Multiagent Systems to Support Planning and Scheduling in Home Health Care Management: A Literature Review

Colja A. Becker(✉), Fabian Lorig, and Ingo J. Timm

Business Informatics I, Trier University, Behringstrasse 21, 54296 Trier, Germany
{beckerc,lorigf,itimm}@uni-trier.de

Abstract. Ensuring sustainable care-giving systems with a focus on human needs and desires is a major challenge. An increasing demand in home health care as well as a limited number of professionals in the labor market have led to a call for efficiency. Thus, managing existing resources has gained relevance. The overall goal is high quality care services, while ensuring economic viability. At the same time, there is a need for modern customer-friendly solutions as well as the consideration of employees' preferences. To achieve this, adequate methods are needed that take current and future developments into account. Operational management processes in terms of planning and scheduling can be supported by multiagent systems as well as decision support systems using agent-based simulation. The aim of this work is to provide an overview of these solutions in the domain of home health care systems. To this end, we conducted a systematic literature review in which 11 relevant approaches were identified. In addition, these publications were analyzed to identify deficiencies and compared to each other. Because none of the approaches offers a sufficient solution, future work will focus on dynamic distributed scheduling for the control of operational processes which increases efficiency and improves the use of limited resources.

Keywords: Multiagent systems · Agent-based simulation · Logistics · Home health care · Scheduling · Software agents · Operations management · Multiagent planning · Distributed artificial intelligence

1 Introduction

Demographic change and urbanization have resulted in an increasing demand for care services. Decreasing birth rates and improved health care cause a higher ratio of elderly people, who potentially become care dependent. Due to globalization and an increasing willingness of younger people to relocate, relatives who could provide care might not be available. Furthermore, it is possible that the employment status of relatives does not allow them to provide intra-familial care services. Hence, it can be assumed that there is an increasing trend in demand

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for professional care services. In the near future, any decrease in the tendency of this development can not be expected, meaning that ensuring sustainable care-giving systems with focus on human needs and desires is a major challenge.

Instead of receiving care services in specialized care facilities, many care-receivers prefer to stay in their familiar environment. Such services are offered by home health care (HHC) service providers. The caregivers are equipped with cars and render the required care services in the respective patients' homes. By this means, care dependent persons receive the required assistance while maintaining their current way of living. To cope with an increasing demand in home health care, additional caregivers must be hired by service providers. However, in the labor market, qualified caregivers can be considered to be a limited rare resource. Following this, managing existing human resources in HHC gains in relevance to enable efficient service delivery. In this regard, the cost-benefit ratio of provided care services must be traded off against ethical aspects of care. The overall goal is to provide high-quality care services, while ensuring economic viability.

At the same time, modern customer-friendly solutions as well as the consideration of employees' preferences are required. Methods from *classic* HHC logistics focus only on scheduling and routing of caregivers. Yet, these methods do not seem sufficient with regard to *modern* HHC logistics, where in addition the individual desires of both caregivers and care recipients are considered as well as interaction between the participants. This includes the flexible adjustment of individual tasks or schedules for adaptively dealing with a dynamic environment. Moreover, taking real-world data into account might be necessary to achieve a proper planning result (e.g., traffic delay data). This also allows for dynamic changes of preferences: On the one hand, caregivers can for instance receive flexible schedules and are able to react on planning disturbances. On the other hand, care receivers are for example able to alter appointment time windows and demanded care services in the short term. Furthermore, management instructions should not only define or designate the tasks, but also define the scope of action based on individual qualifications, preferences, and other personal attributes of each employee. By this means, individuals are provided with both instructions on what tasks they have to accomplish and instructions regarding flexibility in their execution (e.g., sequence of accomplishment, type and manner of execution, as well as individual adaption of a task).

From an HHC provider's perspective, the management of this situation is challenging. Adequate methods are required that take current and future developments into account. To allow for corresponding management with focus on planning and scheduling, resulting requirements can be summarized as a need for flexibility in caregivers' operations, efficiency in the use of resources, and economic viability under present and future conditions. Considering these requirements, it is questionable whether and to what extent they are met by current approaches. In case no satisfying methods can be identified, as a first step, the question of shortcomings arises. To close this gap, the goal of this paper is to provide an overview of current approaches which support operational management in terms planning and scheduling in home health care systems. Moreover, if current approaches show deficiencies, these shortcomings must be analyzed and resulting challenges derived. To this end, a systematic literature review is conducted in order to gather relevant contributions.

