Eurasian Journal of Health Technology Assessment

A literature review on Home Healthcare Routing and Scheduling Problem

Mehmet Erdem*,**‡, Serol Bulkan**

*Department of Industrial Engineering, Faculty of Engineering, Atilim University, Incek, 06836, Ankara, Turkey
**Department of Industrial Engineering, Faculty of Engineering Marmara University, Kadikoy, 34722, Istanbul, Turkey

‡ Corresponding Author; Address: Department of Industrial Engineering, Faculty of Engineering, Atilim University, Incek, 06836, Ankara, Turkey Tel: +90 312 586 83 26, Fax: +90 312 586 80 91, e-mail: mehmet.erdem@atilim.edu.tr

Abstract- The Home Healthcare Routing and Scheduling Problem (HHCRSP) involves some of the features of vehicle routing and nurse rostering problem. Home healthcare is a part of health services, which can be defined as providing the necessary services to the patients and their families within their familiar environments. Some of the issues such as aging population, increasing diseases, shortage of workforce, economic reasons, innovation in medical technologies, preferences etc. increase the importance and the need of Home healthcare. Furthermore, solution procedures for these routing and scheduling problems are varied according to the assumptions. In this review, the most common characteristics of the problem and an overview of recent works related to the HHCRSP are discussed.

Keywords- Literature Review, Home Healthcare, Operation Research, Vehicle Routing, Nurse Scheduling.

1. Introduction

Home healthcare (HHC) covers a set of medical, therapeutic, and nonmedical services for patients at their familiar environments. Generally, it is considered as cost efficient, convenient, and as effective as the care that the patients get in a hospital. Ageing population, shortage of workforce, economic reasons, innovation in medical technologies, preferences of patients and nurses, etc. that increase the demand/need for HHC services in the near future as it is today (Medicine, 2017). In the US, 9 million people demand care services from regulated providers in 2014. The number of HHC agencies was 9024 in 2007 (Statista, 2015) and this figure was 12400 in 2014 (CDC, 2017). According to a report (R&M, 2017) the volume of HHC services reached $86 billion in 2016. In Europe, more than $20 billion increase is expected in the volume of the HHC and nursing care services, and this volume will reach $232 billion in 2020. ın addition, 65 years or over made up a 19.2% share of the EU-28's population and this group will rise and account for 29.1% by 2080 (Eurostat, 2017). Globally, estimations show that in 2050 aged 80 years or over will number 434 million, which was 125 million in 2015 (Colombo and et al.) (UN, 2015). Therefore, the increase in elderly population leads to an increase number of people living with chronic illnesses and disabilities especially in developed societies. The sustainability of HHC system is important in this regard.

The decisions of Operations Management (OM) can be divided into four level with respect to the time horizon. These are strategic (1-5 years), tactical (6-12 months), operational (weeks-months), and detailed operational levels (hours-days) (Matta et al., 2014). Furthermore, each of the level has its own variety of scheduling, assignment, and routing decision in the HHC operations. Heterogeneous nurses and clients who scattered in different geographical areas have a set of characteristics, demands, and preferences. For an appropriate solution, each side of concern should be satisfied as much as possible. This is a time consuming activity for experts who develop a plan manually. Therefore, creating a suitable plan in the predetermined planning horizon with a minimum cost or a minimum deviation from preferences is a necessity.

There are many studies exists in the fields of Operations Research (OR) (Cissé et al., 2017; Milburn, 2012) and OM (Fikar and Hirsch, 2017) which are related to the HHCRSP. Many researchers proposed a series of different models dealt with the HHCRSP. These existing models involve a set of various objectives and constraints. Furthermore, solution procedures for these routing and scheduling problems are varied according to the assumptions, problem dimension, regulations, etc. Consequently, the definition of this problem and the meaning of terms can change in the literature. The aim of this review is not only to give insight about existing related literature, but also to make classification/comparisons between proposed (performance measures) models. Some of the review papers (Braekers et al., 2016; Cissé et al., 2017; Fikar and Hirsch, 2017; Mankowska et al., 2014; Maya Duque et al., 2015) tackled with the same issue and we consider these as a basis for our work.

This review paper organized as follows: Section 2 introduces a brief description of the HHCRSP. Section 3 gives the relevant and important performance measures of the problem. Section 4 analyses existing publications according to their constraints. Exact and metaheuristics solutions are investigated in Section 5. Section 6 covers conclusions and future research directions of the HHCRSP.

2. Home Healthcare Routing and Scheduling Problem

The Home Healthcare Routing and Scheduling Problem (HHCRSP) involves some of the features of vehicles routing problem with time windows (VRPTW) and nurse rostering problem (NRP). These are known as combinatorial optimization problems. HHC is a part of the health services, which can be defined as providing the necessary services to the patients and their families within their living environments. The aim of the HHC is to increase the level of access to the maximum treatment with minimum interruption of daily living, to minimize the effects of the diseases and the disabilities, and to raise the living conditions (Karabağ, 2007). This problem concerns the assignment, routing, and scheduling decisions for a set of patients in different geographical locations who demand care with different qualification levels from a set of heterogeneous healthcare workers. Furthermore, while allocation these workers to the clients, time windows, preferences, features, workload, continuity of care, quality of service level, regulations, etc. should be considered during planning horizon. The issues, modes of transportation, working and waiting times of nurses should not be ignored in this perspective.

The HHC services offer many advantages such as (Ellenbecker et al., 2008; Karabağ, 2007; Marak, 2016):

- Caring a patient in the hospital costs higher than the HHC services.
- A client has the opportunity to recover in her/his own home. This allows freedom and independence. Moreover, it provides more effective psychological support.
- The HHC services are designed as client-centred care.
- Family and friends can be involved in ones' care.
- Caring at a client's home is a safer place than caring at hospital for contagious infections.
- The HHC services improve the quality of care.
- It can reduce and prevent the unplanned hospital admissions/hospitalizations.
- Insurance.

The most common characteristics of the HHCRSP are summarized in this section. Some of these are defined clearly and considered as the

Erdem, M., Bulkan, S., (2017). A literature review on Home Healthcare Routing and Scheduling Problem , Eurasian Journal of Health Technology Assessment, *Vol. 2, No. 1, 19-33*

natural dimension of the problem (Castillo-Salazar et al., 2014).

