Table 1 which proposes an appellation by optimization objective.

Table 2 shows different objective functions that have been reviewed and summarized, where column 1 corresponds to the paper reference, while column 2 correspond to objectives recorded in Table 1. For each article that considers one or more of the objectives proposed in column 2, a symbol (—) is put in the adequate cell.

Table 1. Common Optimization Criteria (Times New Roman 10 pt) – align left.

Abbr.	**Description**
T	Time (Movemnet, Wait, Overtime…)
C	Costs (Movemnet, Wait, Assignement…)
D	Travelled Distance
PP	Patients Preferences
CP	Caregivers Preferences
AS	Accomplished Services

Table 2. Optimization criteria in the literature

	T	C	D	PP	CP	AS
Cheng & Rich (1998)	—					
Everborn et al (2006)		—				
Bertels & Stefan (2006)		—		—	—	
Doerner et al (2007)	—		—			
Akjiratikarl et al (2007)			—			
Bredstörm & Rönnqvist (2007, 2008)			—	—		
Bräysy et al (2009)					—	—
Trautsamwieser & Hirsch (2011)	—			—	—	
Redjem et al (2012)	—					
Rasmusen et al (2012)		—			—	—
Liu et al (2013)		—				
Coppi et al (2013)		—				
Rousseau et al (2013)	—					—
Afifi et al (2013)		—				
Labadie et al (2014)	—					
Ceselli et al (2014)		—				—
Redjem & Marcon (In press)	—					
Issaoui et al (2015)			—	—		
Ait Hadaddene et al (2016)	—	—	—	—		
Shahnejat-Bushehri et al (2019)	—	—	—			—
Borchani et al (2019)	—	—	—			—
Bazirha et al (2020)	—	—				

In regard to this first classification, we generally observe that the cost, time and preference are the most common target in the literature. Doerner et al (2007) is the only to propose a true multi-criteria approach based on the principle of dominance while all authors adopted a mono-objective resolution.

Table 3 presents the second comparison criterion which proposes a list of the most considered constraints in Home Health Care Problem (HHCP). Many constraints were treated in the reviewed articles. Table 4 lists constraints where column 1 corresponds to the document reference, meanwhile columns 2 to 6 correspond to each constraint enumerated in Table 3.

Table 3. Common Constraints

Abbr.	Description
TW	Time Windows
Sync	Simultaneous Syncronization
Prec	Precedence Syncronization
Pref	Patients and/or Caregivers Preferences
CQ	Caregivers Qualificaions

Table 4. Considered Constraints in the literature

	TW	Sync	Prec	Pref	CQ
Cheng & Rich (1998)	—				—
Everborn et al (2006)	—	—		—	—
Bertels & Stefan (2006)				—	—
Doerner et al (2007)	—				
Akjiratikarl et al (2007)	—				
Bredstörm & Rönnqvist (2007, 2008)	—	—			
Bräysy et al (2009)	—	—			—
Trautsamwieser & Hirsch (2011)	—				
Redjem et al (2012)	—	—			
Rasmusen et al (2012)	—		—		
Liu et al (2013)	—	—	—		
Coppi et al (2013)	—				
Rousseau et al (2013)	—		—		—
Afifi et al (2013)	—		—		
Labadie et al (2014)	—	—			—
Ceselli et al (2014)	—				
Redjem & Marcon (In press)	—	—			—
Issaoui et al (2015)	—			—	—
Ait Hadaddene et al (2016)	—	—	—	—	—
Shahnejat-Bushehri et al (2019)	—	—	—		—
Borchani et al (2019)	—	—			
Bazirha et al (2020)	—	—			

Time constraints are not only related to the time windows associated with patients and/or vehicles, it also relates to the interdependence of tours realized by caregivers. Drexl (2012) has defined this interdependence as being the synchronization of the vehicle routing operations. More particularly, in the context of homecare, two synchronization constraints were distinguished by Labadie et al (2014):

- Priority synchronization or precedence: when a patient requires orderly visits. For example, when a patient needs a specific care service before another one, the two services must be in an accurate order.
- Simultaneous synchronization: when a patient requires the presence of more than one caregiver at a time. For example, a patient needs more than one caregiver for a bath especially if the patient is overweight or cannot move properly; this type of service cannot be done by only one caregiver.