The remainder of the paper is structured as follows: Sect. 2 presents background information. Section 3 introduces the methodology pursued in the systematic literature review as well as the applied search and evaluation criteria. Section 4 gives an overview of the surveyed approaches and Sect. 5 describes shortcomings of these approaches. Finally, the conclusion of this article and comments about further work are provided.

2 Background

To increase the efficiency of the operational management processes as well as the managed processes, the need to use information and communication technology is obvious. The application ranges from basic technologies for carrying out daily management tasks to comprehensive support for difficult decisions using special software systems. In particular, the use of methods from the field of *artificial intelligence* is an increasing trend in practical applications. This area includes the concept of *agents*. An agent can be described as a software entity or a robot (hardware), that is able to perceive its environment and to act upon that environment autonomously [17]. Hence, an agent can be for instance a part of an automatic workflow or an individual representative of a real-world person. Taking individual stakeholders into account as well as the need for flexibility as described in Sect. 1, the usage of methods from the field of *multiagent systems* (MAS) and *agent-based simulation* (ABS) seems promising. They can be used in many different ways. For example, a distributed software system can be used to support automatic coordination and group decisions of real-world participants in their operational activities. In particular, multiagent technology is known for offering flexible solutions and adaptive IT systems [9]. Furthermore, assistance systems with ABS components are able to provide decision support based on the execution of simulation runs, which try to imitate the behavior of the real system. Evaluating various ideas on an artificial system as a simulation model of the real world can be less expensive and time-consuming. The use of multiple agents as a modeling paradigm to build artificial societies or social systems is a unique way of testing theories for many application domains [12]. Beside that, simulation can also be used to evaluate the functionality of a developed MAS by placing the system in a simulated environment. The following description from Wooldridge is helpful for classifying the terms: "A multiagent system is one that consists of a number of agents, which *interact* with one another, typically by exchanging messages through some computer network infrastructure." [21, p. 5]. Thus, an agent-based simulation can be seen as an MAS as well. Despite that, in the following we will use the term MAS to describe a distributed software system and distinguish it from a software system which make use of an agent-based simulation.

The development of both MAS and ABS can be observed in relation to the domain of home health care. The term *home health care* refers to "the provision of healthcare services to people of any age at home or in other noninstitutional settings" [5, p. 9]. To distinguish skilled medical services and non-skilled services, like personal care routines, household maintenance, and social service, the latter is described using the term *home care*, while *home health care* includes medical treatments, nursing services, and physical therapies [16]. To support management in both sectors, various research areas are working on innovative methods. For instance, in *operations research* scientists work on the optimization of daily routing and scheduling for HHC services [6]. Here, engineers, social scientists, and computer scientists, among others, are working on similar problems. To reduce the coverage of the entire range of operational management tasks, the following sections focus on supporting the HHC service provider's planning and resource scheduling. This refers in particular to scheduling processes of employees, i.e., which employee takes on which tasks at which point in time.

3 Review Methodology

As mentioned in the previous section, various approaches exist that apply MAS and ABS in home health care. In order to investigate how and to what extent existing approaches contribute to the operational management of HHC systems, applicable approaches must be identified and analyzed. The conducting of a systematic literature review seems reasonable. For this purpose, search criteria must be defined and applied using a methodologically sound procedure. In this section, both key features for the review and corresponding methodology are presented.

3.1 Literature Search

The identification of relevant approaches, which will be analyzed with the use of the presented key features, was started in March 2018 as a systematic literature search. To this end, a *snowballing procedure* was chosen: The reference list of a scientific paper (*backward snowballing*) as well as the list of papers citing this paper (*forward snowballing*) is used for identifying new relevant papers to examine and the references from as well as to these selected papers are also used in further iterations [20]. The application process can be summarized in the following listing.

1. We generated a literature start set by selecting relevant papers with the help of a web search engine.
2. The reference lists of this start set were used to find further relevant papers, so a second literature set was created.
3. Further, the list of papers citing elements of this start set were examined which generates a third literature set.
4. The references of the second set were examined and no further relevant papers could be found.

