A review of Static, Dynamic and Stochastic Vehicle Routing Problems in Home Healthcare

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Abstract
The demand for Home Health care (HHC) service increases gradually in all of its sectors. Vehicle Routing Problem (VRP) is an everyday challenging task for the HHC administrative team. Because of its multi-dimensional resources such as physicians, nurses, medical equipment, drugs, etc. In this review article, we overview the current work of routing problems in HHC and emphasized the problems based on static, dynamic and stochastic strategies along with their solution methodologies, objectives, constraints, etc. Moreover, this paper displays that there exists only very less contribution to work on applying the dynamic and stochastic type of models using metaheuristic algorithms. Metaheuristic algorithm is a technique which is capable of generating good approximation solution within less execution time. Hence, insisting that HHC needs more focus on practical oriented problems such as dynamic and stochastic strategies in the mere future.

***Keywords**: Home Healthcare, Vehicle Routing Problem, Dynamic, Stochastic, Metaheuristic Algorithm.*

1. INTRODUCTION

Home Healthcare is one of the fastest-growing industry in recent years due to increase in several new challenges in all sectors at each level [1] that draw the attention of researchers. This happens due to facing several challenges in hospitals service delivery system such as planning and management of operating rooms, healthcare professional's schedules, care demands for hospitalization when several patients arrived simultaneously becomes pressurised environment, durations of stays which are often unknown in advance and so on. However, to shorten the duration of hospital stay and improve the access to care services, while the demand of hospitalization is still increasing, several alternatives to hospitalization were proposed over the past few decades such as HHC, ambulatory care, hospice, etc. One of the best alternative systems for hospitals are HHC. It is a service delivery system that provides healthcare services at the patient's home by a set of healthcare professionals. A few main contributory features for the growth of HHC [1][2] are:

- Growing in the elderly population
- Increase in chronic and non-communicable diseases
- A rise in life expectancy of people
- Overcrowding in hospitals
- Intensification of communicable disease in a hospital set-up
- Due to an increase in cost for hospital stay (e.g. post-surgical treatments)
- A recent increase in demand for healthcare service in a patient-centric environment (like treatment at home)

- Other therapy management related issues etc.
- To avoid getting the infection from rapidly spreading viruses like Covid-19, SARS, Ebola virus, etc.

Since HHC system needs more exploration in research due to increase in the complexity of the planning and routing related to the decision-makers on account of various resource dimensions, uncertainty and incompleteness on variables like travel time, service time and so on.

HOME HEALTHCARE VEHICLE ROUTING PROBLEM (HHCVRP)

The Home Healthcare vehicle routing problem (HHCVRP) involves usually in the features of Vehicles routing problem with time windows (VRPTW) and Nurse rostering problem (NRP). Generally, these types of problem come under combinatorial optimization problems. Since HHC is a part of the healthcare services, which can be defined as providing the necessary care services to the patients and their families at their respective homes [1]. The HHC service delivery system offers benefits in many ways such as reduce the hospital costs, prevent from contagious infections, patient recover soon at home due to emotionally balanced and psychological support, patient-centric treatment, family and friends can also involve during their treatments, develop good bondage between the patient and caregiver [2] etc.

The HHC aims to increase the level of access to the maximum treatment with minimum interruption of routine schedule, to minimize the effects of the diseases and the disabilities, and to raise the living conditions and life expectancy [48]. This problem concerns the assignment, routing, and scheduling decisions for a set of patients in different geographical locations [51]. Their demand for care with different qualification levels from a set of heterogeneous caregivers. Furthermore, while allocating these caregivers to the patients should include the following considerations like time windows, preferences, features, workload, continuity of care, quality of service level, regulations, etc. in their planning horizon [3][47][49]. Also, the issues such as modes of transportation, working and waiting times of nurses should not be ignored in this perspective. Since there exist many reviews available in the literature for routing and scheduling problem in HHC. As far as we know, there is no specific survey exist on static, dynamic and stochastic models for routing problem in HHC. This type of survey has not been done in the literature yet. Hence, it is worth to explore on it.