Table 5 illustrates the third comparison criteria where the classification of the resolution approaches used by the authors is shown. We distinguish three types of resolutions: (a) Mathematical model using a linear solver (column 2), (b) Exact methods (column 3), (c) Approached methods (column 4).

To illustrate the most optimization criteria used to solve the Logistics problems in the home health care sector, we calculated the percentage of articles reviewed according to all the optimization criteria encountered in this paper, Figure 2 shows the number of optimization criterion used.

The next figure Figure 3 shows the percentage of each optimization criterion used to solve the problems encountered in the papers revised.

Table 5. Resolution methods

	Linear Solver	Exact	Approached
Cheng & Rich (1998)	—		—
Everborn et al (2006)			—
Bertels & Stefan (2006)			—
Doerner et al (2007)	—		—
Akjiratikarl et al (2007)			—
Bredstörm & Rönnqvist (2007, 2008)	—	—	
Bräysy et al (2009)	—		
Trautsamwieser & Hirsch (2011)	—		—
Redjem et al (2012)	—		—
Rasmusen et al (2012)		—	
Liu et al (2013)	—		—
Coppi et al (2013)		—	
Rousseau et al (2013)		—	—
Afifi et al (2013)	—		—
Labadie et al (2014)	—		—
Ceselli et al (2014)		—	
Redjem & Marcon (In press)		—	—
Issaoui et al (2015)			—
Ait Haddadene et al (2016)	—	—	—
Shahnejat-Bushehri et al (2019)			—
Borchani et al (2019)			—
Bazirha et al (2020)	—		—

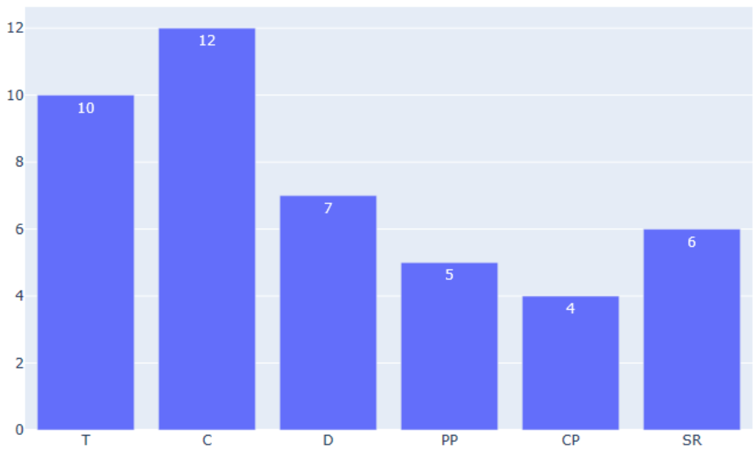

Figure 2. Number of articles dealing with each optimization criterion

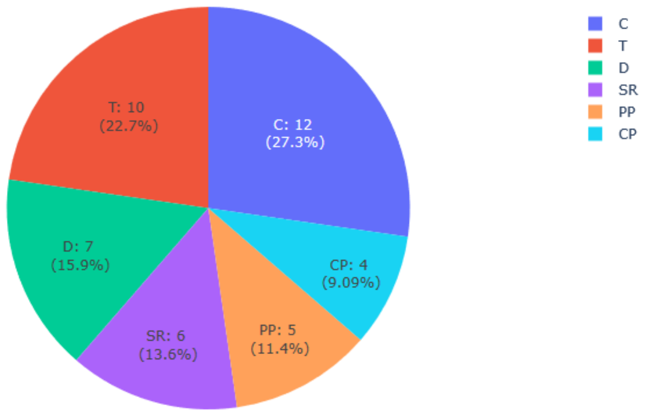

Figure 3. Optimization criteria percentage in reviewed articles

It is obvious that the most optimization criteria used and treated in most of the reviewed papers are the cost and the time, and in a lesser level, the travelled distance criterion. The uncommon used criteria and less dealt with are the caregivers' preferences and patients preferences which are related to quality services and satisfaction neither from patients and/or caregivers.

Resolution methods also differ in their quality and use for solving problems related to home care services, Figure 4 illustrates the number and dominance of each of the three resolution methods (Linear solver, exact methods and approached methods) for each optimization criterion shown in this study.

