Annals of Operations Research
https://doi.org/10.1007/s10479-024-06244-6

ORIGINAL RESEARCH

# Home healthcare routing and scheduling: operations research approaches and contemporary challenges

**Malek Masmoudi**[1,2] · **Jalel Euchi**[3,4] · **Patrick Siarry**[5]

Received: 31 July 2024 / Accepted: 22 August 2024


## Abstract

Home Health Care services aim to provide comprehensive care and support to patients in the comfort of their homes, ensuring a quality of service comparable to that of hospitals while also addressing additional objectives such as cost management and enhancing living conditions. Previous literature, exemplified by the paper authored by Euchi et al. (4OR 20(3):351–389, 2022), delineates the Home Healthcare Routing and Scheduling Problem (HHCRSP), presenting a taxonomy of its characteristics and constraints, along with an overview of state-of-the-art decision-making solutions. This study proposes an update to this research, highlighting the significant evolution of HHCRSP as it adapts to technological advancements and accommodates variant objectives and constraints across past, present, and future challenges. Through exhaustive literature reviews, this paper meticulously constructs a framework that delineates the intricate and diverse paths of HHCRSP's evolution, fostering a deeper understanding of the impacts of emerging challenges such as digitization and sustainability. It offers invaluable insights for academic researchers and industry professionals, facilitating better alignment with the evolving landscape for consistently improved performance.

**Keywords** HHCRSP · Literature review · Objectives · Constraints · Digitization · Sustainability

This is an updated version of the paper "Home health care routing and scheduling problems: a literature review" that appeared in 4OR, 20, 351–389 (2022).

✉ Malek Masmoudi
mmasmoudi@sharjah.ac.ae; malek.masmoudi@univ-st-etienne.fr

1 Department of Industrial Engineering and Engineering Management, University of Sharjah, Sharjah, United Arab Emirates

2 University of Jean Monnet, Saint-Étienne, France

3 Department of Economics, Quantitative Methods, and Computing, Higher Institute of Business Administration, University of Gafsa, Gafsa, Tunisia

4 OLID Lab, Higher Institute of Industrial Management, University of Sfax, Sfax, Tunisia

5 Laboratoire Images, Signaux et Systèmes Intelligents, Université Paris-Est Créteil Val-de-Marne, Créteil, France

## 1 Introduction and methodology

Substantial efforts in the corporate sector have focused on minimizing operational expenses and boosting overall efficiency. Following this trend, healthcare systems, among the most complex production systems, have also pursued optimization despite being historically viewed as non-profit services. This study highlights home health- care (HHC) as an efficient and growing alternative to traditional hospitalization that is evolving due to demographic, political, and economic factors. HHC services encompass a range of nonmedical and medical care activities, including shopping, cleaning, and cooking, social assistance, hygiene and mobility assistance, infusion handling and medication administration, medical treatment oversight, emergency services, and home medical appointments. HHC has gained societal support and evolved into less expensive, more convenient, and equally effective structures than hospitals.

For years, operations research (OR) and management science (MS) have focused on optimizing hospital care logistics to reduce costs while enhancing patient satisfaction and living conditions. Key decisions in home healthcare, such as staff scheduling and route planning, significantly impact service quality and costs. This area, known as the home health care routing and scheduling problem (HHCRSP), is a critical optimization challenge, seen is an application to the Multi-Travelling Salesman Problem (MTSP) or the Vehicle Routing Problem (VRP) with time windows and multiple depots (Euchi et al. 2022).

This paper provides a literature review of HHCRSP, analyzing how OR/MS/IE researchers have addressed it theoretically and practically. We focus on problem characteristics, objectives, and constraints, summarizing current research and identifying new research directions from the Operations Research perspective with a unique discussion of the contemporary Challenges of digitization and sustainability. Practitioners can use this review to evaluate if current solutions align with their current and future operational challenges, while researchers can identify gaps and tailor their studies accordingly.

Using the SCOPUS database, we considered the following keyword combinations: (health OR healthcare OR care OR (hospital AND service)) AND (home) AND (routing OR scheduling). Initially, the search yielded 621 journal articles from 2019 to 2023. Once the literature search was complete, the next step was to screen and select relevant publications. This involved reviewing the titles and abstracts of the retrieved articles to determine their relevance to the research question and scope. Articles that did not meet the inclusion criteria were also excluded. These additional filtering processes led to a final selection of 85 articles utilized for the subsequent citation analysis. This integrative review synthesizes the findings, offering a comprehensive overview of HHCRSP and its variants, and presents the information through detailed tables and analyses.

The remainder of the paper is organized as follows. Section 2 provides an update of the (Euchi et al., 2022), published in 4OR journal. 85 documents from 2019 to 2023 have been considered in the study, and tables summarizing the main contributions of these papers from the OR perspectives are provided and discussed. Section 3 and Sect. 4 discuss the emerging HHCRS variants and techniques related to the new challenges of digitization and sustainability, respectively, with a discussion of new research directions. Section 5 concludes the paper by summarizing the main findings and perspectives of HHCRSP.

## 2 HHCRSP: optimization problems and solutions

This section presents a taxonomy of the HHCRSP characteristics and restrictions. It summarizes the state-of-the-art decision-making solutions for the HHCRSP and studies related to objectives and constraints. As presented in the methodology, papers published from 2019 to 2023 have been considered. The HHCRSP involved caregivers in performing work-related activities at different locations. Begur et al. (1997) proposed the first studies of HHCRSP and developed a heuristic approach to solve the daily nurse scheduling and routing activity provided to residents in several counties of central Alabama. There was more than one activity to be performed in a day at a dependent's home (Euchi, 2020, Euchi & Sadok, 2021, Frifita and Masmoudi, 2020, Kandakoglu et al., 2020, Ozeki et al., 2021). The HHCRSP integrated the assignment of medical staff to patients (Hassani and Behnamian, 2021; Lin et al., 2018, Rahimian et al., 2017) and the design of the routes with visits to patients with different variants of the VRP (Mor & Speranza, 2022)The most studied VRP variant in HHCRSP is VRPTW (Euchi et al., 2021; Expósito et al., 2019; Hoogeboom et al., 2021). Other variations of VRP have been applied to HHCRSP, such as the Multi-Travelling Salesman Problem with Time Windows (MTSPTW) (Bretin et al., 2018), the Vehicle Routing Problem with Multi-Depot (VRPMD) (Contardo and Martinelli, 2014), the Vehicle Routing Problem with Multi-Period (VRPMP) (Li et al., 2019).

The Vehicle Routing Problem (VRP) is among the most studied problems in the OR field. The classical goal of VRP applied to HHCRSP is to minimize the total distance traveled by a set of caregivers serving customers (patients or dependent people) in different locations, while each visit must be covered once by a caregiver. Many variations of VRP exist in HHCRSP and have been studied in the literature. We can mention, for example, the Vehicle Routing Problem with Time Windows (VRPTW) (Euchi, 2020; Masmoudi et al., 2023), where a caregiver must arrive at the customer within a specified time window. If the caregiver arrives before this time window, he/she must wait before visiting. Extensions of the VRPTW include other features, such as multiple trips, multiple resources, multiple depots, and vehicle synchronization. For the extension of the VRPTW with Synchronization, the routes depend on one another. Thus, changing one tour impacts others and may even make them infeasible, which is frequently present in HHCRSP (Masmoudi et al., 2023).

A practical case study in Canada to solve the home healthcare routing and scheduling problems was provided by Grenouilleau et al. (2019). A hybrid heuristic algorithm based on set partitioning was proposed and provided an improvement in terms of minimizing the travel time and the processing time. In (Euchi, 2020), an HHC with time windows with a single structure and synchronized visits were included in the problem. A two-phase approach was used: A clustering algorithm (CA) with a k-mean was given to find several caregiver routes, and an ant colony system (ACS) was applied as a distributed optimization form (Hybrid ACS-CA) to solve the problem. Li et al. (2021b) introduced a new variant of HHCRSP, including an outpatient service, i.e., a medical test that can be done in a medical structure without staying. A hybrid genetic algorithm with the outer approximation method was developed to find a global ε-optimal solution for small and large problems.

Table 1 describes the work on home healthcare routing and scheduling with year, reference, publication, problem characteristics, solution methodology, and benchmark instances.

Based on Table 1, we observe that the studies are almost evenly divided between Theoretical (T) and Practical (P) types, with 44 studies (51.76%) being theoretical and 41 studies (48.24%) being practical. This near-equal distribution indicates a balanced approach in the

**Table 1** Literature on Home Healthcare Routing and Scheduling

| Reference | Journal | Affiliation | Type of study Theoretical (T)/Practical (P) | Horizon Short (S)/Long(L) | Uncertainties | Solution methodology | Benchmarks instances |
|---|---|---|---|---|---|---|---|
| Decerle et al. (2019) | Swarm and Evolutionary Computation | France | T | S | – | MILP, memetic-ant colony algorithm | Bredstrom and Ronnqvist (2008) |
| Dekhici et al. (2019) | Canadian Journal Of Electrical And Computer Engineering | Algeria | T | S | – | Firefly algorithm | – |
| (Demirbilek et al. (2019) | Health Care Management Science | UK | P | S | X | rolling horizon approach and stochastic programming | Realistic instances |
| Du et al. (2019) | Journal of Combinatorial Optimization | China | P | L | X | Memetic algorithm | Realistic instances |
| Gomes and Ramos, (2019) | European Journal of Operational Research | Portugal | P | L | X | MILP, MA, ACO | – |
| Grenouilleau et al. (2019) | European Journal of Operational Research | Canada | T | L | – | Heuristic—LNS | – |
| Heching et al. (2019) | Transportation Science | USA | T | L | – | Logic-Based Benders Decomposition (LBBD) – MILP, CP | Rasmussen et al. (2012) |

**Table 1** (continued)

| Reference | Journal | Affiliation | Type of study Theoretical (T)/Practical (P) | Horizon Short (S)/Long(L) | Uncertainties | Solution methodology | Benchmarks instances |
|---|---|---|---|---|---|---|---|
| Lamine et al. (2019) | Innovation and Research in BioMedical engineering IRBM | France | P | S | – | Plas'O'Soins software paltform | real-world data |
| Liu, et al. (2019) | Computers and Operations Research | China | T | S | – | MILP and ALNS | Bredstrom and Ronnqvist (2008), and derived instances from VRPTW benchmarks (Solomon, 1987; Gehring and Homberger, 1999) |
| Liu, Yuan, et al. (2019) | Flexible Services and Manufacturing Journal | China | T | L | X | Branch and Price algorithm | Generated instances |
| Mosquera et al. (2019) | Omega | Belgium | P | L | X | IP-LS | – |

**Table 1** (continued)

| Reference | Journal | Affiliation | Type of study Theoretical (T)/Practical (P) | Horizon Short (S)/Long(L) | Uncertainties | Solution methodology | Benchmarks instances |
|---|---|---|---|---|---|---|---|
| Moussavi et al.( 2019) | Expert Systems With Applications | France | T | L | – | Matheuristic | Real data |
| Nasir and Dang, (2020) | Health Care Management Science | Hong Kong | T | S | X | MILP, VNS, Bender's method and ROC curves approach | Random data set |
| Restrepo et al. (2019) | Omega | Canada | T | L | X | A context-free grammar, stochastic programming | – |
| Riazi et al. (2019) | IEEE Tase | Sweden | T | S | – | MILP, Gossip-CG and Dantzig Wolf Decomposition | Solomon (1987) and Gehring and Homberger (2002) |
| Ros-McDonnell et al. (2019) | Sustainability | Spain | P | S | X | Approximate algorithm | Real-world data |
| Shi et al. (2019) | Transportation Research Part E | France | T | S | X | MILP, Simulated Annealing, Tabu Search, and Variable Neighborhood Search | Simulation-based data |