2. DATA INFORMATION

The collection of data information regarding the patient's demand is the key source of dimension for the vehicle routing problem in HHC. In some instance, planning for routing problem based on the available information to the assigning the routing may vary during the execution of the plan like including new patients demands in the existing plan. In such instances, there exists uncertainty in travel time and service time. Hence, data information quality plays a major role in designing vehicle routing problem as static, dynamic and stochastic models [50].

A. *Static strategy*

The static approach of VRP in HHC has the following procedures: in most of the review papers[5][6][7][8][10], the undirected graph represents each patients node as vertex and path represent as an edge; they handle both homogenous and heterogeneous vehicle routing from single or multiple depots [14][17]; also it must satisfy each vehicle capacity; it handles only deterministic numbers of patients and their demands have to be visited only once in each route plan[27][28][34][37]; travel time and service time of caregivers are fixed; (i.e.) data relevant to the route planning does not change after the routes have been executed.

B. Dynamic strategy

In this approach, the number of patients to be visited has been uncertain in each route. (i.e.) data relevant to the route planning can be change after the routes have been initiated. In most of the papers have been discussed on partially static model [9][11][18][20]. That means a minimum number of new patients (e.g. one or two) are allowed to insert in each route. So that working time of each caregiver won't deviate much from their planning horizon [29][30][31][32].

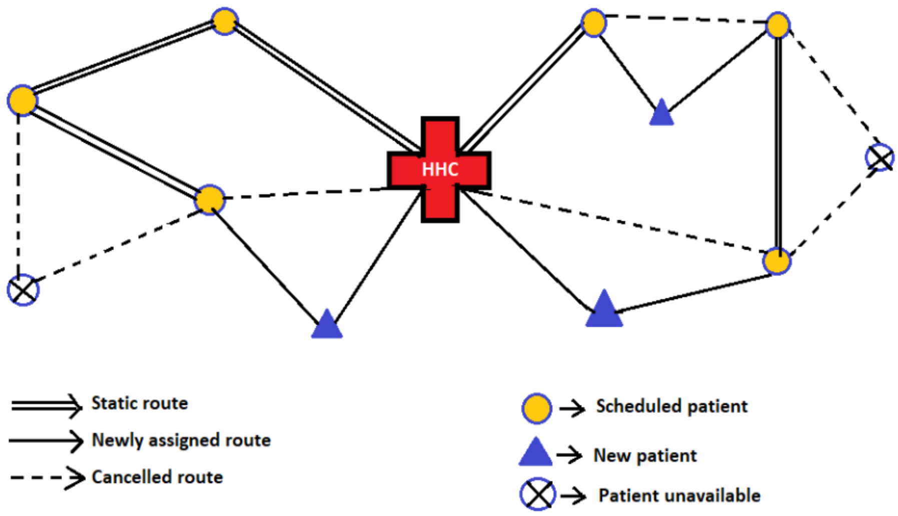

Fig. Example of Dynamic request and uncertainty in travel time in the route plan of HHC

C. Stochastic strategy

The stochastic approach has uncertainty in one or more parameters. Generally, it has some phenomenon that is not able to predict precisely (e.g.) travel time and service time of caregivers [4][12][13][49]. In this approach, it has some relevant data to the route planning that can be change or unknown after the routes have been initiated [23][43][44][46][52]. This has been clearly explained in the above figure. Usually, it has been formulated in a stochastic programming model (SPM) [15]. Moreover, it has a probability distribution of the random variables and hence it has been required to perform optimization techniques before they are executed in the planned route. The planned routes are not changed or update after the execution; thus, often it is referred to as a priori optimization.