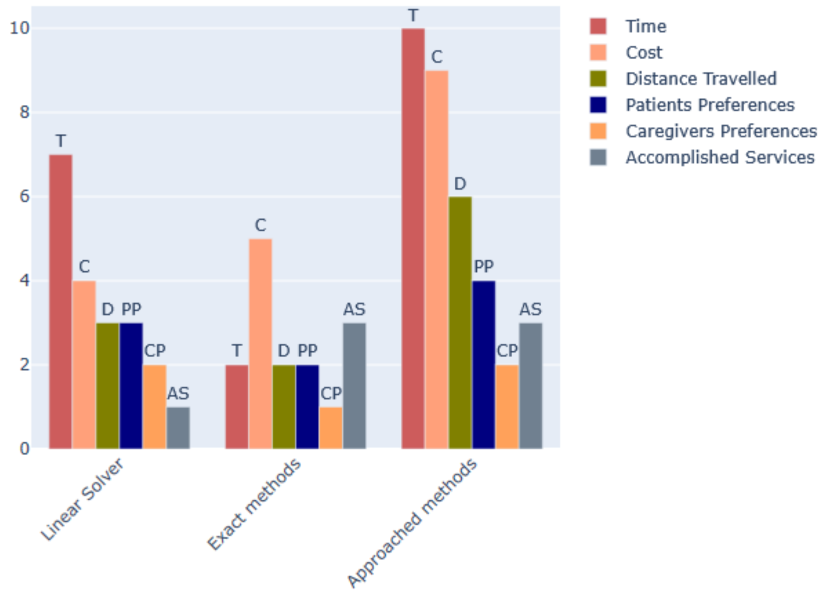

Figure 4. Number of articles according to resolution methods applied for each optimization objective

It is clear that the approached methods are the most common and used for solving the greater amount of optimization criteria, meanwhile the exacts methods are less used (not commonly used due to the complexity of the problem and the dynamicity of it, it is very hard to find an exact solution to a NP-hard problem) and are usually combined with an approached resolution (Hybrid).

7. ROUTING PROBLEMS WITH SYNCHROIZATION

In this section, we will target our research on the papers that are close enough to the problems interesting us which are included in the field of home health care services. There are multitudes of works regarding routing that integrate synchronization constraints and/or priority (precedence). To illustrate this, Ioachim et al (1999) described the routing and allocation problem of aircrafts with simultaneous synchronization constraints. These constraints require the same time start for every regular flight taking off every day of the week. It is a periodic variant of the vehicle routing problem. To resolve this problem, authors proposed a formulation of the problem of immiscible multiple flows and developed a Branch and Price approach by taking into account optimization criteria such as the minimization of total cost associated to flights.

In the context of pickup and delivery, Drexl (2012) introduced synchronization constraints in a Vehicle Routing Problem with Trailer and Transshipment (VRPTT), applied to the collect of raw milk in farms. Two types of vehicles were used in this problem: autonomous vehicles also called trucks that can move alone and non-autonomous vehicles called trailers that can only move using a truck. So, two types of client are considered: client (trailer) that can be visited only by a truck without trailer. The goal is to determine trucks and trailers routes in order to reduce the total cost with the satisfaction of a set of constraints (clients' requests, loading capacity, accessibility constraints, synchronization and time windows between trucks and trailers routes). The author proposed a mathematical model based on graphic representation of the VRPTT. Neither less, not a single resolution method was addressed in the paper. In the same context, constant time feasibility tests for precedence type constraints were conducted by Masson et al (2013) for the pickup and delivery problem with transfer points. In the same order, Del Pia & Flippi (2006) also introduced synchronization constraints in the household waste collect problem. The objective is to minimize the total duration of journeys. Two types of trucks are used in this study: small (satellites) which are authorized to travel on any type of street and a second called large (compactors) which are prohibited to circulate on narrow streets because of their width. The synchronization occurs when a satellite need to cleat its content in the compactor, those last two must arrive simultaneously. To resolve this matter, the authors proposed a heuristic based on a local search procedure with a variable descent (Variable Neighborhood Descent (VND)). The optimization criterion is to minimize the trucks movements cost.