**Table 1** (continued)

| Reference | Journal | Affiliation | Type of study Theoretical (T)/Practical (P) | Horizon Short (S)/Long(L) | Uncertainties | Solution methodology | Benchmarks instances |
|---|---|---|---|---|---|---|---|
| Chaieb et al. (2020) | Health Care Management Science | Saudi Arabia | P | S | – | MILP, K-means, Hungarian algorithm, TS | – |
| Euchi, 2020) | British. J. of Healthcare. Manage | Tunisia | T | S | – | Ant colony | Bredstrom and Ronnqvist (2008) |
| (Euchi et al. (2020) | Arab. J. Sci. Eng | Saudi Arabia | T | L | – | Ant Colony System, K-means | Bredstrom and Ronnqvist (2008) |
| Fathollahi-Fard, et al. 2020) | Neural Computing and Applications | Iran | T | S | – | Lagrangian relaxation-based algorithm, heuristics and a hybrid constructive metaheuristic | – |
| Fathollahi-Fard, et al. (2020) | Applied Soft Computing Journal | Iran | T | S | X | NSGA-II, SEO and modified | Simulation-based data |
| Frifita and Masmoudi, (2020) | International Transactions in Operational Research | France | T | L | – | MIP, VNS | Bredstrom and Ronnqvist (2008) |

**Table 1** (continued)

| Reference | Journal | Affiliation | Type of study Theoretical (T)/Practical (P) | Horizon Short (S)/Long(L) | Uncertainties | Solution methodology | Benchmarks instances |
|---|---|---|---|---|---|---|---|
| Gong et al. (2021) | IEEE Transactions on Automation Science and Engineering | China | P | S | – | IP-Insert VNS algorithm | Realistic instances |
| Grenouilleau et al. (2020) | Computers and Operations Research | Canada | T | S | – | Benders decomposition and column generation | Realistic instances |
| Doulabi et al. (2020) | Transportation Science | Canada | T | S | X | Two-stage stochastic integer programming | Simulation-based data |
| Kandakoglu et al. (2020) | Decision Support Systems | Canada | P | S | – | MILP model | Realistic instances |
| Martin et al. (2020) | Expert systems with applications | Spain | P | S | X | Improved Ant Colony Optimization (IACS-HCSP) algorithm | Realistic instances |
| Nasir and Kuo, (2020) | Decision Support Systems | Hong Kong | P | L | X | MILP, and Hybrid Genetic Algorithm | Realistic instances |
| Quintanilla et al. (2020) | Or Spectrum | Spain | T | S | – | MILP | Realistic instances |

**Table 1** (continued)

| Reference | Journal | Affiliation | Type of study<br>Theoretical (T)/Practical (P) | Horizon<br>Short (S)/Long(L) | Uncertainties | Solution methodology | Benchmarks instances |
|---|---|---|---|---|---|---|---|
| Wang et al. (2020) | Discrete Dynamics in Nature and Society | China | T | S | – | Hybrid optimization algorithm (WOA) with the particle swarm optimization (PSO) algorithm | Solomon (1987) |
| Chaieb & Ben Sassi, (2021) | Applied soft computing | Tunisia | P | S | – | Tabu Search metaheuristic and k-means algorithm | Modified Solomon's benchmark |
| Chen et al. (2021) | Journal of Systems Science and Systems Engineering | China | T | S | X | Stochastic bi-level programming model, and hybrid GA | Simulation-based data |
| Cinar et al. (2021) | European Journal of Operational Research | Turkey | P | S | – | Adaptive Large Neighborhood Search (ALNS) algorithm | Realistic instances |
| Decerle et al. (2021) | RAIRO | France | P | S | – | MILP, and matheuristic-based approach | Solomon (1987) |

**Table 1** (continued)

| Reference | Journal | Affiliation | Type of study Theoretical (T)/Practical (P) | Horizon Short (S)/Long(L) | Uncertainties | Solution methodology | Benchmarks instances |
|---|---|---|---|---|---|---|---|
| Demirbilek et al. (2021) | Flexible Services and Manufacturing Journal | UK | P | S | X | MILP, Scenario-based approach (SBA) | Realistic instances |
| Euchi and Sadok, (2021) | Proceedings Inst. Civil Eng -Transport | Saudi Arabia | T | L | – | MIP, Colony System, GA | Bredström and Rönqvist (2008), Decerle et al. (2018) |
| Goodarzian et al. (2021) | Journal of Computational Design and Engineering | Canada | P | S | – | Improvement of the social engineering optimizer (ISEO) | simulation-based data |
| Li et al. (2021) | Transportation Research Part E | China | T | S | – | Mixed-integer nonlinear and convex programming model, and GA | Realistic instances |

**Table 1** (continued)

| Reference | Journal | Affiliation | Type of study Theoretical (T)/Practical (P) | Horizon Short (S)/Long(L) | Uncertainties | Solution methodology | Benchmarks instances |
|---|---|---|---|---|---|---|---|
| Liu et al. (2021a) | Expert Systems. App | France | T | L | – | MIP, memetic algorithm (MA), hybrid genetic, general variable neighbourhood search (HGGVNS), hybrid genetic simulated annealing (HGSA), hybrid simulated annealing (HSA) | derived from Solomon (1987) |
| Liu et al. (2021b) | Computers & Industrial Engineering | France | P | L | – | Matheuristic combing adaptive large neighborhood search, and MILP | Trautsamwieser and Hirsch (2014) |
| Luo et al. (2021) | Soft Computing | China and France | P | S | – | MIP, and Ant Colony Optimization (ACO)-based heuristic | Realistic instances |
| Malagodi et al. (2021) | Health Care Management Science | Italy | P | S | – | MILP, Cluster-based decomposition | Realistic instances |

**Table 1** (continued)

| Reference | Journal | Affiliation | Type of study Theoretical (T)/Practical (P) | Horizon Short (S)/Long(L) | Uncertainties | Solution methodology | Benchmarks instances |
|---|---|---|---|---|---|---|---|
| Nikzad et al. (2021) | European Journal of Operational Research | Iran | T | L | X | MILP, matheuristic algorithm, Frank and Wolf algorithms | Fikar and Hirsch (2015) |
| (Polnik et al. 2021) | Journal of the Operational Research Society | UK | T | S | – | Constraint programming formulation | Bredstrom and Ronnqvist (2008) |
| (Shahnejat-Bushehri et al. 2021) | Expert Systems With Applications | Iran | T | S | X | MILP, SA, GA, and MA | Solomon (1987) |
| (Shiri et al. 2021) | Computers & Industrial Engineering | Iran | P | S | – | Fuzzy analytic hierarchy process, MILP, and Nimbus method | Realistic instances |
| Tanoumand and Ünlüyurt, (2021) | Annals of Operations Research | Turkey | T | S | – | Branch-and-Price method | Realistic instances |
| Yang et al. (2021) | Computers & Industrial Engineering | China | P | S | X | Multi-objective artificial bee colony (IMOABC) metaheuristic, | simulation-based data |

**Table 1** (continued)

| Reference | Journal | Affiliation | Type of study Theoretical (T)/Practical (P) | Horizon Short (S)/Long(L) | Uncertainties | Solution methodology | Benchmarks instances |
|---|---|---|---|---|---|---|---|
| Ala et al. (2022) | Mathematical Problems in Engineering | China | T | L | X | Metaheuristic algorithms | Realistic instances |
| Cire and Diamant, (2022) | Production and Operations Management | Netherlands | T | S | X | An approximate dynamic programming approach | Simulation data generated |
| Du and Zhang, (2022) | Computers & Industrial Engineering | China | P | S | X | MILP, hybrid Simulated Annealing algorithm | Realistic instances |
| Du et al. (2022) | Applied Soft Computing | China | P | S | – | Multi-Regions-Tabu Search Algorithm | Realistic instances |
| Erdem et al. (2022) | Computers & Industrial Engineering | Turkey | T | | – | Adaptive large neighborhood search heuristic | Generated benchmark |
| Krityakierne et al. (2022) | Plos one | Thailand | P | L | X | Dynamic LP and tabu search | Cordeau et al.(1997) |
| Lahrichi et al. (2022) | Expert Systems with Applications | Canada | P | L | X | First Route Second Assign (FRSA) decomposition algorithm | Realistic instances |

**Table 1** (continued)

| Reference | Journal | Affiliation | Type of study Theoretical (T)/Practical (P) | Horizon Short (S)/Long(L) | Uncertainties | Solution methodology | Benchmarks instances |
|---|---|---|---|---|---|---|---|
| Li et al. (2022) | Computers & Industrial Engineering | China | T | S | X | Discrete multi-objective grey wolf optimizer | Simulation-based data |
| Ma et al. (2022) | Swarm and Evolutionary Computation | China | P | S | X | Multi-objective Cooperative Evolutionary Algorithm | Simulation |
| Nuraiman and Ozlen, (2022) | Computers & Industrial Engineering | Australia | P | L | – | Decomposition Approach | Simulation data |
| Pahlevani et al. (2022) | Transportation Research Part E | Australia | P | S | – | Cluster-Based Algorithm | Realistic instances |
| Salehi-Amiri et al. (2022) | Expert Systems With Applications | Canada | P | | X | Internet of Things (IoT) | Realistic instances |
| Yadav and Tanksale, (2022) | European Journal of Operational Research | India | P | S | X | MIP-based decomposition heuristics | Simulation data |
| Ziya-Gorabi et al. (2022) | Expert Systems With Applications | Iran | P | S | – | Goal attainment and LP-metric methods | |

**Table 1** (continued)

| Reference | Journal | Affiliation | Type of study Theoretical (T)/Practical (P) | Horizon Short (S)/Long(L) | Uncertainties | Solution methodology | Benchmarks instances |
|---|---|---|---|---|---|---|---|
| Akbari et al. (2023) | Or Spectrum | UK and Turkey | T | S | – | IP and GVNS algorithm | Muritiba et al. (2021) |
| Alkaabneh and Diabat, (2023) | Transportation Research Part C: Emerging Technologies | United Arab Emirates | T | S | – | MILP, branch-and-price algorithm, and a two-stage meta-heuristic algorithm | simulation-based data |
| Bazirha et al. (2023) | Computers & Industrial Engineering | Morocco | T | S | – | MILP, SA-based heuristic | random instances |
| Belhor et al. (2023b) | Expert Systems with Applications | France | P | L | X | Multi-objective evolutionary approach based on K-means clustering | Realistic instances |
| Belhor et al. (2023a) | Computer Systems Science and Engineering | France | T | S | – | MIP, Learning Genetic Algorithm for mTSP (LGA-mTSP) | Simulation-based data |
| Clapper et al. (2023) | Computers and Operations Research | The Netherlands | P | L | X | Model-based evolutionary algorithm | Realistic instances |

**Table 1** (continued)

| Reference | Journal | Affiliation | Type of study Theoretical (T)/Practical (P) | Horizon Short (S)/Long(L) | Uncertainties | Solution methodology | Benchmarks instances |
|---|---|---|---|---|---|---|---|
| Dai et al. v2023) | Expert Systems With Applications | China | T | S | – | Competitive Simulated Annealing Algorithm | Simulation-based data |
| Dessevre et al. (2023) | Applied Sciences | France | P | | – | Resilient approach toward the centralization and sharing of information | Close-to-reality use case supported by interviews |
| Erdem and Koç, (2023) | Transportation Letters | Turkey | P | S | – | MILP, adaptive large neighborhood search (ALNS) | Realistic instances |
| (Gobbi et al. (2023) | International Transactions in Operational Research | Italy | T | L | X | MILP, adaptive large neighborhood search with kernel search | Simulation-based data |
| Hung et al. (2023) | Journal of Internet Technology | Taiwan | P | L | – | MIP, Tabu Search | Realistic instances |
| Ma et al. (2023) | Applied Soft Computing | China | P | L | – | MILP, knowledge-based multi-objective evolutionary algorithm (KMoEA) | Realistic instances |

**Table 1** (continued)

| Reference | Journal | Affiliation | Type of study Theoretical (T)/Practical (P) | Horizon Short (S)/Long(L) | Uncertainties | Solution methodology | Benchmarks instances |
|---|---|---|---|---|---|---|---|
| Masmoudi et al. (2023) | Optimization Letters | Tunisia | T | S | – | GA, variable neighborhood descent | Simulation-based data |
| (Méndez-Fernández et al. 2023) | Computers and Operations Research | Spain | P | S/L | – | MILP, Adaptive Large Neighbourhood Search (ALNS) | Realistic instances |
| Naderi et al. (2023) | Omega | Canada | T | S | X | MIP and logic-based Benders branching-decomposition algorithm | Cappanera and Scutellà (2015) |
| Oladzad-Abbasabady et al. (2023) | Engineering Applications of Artificial Intelligence | Iran | T | L | X | MILP, iterated local search (ILS) | Simulation-based data |
| Somar et al. (2023) | Applied Soft Computing | Turkey | T | S | X | Genetic Algorithm Simulated Annealing-Marine Predators Algorithm (GASA-MPA) | Realistic instances |

**Table 1** (continued)

| Reference | Journal | Affiliation | Type of study Theoretical (T)/Practical (P) | Horizon Short (S)/Long(L) | Uncertainties | Solution methodology | Benchmarks instances |
|---|---|---|---|---|---|---|---|
| Xiang et al. (2023) | International Transactions in Operational Research | China | T | S | X | MILP, nondominated sorting genetic algorithm (hybrid NSGA-II) | Solomon (1987) |
| Yadav and Tanksale, (2023) | Expert Systems With Applications | India | P | L | X | MILP, Multi-objective optimization approach | Simulation-based data |
| Yazır et al. (2023) | Or Spectrum | Turkey | P | S | - | MIP, adaptive large neighborhood search metaheuristic | Realistic instances |
| Zhang et al. (2023) | Computers & Industrial Engineering | China | T and P | S | X | Markov decision process and chance-constrained programming | Simulation-based data |
| Zhang et al. (2023) | Health Systems | France | T | L | X | LP, Constraint Satisfaction Problem (CSP) | Simulation-based data |
| Total | | | T: 44 P:41 | S: 55 L:27 | 37 | | |
| Percentage | | | T: 51.76% P: 48.24% | S: 64.71% L:31.76% | 43.53% | | |

literature, with both the development of new theories and their application to real-world scenarios being well-represented.