TABLE I

STRATEGIES FOLLOWED IN EACH PAPER BASED ON QUALITY OF DATA INFORMATION AND THEIR SOLUTION METHODOLOGY

Article	Static	Dynamic	Stochastic	Horizon	Depot	Caregivers	Vehicles	Duration	Solution Methods
A.Errarhout et al (2016) [4]	✗	✗	✓	M	M	Het	✗	W	Monte Carlo sampling with CPLEX
Ait Haddadene et al (2019) [5]	✓	✓	✗	M	S	Het	Homo	D	Non-Dominated Sorting Genetic Algorithm
Akjiratikarl et al. (2007) [6]	✓	✗	✗	S	M	Homo	Het	D	PSO
Alain Hertz et al (2006) [7]	✓	✓	✗	M	M	Het	Het	D,W,M	Tabu Search

Allaoua et al (2013) [8]	✓	✗	✗	S	M	Het	Het	shift	ILP+Set partitioning +bin packing model
Andres Felipe Torres-Ramos et al (2014) [9]	✓	✓	✗	M	M	Het	Het	D	MIP & GAMS commercial software
Ashlea Bennett Milburn et al (2013) [10]	✓	✗	✗	M	M	Het	Het	10 days	Tabu Search
Ashlea R. Bennett et al (2011) [11]	✓	✓	✗	M	M	Homo	Het	W	capacity-based insertion heuristic
Biao Yuan et al (2014) [12]	✓	✗	✓	S	S	Homo	Het	D	Set partitioning
CenChen et al (2017) [13]	✗	✗	✓	M	M	Het	Het	W	Lagrangian relaxation and along with Sample average approximation
David Barrera et al (2012) [14]	✓	✗	✗		M	Homo	Het	W	Branch & Bound procedure along with heuristic approach
Gang Du et (2017) [15]	✗	✓	✓	S	S	Het	Het	D	GA with Local Search
Gerhard Hiermann et al (2015) [16]	✓	✗	✗	S	M	Het	Het	D	Constrained programming with VNS/MA/SA/SS
J. Decerle et al (2017) [17]	✓	✗	✗	M	S	Het	Homo	D	Memitic Algorithm
Jeremy Decerle et al (2019) [18]	✓	✓	✗	S	S	Het	Homo	D	Gurobi and Lagrangian relaxation method
Jalel Euchi et al (2020) [19]	✓	✗	✗	M	S	Het	Homo	D & W	HACO with Distributed optimisation algorithm
Jamal Abdul Nasir et al (2018) [20]	✓	✓	✗	S	S	Het	Het	D	Initial heuristic solution, VNS and SCVNS algorithms
Jonathan Bard et al (2014) [21]	✓	✗	✗	M	M	Het	Het	W	MIP & GRASP
K. Braekers et al (2016) [22]	✓	✗	✗	S	M	Het	Het	D	Large neighbourhood search and multi-directional local search
Khaoula Besbes et al (2017) [23]	✗	✗	✓	S	S	Het	Het	D	ILOG CPLEX optimization
Laila En-nahli et al (2015) [24]	✓	✗	✗	S	S	Het	Het	D	ILOG CPLEX
Laila En-nahli et al (2016) [25]	✓	✗	✗	S	S	Het	Het	D	Random Variable neighbourhood decent method
Mankowska et al (2013) [26]	✓	✗	✗	S	S	Het	Het	D	AVNS
Maya Duque et al (2015) [27]	✓	✗	✗	M	M	Het	Het	W	Set partitioning
Mona Issabakhsh et al (2017) [28]	✓	✗	✗	S	S	Het	Homo	D	General Algebraic Modelling System (GAMS) software
Mustafa Demirbilek et al (2018) [29]	✓	✓	✗	S	M	Homo	Het	LP	Heuristic-Scenario Based Approach
Mustafa Demirbilek et al (2019) [30]	✓	✓	✗	M	M	Homo	Het	W	SBA-Multiple nurses
Nasreddine Ouertani et al (2020) [31]	✓	✓	✗	S	S	Homo	Homo	S	Hypermutation Genetic Algorithm
Nizar Triki et al (2014) [32]	✓	✓	✗	M	S	Het	Het	W	TS with heuristic approach
Rahma Borchan et al (2019) [33]	✓	✗	✗	S	S	Het	Het	D	Hybrid Genetic Algorithm with Variable Neighbourhood Descent search (GA-VND)
Rest, K.-D et al (2015) [34]	✓	✓	✗	M	S	Het	Het	D	Tabu Search
Salma Had Taieb et al (2019) [35]	✓	✗	✗	S	S	Het	Het	D	CPLEX
Semih Yalcındag et al (2016) [36]	✓	✗	✗	S	M	Homo	Het	D	GA for the assignment problem with Kernal regression approach
Shao, Y et al (2012) [37]	✓	✗	✗	M	M	Het	Het	W	GRASP
Stefan Bertels et al (2006) [38]	✓	✗	✗	S	M	Het	Het	D	Constrained programming with SA and TS (CS+SA or CS+TS)
Stefan Nickel et al (2012) [39]	✓	✓	✗	S	S	Het	Het	W	Constrained programming, ALNSM & Tabu Search
Trautsamwieser.A et al (2011) [40]	✓	✗	✗	S	M	Het	Het	D	Variable neighbourhood solution
Trautsamwieser.A et al (2011) [41]	✓	✗	✗	S	M	Het	Het	D	VNS
Trautsamwieser.A et al (2014) [42]	✓	✗	✗	M	M	Het	Het	W	Branch and cut solution for exact solution and Variable neighbourhood solution
Xintong Yang et al (2018) [43]	✗	✗	✓	S	S	Het	Het	D	Constrained Programming; Markov Decision Process; Q-learning; ACO
Yong Shi et al (2017) [44]	✗	✗	✓	S	S	Homo	Homo	D	Hybrid Genetic Algorithm
R V Sangeetha et al (2020) [45]	✓	✗	✗	S	S	Het	Het	Shift based	Elitism of ACO using Neighborhood Structures
Yuan, Liu, and Jiang (2015) [46]	✗	✗	✓	S	S	Het	Homo	D	Branch-and-price