Healthcare workers: This is the basic component of the healthcare system. Healthcare workers consist of nurses, assistants, and unskilled workers. In the real world cases, a list of competencies is specified based upon experience level and educational level of the workers. Each worker has a specified working time window, a specified home location (latitude-longitude), and a set of features such as gender, speaking language, pet allergy, smoking habit, etc.

Jobs: The citizens/clients who are elderly or handicapped receive care from the healthcare system. They can demand more than one job on the scheduling horizon, and these jobs can be carried out by more than one nurse. All of the jobs must be serviced by nurse(s) for the satisfaction of clients. For each job, a time window, preferred starting time, and duration are determined by the healthcare providers or clients. Therefore, each job must be performed within a predetermined time window and the preferred starting time of the job should be taken into consideration as much as possible. The graphical representation of a job with its route and time window is illustrated in Figure 1, where circular and square nodes correspond to nurse and job, respectively. Above part of Figure 1 summarizes job *j* is carried out by nurse *n.* In order to perform job *j*, nurse *n* must be wait if s/he arrives before the starting time and job *j* should be covered before the ending time of the job.

Time windows: Working time windows can be considered tight or flexible with respect to contractual arrangements. Moreover, in some cases, employees work annually hours without considering time windows. In the flexible cases, employees can work overtime. In some case (Erdem and Bulkan, 2017), a nurse is not assigned a job before starting working time, and if a nurse starts to perform a job within her/his working time windows, the job must be covered without considering ending working time.

Time window of each job can be considered as being soft and hard. In the first case, when the employees can start work as soon as they arrive. The violation of a soft time window results higher penalty costs. In the second case, nurses cannot start to achieve job before starting time and must complete before ending time. The concept of a time window is presented in Figure 2 (Bertels and Fahle, 2006). If a nurse arrives before hard-starting time it means that, this roster yields waiting time. Similarly, if a nurse arrives after a hard-ending time, which means this roster is infeasible.

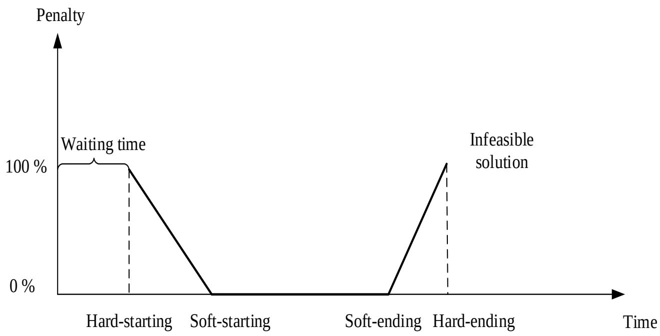

Fig. 2. The penalty concept of a time window (Bertels and Fahle, 2006)

Healthcare organizations deal with a variety of demands, hence the duration of jobs differs depending on the staff member and performing tasks. In some of the cases, the duration of jobs is less and equal to the difference of ending and starting time. When the duration is greater than to the difference, it is necessary to be considered as being soft. In order to relax the time windows, a penalty term can be used according to the existing fields of the VRPTW (Bräysy and Gendreau, 2005a, 2005b).

Mode of transport: It means that nurses can use different modes of transportation like cars, bikes, public transport or else they can walk (Erdem and Bulkan, 2017; Fikar and Hirsch, 2015; Hiermann et al., 2015). It is assumed that travelling time and the cost of transportation differ between two locations.

Start and end locations: All healthcare workers can start at the office (Eveborn et al., 2006) or each nurse may start from her/his home. Moreover, in some cases, executives force staff to start work at the office, but they can return home after achieving the last job. In our case, the home location of nurses defined by latitude and longitude is considered as starting and ending points.

Skills and qualifications: Some of the works require different abilities to perform tasks. In literature, there are two different approaches. (1) A homogeneous group means having the same skills and qualifications. (2) A heterogeneous group means having different levels of proficiencies. In the two cases, both have pros and cons. Employing homogenous workers usually unpractical and it leads to higher costs. The assignment of qualified employees to the right tasks is also a different challenge for organizations. As mentioned earlier, each nurse has a set of skills that is represented by the qualification levels. These levels are employed to satisfy a series of customer needs with well-qualified nurses.

Connected activities: It corresponds to the interdependence of activities (Figure 3). One activity must be achieved before or after another, which is called sequential dependency. Rasmussen et al. (2012) proposed a series of temporal

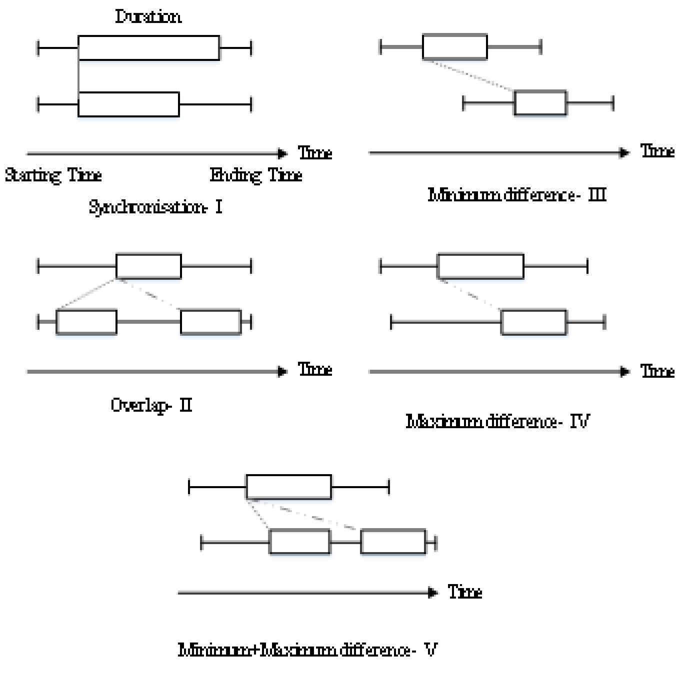

Fig. 3. Temporal dependencies (Rasmussen et al., 2012)

dependencies. Synchronization occurs, i.e. when the two jobs are required to start at the same time. Overlap means activities happen simultaneously (Figure 3-II). In other words, the second (bottom) job must start when the first job has finished. Minimum difference dependency, i.e. a nurse starts a job at a client's home and a following nurse (perhaps the same nurse) finishes the same job at the same client home. Maximum difference dependencies built a starting time limit for the second job with respect to the start of the first job. In this temporal dependency, there is at least an overlap between the two jobs. The min-max difference can be accomplished by employing time windows dependency and it is also shown in Figure 3-V. The dotted line and the dashed-dotted line correspond to the earliest and latest feasible start time for the bottom of the job in Figure 3-V, respectively.