5. The list of papers citing papers of the second set were examined and no further relevant papers could be found, too.
6. Thereafter, references of the third set were analyzed and no further relevant papers could be found.
7. Papers citing papers of the third set were also examined and no further relevant papers could be found.
8. All papers found were analyzed in detail and finally 11 contributions can be presented as the result.

The publication dates of the identified approaches range from 2006 to 2017, but in the literature search no temporal restrictions were applied as exclusion criteria. Since background-related biases are possible, it should be mentioned that the education and experience of the authors focus on the field of design-oriented information systems research and artificial intelligence.

As a first step, a web search engine is chosen for the generation of the literature start set. Despite the risk of grey literature *Google Scholar* was chosen because of an absence of knowledge of relevant databases for the considered domain and also because of the fact that the web search engine was only used to create the literature start set. To achieve a small number of iterations in the snowballing procedure, multiple keywords were combined in a search string to generate a suitable literature start set which comprises a high number of papers containing relevant information. The search string used in the web search engine is presented in Table 1. The string contains three groups of keywords, separated by the use of brackets. Each group refers to a domain, which should be represented in a search result. To increase the probability that the content of a search result is a combination of contents of all three domains, the groups are concatenated with logical conjunctions. The first group of keywords specifies the considered operational management in terms of the HHC provider's planning and resource scheduling. The second group specifies the domain of home health care. The third group focuses on the use of the concept of software agents as described in Sect. 2. The use of quotation marks defines a string-based search. For example, any document containing the character string "plan" will be part of the result set, like documents containing the word "planning" or "planner". Due to different spellings, several alternatives are concatenated with logical disjunctions. Furthermore, disjunctions are used for different keywords which describe the same domain.

Table 1. String used in the search engine for generating literature start set.

Domain	String
Planning and Scheduling	*("scheduling" | "roster" | "plan")*
HHC	*("home-care" | "home care" | "home health-care" | "home healthcare" | "home health care" | "home health nursing" | "caregiver" | "caregiving" | "long-term care" | "long term care")*
MAS	*("multiagent" | "multi-agent" | "agent-based" | "agent based")*

As the inclusion criterion for the snowballing procedure, each domain listed in Table 1 should be represented such that one contribution addresses the application of an agent-based approach that in some way support planning and scheduling in operational HHC management. 16 scientific papers were selected by examining 200 search results (20 result pages) as a result of the usage of the explicated search string in order to create the literature start set. All relevant papers of this start set were found in the first one hundred results. Following the backward snowballing procedure, the reference lists of those 16 papers were evaluated and a second literature set was generated containing two scientific papers. After another iteration, no further publications were found. Following the forward snowball procedure, papers citing a paper of the start set were examined and a third set was created containing five papers. Further, the list of publications citing one of this set was examined and no further papers were found. The remaining iterations, forward procedure with the second set and backward procedure with the third set, neither generated new papers. Afterwards, all 23 papers were analyzed in detail to find only contributions which support operational HHC management in terms of planning and scheduling comprising the conception of a multiagent system or an agent-based simulation. For example, pure literature studies were sorted out. Finally, 11 contributions can be presented as a result. Further iterations of the snowball procedure have already been counteracted by finding useful results with the web search engine in the first step. In addition, due to the application of a comprehensive search string, several papers within the first literature set have mutual references.

3.2 Key Features

To analyze the suitability of the identified approaches, different perspectives of the scientific process must be considered. Before the respective content is presented in the next section, the categorization and the usage of the review key features are outlined. The key features can be divided in *concept*, *implementation*, and *evaluation*. As a first step, the *concept* is examined to determine how and to which purpose the agent-based system is utilized. Further, the practical *implementation* as well as the *evaluation* of the system are investigated. While the implementation focuses on the availability of software and hardware systems, the evaluation makes sure that the developed concept is applicable in the field.

Five key features are related to the concept. Beside a brief description of the *approach*'s main ideas, the target group of users is identified. In this regard, the *outcome* or *product* is described that is provided to the user. Moreover, methodical limitations and focus of the considered approach are characterized by the key features *spatial aspects*, *goals and constraints*, and *agents*. The latter designates the agents, which are identified in the approach. The feature *goals and constraints* comprises the targeted performance measures as well as restrictions of the parameter or solution space. The feature *spatial aspects* determines the consideration of any geographic related entities or factors in the model, such as distance computations, traffic predictions, map data, and regional specifications or restrictions.