S-Single period; M-Multiple period; Het-Heterogeneous; Homo-Homogeneous; D-Daily; W-Weekly; LP-Long Period

3. *OBJECTIVE FUNCTION*

The objective functions for routing problem in HHC are classified in many ways like single, bi and multiple. The most common objectives discussed in this review are minimizing in cost[26][31][37][44], time[9][18][25], distance[6][20][27][39], balanced workload[4][7][45], number of vehicles, soft constraint violation[19][40] and caregivers uncovered visits[39] etc. Maximizing utilization of vehicles and caregivers [8][14], patients-caregiver's preferences [5][22], number of visits [29][30], continuity of care [39], patient's satisfaction [13] [23][46] etc.

4. *CONSTRAINTS*

Limited constraints have been discussed below which are most often consider in the standard routing and scheduling problem of HHC has followed:

A. Start and end nodes

In most of the papers have been studied about single or multiple depots. Single depot operates in such a way that all caregivers must start and end at the same HHC office [5][12][13][15][45]. Whereas, multiple depots should operate in the process of every caregiver can start and end at their respective home or a different location of the HHC office [4][16][21][22][36][42]. Similarly, a few papers have been explored on starting and ending at different locations such that they can start at their home or HHC office and end at the lab [12].

B. Skills and qualifications

In the literature, caregivers have explored as homogeneous caregivers [14][30][36][44] or heterogeneous caregivers [13][25][37][46]. In homogeneous caregivers routing, there is no need for skill matching since all caregivers have the same qualification. But in heterogeneous caregivers routing, it has a different set of caregivers whose skill is unique. So, here it is essential to match the most appropriately skilled caregivers to the corresponding patient.

C. Synchronization

Synchronization means interdependence of care services [24][30][34][41]. (i.e.) a patient has needed more than one or two caregivers to perform the task. This task can be started simultaneously or one after another or there can be a minimum difference in time dependency.

D. Time windows

Since time is a crucial parameter in HHC vehicle routing problem. Every caregiver must start and end their service within their respective time window [7][10][21][32]. Those who violating the soft window time must pay the penalty cost [16][19][22][26][40][49]. Also, estimate the waiting time of caregivers [24][34][41][42][43][52] for each visit and hence it is avoided. In some cases, overtime can be allowed during the emergency case or flexible concerning the working agreements.

E. Types of vehicles

HHCVRP has only two categories of vehicles are explored such as homogeneous vehicles and heterogeneous vehicles. In homogeneous vehicle routing [5][17][18][19][28][31][44][46], all caregivers must start at HHC office or at their respective home. In heterogeneous vehicle routing [4][20][33][45], caregivers can use a different mode of transportation such as a car, bike, public transport, van, ambulance etc. They either start at HHC office or their respective home. In each problem, travelling time and the cost varies according to their corresponding mode of transportation.