Teaming: In order to achieve a job sometimes a group work necessitates because of the special case of the work. When members of the team are fixed, then it is assumed that they are treated as a single entity; hence, it is perceived that they achieve the jobs at the same time. On the other hand, team synchronization is necessary to perform the jobs. Here, synchronization corresponds to the staffs not to activities. If the members of the groups change regularly, then skill matching must be considered to achieve multiple jobs.

Clusterisation is sometimes reasonable to apply. For instance, it can decrease the travelled distance of the staff member. The assignment of employees in a certain region is more preferable for the organizations. It can be also used to decrease the size of the problem (Erdem and Bulkan, 2017).

In the literature, most publications deal with deterministic and static problems, all problem parameters are known beforehand. In dynamic problems, at least one of the input is unknown and revealed dynamically. Similar to the dynamic problems, in stochastic problems part or all of the inputs are unknown in advance and revealed during the optimization process. The difference between the two are stochastic knowledge (Pillac et al., 2013). In contrast to the deterministic problems, some authors also tackle with dynamic (Bennett and Erera, 2011; Bowers et al., 2015;

Koeleman et al., 2012) and stochastic (Carello and Lanzarone, 2014; Lanzarone and Matta, 2014; Rodriguez et al., 2015; B. Yuan et al., 2015) problems.

3. Objectives

The performance measure and objectives of the HHCRSP are classified in Table 1 and Table 2. These works are sorted in the first column by date instead of alphabetically as in the works of Cissé et al. (2017); Fikar and Hirsch (2017). The rest column represents the measures. The meanings of the abbreviations in the tables are given under the tables. Table 1 and Table 2 involves 36 single-period and 29 multi-period works, respectively. Many of the deterministic publications involve an extension of VRP, and travelling salesman problem (TSP) (Allaoua et al., 2013) and dial-a-ride-problem (DARP) (Fikar and Hirsch, 2015) based models also developed.

The most common objectives are the

Table 1. Objectives of the single-period HHCRSP (Fikar and Hirsch, 2017)

Paper	H	T	C	D	WT	OT	BW	PR	NJ	NN	NU	CV	SM	PRI	CC
Fernandez et al. (1974)	S			+											
Cheng and Rich (1998)	S	+	+												
Hindle et al. (2000)	S	+		+											
Bertels and Fahle (2006)	S		+					+				+			
Eveborn et al. (2006)	S		+												
Akjiratikarl et al. (2007)	S			+											
Bredström and Rönnqvist (2008)	S	+					+	+							
Elbenania et al. (2008)	S	+								+					
Yannick Kergosien et al. (2009)	S		+												
Bräysy et al. (2009)	S			+											
Dohn et al. (2009)	S								+						
Hindle et al. (2009)	S	+													
Misir et al. (2010)	S	+			+							+			
Redjem et al. (2011)	S	+			+										
Trautsamwieser and Hirsch (2011)	S	+			+	+		+				+			
Trautsamwieser et al. (2011)	S	+			+	+		+				+			
Rasmussen et al. (2012)	S		+					+			+				
Rendl et al. (2012)	S	+				+		+				+			
Allaoua et al. (2013)	S									+					
Coppi et al. (2013)	S		+												
Liu et al. (2013)	S		+												
Di Mascolo et al. (2014)	S				+										
Castillo-Salazar et al. (2014)	S	+	+					+			+				
Lanzarone and Matta (2014)	S					+	+								
Mankowska et al. (2014)	S	+		+			+					+			
Mutingi and Mbohwa (2014)	S			+			+					+			
Fikar and Hirsch (2015)	S	+			+										
Issaoui et al. (2015)	S			+											
Hiermann et al. (2015)	S	+				+		+				+			
Mısır et al. (2015)	S	+			+	+		+				+			
B. Yuan et al. (2015)	S		+							+		+			
Braekers et al. (2016)	S		+			+	+	+				+			
Redjem and Marcon (2016)	S	+			+										
Rest and Hirsch (2016)	S	+			+	+									
Yalçındağ, Matta et al. (2016)	S	+					+								
Erdem and Bulkan (2017)	S	+		+	+	+			+	+	+	+			

H: Horizon (S:single-M:multi), Time:T, Cost:C, Distance:D, Waiting:WT, Overtime:OT, Balance of the workload:BW, Patient-Staff preferences:PR, Number of patients or jobs:NJ, Number of nurses:NN, Uncovered visits:NU, CV: Violations of constraints ,Skill matching:SM, Priority:PRI, Continuity of care:CC.

minimization of travelling time and distance. Furthermore, some of the works include overtime work and waiting/idle time of workers. Generally, allocating minimum number of nurses is considered in the long or multi-period publications. Furthermore, the deviations of a set of hard and soft constraints are also taken into account as objectives (Hiermann et al., 2015). Many of the works utilize the multi-objective function in which weights represent different priorities/precedence. The determination of weights is a crucial process and generally computations of these lead to an obstacle for computational comparisons. In contrast to the

Table 2. Objectives of the multi-period HHCRSP (Fikar and Hirsch, 2017)