In terms of the "Horizon" of the studies, which distinguishes between Short (S) and Long (L) durations, the majority (64.71%) are short-term, encompassing 55 studies. This suggests a prevailing focus on addressing immediate and short-term issues, likely due to the challenges and uncertainties inherent in long-term forecasting.

Furthermore, the "Uncertainties" column reveals that fewer than half of the studies, 37 out of 85 (43.53%), explicitly consider uncertainties. This underrepresentation of uncertainty considerations points to a potential gap in the research, underscoring the need for future studies to incorporate uncertainties to enhance the robustness and applicability of their findings.

## 2.1 Objective functions

Many objective functions have been considered in the HHCRSP literature and can be divided into load/time-based, patient-based, and others. The objective function is defined in consultation with HHC services to make a high-quality solution. Hereafter is the list of main objective functions considered in HHCRSP (see Table 2):

- Minimize total operating time and distance traveled, and related cost; see e.g., Yazır et al. (2023).
- Minimize the waiting time (due to synchronization or a time window, for example. See, e.g., Chaieb et al. (2020), Euchi et al. (2020), Malagodi et al. (2021)
- Minimize the overtime and the related costs. See e.g., Dekhici et al. (2019), Hassani and Behnamian, 2021, Kandaoglu et al., 2020
- Minimize the number of routes to be carried out, which relates to the completion time, see e.g., Heching et al., 2019b, Kandakoglu et al. (2020), Liu et al. (2021)
- Minimize the preferred time slot, see e.g., Mosquera et al. (2019)
- Minimize the patients' preferences regarding skill and doctor-patient familiarity, see e.g., Du et al. (2019), Grenouilleau et al. (2019), Li et al. (2021)
- Minimize the continuity of care, see e.g., Gong et al., 2021
- Minimize the number of uncovered patients and the turnover of medical personnel per patient, see e.g., Erdem et al. (2022)
- Minimize the cost related to overtime of personnel and reassignments, see e.g., Malagodi et al. (2021).
- Minimize the violation of time windows of visits, see e.g., Belhor et al. (2023b)
- Balance the workload, and minimize the understaffing and overtime, see e.g., Méndez-Fernández et al. (2023).

Nearly all the researchers consider minimizing travel costs, distances, or travel times because it is a usual criterion for the VRP problem and a real concern for HHC organizations. However, this optimality criterion is not considered alone in the most recent publications. Most recent HHCRSP are modeled as a bi-objective optimization problem. (Malagodi et al., 2021) presented a multiobjective home care VRP that optimizes four objective functions, i.e., total working time, waiting time, overtime, and maximum patients' preferences. Liu et al. (2021) considered two conflicting objectives in the research: the number of routes and the total duration of the visits. Recently, Yazır et al., 2023 included three objective functions, i.e., min Traveling time/cost/distance, Min Wage/Hiring costs, and Min Uncovered visits.

According to Table 2, minimizing traveling time, cost, and distance emerges as the highest priority objective, featuring in 77.65% of the studies. This emphasizes the critical role of reducing travel-related factors for operational efficiency and cost-effectiveness in home

**Table 2** The objective functions in the HHCRSP

| References | Load/time objective | | | | | | Patients' objective | | | | Other objectives |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min Traveling time/cost/distance | Min Total working time/cost | Min total waiting time/cost | Min/Max overtime | Min Wage/Hiring costs | Min Unbalanced workload | Max patient preferences | Max continuity of care | Min Uncovered visits | Min TW violation | |
| Decerle et al. (2019) | X | – | – | – | – | X | – | – | – | X | Min synchronized visits non-respect |
| Dekhici et al. (2019) | X | – | – | X | – | X | – | – | – | – | – |
| Demirbilek et al. (2019) | – | – | – | – | – | – | – | – | – | – | – |
| Du et al. (2019) | X | – | – | – | – | – | X | – | – | – | – |
| Gomes and Ramos, (2019) | X | – | – | – | – | X | – | – | – | – | Min total deviation of the visit starting time |
| Grenouilleau et al. (2020) | X | – | – | – | – | – | X | X | – | – | – |
| Heching et al. (2019) | – | – | – | – | – | – | – | – | X | – | Max patient visits |
| Lamine et al. (2019) | X | X | X | – | – | X | X | – | X | X | Max overtime balance, max preferred time slot |
| Liu, et al. (2019) | X | – | – | – | – | X | X | – | – | – | – |
| Liu, et al. (2019) | X | – | – | – | – | – | – | – | X | – | – |
| Mosquera et al. (2019) | X | – | – | – | – | – | X | X | X | – | Max preferred time slot |
| Moussavi et al. (2019) | X | – | – | – | – | X | – | – | – | – | – |

**Table 2** (continued)

| References | Load/time objective | | | | | | Patients' objective | | | | Other objectives |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min Traveling time/cost/distance | Min Total working time/cost | Min total waiting time/cost | Min/Max overtime | Min Wage/Hiring costs | Min Unbalanced workload | Max patient preferences | Max continuity of care | Min Uncovered visits | Min TW violation | |
| Nasir and Dang, (2020) | X | – | X | – | X | – | – | – | – | – | – |
| Restrepo et al. (2020) | X | – | – | – | – | – | – | – | X | – | Min reassignment |
| Riazi et al. (2019) | X | – | – | – | – | – | – | – | – | – | – |
| Ros-McDonnell et al. (2019) | X | – | X | – | – | – | X | X | – | X | – |
| Shi et al. (2019) | X | – | | – | X | – | – | – | – | – | – |
| Chaieb et al. (2020) | X | – | X | – | – | X | – | – | X | – | – |
| Euchi, (2020) | | X | | – | – | – | – | – | – | X | – |
| Euchi et al. (2020) | X | X | X | – | – | – | X | – | – | – | – |
| Fathollahi-Fard et al. (2020) | X | – | – | X | – | – | – | – | – | – | – |
| Fathollahi-Fard, et al. (2020) | X | X | – | – | – | – | X | – | – | – | – |
| Frifita and Masmoudi, (2020) | X | – | – | – | – | – | – | – | – | – | – |
| Gong et al. (2021) | X | – | – | X | – | – | X | X | – | – | – |
| Grenouilleau et al. (2020) | – | – | – | | – | – | – | – | – | – | Max patient visits |

**Table 2** (continued)

| References | Load/time objective | | | | | | Patients' objective | | | | Other objectives |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min Traveling time/cost/distance | Min Total working time/cost | Min total waiting time/cost | Min/Max overtime | Min Wage/Hiring costs | Min Unbalanced workload | Max patient preferences | Max continuity of care | Min Uncovered visits | Min TW violation | |
| Doulabi et al. (2020) | X | – | X | X | – | – | – | – | – | – | Min delayed service |
| Kandakoglu et al. (2020) | X | – | – | X | X | X | – | – | – | – | – |
| Martin et al. (2020) | X | – | X | – | – | – | – | – | – | – | – |
| Nasir and Kuo, (2020) | X | – | – | – | X | | – | – | – | – | Min number of vehicle routes |
| Quintanilla et al. (2020) | X | – | X | – | – | – | – | – | – | – | – |
| Wang et al. (2020) | X | X | X | X | – | | X | – | X | X | – |
| Chaieb & Ben Sassi, (2021) | X | – | – | – | – | – | – | – | – | – | – |
| Chen et al. (2021) | X | – | – | X | – | – | X | – | – | – | – |
| Cinar et al. (2021) | X | – | – | – | – | – | – | – | – | – | Max the total prize of visited patients |
| Decerle et al. (2021) | X | – | – | – | – | – | – | – | – | – | – |
| Demirbilek et al. (2021) | – | – | – | – | – | – | – | – | X | – | Max patient visits |

**Table 2** (continued)

| References | Load/time objective | | | | | | Patients' objective | | | | Other objectives |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min Traveling time/cost/distance | Min Total working time/cost | Min total waiting time/cost | Min/Max overtime | Min Wage/Hiring costs | Min Unbalanced workload | Max patient preferences | Max continuity of care | Min Uncovered visits | Min TW violation | |
| Euchi and Sadok, (2021) | – | X | – | – | – | – | – | – | – | – | – |
| Goodarzian et al. (2021) | – | X | – | – | – | X | – | – | – | – | – |
| Li et al. (2021) | X | – | X | – | – | – | X | – | – | – | – |
| Liu et al. (2021a) | X | X | – | – | X | – | – | – | – | – | Min costs of vehicles |
| Liu et al. (2021b) | X | – | – | – | – | X | X | – | – | – | – |
| Luo et al. (2021) | X | – | – | – | – | – | – | – | – | – | min carbon emissions |
| Malagodi et al. (2021) | X | – | – | X | – | – | X | X | – | – | – |
| Nikzad et al. (2021) | X | – | – | – | X | – | – | X | – | – | – |
| Polnik et al. (2021) | X | – | – | – | – | – | – | – | – | – | – |
| Shahnejat-Bushehri et al. (2021) | X | – | – | – | X | – | X | X | – | – | – |

**Table 2** (continued)

| References | Load/time objective | | | | | | Patients' objective | | | | Other objectives |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min Traveling time/cost/distance | Min Total working time/cost | Min total waiting time/cost | Min/Max overtime | Min Wage/Hiring costs | Min Unbalanced workload | Max patient preferences | Max continuity of care | Min Uncovered visits | Min TW violation | |
| Shiri et al. (2021) | X | – | – | – | – | – | – | – | – | – | Min overqualification costs, max the qualitative factors of healthcare facilities, and max preferred time slot |
| Tanoumand and Ünlüyurt, (2021) | X | – | – | – | – | – | – | – | – | – | – |
| Yang et al. (2021) | X | – | – | – | – | X | – | X | – | – | Min delayed service |
| Ala et al. (2022) | – | X | – | – | X | – | – | – | – | – | – |
| Cire and Diamant, (2022) | – | X | X | – | | – | – | – | X | – | – |
| Du and Zhang, (2022) | X | – | X | – | X | – | X | – | X | X | Min overtime workload, overqualification costs |
| Du et al. (2022) | X | – | X | – | – | – | – | – | X | – | – |