F. Planning Horizon

In this literature, the planning horizon of caregivers is much broadly studied on their shift-based planning [8][45], single day or daily bases[5][6][12][16][24], a week[11][32][39][42], 10 days[10], two weeks[7], a month, or more[29].

TABLE II

OBJECTIVE FUNCTIONS AND CONSTRAINTS CONCERNING BOTH CAREGIVERS AND PATIENTS

Article	TW	Sync.	Skill	WT	Break	UV	CC	WL	TT	TD	TC	PR	OT	SCV	PS	WA	No. of Visits
A.Errarhout et al (2016) [4]	✓	✓	✓	✓	✗	✗	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗
Ait Haddadene et al (2019) [5]	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗
Akjiratikarl et al. (2007) [6]	✓	✗	✓	✓	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗
Alain Hertz et al (2006) [7]	✓	✗	✗	✗	✗	✗	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗
Allaoua et al (2013) [8]	✓	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Andres Felipe Torres-Ramos et al (2014) [9]	✓	✗	✓	✗	✓	✗	✗	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗
Ashlea Bennett Milburn et al (2013) [10]	✓	✗	✗	✓	✗	✗	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗
Ashlea R. Bennett et al (2011) [11]	✓	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗	✓	✗	✗	✗	✗	✓
Biao Yuan et al (2014) [12]	✓	✗	✗	✓	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗
CenChen et al (2017) [13]	✓	✓	✓	✗	✗	✓	✓	✓	✗	✗	✗	✗	✗	✗	✓	✗	✗
David Barrera et al (2012) [14]	✓	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗
Gang Du et (2017) [15]	✓	✗	✓	✓	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗
Gerhard Hiermann et al (2015) [16]	✓	✗	✓	✗	✗	✗	✗	✗	✓	✗	✗	✓	✓	✓	✗	✗	✗
J. Decerle et al (2017) [17]	✓	✓	✓	✗	✗	✗	✗	✓	✓	✗	✗	✗	✗	✓	✗	✗	✗
Jeremy Decerle et al (2019) [18]	✓	✓	✓	✓	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗
Jalel Euchi et al (2020) [19]	✓	✓	✓	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✓	✗	✗	✗
Jamal Abdul Nasir et al (2018) [20]	✓	✗	✓	✗	✓	✗	✗	✓	✗	✓	✓	✗	✗	✗	✗	✗	✗
Jonathan Bard et al (2014) [21]	✓	✗	✓	✓	✓	✗	✗	✗	✗	✗	✓	✗	✓	✗	✗	✗	✗
K. Braekers et al (2016) [22]	✓	✗	✓	✓	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓	✗	✗	✗
Khaoula Besbes et al (2017) [23]	✓	✗	✓	✗	✓	✗	✗	✗	✗	✗	✓	✗	✗	✓	✓	✗	✗
Laila En-nahli et al (2015) [24]	✓	✗	✓	✗	✓	✗	✗	✓	✓	✗	✗	✓	✗	✗	✗	✓	✗
Laila En-nahli et al (2016) [25]	✓	✓	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗
Mankowska et al (2013) [26]	✓	✓	✓	✗	✗	✗	✗	✓	✗	✗	✓	✗	✗	✓	✗	✗	✗
Maya Duque et al (2015) [27]	✓	✗	✓	✓	✗	✗	✗	✗	✗	✓	✗	✓	✗	✗	✗	✗	✗
Mona Issabakhsh et al (2017) [28]	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✓	✗	✗	✓	✗	✗	✗
Mustafa Demirbilek et al (2018) [29]	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓

Mustafa Demirbilek et al (2019) [30]	✓	✗	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓
Nasreddine Ouertani et al (2020) [31]	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗
Nizar Triki et al (2014) [32]	✗	✗	✓	✓	✗	✗	✗	✗	✗	✗	✓	✗	✓	✗	✗	✗	✗
Rahma Borchan et al (2019) [33]	✓	✓	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗
Rest, K.-D et al (2015) [34]	✓	✗	✓	✓	✓	✗	✗	✗	✓	✗	✗	✗	✓	✗	✗	✓	✗
Salma Hadj Taieb et al (2019) [35]	✓	✓	✗	✓	✓	✗	✗	✗	✓	✗	✗	✗	✗	✗	✓	✗	✗
Semih Yalcındag et al (2016) [36]	✓	✗	✗	✓	✗	✗	✗	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗
Shao, Y et al (2012) [37]	✓	✗	✓	✗	✓	✗	✗	✗	✗	✗	✓	✗	✓	✗	✗	✗	✗
Stefan Bertels et al (2006) [38]	✓	✗	✓	✓	✓	✗	✗	✗	✗	✓	✗	✓	✗	✗	✗	✗	✗
Stefan Nickel et al (2012) [39]	✓	✗	✓	✓	✗	✓	✓	✗	✗	✓	✗	✗	✓	✗	✗	✗	✗
Trautsamwieser.A et al (2011) [40]	✓	✗	✓	✓	✓	✗	✗	✗	✗	✗	✓	✓	✓	✓	✗	✗	✗
Trautsamwieser.A et al (2011) [41]	✓	✗	✓	✓	✓	✗	✗	✗	✓	✗	✗	✓	✓	✓	✗	✓	✗
Trautsamwieser.A et al (2014) [42]	✓	✗	✓	✓	✓	✗	✗	✗	✓	✗	✗	✓	✗	✗	✗	✓	✗
Xintong Yang et al (2018) [43]	✓	✗	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	✗
Yong Shi et al (2017) [44]	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗
R V Sangeetha et al (2020) [45]	✓	✗	✗	✗	✗	✗	✓	✓	✓	✗	✗	✗	✗	✗	✗	✓	✗
Yuan, Liu, and Jiang (2015) [46]	✓	✗	✓	✓	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✓	✗	✗

TW-Time Window; Sync- Synchronization; WT-Working time regulations; UV-Uncovered Visits; CC-Continuity of Care; WL-Work Load; TT-Travel time; TD-Travel Distance; TC-Travel Cost; PR-Preference; OT-Overtime; SCV-Soft Constraints Violation; PS-Patient Satisfaction; WA-Waiting Time

5. *Solution Methodology*

The main purpose of this review article is to insist on the broad study of static, dynamic, and stochastic strategy. In most of these papers, deals with the static and dynamic type of models. It often highlights the mixed integer programming problem[9], constraint programming[16][38][39][43], CPLEX [4][23][24][35], heuristics algorithm[29][30][32] and few meta-heuristic algorithms like Tabu search[7][10][34][38][39], Genetic algorithm[5][15][31][33][44], PSO[6], ACO[19][45], Branch and bound[14], VNS[16][20][25][26][33][41][42] etc. Whereas in the stochastic type of models have been discussed much lesser in the review. They were solved using Monte Carlo sampling with CPLEX [4], Markov Q-learning with ACO [43], branch-and-price [46], ILOG CPLEX [23][24] etc. In all of these methods, they usually investigated only on a daily and weekly planning horizon. Very few papers have been explained about a longer period (i.e.) a month or 360 days [29].

6. *Conclusion*

In this survey paper, it clearly shows that most of the papers consider only static and dynamic models for solving VRP in HHC under operational and tactical planning horizon. These models would not match exactly for real-time oriented problems. In such scenarios, it is necessary to explore and include uncertainty and dynamic models. Very rarely such models have been discussed in the literature. Hence, it is necessary to get more attention from researchers on such actual-world problems of HHC. Considering the objectives commonly deal with travel time, distance and cost, workload balance, preferences, patients satisfaction, etc.

and have less attention on waiting time, over time, soft constraint violations, etc. Also, it often includes constraints like time window, skill matching, synchronization, working time regulations such as overtime, hard and soft time window, and so on. Very few studies have done on break, continuity of care, etc.

Hence for future work, need to investigate more on stochastic and dynamic models by solving using meta-heuristic algorithms. About priority-based visits, breaks, the flexibility of caregivers, periodic visits of caregivers, strategic planning horizon, etc. also been taken into consideration.

7. References

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