Paper	H	T	C	D	WT	OT	BW	PR	NJ	NN	NU	CV	SM	PRI	CC
Begur et al. (1997)	M	+		+											
De Angelis (1998)	M								+						
Borsani et al. (2006)	M		+						+						+
Steeg and Schröder (2008)	M		+	+				+							
Hertz and Lahrichi (2009)	M			+			+						+		
Bachouch et al. (2011)	M			+											
Bennett and Erera (2011)	M								+						
Barrera et al. (2012)	M						+			+					
Cattafi et al. (2012)	M						+			+					
Gamst and Jensen (2012)	M	+	+					+						+	
Koeleman et al. (2012)	M								+						
Nickel et al. (2012)	M			+		+					+				+
Shao et al. (2012)	M		+			+									
Bennett-Milburn and Spicer (2013)	M		+				+								+
Cappanera and Scutellà (2013)	M						+								
Y. Kergosien et al. (2014)	M	+	+	+											
Bard Shao et al. (2014)	M		+			+									
Bard, Shao et al. (2014)	M		+			+									
Carello and Lanzarone (2014)	M					+									+
Di Gaspero and Urli (2014)	M	+		+		+					+				
Ramos et al. (2014)	M	+													
Trautsamwieser and Hirsch (2014)	M	+			+										
Bowers et al. (2015)	M	+													+
Cappanera and Scutellà (2015)	M						+								
Maya Duque et al. (2015)	M			+				+							
Rodriguez et al. (2015)	M									+					
Z. Yuan and Fügenschuh (2015)	M	+					+			+					
Wirnitzer et al. (2016)	M								+						+
Yalçındağ, Cappanera et al. (2016)	M		+				+								

H: Horizon (S:single-M:multi), Time:T, Cost:C, Distance:D, Waiting:WT, Overtime:OT, Balance of the workload:BW, Patient-Staff preferences:PR, Number of patients or jobs:NJ, Number of nurses:NN, Uncovered visits:NU, CV: Violations of constraints ,Skill matching:SM, Priority:PRI, Continuity of care:CC.

single-period models, workload balance and continuity of care terms are the most common features discussed in the multi-period models.

When Table 1 and Table 2 are investigated further, the terms such as balancing workload (also named as fairness of schedule), skill matching, preferences of clients' and nurses, continuity of care are taken into consideration. The number of nurses and patients or jobs and also minimizing the number of unscheduled jobs are used as objectives.

4. Constraints

The existing literature can be divided into two groups such as single-period and multi-period. However, the most observed constraints are time windows, skill matching, working regulations, and synchronization without considering scheduling horizon.

As mentioned before, nurses and clients are crucial components of the problem and each side has different characteristics. Nurses have different types of qualification levels and clients can request a series of services at different levels. In addition to this, the allocation of nurse to the patients predetermined a variety of features, which should be considered for an appropriate assignment. These features can be language, gender, pet ownership/allergy, smoking habit, etc. (Erdem and Bulkan, 2017; Hiermann et al., 2015; Trautsamwieser and Hirsch, 2011, 2014). The downgrading of the competence is also taken into account in some publications (Trautsamwieser and Hirsch, 2011, 2014).

In order to perform some types of jobs, more than one nurse can be required. This issue is generally defined as the term temporal dependency. The single-period works (Bredström and Rönnqvist, 2008; Dohn et al., 2009; Eveborn et al., 2006) (Rasmussen et al., 2012) and the multi-period works (Bachouch et al., 2011) take into this account in their models. ın most of the reviewed publications, synchronized jobs are considered in the HHC services.

As previously mentioned, nurses should visit all assigned jobs within a variety of predetermined time windows. In addition to this, within the time windows, each patient can demand services desired starting times. In these cases, deviations from the time windows and desired starting time can be defined in the constraint set and penalized in the objective function (Erdem and Bulkan, 2017; Hiermann et al., 2015).

The single-period works (Fikar and Hirsch, 2015; Trautsamwieser et al., 2011; Trautsamwieser and Hirsch, 2011) and the multi-period (Rodriguez et al., 2015; Trautsamwieser and Hirsch, 2014) works employ a series of constraints for satisfying the mandatory working and breaks regulations. There are two types of breaks defined (Cissé et al., 2017). Nurses have a break either within a predetermined time interval or according to the length of the travelled time/distance.

Overtime work means any time worked beyond normal working hours (UK, 2017). In general, nurses work within the working time windows which is determined by contractual agreements. When nurse exceed the predetermined time windows, the additional compensation is paid for the overtime work. In other words, this yields infeasible solutions. In the model that employed soft working time windows, violations are penalized with a higher cost in the objective as the deviation of job or visiting time windows. Furthermore, the upper limit can be added for the overtime work (Bertels and Fahle, 2006).

Visiting pattern is also another temporal issue of the multi-period publications. Throughout planning horizon, nurses visit clients either on the predetermined days or times. In the first case, clients determine visiting days (i.e. Tuesday and Sunday) on each week. In the second case visiting times (i.e. two time a week or everyday visit) is determined.

In order to guarantee the fairness of the schedule and to evaluate workload balance many authors propose measurements. The single-period works (Bredström and Rönnqvist, 2008; Lanzarone and Matta, 2014; Mankowska et al., 2014) and the multi-period works (Hertz and Lahrichi, 2009) (Barrera et al., 2012; Cappanera and Scutellà, 2013)focus on the workload balance issue. Moreover, the workload of nurses regulates/limits according to the daily and weekly working hours which depend on each country. For instance, the number of daily working hours is limited to 7.5 h in the UK and 8 h in Finland (Akjiratikarl et al., 2007; Cissé et al., 2017).

The continuity of care is used for the person oriented consistency (Cissé et al., 2017) between nurses and clients. The aim is to assign the minimum number of different nurses to the same client during planning horizon. It is also defined as loyalty (Nickel et al., 2012) and regularity (Gamst and Jensen, 2012).

5. Solution Methods

In order to deal with the HHCRSP, the reviewed works focus on exact and metaheuristic solution procedures. The review paper dealing with metaheuristics (Cissé et al., 2017) can be divided into three local search-based (Mankowska et al., 2014; Rest and Hirsch, 2016), population based (Akjiratikarl et al., 2007; Cheng and Rich, 1998; Mutingi and Mbohwa, 2014), and hybrid (Bertels and Fahle, 2006; Bredström and Rönnqvist, 2008; Hiermann et al., 2015) methods. There are no benchmark instances available; hence, Cissé et al. (2017) compared the existing some of the publications dealing with metaheuristics to winning strategies proposed by (Vidal et al., 2013). The majority of single-period works propose a procedure based on the metaheuristics.

On the other hand, in order to deal with the small-size of the HHCRSPs, branch-and bound algorithms (Dohn et al., 2009; Rasmussen et al., 2012; B. Yuan et al., 2015) are mostly used. Moreover, set portioning problem (SPP) (Allaoua et al., 2013; Eveborn et al., 2006; Fikar and Hirsch, 2017) is also implemented.