Various studies on the arc routing problem introducing synchronization constraints can be found in the literature. Salazar-Aguillar et al (2013) worked on the arc routing problem by introducing synchronization constraints modeling snow removal operations in Canada. To describe this problem, a fleet of special vehicles designed to remove snow are available at the initial depot to treat a set of predefined routes. Each route segment has one or two direction and for reach direction, the number of tracks is between 1 and 3. An imposition of synchronization constraints about roads with more than one track are to be cleared simultaneously with different synchronized vehicles. The objective is to determine the set of routes minimizing the duration of the longest route alongside executing all the tasks of snow removal. In order to resolve this problem, an integer mixed non-linear programming model and a heuristic based on the Adaptive Large Neighborhood Search (ALNS) metaheuristic is proposed by the authors. The heuristic constructs an initial set of feasible routes and destruction/repair techniques are used to improve this solution. Numerical tests were realized both on big instances generated randomly and on real ones.

8. DISCUSSION

The aging of population nowadays and the appearance of various diseases helped in the emerging of new needs such as the access to cares and the improvement of quality life and taking charge of patients. The work papers reviewed in this article, all but the exception of none, have a common goal of setting in place an optimized planning and a fine coordination of human and material resources in order to ensure care and a follow-up care of high quality without neglecting the costs and trying to control them as much as possible.

The first point concluded is that there is not a lot of paper research working on the caregiver routing problem in a home care prospect, associating various real time constraints which encourage us to start researches in that way.

The first model that was reviewed was the mixed integer linear model usually used for the mono-objective optimization for the VRPTW-SP. Across the papers, multiple optimization criteria were optimized by combining them in the same mono-objective function. Without regarding the different objectives that these papers aim to solve, the first remark to take into consideration in regard of the results obtained is the adequacy and capability of this mathematical model introducing multiple and different common constraints in the home care services. The limits of this resolution approach can be seen in the complexity of the problem and in instances higher than 40 clients (patients), however this limits led researches to investigate more and adequate algorithms to overcome such limits by introducing constructive heuristics to initiate more sophisticated methods.

More efficient and powerful methods based on metaheuristics were elaborated and proposed in the same direction, different proposal were made in various papers such as iterative method based on a glutton and randomized heuristic (GRASP), iterative local search (ILS), hybridization form of 2 methods… The results of heuristics were ameliorated by each one of these methods, but the hybridization form dominates and display better results than the other methods.

Multi-criteria problems were addressed in the home health care sector, by the use of metaheuristics based on population which almost all authors applied a recent form of multi-objective genetic algorithms, which led to many different algorithms and thus, it is a must to analyze the impact of each parameter in order to determine the suitable configuration in accordance to wished results.

Another issue detected is the synchronization constraints validation. It is a must to ensure the movements applications for all type of clients (synchronized or not). Notice that the complexity of the problem increases considerably in accordance to number of synchronized clients available, so it comes to mind that a deep reflection on the efficiency of feasibility tests including synchronized clients is much needed. Feasibility tests that consider freely synchronized clients with respect of synchronization constraints is much required to adapt to real life situations. The lack of practical use cases on a real HHC structure in papers do not show the real capabilities and efficiency of methods illustrated and the limits of each proposal in real life scenarios.

9. CONCLUSION AND PERSPECTIVES

In this paper, we have presented an overall state of the art on the problems related to touring and applied to the home care sector. In general, travelling costs and preferences are the most studied criteria in the literature. Indeed, those two criteria remain the most important to optimize the costs of home care structures and in order to improve quality services. In this context, we have identified three classification criteria of the articles treated: the objective to be optimized, the constraints and the resolution methods. We also find in the literature that time constraints like time windows and synchronization are usually considered. It is well spread and covers a wide range of real applications particularly in transport logistics. Therefore, the interest of studying these time constraints is major. Also, approached methods seem to be the most used to solve this type of problems. The key point of the effectiveness of these methods lies precisely in the adaptation of local search movement with synchronization constraints.

In order to improve the work of the actual literature on this kind of problems, it could be interesting to develop a new instance sets with more than two services requested by customers (patients) in the case caregivers could offer many services. Also, it is considered to integrate new constraints into the problem seems relevant for practical applications, such as introducing preferences of customers in constraints, or even considerate regulatory constraints relating to breaks, caregivers leaves… We could also improve the quality of structures services of home health care by the addition of another optimization constraint reducing the wait time of clients (patients) seems very important in order to approach better realistic aspect of the problem.