**Table 2** (continued)

| References | Load/time objective | | | | | | Patients' objective | | | | Other objectives |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min Traveling time/cost/distance | Min Total working time/cost | Min total waiting time/cost | Min/Max overtime | Min Wage/Hiring costs | Min Unbalanced workload | Max patient preferences | Max continuity of care | Min Uncovered visits | Min TW violation | |
| Erdem et al. (2022) | X | – | – | – | – | – | – | – | X | – | Min energy charging costs |
| Krityakierne et al. (2022) | X | – | – | – | – | – | X | X | – | – | – |
| Lahrichi et al. (2022) | X | – | – | X | – | – | – | – | – | – | – |
| Li et al. (2022) | X | X | – | – | – | – | X | – | – | X | – |
| Ma et al. (2022) | X | X | – | – | – | X | – | – | – | X | – |
| Nuraiman and Ozlen, (2022) | – | X | – | – | – | – | – | – | – | – | – |
| Pahlevani et al. 2022) | – | X | – | – | – | X | X | – | – | – | – |
| Salehi–Amiri et al. 2022) | X | – | – | – | – | – | – | – | X | – | Min carbon emissions |
| Yadav & Tanksale, 2022) | – | X | X | – | – | – | – | – | – | – | Max the generated revenue |
| Ziya–Gorabi et al. (2022) | X | – | X | – | – | – | – | – | – | – | Min carbon emissions |
| Akbari et al. (2023) | – | – | X | – | – | – | – | – | – | – | – |

**Table 2** (continued)

| References | Load/time objective | | | | | | Patients' objective | | | | Other objectives |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min Traveling time/cost/distance | Min Total working time/cost | Min total waiting time/cost | Min/Max overtime | Min Wage/Hiring costs | Min Unbalanced workload | Max patient preferences | Max continuity of care | Min Uncovered visits | Min TW violation | |
| Alkaabneh and Diabat, (2023) | X | – | – | – | X | – | X | – | – | – | Max the compatibility between patients and nurses |
| Baziriha et al. (2023) | – | – | X | – | – | X | – | – | – | – | – |
| Belhor et al. (2023b) | X | X | – | – | – | – | – | – | – | X | Min difference between start time of services and visiting time preferences of patients |
| Belhor et al. (2023a) | X | – | – | – | – | – | X | – | – | – | – |
| Clapper et al. (2023) | X | – | X | X | – | – | – | – | – | – | – |
| Dai et al. (2023) | X | – | – | – | – | – | – | – | – | – | Min HHC center construction costs and carbon emission costs |
| Dessevre et al. (2023) | X | – | X | – | – | – | – | – | – | – | Min number of late arrivals |

**Table 2** (continued)

| References | Load/time objective | | | | | | Patients' objective | | | | Other objectives |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min Traveling time/cost/distance | Min Total working time/cost | Min total waiting time/cost | Min/Max overtime | Min Wage/Hiring costs | Min Unbalanced workload | Max patient preferences | Max continuity of care | Min Uncovered visits | Min TW violation | |
| Erdem and Koç, (2023) | X | – | – | – | X | – | – | – | – | – | Min energy charging costs in routes, charging cost at depot |
| Gobbi et al. (2023) | – | – | – | – | – | – | X | – | – | – | – |
| Hung et al. (2023) | X | X | – | – | – | – | – | – | – | – | Time period |
| Ma et al. (2023) | X | – | – | – | – | – | X | – | – | – | – |
| Masmoudi et al. (2023) | X | – | – | – | – | X | X | – | – | – | – |
| Méndez-Fernández et al. (2023) | – | X | – | X | – | – | X | – | – | X | – |
| Naderi et al. (2023) | – | – | – | X | X | – | – | – | – | – | – |
| Oladzad-Abbasabady et al. (2023) | – | X | – | – | – | – | X | – | X | – | – |
| Somar et al. (2023) | X | X | – | – | – | – | – | – | – | – | – |
| Xiang et al. (2023) | – | X | – | X | – | – | X | X | – | – | – |
| Yadav and Tanksale, (2023) | X | X | – | – | – | X | – | – | X | X | Equal distribution of overtime, min loss of employed labor |

**Table 2** (continued)

| References | Load/time objective | | | | | | Patients' objective | | | | Other objectives |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min Traveling time/cost/distance | Min Total working time/cost | Min total waiting time/cost | Min/Max overtime | Min Wage/Hiring costs | Min Unbalanced workload | Max patient preferences | Max continuity of care | Min Uncovered visits | Min TW violation | |
| Yazır et al. (2023) | X | – | – | – | X | – | – | – | X | – | min energy charging costs |
| Zhang et al. (2023) | X | – | X | – | – | – | – | X | – | – | Quality of life' and empowerment |
| Zhang et al. (2023) | X | – | – | – | – | – | – | – | – | – | min overtime workload |
| Total | 66 | 22 | 20 | 13 | 13 | 16 | 27 | 11 | 16 | 11 | – |
| Percentage | 77.65% | 25.88% | 23.53% | 15.29% | 15.29% | 18.82% | 31.76% | 12.94% | 18.82% | 12.94% | – |

healthcare scheduling. The objective of minimizing total working time and cost, present in 25.88% of the studies, highlights a significant focus on reducing overall working hours and associated expenses to enhance efficiency and manage costs effectively.

Minimizing total waiting time and cost is moderately prioritized, with 20 out of 85 studies addressing it, underscoring the importance of reducing downtime and ensuring prompt service delivery. Managing overtime is essential for balancing staff workload and avoiding additional labor costs, with this objective addressed in 15.29% of the studies (13 papers). Controlling wage and hiring costs, though crucial for financial management, is less frequently prioritized, sharing the same percentage as the overtime management objective.

Ensuring a balanced workload among staff, represented in 18.82% of the studies (16 out of 85), is vital for maintaining employee satisfaction and preventing burnout. Addressing patient preferences, a key component of patient-centric care, is relatively well-prioritized, with 31.76% of the studies (27 papers) considering it in scheduling decisions.

From the analysis of 85 journal papers, it is observed that 11 papers (12.94%) address two additional objectives: maximizing continuity of care, which is essential for maintaining the quality of patient care, and minimizing time window violations, which is crucial for upholding service punctuality and patient satisfaction. These objectives, although the least prioritized, remain important for comprehensive home healthcare scheduling.

We observe that the objective of minimizing uncovered visits, which ensures all visits are covered, is essential for comprehensive patient care and service reliability. This objective is addressed in 16 out of 85 papers, representing 18.82% of the considered studies.

## 2.2 Constraints

We here describe the numerous constraints considered in our selected literature, mainly classified into staff-based, patient-based, and visits constraints (see Table 3):

- Time Windows: No (-), hard (h), Soft(S); see e.g., Xiang et al. (2023), Méndez-Fernández et al. (2023), Yadav & Tanksale (2023).
- Legislative rules: break lunch. Max working time; see e.g., Clapper et al. (2023)
- Restriction to District/region; see e.g., Hung et al. (2023), Yadav & Tanksale (2022).
- Continuity of care; see e.g., Lahrichi et al. (2022), Dai et al. (2023)
- Time Windows: No (-), hard (h), Soft(S); see e.g., Nuraiman & Ozlen (2022), Ziya-Gorabi et al. (2022), Ma et al. (2022).
- Required skills; see e.g., L. Zhang et al. 2023, Gobbi et al. (2023)
- Multiple visits per period; see e.g., Erdem & Koç (2023), Yazır et al. (2023)
- Visits patterns; see e.g., Alkaabneh & Diabat (2023), Krityakierne et al. (2022), Cire & Diamant (2022).
- Synchronization; see e.g., Oladzad-Abbasabady et al. (2023), Bazirha et al. (2023), Yadav & Tanksale (2022).

Table 3 provides a detailed analysis of how various constraints are prioritized in the literature regarding home healthcare scheduling, focusing on staff, patients, and visits.

For staff constraints, 43.53% of the studies enforce hard time windows (H), while 11.76% use soft time windows (S), indicating a strong preference for strict adherence to specific time frames. Legislative rules, such as breaks, lunch periods, and maximum working hours, are considered in 48.24% of the studies, highlighting the importance of complying with labor laws and ensuring staff welfare. Restrictions based on district or region are included in only 15.29% of the studies, suggesting that geographic constraints are less frequently prioritized.

**Table 3** The constraints in the HHCRSP

| References | Staffs' constraints | | | Patients' constraints | | Visit's constraints | | | | Other constraints |
|---|---|---|---|---|---|---|---|---|---|---|
| | Time Windows: No (-), hard (H), Soft(S) | Legislative rules: break lunch. Max working time | Restriction to District/region | Continuity of care | Time Windows: No (-), hard (H), Soft(S) | Required skills | Multiple visits per period | Visits patterns | Synchronization | |
| Decerle et al. (2019) | H | X | – | – | H, S | X | – | – | X | – |
| Dekhici et al. (2019) | H | – | – | – | S | – | – | – | X | – |
| Demirbilek et al. (2019) | H | – | – | – | – | – | – | X | – | Visits frequency |
| Du et al. (2019) | – | – | – | – | H | – | – | – | – | Visits frequency and preferred starting time |
| Gomes and Ramos, (2019) | – | X | – | – | H | – | X | – | – | – |
| Grenouilleau et al. (2020) | S | – | – | – | H | X | – | – | – | Temporal dependencies |
| Heching et al. (2019) | H | X | – | – | H | X | – | – | – | Temporal dependencies |
| Lamine et al. (2019) | H,S | X | | X | H, S | X | X | – | – | – |
| Liu, et al. (2019) | H | – | – | – | H | – | – | – | X | – |
| Liu, et al. (2019) | – | – | – | – | S | X | – | – | – | – |
| Mosquera et al. (2019) | H | X | X | X | H, S | X | X | – | – | Preferred starting time |

**Table 3** (continued)

| References | Staffs' constraints | | | Patients' constraints | | Visit's constraints | | | | Other constraints |
|---|---|---|---|---|---|---|---|---|---|---|
| | Time Windows: No (-), hard (H), Soft(S) | Legislative rules: break lunch. Max working time | Restriction to District/region | Continuity of care | Time Windows: No (-), hard (H), Soft(S) | Required skills | Multiple visits per period | Visits patterns | Synchronization | |
| Moussavi et al. (2019) | – | X | – | – | – | – | X | – | – | – |
| Nasir and Dang, (2020) | H | X | – | – | H | X | – | – | – | – |
| Restrepo et al. (2020) | – | X | X | – | – | – | – | – | – | – |
| Riazi et al. (2019) | H | X | – | – | H | X | – | – | – | – |
| Ros–McDonnell et al. (2019) | H | X | – | – | H, S | X | X | – | – | Multi–modality of transport |
| Shi et al. (2019) | – | – | – | – | H | X | | – | – | Limited number of the patients |
| Chaieb et al. (2020) | H | X | – | – | H | X | – | – | – | Multi-modality of transport, precedence and incompatibility with patients |
| Euchi, (2020) | H | – | – | – | H, S | X | – | – | X | – |

**Table 3** (continued)

| References | Staffs' constraints | | | Patients' constraints | | Visit's constraints | | | | Other constraints |
|---|---|---|---|---|---|---|---|---|---|---|
| | Time Windows: No (-), hard (H), Soft(S) | Legislative rules: break lunch. Max working time | Restriction to District/region | Continuity of care | Time Windows: No (-), hard (H), Soft(S) | Required skills | Multiple visits per period | Visits patterns | Synchronization | |
| Euchi et al. (2020) | S | – | X | – | H, S | – | – | – | X | – |
| Fathollahi-Fard et al. (2020) | – | – | – | – | H | – | – | – | – | Multi-modality of transport |
| Fathollahi-Fard, et al. (2020) | – | – | – | – | H | X | X | – | – | Travel balancing |
| Frifita and Masmoudi, (2020) | H | – | – | – | H, S | – | – | – | X | Disjunctions and precedence |
| Gong et al. (2021) | – | X | – | X | – | X | – | – | – | – |
| Grenouilleau et al. (2020) | H | X | – | X | H | X | – | X | – | travel time constraints |
| Doulabi et al. (2020) | – | – | – | – | – | – | – | – | X | capacity |
| Kandakoglu et al. (2020) | S | **X** | – | – | H | X | X | – | – | – |
| Martin et al. (2020) | H | X | – | X | H | – | – | – | – | – |
| Nasir and Kuo, (2020) | H | – | – | – | H | X | X | – | X | Balanced workload and precedence |