Hybrid methods generally start with a feasible solution. Then metaheuristics improve the initial generated solution. In each phase different decisions such as assignment and routing can be performed. The combination of exact and heuristic methods is applied to obtain more improve solutions (Bertels and Fahle, 2006; Braekers et al., 2016; Bredström and Rönnqvist, 2008; Hiermann et al., 2015; Rendl et al., 2012).

While commonly used population-based algorithms are genetic algorithm (GA) (Cheng and Rich, 1998; Liu et al., 2013; Yalçındağ, Matta et al., 2016), particle swarm optimization (PSO) (Akjiratikarl et al., 2007; Mutingi and Mbohwa, 2014), memetic algorithm (MA) (Hiermann et al., 2015), the local search-based algorithms are tabu search (TS) (Bertels and Fahle, 2006; Elbenania et al., 2008; Liu et al., 2013; Rest and Hirsch, 2016), simulated annealing (SA) (Hiermann et al., 2015), and variable neighbourhood search (VNS) (Erdem and Bulkan, 2017; Hiermann et al., 2015; Issaoui et al., 2015; Rendl et al., 2012; Trautsamwieser et al., 2011; Trautsamwieser and Hirsch, 2011).

In contrary to Cissé et al. (2017) single-period problems grouping, the multi-period problems are classified as construction-based (Bard Shao et al., 2014; Shao et al., 2012), local search-based (Hertz and Lahrichi, 2009), and hybrid (Steeg and Schröder, 2008; Trautsamwieser and Hirsch, 2014) methods.

The BP (Gamst and Jensen, 2012) and branch-price-and-cut (BPC) (Trautsamwieser and Hirsch, 2014) algorithms are also implemented for multi-period problems.

In order to deal with the multi-period HHCRSP, a construction-based algorithms called greedy randomized adaptive search procedure (GRASP) (Bard Shao et al., 2014; Shao et al., 2012) is employed. The local search-based algorithms are TS (Hertz and Lahrichi, 2009; Yannick Kergosien et al., 2009), VNS(Y. Kergosien et al., 2014), and adaptive large neighbourhood search (ALNS) (Nickel et al., 2012; Steeg and Schröder, 2008) heuristics.

In the literature, some of the multi-period works concern that some of the parameters are unknown throughout the planning horizon. Stochastic parameters such as travelling time, the duration of services, the demands of a varied services, etc. are considered in this framework. Hence, dynamic (Bennett and Erera, 2011) and stochastic (Bowers et al., 2015; Koeleman et al., 2012; Rodriguez et al., 2015) problems are proposed in the field of multi-period HHC.

6. Conclusions

This review paper evaluates 65 publications related to the HHCRSP which combines nurse scheduling and vehicle routing. In order to solve this problem, mixed integer programming (MIP), integer programming (IP), stochastic programming (SP), constraint programming (CP) using SPP and network flow models are applied. Moreover, local search-based metaheuristics such as VNS, TS, SA, etc. and population-based metaheuristics such as GA, PSO, MA, etc. implemented. The publications that involve stochastic setting focuses on the limited real world stochastic parameters. In other words, these consider simplified version of real world problems and did not involve all decisions such as routing, assignment, and scheduling. And these are tested on synthesis data or employing mathematical proof of lemma, theorem, and proposition. Based on the classification, the majority of the model considers multi-objective function, which employs minimization of cost, working time, and distance. In terms of constraints, most research focus on time windows, skill matching, and regulations. Furthermore, preferences, temporal dependency, especially synchronization, workload, and continuity of care are used in many recently proposed problems.

In terms of solution technique, in the HHCRSP literature, there is no work dealing with graphical processing units (GPU) and/or parallel computing. The advantage of these can reduce the runtime of the optimization process.

The majority of publications is based upon the deterministic parameter setting; hence, the issues covering uncertainty in some types of emergencies, traffic conditions, etc., should not be ignored in terms of HHC services. The choice of a suitable mode pf transportation is another crucial issue because of its direct relationship with the energy consumption. Switching between the modes of transportation can be a new direction for the HHCRSP. Moreover, in term of (economic) sustainability the healthcare workers can use green or electrical vehicles. In this case, in addition to the assignment, scheduling, and routing decisions, a new recharging strategy should be determined. Therefore, the HHCRSP can cover a set of constraints for these vehicles such as refuelling of green vehicles or full/partial recharge strategies for electrical vehicles.

References

Akjiratikarl, C., Yenradee, P., & Drake, P. R. (2007). PSO-based algorithm for home care worker scheduling in the UK. *Computers & Industrial Engineering, 53*(4), 559-583. doi:10.1016/j.cie.2007.06.002

Allaoua, H., Borne, S., Létocart, L., & Wolfler Calvo, R. (2013). A matheuristic approach for solving a home health care problem. *Electronic Notes in Discrete Mathematics, 41*, 471-478. doi:10.1016/j.endm.2013.05.127

Bachouch, R. B., Guinet, A., & Hajri-Gabouj, S. (2011). A Decision-Making Tool for Home Health Care Nurses' Planning. *Supply Chain Forum: An International Journal, 12*(1), 14-20. doi:10.1080/16258312.2011.11517250

Bard, J. F., Shao, Y., & Jarrah, A. I. (2014). A sequential GRASP for the therapist routing and scheduling problem. *Journal of Scheduling, 17*(2), 109-133. doi:10.1007/s10951-013-0345-x

Bard, J. F., Shao, Y., Qi, X., & Jarrah, A. I. (2014). The traveling therapist scheduling problem. *IIE Transactions, 46*(7), 683-706. doi:10.1080/0740817X.2013.851434

Barrera, D., Velasco, N., & Amaya, C. A. (2012). A network-based approach to the multi-activity combined timetabling and crew scheduling problem: Workforce scheduling for public health policy implementation. *Computers & Industrial Engineering, 63*(4), 802-812. doi:http://dx.doi.org/10.1016/j.cie.2012.05.002

Begur, S. V., Miller, D. M., & Weaver, J. R. (1997). An Integrated Spatial DSS for Scheduling and Routing Home-Health-Care Nurses. *Interfaces, 27*(4), 35-48. doi:doi:10.1287/inte.27.4.35

Bennett-Milburn, A., & Spicer, J. (2013). Multi-objective home health nurse routing with remote monitoring devices. *Int J Plan Sched, 1*(4), 242-263.