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Appendix

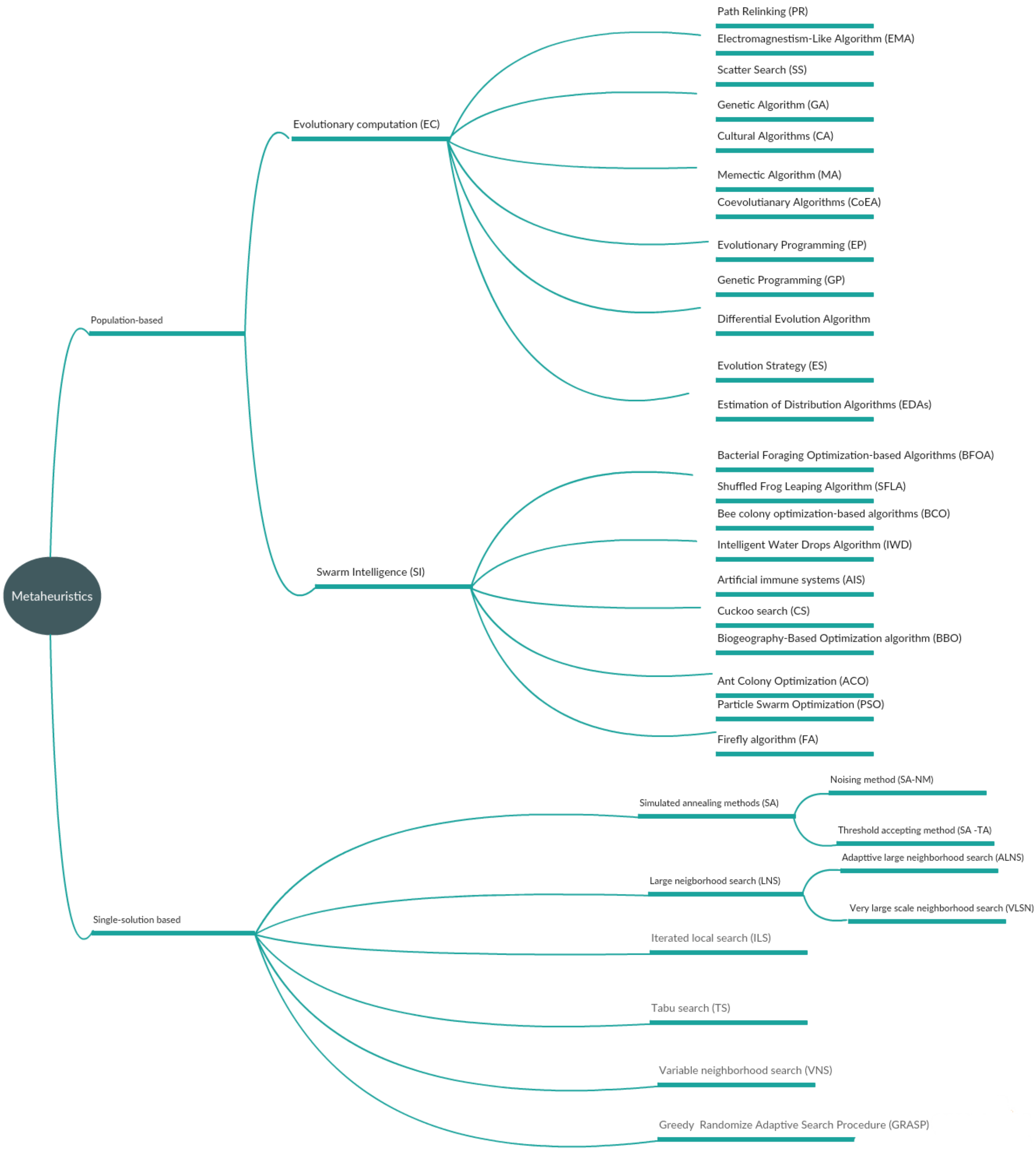

Figure 1. Classification tree of Metaheuristic Algorithms