**Table 3** (continued)

| References | Staffs' constraints | | | Patients' constraints | | Visit's constraints | | | | Other constraints |
|---|---|---|---|---|---|---|---|---|---|---|
| | Time Windows: No (-), hard (H), Soft(S) | Legislative rules: break lunch. Max working time | Restriction to District/region | Continuity of care | Time Windows: No (-), hard (H), Soft(S) | Required skills | Multiple visits per period | Visits patterns | Synchronization | |
| Quintanilla et al. (2020) | – | – | – | – | – | – | – | – | – | Balanced workload |
| Wang et al. (2020) | H | – | – | X | H | – | – | – | – | – |
| Chaieb & Ben Sassi, (2021) | – | – | – | – | H | X | – | – | – | – |
| Chen et al. (2021) | H | X | – | – | H | X | – | – | – | – |
| Cinar et al. (2021) | H | – | – | – | H | – | – | – | – | – |
| Decerle et al. (2021) | – | – | – | – | H | X | – | – | X | – |
| Demirbilek et al. (2021) | – | – | – | X | – | X | – | X | – | Visits frequency |
| Euchi and Sadok, (2021) | H | – | X | X | H | – | – | – | X | Limited number of patients |
| Goodarzian et al. (2021) | H | X | – | – | H | – | – | – | – | – |
| Li et al. (2021) | – | – | – | – | H | X | – | – | – | Consideration of outpatient |

**Table 3** (continued)

| References | Staffs' constraints | | | Patients' constraints | | Visit's constraints | | | | Other constraints |
|---|---|---|---|---|---|---|---|---|---|---|
| | Time Windows: No (-), hard (H), Soft(S) | Legislative rules: break lunch. Max working time | Restriction to District/region | Continuity of care | Time Windows: No (-), hard (H), Soft(S) | Required skills | Multiple visits per period | Visits patterns | Synchronization | |
| Liu et al. (2021a) | – | X | – | – | H | X | – | – | X | Flexible departure modes of caregivers |
| Liu et al. (2021b) | – | X | – | X | H | X | – | – | X | workload balancing, and Multi–modality of transport |
| Luo et al. (2021) | – | – | – | – | H | – | – | – | X | |
| Malagodi et al. (2021) | – | X | – | X | – | X | – | – | – | – |
| Nikzad et al. (2021) | – | X | X | – | – | X | – | – | – | Geographical obstacles |
| Polnik et al. (2021) | H | X | – | X | H | X | – | – | X | – |
| Shahnejat-Bushehri et al. (2021) | – | X | – | – | S | – | X | – | X | Disjunctions and precedence |
| Shiri et al. (2021) | – | – | X | – | H | X | – | – | – | – |

**Table 3** (continued)

| References | Staffs' constraints | | | Patients' constraints | | Visit's constraints | | | | Other constraints |
|---|---|---|---|---|---|---|---|---|---|---|
| | Time Windows: No (-), hard (H), Soft(S) | Legislative rules: break lunch. Max working time | Restriction to District/region | Continuity of care | Time Windows: No (-), hard (H), Soft(S) | Required skills | Multiple visits per period | Visits patterns | Synchronization | |
| Tanoumand and Ünlüyurt, (2021) | – | X | – | – | H | X | – | – | – | Resource constraint and working hours |
| Yang et al. (2021) | – | X | – | – | – | – | – | X | – | Preferred starting time |
| Ala et al. (2022) | – | – | – | – | – | X | – | – | – | – |
| Cire and Diamant, (2022) | – | – | X | X | – | X | – | X | – | – |
| Du and Zhang, (2022) | – | – | X | – | S | – | – | – | – | – |
| Du et al. (2022) | – | – | X | – | H | – | – | – | – | – |
| Erdem et al. (2022) | H | – | – | – | H | X | – | – | X | incompatibility with patients |
| Krityakierne et al. (2022) | H | – | – | – | H, S | X | – | X | – | – |
| Lahrichi et al. (2022) | S | – | – | X | – | – | – | X | – | Visits frequency |

**Table 3** (continued)

| References | Staffs' constraints | | | Patients' constraints | | Visit's constraints | | | | Other constraints |
|---|---|---|---|---|---|---|---|---|---|---|
| | Time Windows: No (-), hard (H), Soft(S) | Legislative rules: break lunch. Max working time | Restriction to District/region | Continuity of care | Time Windows: No (-), hard (H), Soft(S) | Required skills | Multiple visits per period | Visits patterns | Synchronization | |
| Li et al. 2022) | – | X | – | X | S | X | – | – | – | – |
| Ma et al. 2022) | – | X | – | – | S | X | – | – | – | Preferred starting time |
| Nuraiman & Ozlen, 2022) | – | – | – | – | H, S | X | – | – | X | – |
| Pahlevani et al. (2022) | – | – | – | – | H | X | – | – | – | Clients' requirements and caregivers' preferences |
| Salehi-Amiri et al. (2022) | – | – | – | – | – | – | – | – | – | vehicle capacity and load constraints |

**Table 3** (continued)

| References | Staffs' constraints | | | Patients' constraints | | Visit's constraints | | | | Other constraints |
|---|---|---|---|---|---|---|---|---|---|---|
| | Time Windows: No (-), hard (H), Soft(S) | Legislative rules: break lunch. Max working time | Restriction to District/region | Continuity of care | Time Windows: No (-), hard (H), Soft(S) | Required skills | Multiple visits per period | Visits patterns | Synchronization | |
| Yadav and Tanksale, (2022) | H | X | X | – | H | X | X | – | X | Disjunction, patient preference, contact restriction, workload and precedence |
| Ziya–Gorabi et al. (2022) | – | – | – | – | H | – | – | – | – | capacity |
| Akbari et al. (2023) | – | – | – | – | – | – | – | – | – | – |
| Alkaabneh and Diabat, (2023) | – | X | – | – | – | – | – | X | – | – |
| Bazirha et al. (2023) | H | – | – | – | H, S | X | – | – | X | Multi-TW |
| Belhor et al. (2023b) | H, S | X | – | – | H | – | – | – | – | Preferred starting time |
| Belhor et al. (2023a) | H | X | – | – | H | – | – | – | – | Workload balancing |

**Table 3** (continued)

| References | Staffs' constraints | | | Patients' constraints | | Visit's constraints | | | | Other constraints |
|---|---|---|---|---|---|---|---|---|---|---|
| | Time Windows: No (-), hard (H), Soft(S) | Legislative rules: break lunch. Max working time | Restriction to District/region | Continuity of care | Time Windows: No (-), hard (H), Soft(S) | Required skills | Multiple visits per period | Visits patterns | Synchronization | |
| Clapper et al. (2023) | H, S | X | X | – | H, S | X | – | – | – | Preferred starting time |
| Dai et al. (2023) | – | – | – | X | H | X | – | – | X | Load capacities and battery capacities |
| Dessevre et al. (2023) | H | – | – | – | H, S | – | – | – | – | – |
| Erdem and Koç, (2023) | H | X | – | – | H | – | X | – | – | Battery capacity |
| Gobbi et al. (2023) | – | X | – | – | – | X | X | – | – | Incompatibility with patients |
| Hung et al. (2023) | H | | X | X | – | | – | – | – | Time/period formula |
| Ma et al. (2023) | – | X | – | – | – | X | – | – | – | – |
| Masmoudi et al. (2023) | H | – | – | – | H | – | – | – | X | – |

**Table 3** (continued)

| References | Staffs' constraints | | | Patients' constraints | | Visit's constraints | | | | Other constraints |
|---|---|---|---|---|---|---|---|---|---|---|
| | Time Windows: No (-), hard (H), Soft(S) | Legislative rules: break lunch. Max working time | Restriction to District/region | Continuity of care | Time Windows: No (-), hard (H), Soft(S) | Required skills | Multiple visits per period | Visits patterns | Synchronization | |
| Méndez–Fernández et al. (2023) | H, S | X | – | X | H, S | X | – | – | – | Incompatibility with patients |
| Naderi et al. (2023) | – | X | – | – | | X | – | – | – | – |
| Oladzad-Abbasabady et al. (2023) | H, S | – | – | – | H, S | X | – | – | X | Precedence |
| Somar et al. (2023) | – | – | – | – | H | X | – | – | – | Travel balancing and multi modal transportation |
| Xiang et al. (2023) | H | X | – | – | H | X | – | – | – | – |
| Yadav and Tanksale, (2023) | S | X | – | – | S | X | – | – | – | – |
| Yazır et al. (2023) | – | – | X | – | H | X | X | – | – | Charging technologies |
| Zhang et al. (2023) | – | X | – | – | H, S | X | X | – | – | Workload balancing |
| Zhang et al. (2023) | H | X | – | – | H | X | – | – | – | Multi–TW |

**Table 3** (continued)

| References | Staffs' constraints | | | Patients' constraints | | Visit's constraints | | | | Other constraints |
|---|---|---|---|---|---|---|---|---|---|---|
| | Time Windows: No (-), hard (H), Soft(S) | Legislative rules: break lunch. Max working time | Restriction to District/region | Continuity of care | Time Windows: No (-), hard (H), Soft(S) | Required skills | Multiple visits per period | Visits patterns | Synchronization | |
| Total | H:37 S:10 | 41 | 13 | 17 | H:58 S:22 | 52 | 14 | 8 | 22 | – |
| Percentage | H: 43.53% S: 11.76% | 48.24% | 15.29% | 20.00% | H: 68.24% S: 25.88% | 61.18% | 16.47% | 9.41% | 25.88% | – |

The continuity of care constraint, which ensures consistent care by the same caregivers, is considered in 20.00% of the studies, reflecting its importance for better patient outcomes.

For patient constraints, 68.24% of the studies enforce hard time windows (H), and 25.88% use soft time windows (S), emphasizing the critical need to meet patient scheduling requirements within specific time frames. The need for caregivers to possess specific skills is addressed in 61.18% of the studies, indicating a high priority on matching caregivers' skills with patient needs. The requirement for multiple visits per period is considered in 16.47% of the studies, which is important for patients needing frequent care. Finally, visit patterns are addressed in 9.41% of the studies, and synchronization is considered in 25.88% of the studies, showing a moderate emphasis on coordinating visits to optimize care delivery.

## 3 HHCRSP and digitization: new challenges

Digitization is a primary driver of excellence in all sectors. In the HHC section, the use of 4.0 technologies is minimal, and few papers have been published. However, the potential of using technologies like AI, real-time dynamics, IoT, and digitalization can revolutionize how routing and scheduling caregivers in home healthcare are managed and lead to significant improvements. The possible solutions provided in the literature are collaborative Platforms and Shared Economy Models, Real-Time monitoring and Dynamic Scheduling, and Predictive Analytics.

**Collaborative platforms and shared economy models:** The availability of innovative technologies (e.g., IoT, big data analytics, cloud) permits the development of collaborative platforms and shared economy models, where multiple home healthcare agencies can pool their resources and share caregivers to optimize routing and scheduling across a more extensive network. Such technology can ensure that each caregiver's time is efficiently allocated, minimizing idle time and maximizing the coverage of patient needs. In addition, through such technology, agencies can quickly find replacements or redistribute resources as needed to ensure continuity of care. (Asghari & Mirzapour Al-e-hashem, 2020) studied the sharing economy between individuals in distributing scarce resources and dealt with the green delivery pickup for home hemodialysis machines. (Wang et al., 2020) studied the impact of resource sharing on the performance of the HHCRSP in terms of cost structure and customer satisfaction. (Lin et al., 2021) studied the shift in providing home healthcare (HHC) services from traditional institutions to service-sharing platforms. They proposed mixed-integer linear programming models with four matching strategies ("self-interested", "customer-first", "hard-work-happy-life", and "social-welfare") for the HHCRSP of peer-to-peer service-sharing platforms while considering several key rules such as flexible service durations, break requirements, and temporal dependencies. (Dessevre et al., 2023) showed the importance of centralization and sharing of information at a Local Home Health Care Center in Improving Resilient routing and scheduling and proposed the use of a device, such as a smartphone application, to centralize and share information and better mutual assistance between caregivers. (Lamine et al., 2019) designed an interactive ICT platform to support home care services called Plas'O'Soins, favoring communication among actors, activities coordination, and care continuity.