Bennett, A. R., & Erera, A. L. (2011). Dynamic periodic fixed appointment scheduling for home health. *IIE Transactions on Healthcare Systems Engineering, 1*(1), 6-19. doi:10.1080/19488300.2010.549818

Bertels, S., & Fahle, T. (2006). A hybrid setup for a hybrid scenario: combining heuristics for the home health care problem. *Computers & Operations Research, 33*(10), 2866-2890. doi:http://dx.doi.org/10.1016/j.cor.2005.01.015

Borsani, V., Matta, A., Beschi, G., & Sommaruga, F. (2006, Oct. 2006). *A Home Care Scheduling Model For Human Resources.* Paper presented at the 2006 International Conference on Service Systems and Service Management.

Bowers, J., Cheyne, H., Mould, G., & Page, M. (2015). Continuity of care in community midwifery. *Health Care Management Science, 18*(2), 195-204. doi:10.1007/s10729-014-9285-z

Braekers, K., Hartl, R. F., Parragh, S. N., & Tricoire, F. (2016). A bi-objective home care scheduling problem: Analyzing the trade-off between costs and client inconvenience. *European Journal of Operational Research, 248*(2), 428-443. doi:http://dx.doi.org/10.1016/j.ejor.2015.07.028

Bräysy, O., Dullaert, W., & Nakari, P. (2009). The potential of optimization in communal routing problems: case studies from Finland. *Journal of Transport Geography, 17*(6), 484-490. doi:http://dx.doi.org/10.1016/j.jtrangeo.2008.10.003

Bräysy, O., & Gendreau, M. (2005a). Vehicle Routing Problem with Time Windows, Part I: Route Construction and Local Search Algorithms. *Transportation Science, 39*(1), 104-118. doi:10.1287/trsc.1030.0056

Bräysy, O., & Gendreau, M. (2005b). Vehicle Routing Problem with Time Windows, Part II: Metaheuristics. *Transportation Science, 39*(1), 119-139. doi:10.1287/trsc.1030.0057

Bredström, D., & Rönnqvist, M. (2008). Combined vehicle routing and scheduling with temporal precedence and synchronization constraints. *European Journal of Operational Research, 191*(1), 19-31. doi:10.1016/j.ejor.2007.07.033

Cappanera, P., & Scutellà, M. G. (2013). Home Care optimization: impact of pattern generation policies on scheduling and routing decisions. *Electronic Notes in Discrete Mathematics, 41*, 53-60. doi:10.1016/j.endm.2013.05.075

Cappanera, P., & Scutellà, M. G. (2015). Joint Assignment, Scheduling, and Routing Models to Home Care Optimization: A Pattern-Based Approach. *Transportation Science, 49*(4), 830-852. doi:doi:10.1287/trsc.2014.0548

Carello, G., & Lanzarone, E. (2014). A cardinality-constrained robust model for the assignment problem in Home Care services. *European Journal of Operational Research, 236*(2), 748-762. doi:http://dx.doi.org/10.1016/j.ejor.2014.01.009

Castillo-Salazar, J. A., Landa-Silva, D., & Qu, R. (2014). Workforce scheduling and routing problems: literature survey and computational study. *Annals of Operations Research*, 1-29. doi:10.1007/s10479-014-1687-2

Cattafi, M., Herrero, R., Gavanelli, M., Nonato, M., Malucelli, F., & Ramos, J. J. (2012). *Improving Quality and Efficiency in Home Health Care: an application of Constraint Logic Programming for the Ferrara NHS unit*. Paper presented at the Technical Communications of the 28th International Conference on Logic Programming (ICLP'12). http://drops.dagstuhl.de/opus/volltexte/2012/3641/

CDC. (2017). Home Health Care. Retrieved from https://www.cdc.gov/nchs/fastats/home-health-care.htm

Cheng, E., & Rich, J. L. (1998). A home health care routing and scheduling problem.

Cissé, M., Yalçındağ, S., Kergosien, Y., Şahin, E., Lenté, C., & Matta, A. (2017). OR problems related to Home Health Care: A review of relevant routing and scheduling problems. *Operations Research for Health Care*. doi:http://dx.doi.org/10.1016/j.orhc.2017.06.001

Colombo, F., ., & et al. *Help Wanted?* : OECD Publishing.

Coppi, A., Detti, P., & Raffaelli, J. (2013). A planning and routing model for patient transportation in health care. *Electronic Notes in Discrete Mathematics, 41*, 125-132. doi:10.1016/j.endm.2013.05.084

De Angelis, V. (1998). Planning Home Assistance for AIDS Patients in the City of Rome, Italy. *Interfaces, 28*(3), 75-83. doi:doi:10.1287/inte.28.3.75

Di Gaspero, L., & Urli, T. (2014). A CP/LNS Approach for Multi-day Homecare Scheduling Problems. In M. Blesa, et al. (Eds.), *Hybrid Metaheuristics* (Vol. 8457, pp. 1-15): Springer International Publishing.

Di Mascolo, M., Espinouse, M.-L., & Ozkan, C. E. (2014). Synchronization Between Human Resources in Home Health Care Context. In A. Matta, et al. (Eds.), *Proceedings of the International Conference on Health Care Systems Engineering* (pp. 73-86). Cham: Springer International Publishing.

Dohn, A., Kolind, E., & Clausen, J. (2009). The manpower allocation problem with time windows and job-teaming constraints: A branch-and-price approach. *Computers & Operations Research*, *36*(4), 1145-1157. doi:http://dx.doi.org/10.1016/j.cor.2007.12.011

Elbenania, B., Ferland, J. A., & Gascon, V. (2008). *Mathematical Programming Approach for Routing Home Care Nurses*. Paper presented at the Industrial Engineering and Engineering Management, 2008. IEEM 2008.

Ellenbecker, C. H., Samia, L., Cushman, M. J., & Alster, K. (2008). Chapter 13-Patient Safety and Quality in Home Health Care. In R. G. Hughes (Ed.), *Patient Safety and Quality: An Evidence-Based Handbook for Nurses*. Rockville Agency for Healthcare Research and Quality.