After taking a conceptual perspective, the provided implementation is analyzed. When implementing a MAS or an ABS, the use of an existing modeling and simulation (*software*) framework is feasible. By this means, common functionalities are provided, which improves the re-usability of the implemented concept. Here, a differentiation has to be made between free-to-use and commercial frameworks. This is directly related to the key feature *accessibility*, which describes whether or not the implementation is available for further use in terms of the used licensing model as well as the provision, e.g., in a public repository. Furthermore, the *interactivity* of the implemented approaches might vary. While some approaches do not allow for real-time interaction, others are equipped with interfaces, which enable the interaction with one or multiple users and also between the involved users.

In the evaluation perspective, the implemented concept is practically applied to home health care scenarios. In terms of MAS or ABS, the evaluation commonly consists of simulation experiments that are conducted as part of a study. This includes design, execution, and analysis of simulation experiments. The *design of experiments* comprises techniques for the identification of relevant experiments (design points; DP) as well as the systematic limitation of the considered parameter space. For stochastic models, the estimation of the required number of replications (sample size; N) is another important task. In addition, input data is required for the definition of the simulated scenario. The key feature *input data* distinguishes between synthetic and real-world data and gives background information like geographical affiliation. Output data that is generated during the execution of the model must be analyzed to draw conclusions about the observed behavior of the system. Based on this, the key feature *output data analysis* describes what means are applied and what efforts are made for assessing statistical significance.

4 Approaches for Supporting Planning and Scheduling

The goal of this work is to survey existing approaches that make use of ABS or MAS to support operational HHC management in terms of planning and resource scheduling. With respect to the conducting of a systematic literature study, the applied research methodology as well as the key features for the assessment of the surveyed approaches were presented in the previous section. As a result of the execution of the literature study, 11 relevant approaches for home health care management were identified. In this section, a comprehensive overview on as well as a comparison of these approaches is presented, which allows for the identification of shortcomings (cf. Tables 2, 3, and 4).

To judge whether and to what extent each of the specified key features (cf. Sect. 3) is satisfied by the approaches, only evidence is used that is directly provided by the scientific publication in which the approach is proposed. Accordingly, in case specific aspects of the system are not discussed in the publication, it is assumed that the approach is not capable of fulfilling the respective key feature. The same applies for ambiguous descriptions or assertions regarding

Table 2. Overview of the concepts (part 1) of the surveyed approaches.

	Approach	User	Outcome/product
Castelnovo et al. [1]	ABS of home care organization model	HHC service provider	Framework to control the home care processes at an operational level
Itabashi et al. [8]	MAS for negotiation of care schedules	HHC service provider	Communication platform for caregivers and patients, care schedule
López-Santana et al. [10]	Multiagent approach using mixed integer programming model	HHC service provider	Communication platform, scheduling and routing for caregivers
Marcon et al. [11]	Global optimizer and ABS of caregiver behavior to solve routing problems	HHC service provider	System for solving scheduling and routing problem in dynamic context
Mohammadi & Eneyo [13]	Sweep-coverage for efficient monitoring of patients by means of a MAS	HHC service provider	Information management system, solving of scheduling and routing problem
Mutingi & Mbohwa [14]	MAS with satisficing heuristic for staff scheduling	HHC service provider	Theoretical framework for staff scheduling and task assignment
Stojanova et al. [18]	Scheduling algorithm and ABS	HHC service provider	Support system for generation and analysis of staff schedules
Widmer & Premm [19]	MAS for negotiation of caregiving resources using double auctions	HHC service provider	Agent-based decision support system for allocation of resources
Xie et al. [22]	MAS for negotiation between home health agency and practitioners	Home health agency	Iterative bidding framework as a decentralized decision making tool
Xie & Wang [23]	ABS for evaluation of schedules generated by repair algorithm	HHC service provider	System for generating and evaluating schedules
Zarour et al. [25]	MAS/agent-based architecture	Set of HHC partners	Platform for communication and cooperation

functionalities of the approaches. To avoid misinterpretations, the assessment which is presented in this section is not based on assumptions in terms of interpretations of text passages. Instead, the wording of the authors is adopted for the description of the approaches. As the terminology that is used for describing the surveyed approaches is not unified, ambiguousness and terminological inconsistencies might occur in the following discussion of the contributions.