***Possible extension:****Besides caregivers, the devices could be shared between coordinated agencies, such as robotics, providing recurrent care to patients or assistance with mobility. Different caregivers from different agencies can exploit these resources and collectively manage the transportation of these devices between customers.*

**Real-Time Monitoring And Dynamic Scheduling:** real-time monitoring of caregivers' locations, tasks, and patient conditions through IoT devices and wearable sensors provides real-time data about traffic conditions, caregiver availability, new requests/needs, and cancellations. This data is helpful for real-time dynamic scheduling. Dynamic scheduling algorithms can adapt in real-time to unexpected events such as caregiver delays or patient emergencies and automatically reroute caregivers to ensure timely care delivery and high performance. Caregivers receive real-time updated schedules, task assignments, and patient information through mobile applications and communication Platforms, improving coordination and efficiency. (Salehi-Amiri et al., 2022) proposed a smart platform's application of interconnected devices and services, i.e., patients' homes and all medical equipment, linked to the cloud network through an IoT system to prevent unnecessary trips and visit each home in a real-time fashion and optimize the caregivers' routes depending on the available routes, available time, and best path to visit every patient's home. A set of newly developed multiobjective metaheuristic algorithms are employed for real-time fashion. (Du et al., 2019) proposed an effective real-time scheduling model leading to medical scheduling conflicts to decrease patient satisfaction due to unexpected events such as cancellation of services and demand for emergency care and medical device failures and proposed an improved memetic algorithm to optimize the model. (Demirbilek et al., 2019) considered other new events, such as new patients and proposed a scenario-based approach for dynamic acceptation and scheduling of new patients. They compared it with two greedy algorithms from the literature to show its performance. (Cire & Diamant, 2022) proposed a dynamic scheduling framework to assign the patients who arrive stochastically over time to caregivers while the decision is modeled as a discrete-time, rolling-horizon, infinite-stage Markov decision process. They proposed an approximate dynamic programming approach and particularly investigated the caregiver's fairness by balancing service and travel times. (Hung et al., 2023) proposed a new portable support system for flexible real-time routing and scheduling to help home care nurses optimize before, during, and after-visit work through functions like Google Maps graphically presenting the daily routes. It includes an algorithm with three modes of schedule planning: shortest route, micro-adjustment, and timeline, that assists the home care nurses in operating the system intuitively and displays the routes through functions like Google Maps, intending to increase the mobility of the caring personnel and reduce the time for look-up and arrangement and even reduce the transportation cost of the home care department.

***Possible extension:****Data about traffic conditions, caregiver availability, new requests/needs, and cancellations can be collected in real time through IoT devices and wearable sensors. Proactive and reactive scheduling, including all data collected and related uncertainties, can be integrated to update the HHC routes and Schedules efficiently. The use of such a problem-solving approach in real-time within a mobile application and communication platform intuitively improves the coordination and efficiency of HHC activities.*

**Predictive analytics:** By leveraging historical data and predictive analytics, home healthcare agencies can anticipate future demand for caregiver services and proactively adjust schedules and routes to meet patient needs. This can help prevent understaffing or overstaffing situations, ensuring efficient use of resources. In addition, predictive analytics can enhance the performance of decision-making techniques, e.g., learning techniques that are used to enhance optimization. (Jouini et al., 2020), proposed a Predictive model for elderly dependency assessment at home, enhancing real-time monitoring and Dynamic scheduling. (Belhor et al., 2023a) and (Belhor et al., 2023b) proposed an evolutionary approach based on K-means clustering and a Learning-Based Metaheuristic approach for HHCRSP. (Zhang et al., 2023) studied the environmental, social, and economic perspectives of HHCRP and proposed a model-free reinforcement learning algorithm, Q-learning (QL), and the ant colony optimization (ACO) algorithm to deal with complex human behaviors in HHCRSP.

*Possible extension:* Machine learning algorithms can be used to assess and predict patient needs and enhance real-time optimization algorithms for HHCRSP.

Based on real-time data, many other solutions could be generated to increase the patient's satisfaction and reduce the total. For example, remote monitoring of patient's vital signs and health conditions through IoTs and telehealth technologies could reduce the need for frequent in-person visits from caregivers. Prioritizing in-person visits for patients with higher acuity levels or specific care needs could be a solution to optimize the HHC activity efficiently.

## 4 Sustainable HHCRSP: new goals

By optimizing routes, healthcare providers ensure timely arrivals and departures, enhancing patient satisfaction and adherence to treatment plans. Despite the importance of efficient routing, a few papers in the literature consider the sustainability of home health care. This Literature Review section contains some solutions that optimize the efficiency of healthcare service delivery, minimize negative environmental impacts, promote social equity, and ensure economic viability. Here are several solutions to consider for addressing sustainability in home healthcare routing and scheduling:

**Alternative fuel vehicles:** Transitioning to alternative fuel vehicles such as electric, hybrid, or hydrogen-powered vehicles can significantly reduce carbon emissions and reliance on fossil fuels. (Euchi & Yassine, 2023) introduce a hybrid metaheuristic algorithm designed to address the Electric Vehicle Routing Problem (EVRP) with Battery Recharging Stations (BRS) for sustainable environmental and energy optimization. The proposed algorithm combines multiple metaheuristic techniques to solve this complex optimization problem efficiently. The algorithm aims to minimize carbon emissions, optimize energy consumption, and promote environmentally friendly transportation solutions by integrating sustainable practices and energy-efficient routing strategies. (Erdem et al., 2022) considered that vehicles might be charged during the working day at a charging station or the end of the working day at the depot. They proposed a mathematical model and an adaptive large neighborhood search metaheuristic HHC routing and scheduling problem while minimizing the total cost that comprises the fixed cost of utilizing healthcare nurses, the energy charging costs, the costs associated with depot-to-nurse home transfer services, and the costs of a patient left unserved. (Erdem & Koç, 2023) considered electric vehicles in HHCRSP and proposed a mixed integer linear programming model and a hybrid adaptive large neighborhood search (ALNS) algorithm that combines existing heuristic mechanisms with several new problem-specific procedures to investigate various options such as constructed teams, usage rate of fast and super-fast charging technologies, and public and private charging stations. (Dai et al., 2023) Considered a mixed fleet of conventional and electric vehicles with battery swapping stations and provided a competitive simulated annealing algorithm to solve the HHCRSP. (Yin et al., 2023) considered the HHCRSP with electric vehicles and synergistic-transport mode, where the EVs are used to transport care workers to serve patients. They minimized the sum of the dispatching cost, the transport cost by EV and walking, and the incompatibility cost of care-workers and patients.

*As a possible extension, the investment in Green Infrastructure Development that supports sustainable transportation, such as bike lanes, electric vehicle charging stations, and public* *transportation hubs, can encourage the use of alternative modes of transportation and reduce reliance on individual car travel.*

**Multimodal:** provides more sustainable options and reduces congestion on roads (Fikar & Hirsch, 2018) combined the car-sharing concept with the operation of a transport system, which delivers and picks up nurses to and from clients, with the additional option of walking. (Quintanilla et al., 2020) proposed two sustainable strategies: workers can walk between houses, and workers transported by a taxi may change during the route. (Yin et al., 2023) considered the option to serve patients by other transport modes than cars, referred to as by walking, when the EV is recharging at a recharging station, and then rendezvous with the EV either at the recharging station or at a patient node.

As a possible extension, using vehicle sharing or taxis or bikes/scooters with public transportation hubs could be a relevant solution for reducing reliance on individual cars.

**Eco-driving practices:** Promote eco-driving practices among drivers, such as maintaining optimal speeds, reducing idling time, and minimizing harsh acceleration and braking to improve fuel efficiency and reduce emissions (Cheaitou et al., 2021).This practice has been studied for HHC by (Hongyuan Luo et al., 2021), who address a joint daily route and speed optimization problem in HHC with the constraints of synchronized visits and carbon emissions to minimize the carbon emissions, which has a linear relationship with fuel consumption.

*As a possible extension, develop speed optimization in home healthcare, propose a comparison between eco-driving and alternative fuel, and combine both in one study, i.e., the positive impact of eco-driving on different categories of cars.*

**Vehicle and trip sharing consolidation:** Introduce vehicle-sharing schemes where multiple users or companies share vehicles for transportation needs, reducing the number of vehicles on the road and promoting resource efficiency. (Fikar & Hirsch, 2018) investigated a car-sharing concept and a transport system that delivers and picks up nurses to and from clients. (Fikar et al., 2016) utilize real-time data and dynamic routing algorithms to adapt routes based on changes, such as cancellations or new requests, to optimize efficiency and reduce environmental impact with synchronized trip sharing. Quintanilla et al. (2020) proposed a mathematical model to solve the specific HHCRSP while considering the distribution of caregivers into teams who share the same taxi.

As a possible extension, combining multimodal (walking and *car* usage) with carpooling or *car* sharing could be a relevant research direction.

**A bi or multiobjective optimization:** Several papers implement advanced algorithms to optimize several objectives simultaneously, with at least one social or environmental objective. (Hao Luo et al., 2020) provided an ACO-based heuristic approach to tackle routing and scheduling in home health care while optimizing fuel consumption, emissions, and vehicle routing efficiency. (Fathollahi-Fard, Ahmadi, et al., 2020) developed a non-dominated sorting Genetic Algorithm (NSGA-II), a social engineering optimizer (SEO), and an adaptive memory SEO (AMSEO) to deal with the multi-period and multi-depot home healthcare routing and scheduling problem while minimizing the total cost of logistics activities and maximizing the patients' satisfaction under uncertainty. (Makboul et al., 2024) employed the NSGA-II algorithm to tackle the multiperiodic Green Home Health Care (GHHC) and minimize travel distance and CO emissions while ensuring the efficient distribution of caregivers' workload. (Du & Li, 2024) proposed several variants of a non-dominated sorting genetic algorithm (NSGA) to tackle the green home healthcare routing and scheduling problem with simultaneous consideration of physician–patient satisfaction and sustainability based on prospect theory, which simultaneously optimizes four objectives, including minimizing total cost, carbon emission, maximizing customer satisfaction, and caregiver satisfaction.

*As a possible extension, all the previously mentioned solutions toward sustainable HHCRSP, such us Alternative Fuel vehicles, multimodal and car sharing, and speed optimization, could be combined and solved using multiobjective optimization techniques covering the three pillars of sustainability: social, economic, and environmental.*

## 5 Conclusion and perspectives

In this review, we have explored the multifaceted domain of Home Healthcare (HHC) routing and scheduling, emphasizing the critical role of Operations Research (OR) methodologies in addressing the complexities inherent in this field. The application of OR techniques has shown significant potential in optimizing various aspects of HHC, including the efficient allocation of resources, minimization of travel time, and improvement of service quality for patients. This research is conducted through a literature review of all selected studies from 2019 to 2023. It presents an update of a previous literature review of the same team (Euchi, Siarry, and Masmoudi, 2022, in 4OR journal) and a projection towards the contemporary challenges of sustainability and digitalization in HHCRSP.

We examined all the selected papers through numerical analysis and classification of articles, emphasizing the solution methodologies and the instances used for each paper, the objective functions, and the constraints considered for visits, patients, and staff. Different opportunities in the OR/MS field for future research have been determined, which justifies the application of advanced optimization techniques.

Key findings from the literature indicate that while traditional OR models have provided a strong foundation for addressing HHC challenges, contemporary issues such as the integration of real-time data, patient-centric care models, and the need for adaptive scheduling in dynamic environments necessitate the evolution of these approaches. The incorporation of advanced technologies such as machine learning, artificial intelligence, and Internet of Things (IoT) devices presents promising avenues for further enhancement of HHC operations.

To the best of our knowledge, this paper is the first literature review paper proposing a comprehensive overview of Sustainable Solutions and key digitization studies in Home Healthcare Routing and Scheduling Problems (HHCRSP). Regarding sustainability concerns, we mainly delved into the complexities of alternative fuel adoption, multimodal transportation, eco-driving practices, vehicle sharing, and multiobjective optimization. However, regarding Digitalization studies in HHCRSP, we delved into collaborative platforms, shared economy models, real-time monitoring, dynamic scheduling, big data, and predictive Analytics. A comprehensive interpretation of the challenges, solutions, possible extensions, and overall impact related to sustainability and digitalization in HHCRSP has been discussed to pave the way toward a more sustainable and digital future in home healthcare.

The challenge for future home healthcare routing and scheduling lies in devising realistic solutions that incorporate emerging technologies such as the Internet of Things (IoT), connected platforms, and cloud computing, all while promoting sustainability and environmental consciousness. Future research should prioritize the development of hybrid models that harness the strengths of both traditional Operations Research (OR) techniques and modern technological advancements. Furthermore, it is essential to foster collaboration among healthcare practitioners, OR specialists, and technology developers to create solutions that are not only theoretically robust but also practically viable in real-world home healthcare settings.