Erdem, M., & Bulkan, S. (2017). A Two-Stage Solution Approach For The Large-Scale Home Healthcare Routing And Scheduling Problem. *The South African Journal of Industrial Engineering*, *28 (4)*, 133-149. doi:http://dx.doi.org/10.7166/28-4-1754

Eurostat. (2017). Population structure and ageing Retrieved from http://ec.europa.eu/eurostat/statistics-explained/index.php/Population_structure_and_ageing

Eveborn, P., Flisberg, P., & Rönnqvist, M. (2006). Laps Care—an operational system for staff planning of home care. *European Journal of Operational Research, 171*(3), 962-976. doi:10.1016/j.ejor.2005.01.011

Fernandez, A., Gregory, G., Hindle, A., & Lee, C. A. (1974). A Model for Community Nursing in a Rural County. *Journal of the Operational Research Society*, *25*(2), 231-239. doi:10.1057/jors.1974.40

Fikar, C., & Hirsch, P. (2015). A matheuristic for routing real-world home service transport systems facilitating walking. *Journal of Cleaner Production*, *105*, 300-310. doi:10.1016/j.jclepro.2014.07.013

Fikar, C., & Hirsch, P. (2017). Home health care routing and scheduling: A review. *Computers & Operations Research*, *77*, 86-95. doi:http://dx.doi.org/10.1016/j.cor.2016.07.019

Gamst, M., & Jensen, T. S. (2012). A branch-and-price algorithm for the long-term home care scheduling problem. In D. Klatte, et al. (Eds.), *Operations Research Proceedings 2011* (pp. 483-488): Springer Berlin Heidelberg.

Hertz, A., & Lahrichi, N. (2009). A patient assignment algorithm for home care services. *Journal of the Operational Research Society*, *60*(4), 481-495. doi:10.1057/palgrave.jors.2602574

Hiermann, G., Prandtstetter, M., Rendl, A., Puchinger, J., & Raidl, G. (2015). Metaheuristics for solving a multimodal home-healthcare scheduling problem. *Central European Journal of Operations Research, 23*(1), 89-113. doi:10.1007/s10100-013-0305-8

Hindle, T., Hindle, A., & Spollen, M. (2000). Resource Allocation Modelling for Home-Based Health and Social Care Services in Areas Having Differential Population Density Levels: A Case Study in Northern Ireland *Health Serv Manage Res*, *13*(3), 164-169. doi:10.1177/095148480001300304

Hindle, T., Hindle, G., & Spollen, M. (2009). Travel-related costs of population dispersion in the provision of domiciliary care to the elderly: a case study in English Local Authorities *Health Serv Manage Res*, *22*(1), 27-32. doi:10.1258/hsmr.2008.008012

Issaoui, B., Zidi, I., Marcon, E., & Ghedira, K. (2015). New Multi-Objective Approach for the Home Care Service Problem Based on Scheduling Algorithms and Variable Neighborhood Descent. *Electronic Notes in Discrete Mathematics, 47*, 181-188. doi:10.1016/j.endm.2014.11.024

Karabağ, H. (2007). *Evde Sağlik Bakim Hizmetlerinin Türkiye'de Uygulanabilirliğine İlişkin Hekimlerin Görüşleri Ve Kardiyoloji Hastalari İçin Hastane*

Destekli Evde Bakim Hizmetleri Modeli Önerisi. (Master Thesis), Gazi University, Ankara.

Kergosien, Y., Lenté, C., & Billaut, J.-C. (2009). *Home health care problem: An extended multiple Traveling Salesman Problem*. Paper presented at the Proceedings of the 4th Multidisciplinary International Scheduling Conference: Theory and Applications (MISTA 2009), Dublin, Ireland.

Kergosien, Y., Ruiz, A., & Soriano, P. (2014). A Routing Problem for Medical Test Sample Collection in Home Health Care Services. In A. Matta, et al. (Eds.), *Proceedings of the International Conference on Health Care Systems Engineering* (pp. 29-46). Cham: Springer International Publishing.

Koeleman, P. M., Bhulai, S., & van Meersbergen, M. (2012). Optimal patient and personnel scheduling policies for care-at-home service facilities. *European Journal of Operational Research, 219*(3), 557-563. doi:10.1016/j.ejor.2011.10.046

Lanzarone, E., & Matta, A. (2014). Robust nurse-to-patient assignment in home care services to minimize overtimes under continuity of care. *Operations Research for Health Care, 3*(2), 48-58. doi:http://dx.doi.org/10.1016/j.orhc.2014.01.003

Liu, R., Xie, X., Augusto, V., & Rodriguez, C. (2013). Heuristic algorithms for a vehicle routing problem with simultaneous delivery and pickup and time windows in home health care. *European Journal of Operational Research, 230*(3), 475-486. doi:10.1016/j.ejor.2013.04.044

Mankowska, D. S., Meisel, F., & Bierwirth, C. (2014). The home health care routing and scheduling problem with interdependent services. *Health Care Management Science, 17*(1), 15-30. doi:10.1007/s10729-013-9243-1

Marak, C. (2016). Benefits of Home Care. Retrieved from http://www.homehealthcareagencies.com/resources/benefits-of-home-care/

Matta, A., Chahed, S., Sahin, E., & Dallery, Y. (2014). Modelling home care organisations from an operations management perspective. *Flexible Services and Manufacturing Journal, 26*(3), 295-319. doi:10.1007/s10696-012-9157-0

Maya Duque, P. A., Castro, M., Sörensen, K., & Goos, P. (2015). Home care service planning. The case of Landelijke Thuiszorg. *European Journal of Operational Research, 243*(1), 292-301. doi:10.1016/j.ejor.2014.11.008

Medicine, U. S. N. L. o. (2017). Home Care Services Retrieved from https://medlineplus.gov/homecareservices.html

Milburn, A. B. (2012). Operations Research Applications in Home Healthcare. In R. Hall (Ed.), *Handbook of Healthcare System Scheduling* (pp. 281-302). Boston, MA: Springer US.