Table 3. Overview of the concepts (part 2) of the surveyed approaches.

	Spatial aspects	Goals and constraints	Agents
[1]	-	-	Assumption: participants of a proposed home care reference model
[8]	-	G: MIN total cost of service; C: skills, date/time interval	interface, schedule, helper
[10]	Arrival/departure location, static travel times, multi-depot	G: MIN travel time, MIN delay arrival time; C: skills, locality, priority	Patients, organizer, coordinator, caregiver
[11]	Random events (e.g., traffic jams and road accidents)	G: agents' decision rule (e.g., MIN travel or waiting time); C: unspecified	Patient, caregiver
[13]	Distance from service provider's facility to patient's location	G: MIN no. of therapists; C: location of patients and therapists	Patient, therapist, hospital
[14]	-	G: MIN schedule cost, MAX patient/worker satisfaction; C: tasks, preferences	Manager, patient, nurse, supervisor, resource, scheduler
[18]	-	G: MIN processing time; C: servicing time	Patient, caregiver
[19]	-	G: MAX social welfare; C: time/priority for service, skills, valuation of patient	Patient, caregiver, auctioneer
[22]	-	G: MIN service costs; C: time, skill set, preferences	-
[23]	GIS map as operative environment in simulation	G: MIN service costs; C: practitioner's availability/eligibility, visit time	Practitioner, healthcare agency
[25]	-	-	Patient, broker, doctor, and each cooperation partner

The framework proposed by **Castelnovo, Matta, Tolio, Saita, and De Conno** [1] consists of an ABS of the interactions between different actors that are involved in home care processes. In this regard, the authors make use of the *contract net protocol* to model task distribution between the agents. The goal of the model is to enable patients to stay at home instead of being forced to stay in professional care facilities in case this is not medically necessary. To give a better understanding of possible involved actors, the authors proposed a reference model for the home care domain. The presented approach is implemented in *Arena* and evaluated in a case study of a *Palliative Home Care Program* from Italy.

Itabashi, Chiba, Takahashi, and Kato [8] presented a more comprehensible approach using MAS for the negotiation of care schedules. Equipping caregivers and patients with PDA devices enables the dynamic request of care services as well as the real-time confirmation or rejection of resulting care schedules. The approach aims at minimizing the overall costs of service as care schedules can be adjusted to efficiently take current care requests into account.

In this negotiation process, individual skills of the caregivers as well as date and time preferences of the patients are taken into account. The authors used *JADE* to implement the approach, yet, only presented a synthetic example request to demonstrate its feasibility.

López-Santana, Espejo-Díaz, and Méndez-Giraldo [10] make use of a multi-objective mixed integer programming model to enable scheduling and routing of caregivers in home health care. To consider driveways in the routing and to minimize travel times and delays, departure and arrival locations of the caregivers are specified. However, the presented approach is limited to a single geographical area and travel times are assumed to be static, i.e., not influenced by road closures or traffic-related delays. The proposed platform works well for small numbers of patients (less than 15) but requires heuristics for the calculation of larger amounts of patients. Like the previously introduced approach, the implementation is based on *JADE*. To this end, the authors presented four scenarios with four different parametrizations of the model to illustrate the variation of waiting times.

Of the analyzed approaches, the system presented by **Marcon, Chaabane, Sallez, Bonte, and Trentesaux**. [11] provides the most sophisticated and realistic routing. The combination of a global optimizer with a simulation of individual caregiver decision behavior using MAS allows for the agents' perception of random spatial events such as traffic jams to minimize travel or waiting times. By this means, new requests can also be considered by the system and included in the scheduling and routing process. Constraints that must be considered during the scheduling and routing are unspecified and provided by mixed integer linear programming (MILP) or heuristics. For the implementation of the system, *NetLogo* were used and a comprehensive evaluation is provided. The authors presented two case studies which were derived from French HHC providers and for each case study 500 working days were simulated. As the proposed model consists of stochastic components, the authors executed 100 replications of each parametrization of the model. Finally, they analyzed the performance of the proposed system according to five properties: efficiency, pertinence, scalability, robustness, and implementability.