In conclusion, while significant strides have been made in the field of HHC routing and scheduling through OR approaches, addressing contemporary challenges requires a holistic and interdisciplinary effort. By continuing to innovate and adapt, we can enhance the efficiency and effectiveness of home healthcare services, ultimately improving the quality of life for patients and optimizing resource utilization for providers.

### Declarations

**Conflict of interests** The authors declare no competing interests.

**Ehical approval** This article does not contain any studies with human participants or animals performed by any of the authors.

## References


Asghari, M., & Al-e, S. M. J. M. (2020). A green delivery-pickup problem for home hemodialysis machines; sharing economy in distributing scarce resources. *Transportation Research Part E: Logistics and Transportation Review, 134*, 101815.

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.

Belhor, M., El-Amraoui, A., Jemai, A., & Delmotte, F. (2023a). Multi-objective evolutionary approach based on K-means clustering for home health care routing and scheduling problem. *Expert Systems with Applications, 213*, 119035.

Belhor, M., El-Amraoui, A., Jemai, A., & Delmotte, F. (2023b). Learning-based metaheuristic approach for home healthcare optimization problem. *Computer Systems Science and Engineering, 45*(1), 1–19.

Bretin, A., Desaulniers, G., & Rousseau, L. M. (2021). The traveling salesman problem with time windows in postal services. *Journal of the Operational Research Society, 72*(2), 383–397.

Chaieb, M., Jemai, J., & Mellouli, K. (2020). A decomposition-construction approach for solving the home health care scheduling problem. *Health Care Management Science, 23*(2), 264–286.

Cheaitou, A., Hamdan, S., Larbi, R., & Alsyouf, I. (2021). Sustainable traveling purchaser problem with speed optimization. *International Journal of Sustainable Transportation, 15*(8), 621–640.

Cire, A. A., & Diamant, A. (2022). Dynamic scheduling of home care patients to medical providers. *Production and Operations Management, 31*(11), 4038–4056.

Contardo, C., & Martinelli, R. (2014). A new exact algorithm for the multi-depot vehicle routing problem under capacity and route length constraints. *Discrete Optimization, 12*, 129–146.

Dai, Z., Zhang, Z., & Chen, M. (2023). The home health care location-routing problem with a mixed fleet and battery swapping stations using a competitive simulated annealing algorithm. *Expert Systems with Applications, 228*, 120374.

Dekhici, L., Redjem, R., Belkadi, K., & El Mhamedi, A. (2019). Discretization of the firefly algorithm for home care. *Canadian Journal of Electrical and Computer Engineering, 42*(1), 20–26.

Demirbilek, M., Branke, J., & Strauss, A. (2019). Dynamically accepting and scheduling patients for home healthcare. *Health Care Management Science, 22*, 140–155.

Dessevre, G., Martinez, C., Zhang, L., Bortolaso, C., & Fontanili, F. (2023). The centralization and sharing of information for improving a resilient approach based on decision-making at a local home health care center. *Applied Sciences, 13*(15), 8576.

Du, G., & Li, W. (2024). Multi-objective home healthcare routing and scheduling problem based on sustainability and “physician–patient” satisfaction. Annals of Operations Research, pp. 1–43.

Du, G., Zheng, L., & Ouyang, X. (2019). Real-time scheduling optimization considering the unexpected events in home health care. *Journal of Combinatorial Optimization, 37*, 196–220.

Erdem, M., & Koç, Ç. (2023). Home health care and dialysis routing with electric vehicles and private and public charging stations. *Transportation Letters, 15*(5), 423–438.

Erdem, M., Koç, Ç., & Yücel, E. (2022). The electric home health care routing and scheduling problem with time windows and fast chargers. *Computers and Industrial Engineering, 172*, 108580.

Euchi, J. (2020). Optimising the routing of home health caregivers: Can a hybrid ant colony metaheuristic provide a solution? *British Journal of Healthcare Management, 26*(7), 192–196.

Euchi, J., & Sadok, A. (2021). Optimising the travel of home health carers using a hybrid ant colony algorithm. In: Proceedings of the institution of civil engineers-transport (Vol. 176, No. 6, pp. 325–336). Emerald Publishing Limited.

Euchi, J., & Yassine, A. (2023). A hybrid metaheuristic algorithm to solve the electric vehicle routing problem with battery recharging stations for sustainable environmental and energy optimization. *Energy Systems, 14*(1), 243–267.

Euchi, J., Masmoudi, M., & Siarry, P. (2022). Home health care routing and scheduling problems: a literature review. 4OR, 20(3), 351–389.

Euchi, J., Zidi, S., & Laouamer, L. (2020). A hybrid approach to solve the vehicle routing problem with time windows and synchronized visits in-home health care. *Arabian Journal for Science and Engineering, 45*(12), 10637–10652.

Euchi, J., Zidi, S., & Laouamer, L. (2021). A new distributed optimization approach for home healthcare routing and scheduling problem. *Decision Science Letters, 10*(3), 217–230.

Expósito, A., Brito, J., Moreno, J. A., & Expósito-Izquierdo, C. (2019). Quality of service objectives for vehicle routing problem with time windows. *Applied Soft Computing, 84*, 105707.

Fikar, C., & Hirsch, P. (2018). Evaluation of trip and car sharing concepts for home health care services. *Flexible Services and Manufacturing Journal, 30*, 78–97.

Fikar, C., Juan, A. A., Martinez, E., & Hirsch, P. (2016). A discrete event driven metaheuristic for dynamic home service routing with synchronised trip sharing. *European Journal of Industrial Engineering, 10*(3), 323–340.

Frifita, S., & Masmoudi, M. (2020). VNS methods for home care routing and scheduling problem with temporal dependencies, and multiple structures and specialties. *International Transactions in Operational Research, 27*(1), 291–313.

Grenouilleau, F., Legrain, A., Lahrichi, N., & Rousseau, L. M. (2019). A set partitioning heuristic for the home health care routing and scheduling problem. *European Journal of Operational Research, 275*(1), 295–303.

Hassani, M. R., & Behnamian, J. (2021). A scenario-based robust optimization with a pessimistic approach for nurse rostering problem. *Journal of Combinatorial Optimization, 41*, 143–169.

Heching, A., Hooker, J. N., & Kimura, R. (2019). A logic-based benders approach to home healthcare delivery. *Transportation Science, 53*(2), 510–522.

Hoogeboom, M., Adulyasak, Y., Dullaert, W., & Jaillet, P. (2021). The robust vehicle routing problem with time window assignments. *Transportation Science, 55*(2), 395–413.

Hung, L. P., Peng, S. L., Lin, C. C., & Hsu, J. L. (2023). A new portable home nursing care support system with scheduling and flexible real-time routing mechanism. *Journal of Internet Technology, 24*(1), 77–87.

Jouini, R., Houaidia, C., & Saidane, L. A. (2020, December). Predictive model for elderly dependency assessment in ambient assisted living. In: 2020 9th IFIP international conference on performance evaluation and modeling in wireless networks (PEMWN) (pp. 1–6). IEEE.

Kandakoglu, A., Sauré, A., Michalowski, W., Aquino, M., Graham, J., & McCormick, B. (2020). A decision support system for home dialysis visit scheduling and nurse routing. *Decision Support Systems, 130*, 113224.

Liu, E., Bastide, R., Bouet, M., Gaborit, P., Gourc, D., Marmier, F., ... & Toumani, F. (2019). Plas' O'Soins: An Interactive ICT Platform to Support Care Planning and Coordination within Home-Based Care. *Irbm*, *40*(1), 25–37.

Li, X., Ren, S., & Gu, F. (2021a). Medical Internet of Things to realize elderly stroke prevention and nursing management. *Journal of Healthcare Engineering, 2021*(1), 9989602.

Li, Y., Soleimani, H., & Zohal, M. (2019). An improved ant colony optimization algorithm for the multi-depot green vehicle routing problem with multiple objectives. *Journal of Cleaner Production, 227*, 1161–1172.

Li, Y., Xiang, T., & Szeto, W. Y. (2021b). Home health care routing and scheduling problem with the consideration of outpatient services. *Transportation Research Part E: Logistics and Transportation Review, 152*, 102420.

Lin, C. C., Hung, L. P., Liu, W. Y., & Tsai, M. C. (2018). Jointly rostering, routing, and rerostering for home health care services: A harmony search approach with genetic, saturation, inheritance, and immigrant schemes. *Computers & Industrial Engineering, 115*, 151–166.

Lin, M., Ma, L., & Ying, C. (2021). Matching daily home health-care demands with supply in service-sharing platforms. *Transportation Research Part E: Logistics and Transportation Review, 145*, 102177.

Luo, H., Dridi, M., & Grunder, O. (2021). An ACO-based heuristic approach for a route and speed optimization problem in home health care with synchronized visits and carbon emissions. *Soft Computing, 25*, 14673–14696.

Luo, H., Lou, V. W., Chen, C., & Chi, I. (2020). The effectiveness of the positive mood and active life program on reducing depressive symptoms in long-term care facilities. *The Gerontologist, 60*(1), 193–204.

Makboul, S., Kharraja, S., Abbassi, A., & Alaoui, A. E. H. (2024). A multiobjective approach for weekly Green Home Health Care routing and scheduling problem with care continuity and synchronized services. *Operations Research Perspectives, 12*, 100302.

Malagodi, L., Lanzarone, E., & Matta, A. (2021a). Home care vehicle routing problem with chargeable overtime and strict and soft preference matching. *Health Care Management Science, 24*, 140–159.

Masmoudi, M., Jarboui, B., & Borchani, R. (2023). Efficient metaheuristics for the home (health)-care routing and scheduling problem with time windows and synchronized visits. *Optimization Letters, 17*(9), 2135–2167.

Mor, A., & Speranza, M. G. (2022). Vehicle routing problems over time: A survey. *Annals of Operations Research, 314*(1), 255–275.

Ozeki, T., Mouri, T., Sugiura, H., Yano, Y., & Miyosawa, K. (2021). Impression survey and grounded theory analysis of the development of medication support robots for patients with schizophrenia. *Journal of Robotics and Mechatronics, 33*(4), 747–755.

Quintanilla, S., Ballestín, F., & Pérez, Á. (2020). Mathematical models to improve the current practice in a home healthcare unit. *Or Spectrum, 42*(1), 43–74.

Rahimian, E., Akartunalı, K., & Levine, J. (2017). A hybrid integer programming and variable neighbourhood search algorithm to solve nurse rostering problems. *European Journal of Operational Research, 258*(2), 411–423.

Salehi-Amiri, A., Jabbarzadeh, A., Hajiaghaei-Keshteli, M., & Chaabane, A. (2022). Utilizing the Internet of Things (IoT) to address uncertain home health care supply chain network. *Expert Systems with Applications, 208*, 118239.

Wang, H., He, Y., Li, Y., & Wang, F. (2020). Study on the home health caregiver scheduling problem under a resource sharing mode considering differences in working time and customer satisfaction. *Discrete Dynamics in Nature and Society, 2020*(1), 7360765.

Yin, Y., Liu, X., Chu, F., & Wang, D. (2023). An exact algorithm for the home health care routing and scheduling with electric vehicles and synergistic-transport mode. Annals of Operations Research, 1–36.

Zhang, T., Liu, Y., Yang, X., Chen, J., & Huang, J. (2023a). Home health care routing and scheduling in densely populated communities considering complex human behaviours. *Computers & Industrial Engineering, 182*, 109332.

Decerle, J., Grunder, O., Hajjam El Hassani, A., & Barakat, O. (2019). A hybrid memetic-ant colony optimization algorithm for the home health care problem with time window, synchronization and working time balancing. *Swarm and Evolutionary Computation, 46*, 171–183.

Nasir, J. A., & Dang, C. (2020). Quantitative thresholds-based decision support approach for the home health care scheduling and routing problem. *Health Care Management Science, 23*(2), 215–238.

Gomes, M. I., & Ramos, T. R. P. (2019). Modelling and (re-) planning periodic home social care services with loyalty and non-loyalty features. *European Journal of Operational Research, 277*(1), 284–299.