Mısır, M., Smet, P., & Vanden Berghe, G. (2015). An analysis of generalised heuristics for vehicle routing and personnel rostering problems. *Journal of the Operational Research Society, 66*(5), 858-870. doi:10.1057/jors.2014.11

Misir, M., Verbeeck, K., De Causmaecker, P., & Berghe, G. V. (2010, 18-23 July 2010). *Hyper-heuristics with a dynamic heuristic set for the home care scheduling problem.* Paper presented at the Evolutionary Computation (CEC), 2010 IEEE Congress on.

Mutingi, M., & Mbohwa, C. (2014). *Home Healthcare Staff Scheduling: A Clustering Particle Swarm Optimization Approach*. Paper presented at the International Conference on Industrial Engineering and Operations Management, Bali, Indonesia,.

Nickel, S., Schröder, M., & Steeg, J. (2012). Mid-term and short-term planning support for home health care services. *European Journal of Operational Research, 219*(3), 574-587. doi:10.1016/j.ejor.2011.10.042

Pillac, V., Gendreau, M., Guéret, C., & Medaglia, A. L. (2013). A review of dynamic vehicle routing problems. *European Journal of Operational Research, 225*(1), 1-11. doi:https://doi.org/10.1016/j.ejor.2012.08.015

R&M. (2017). Europe Home Healthcare and Residential Nursing Care Services Market Report 2017. Retrieved from https://www.researchandmarkets.com/research/xjwcsf/europe_home

Ramos, A. F. T., Lizarazo, E. H. A.-., Rubiano, L. S. R.-., & Araújo, C. L. Q. (2014). *Mathematical Model for the Home Health Care routing and scheduling* *problem with multiple treatment and time windows.* Paper presented at the Mathematical Methods in Science and Engineering, Athens.

Rasmussen, M. S., Justesen, T., Dohn, A., & Larsen, J. (2012). The Home Care Crew Scheduling Problem: Preference-based visit clustering and temporal dependencies. *European Journal of Operational Research, 219*(3), 598-610. doi:10.1016/j.ejor.2011.10.048

Redjem, R., Kharraja, S., & Marcon, E. (2011). Collaborative model for planning and scheduling caregivers' activities in homecare. *IFAC World Congress, Volume 18,* 2877-2882. doi:10.3182/20110828-6-IT-1002.01043

Redjem, R., & Marcon, E. (2016). Operations management in the home care services: a heuristic for the caregivers' routing problem. *Flexible Services and Manufacturing Journal, 28*(1), 280-303. doi:10.1007/s10696-015-9220-8

Rendl, A., Prandtstetter, M., Hiermann, G., Puchinger, J., & Raidl, G. (2012). Hybrid Heuristics for Multimodal Homecare Scheduling. In N. Beldiceanu, et al. (Eds.), *Integration of AI and OR Techniques in Contraint Programming for Combinatorial Optimzation Problems* (Vol. 7298, pp. 339-355): Springer Berlin Heidelberg.

Rest, K.-D., & Hirsch, P. (2016). Daily scheduling of home health care services using time-dependent public transport. *Flexible Services and Manufacturing Journal, 28*(3), 495-525. doi:10.1007/s10696-015-9227-1

Rodriguez, C., Garaix, T., Xie, X., & Augusto, V. (2015). Staff dimensioning in homecare services with uncertain demands. *International Journal of Production Research, 53*(24), 7396-7410. doi:10.1080/00207543.2015.1081427

Shao, Y., Bard, J. F., & Jarrah, A. I. (2012). The therapist routing and scheduling problem. *IIE Transactions, 44*(10), 868-893. doi:10.1080/0740817X.2012.665202

Statista. (2015). Number of home health agencies in the U.S. 1967-2015. Retrieved from https://www.statista.com/statistics/195318/number-of-medicare-home-health-agencies-in-the-us/

Steeg, J., & Schröder, M. (2008). A Hybrid Approach to Solve the Periodic Home Health Care Problem. In J. Kalcsics & S. Nickel (Eds.), *Operations Research Proceedings 2007* (Vol. 2007, pp. 297-302): Springer Berlin Heidelberg.

Trautsamwieser, A., Gronalt, M., & Hirsch, P. (2011). Securing home health care in times of natural disasters. *OR Spectrum, 33*(3), 787-813. doi:10.1007/s00291-011-0253-4

Trautsamwieser, A., & Hirsch, P. (2011). Optimization of daily scheduling for home health care services. *Journal of Applied Operational Research, 3,* 124-136.

Trautsamwieser, A., & Hirsch, P. (2014). A Branch-Price-and-Cut approach for solving the medium-term home health care planning problem. *Networks, 64*(3), 143-159. doi:10.1002/net.21566

UK. (2017). *Overtime: your rights*. Retrieved from https://www.gov.uk/overtime-your-rights.

UN. (2015). *World Population Ageing 2015* Retrieved from http://www.un.org/en/development/desa/population/publications/pdf/ageing/WPA2015_Report.pdf

Vidal, T., Crainic, T. G., Gendreau, M., & Prins, C. (2013). Heuristics for multi-attribute vehicle routing problems: A survey and synthesis. *European Journal of Operational Research, 231*(1), 1-21. doi:https://doi.org/10.1016/j.ejor.2013.02.053

Wirnitzer, J., Heckmann, I., Meyer, A., & Nickel, S. (2016). Patient-based nurse rostering in home care. *Operations Research for Health Care, 8,* 91-102. doi:http://dx.doi.org/10.1016/j.orhc.2015.08.005

Yalçındağ, S., Cappanera, P., Grazia Scutellà, M., Şahin, E., & Matta, A. (2016). Pattern-based decompositions for human resource planning in home health care services. *Computers & Operations Research, 73,* 12-26. doi:http://dx.doi.org/10.1016/j.cor.2016.02.011

Yalçındağ, S., Matta, A., Şahin, E., & Shanthikumar, J. G. (2016). The patient assignment problem in home health care: using a data-driven method to estimate the travel times of care givers. *Flexible Services and Manufacturing Journal, 28*(1), 304-335. doi:10.1007/s10696-015-9222-6

Yuan, B., Liu, R., & Jiang, Z. (2015). A branch-and-price algorithm for the home health care scheduling and routing problem with stochastic service times and skill requirements. *International Journal of Production Research, 53*(24), 7450-7464. doi:10.1080/00207543.2015.1082041

Yuan, Z., & Fügenschuh, A. (2015). *Home Health Care Scheduling A Case Study*. Paper presented at the MISTA.