Liu, R., Yuan, B., & Jiang, Z. (2019b). A branch-and-price algorithm for the home-caregiver scheduling and routing problem with stochastic travel and service times. *Flexible Services and Manufacturing Journal, 31*, 989–1011.

Mosquera, F., Smet, P., & Berghe, G. V. (2019). Flexible home care scheduling. *Omega, 83*, 80–95.

Moussavi, S., Mahdjoub, M., & Grunder, O. (2019). A matheuristic approach to the integration of worker assignment and vehicle routing problems: Application to home healthcare scheduling. *Expert Systems with Applications, 125*, 317–332.

Restrepo, M. I., Rousseau, L. M., & Vallée, J. (2020). Home healthcare integrated staffing and scheduling. *Omega, 95*, 102057.

Riazi, S., Wigström, O., Bengtsson, K., & Lennartson, B. (2019). A column generation-based gossip algorithm for home healthcare routing and scheduling problems. *IEEE Transactions on Automation Science and Engineering, 16*(1), 127–137.

Ros-McDonnell, L., Szander, N., & de-la-Fuente-Aragón, M. V., & Vodopivec, R. (2019). Scheduling sustainable homecare with urban transport and different skilled nurses using an approximate algorithm. *Sustainability, 11*(22), 6210.

Shi, Y., Boudouh, T., & Grunder, O. (2019). A robust optimization for a home health care routing and scheduling problem with consideration of uncertain travel and service times. *Transportation Research Part E: Logistics and Transportation Review, 128*, 52–95.

Fathollahi-Fard, A. M., Hajiaghaei-Keshteli, M., & Mirjalili, S. (2020a). A set of efficient heuristics for a home healthcare problem. *Neural Computing and Applications, 32*, 6185–6205.

Fathollahi-Fard, A. M., Ahmadi, A., Goodarzian, F., & Cheikhrouhou, N. (2020b). A bi-objective home healthcare routing and scheduling problem considering patients' satisfaction in a fuzzy environment. *Applied Soft Computing, 93*, 106385.

Gong, X., Geng, N., Zhu, Y., Matta, A., & Lanzarone, E. (2020). A matheuristic approach for the home care scheduling problem with chargeable overtime and preference matching. *IEEE Transactions on Automation Science and Engineering, 18*(1), 282–298.

Grenouilleau, F., Lahrichi, N., & Rousseau, L. M. (2020). New decomposition methods for home care scheduling with predefined visits. *Computers and Operations Research, 115*, 104855.

Hashemi Doulabi, H., Pesant, G., & Rousseau, L. M. (2020). Vehicle routing problems with synchronized visits and stochastic travel and service times: applications in healthcare. *Transportation Science, 54*(4), 1053–1072.

Martin, E., Cervantes, A., Saez, Y., & Isasi, P. (2020). IACS-HCSP: Improved ant colony optimization for large-scale home care scheduling problems. *Expert Systems with Applications, 142*, 112994.

Nasir, J. A., & Kuo, Y. H. (2020). A decision support framework for home health care transportation with simultaneous multi-vehicle routing and staff scheduling synchronization. *Decision Support Systems, 138*, 113361.

Chaieb, M., & Sassi, D. B. (2021). Measuring and evaluating the home health care scheduling problem with simultaneous pick-up and delivery with time window using a Tabu search metaheuristic solution. *Applied Soft Computing, 113*, 107957.

Chen, H., Luo, X., Zhang, Z., & Zhou, Q. (2021). Stochastic bi-level programming model for home healthcare scheduling problems considering the degree of satisfaction with visit time. *Journal of Systems Science and Systems Engineering, 30*, 572–599.

Cinar, A., Salman, F. S., & Bozkaya, B. (2021). Prioritized single nurse routing and scheduling for home healthcare services. *European Journal of Operational Research, 289*(3), 867–878.

Decerle, J., Grunder, O., El Hassani, A. H., & Barakat, O. (2021). A matheuristic-based approach for the multi-depot home health care assignment, routing and scheduling problem. *RAIRO-Operations Research, 55*, S1013–S1036.

Demirbilek, M., Branke, J., & Strauss, A. K. (2021). Home healthcare routing and scheduling of multiple nurses in a dynamic environment. *Flexible Services and Manufacturing Journal, 33*, 253–280.

Goodarzian, F., Abraham, A., & Fathollahi-Fard, A. M. (2021). A biobjective home health care logistics considering the working time and route balancing: A self-adaptive social engineering optimizer. *Journal of Computational Design and Engineering, 8*(1), 452–474.

Li, Y., Xiang, T., & Szeto, W. Y. (2021c). Home health care routing and scheduling problem with the consideration of outpatient services. *Transportation Research Part E: Logistics and Transportation Review, 152*, 102420.

Liu, W., Dridi, M., Fei, H., & El Hassani, A. H. (2021a). Solving a multi-period home health care routing and scheduling problem using an efficient matheuristic. *Computers and Industrial Engineering, 162*, 107721.

Liu, W., Dridi, M., Fei, H., & El Hassani, A. H. (2021b). Hybrid metaheuristics for solving a home health care routing and scheduling problem with time windows, synchronized visits and lunch breaks. *Expert Systems with Applications, 183*, 115307.

Malagodi, L., Lanzarone, E., & Matta, A. (2021b). Home care vehicle routing problem with chargeable overtime and strict and soft preference matching. *Health Care Management Science, 24*, 140–159.

Nikzad, E., Bashiri, M., & Abbasi, B. (2021). A matheuristic algorithm for stochastic home health care planning. *European Journal of Operational Research, 288*(3), 753–774.

Polnik, M., Riccardi, A., & Akartunalı, K. (2021). A multistage optimisation algorithm for the large vehicle routing problem with time windows and synchronised visits. *Journal of the Operational Research Society, 72*(11), 2396–2411.

Shahnejat-Bushehri, S., Tavakkoli-Moghaddam, R., Boronoos, M., & Ghasemkhani, A. (2021). A robust home health care routing-scheduling problem with temporal dependencies under uncertainty. Expert Systems with Applications, 115209.

Shiri, M., Ahmadizar, F., & Mahmoudzadeh, H. (2021). A three-phase methodology for home healthcare routing and scheduling under uncertainty. *Computers and Industrial Engineering, 158*, 107416.

Tanoumand, N., & Ünlüyurt, T. (2021). An exact algorithm for the resource constrained home health care vehicle routing problem. *Annals of Operations Research, 304*, 397–425.

Yang, M., Ni, Y., & Yang, L. (2021). A multi-objective consistent home healthcare routing and scheduling problem in an uncertain environment. *Computers and Industrial Engineering, 160*, 107560.

Ala, A., Goli, A., & Nejad Attari, M. Y. (2022). Scheduling and routing of dispatching medical staff to homes healthcare from different medical centers with considering fairness policy. *Mathematical Problems in Engineering, 2022*(1), 3189574.

Du, G., & Zhang, J. (2022). Cross-regional manpower scheduling and routing problem with stochastic service times in home health care. *Computers and Industrial Engineering, 173*, 108668.

Du, G., Tian, Y., & Ouyang, X. (2022). Multi-resources co-scheduling optimization for home healthcare services under the constraints of service time windows and green transportation. *Applied Soft Computing, 131*, 109746.

Krityakierne, T., Limphattharachai, O., & Laesanklang, W. (2022). Nurse-patient relationship for multi-period home health care routing and scheduling problem. *PLoS ONE, 17*(5), e0268517.

Lahrichi, N., Lanzarone, E., & Yalçındağ, S. (2022). A First Route Second Assign decomposition to enforce continuity of care in home health care. *Expert Systems with Applications, 193*, 116442.

Li, Y., Ye, C., Wang, H., Wang, F., & Xu, X. (2022). A discrete multi-objective grey wolf optimizer for the home health care routing and scheduling problem with priorities and uncertainty. *Computers and Industrial Engineering, 169*, 108256.

Ma, X., Fu, Y., Gao, K., Sadollah, A., & Wang, K. (2022). Integration routing and scheduling for multiple home health care centers using a multi-objective cooperation evolutionary algorithm with stochastic simulation. *Swarm and Evolutionary Computation, 75*, 101175.

Nuraiman, D., & Ozlen, M. (2022). A decomposition approach for the prioritised home health care problem with synchronised visits and multi-period planning. *Computers and Industrial Engineering, 174*, 108722.

Pahlevani, D., Abbasi, B., Hearne, J. W., & Eberhard, A. (2022). A cluster-based algorithm for home health care planning: A case study in Australia. *Transportation Research Part E: Logistics and Transportation Review, 166*, 102878.

Yadav, N., & Tanksale, A. (2022). An integrated routing and scheduling problem for home healthcare delivery with limited person-to-person contact. *European Journal of Operational Research, 303*(3), 1100–1125.

Ziya-Gorabi, F., Ghodratnama, A., Tavakkoli-Moghaddam, R., & Asadi-Lari, M. S. (2022). A new fuzzy tri-objective model for a home health care problem with green ambulance routing and congestion under uncertainty. *Expert Systems with Applications, 201*, 117093.

Akbari, V., Sadati, İ, Salman, F. S., & Shiri, D. (2023). Minimizing total weighted latency in home healthcare routing and scheduling with patient prioritization. *Or Spectrum, 45*(3), 807–852.

Alkaabneh, F., & Diabat, A. (2023). A multi-objective home healthcare delivery model and its solution using a branch-and-price algorithm and a two-stage meta-heuristic algorithm. *Transportation Research Part C: Emerging Technologies, 147*, 103838.

Bazirha, M., Benmansour, R., & Kadrani, A. (2023). An efficient two-phase heuristic for the home care routing and scheduling problem. *Computers and Industrial Engineering, 181*, 109329.

Clapper, Y., Berkhout, J., Bekker, R., & Moeke, D. (2023). A model-based evolutionary algorithm for home health care scheduling. *Computers and Operations Research, 150*, 106081.

Gobbi, A., Manerba, D., Mansini, R., & Zanotti, R. (2023). Hybridizing adaptive large neighborhood search with kernel search: A new solution approach for the nurse routing problem with incompatible services and minimum demand. *International Transactions in Operational Research, 30*(1), 8–38.

Hung, L. L. (2022). Intelligent sensing for internet of things systems. *Journal of Internet Technology, 23*(1), 185–191.

Ma, X., Fu, Y., Gao, K., Zhang, H., & Mou, J. (2023). A knowledge-based multi-objective evolutionary algorithm for solving home health care routing and scheduling problems with multiple centers. *Applied Soft Computing, 144*, 110491.

Méndez-Fernández, I., Lorenzo-Freire, S., & González-Rueda, Á. M. (2023). An adaptive large neighbourhood search algorithm for a real-world home care scheduling problem with time windows and dynamic breaks. *Computers and Operations Research, 159*, 106351.

Naderi, B., Begen, M. A., Zaric, G. S., & Roshanaei, V. (2023). A novel and efficient exact technique for integrated staffing, assignment, routing, and scheduling of home care services under uncertainty. *Omega, 116*, 102805.

Oladzad-Abbasabady, N., Tavakkoli-Moghaddam, R., Mohammadi, M., & Vahedi-Nouri, B. (2023). A bi-objective home care routing and scheduling problem considering patient preference and soft temporal dependency constraints. *Engineering Applications of Artificial Intelligence, 119*, 105829.

Somar, S., Urazel, B., & Sahin, Y. B. (2023). A modified metaheuristic algorithm for a home health care routing problem with health team skill levels. *Applied Soft Computing, 148*, 110912.

Xiang, T., Li, Y., & Szeto, W. Y. (2023). The daily routing and scheduling problem of home health care: Based on costs and participants' preference satisfaction. *International Transactions in Operational Research, 30*(1), 39–69.

Yadav, N., & Tanksale, A. (2023). A multi-objective approach for reducing Patient's inconvenience in a generalized home healthcare delivery setup. *Expert Systems with Applications, 219*, 119657.

Yazır, O. A., Koç, Ç., & Yücel, E. (2023). The multi-period home healthcare routing and scheduling problem with electric vehicles. *Or Spectrum, 45*(3), 853–901.

Zhang, L., Pingaud, H., Fontanili, F., Lamine, E., Martinez, C., Bortolaso, C., & Derras, M. (2023b). Balancing the satisfaction of stakeholders in home health care coordination: a novel OptaPlanner CSP model. *Health Systems, 12*(4), 408–428.