In the approach presented by **Mohammadi and Eneyo** [13], the scheduling and routing problem is solved by a central unit and by applying sweep-coverage mechanisms. To this end, the authors goal was not the minimization of travel times but the reduction of the required number of therapists. To demonstrate the feasibility of the proposed algorithm, the authors used a *MATLAB* implementation to execute two scenarios each consisting of ten different parametrizations of the model. To take stochastic uncertainties into account, each simulation run was replicated 100 times.

In contrast to other approaches which aim at optimizing HHC scheduling, the architecture proposed by **Mutingi and Mbohwa** [14] makes use of a satisficing heuristic. Here, a schedule that is acceptable for all caregivers is generated based on specific thresholds. To this end, an acceptable schedule is not necessarily optimal. Still, the authors aimed at minimizing scheduling costs while maximizing both patient and worker satisfaction. Of all the analyzed approaches, this one consists of the most agent types. Besides the types manager, nurse, and patient, the authors defined resource, supervisor, and scheduler agents to accomplish multi-objective decision making. The approach was published in 2013. In 2015, the authors applied the approach to decision making for drug delivery in home care services [15].

Stojanova, Stojkovic, Kocaleva, and Koceski [18] focused on scheduling and did not address the routing problem. The authors illustrated analogies between job shop scheduling in logistics and the scheduling of caregivers and elderly people. In the presented ABS, the individuals from both groups are modeled as individual agents which enables communication between the groups. Unfortunately, the resulting simulation is only presented briefly in the paper such that the implemented mechanics remain mostly unclear. *AnyLogic* was used for the implementation of the model, however, experiments or generated results are not presented.

The decision support system proposed by **Widmer and Premm** [19] makes use of an auction-based protocol (double-auctions) to achieve an optimal allocation of caregivers to dementia patients. By this means, they aimed at maximizing social welfare by taking the time required for each service, the skills of each caregiver, service priorities, and valuations of the patients into account. The specification and justification of the proposed auction protocol is the main contribution of the paper. In this regard, a software architecture as well as dementia-specific requirements are introduced. Unlike other contributions that use simulation for their evaluation, the authors presented a scenario-based evaluation to demonstrate the submission of bids as would take place during an auction. The prototype is developed using only the *Java Development Kit* (JDK) and without a dedicated software framework for agent-based approaches.

Xie, Sharath, and Wang [22] presented an MAS framework that implements an iterative bidding procedure for the negotiation of HHC schedules. The parties that are involved in this negotiation process are just the home health agency and the caregivers, leaving out the patients. As the routing of the caregivers is not the primary goal of the presented system, spatial aspects such as traffic or street maps are not considered. The optimization goal which is pursued by this approach is related to the minimization of service costs. To achieve this, time windows, skill sets of caregivers, and preferences of clients are considered. Even though the authors do not present an implementation of the model, they provide experimental results and compared them to the optimal problem solution generated by means of the optimization software *ILOG CPLEX*. For this purpose, eight scenarios were defined each of which is replicated ten times.

Two years after their publication in 2015, two of the authors from the previously presented work proposed another scheduling approach for home health care. As the approaches differ considerably, the system presented by **Xie and Wang** [23] is discussed as well. Unlike the previous publication, the authors proposed an ABS for generating and evaluating HHC schedules using a repair algorithm. Moreover, a spatial aspect was added, so a GIS map serves as operative environment in the simulation. For the implementation, the authors used

AnyLogic and demonstrate the feasibility of the approach based on ten repair runs. As no information on the chosen scenario is given, it must be assumed that the data basis was generated synthetically.

Table 4. Overview of implementation, experimentation, and domain of the surveyed approaches.

	Software	Interactivity	Design of experiment	Input data	Output data analysis	Domain
[1]	*Arena*	-	Sensitivity analysis	1 case study (palliative home care provider in Milan, Italy)	Average values of a performance measure (waiting time)	Palliative Home Care
[8]	*JADE*	Participants reject/accept proposed schedules	-	1 example of single request (synthetic data)	-	HHC
[10]	*JADE*	Allows for new requests during run time	DP = 16, N = 1, deterministic/ stochastic model (unclear)	4 Scenarios (synthetic data)	Average values of a performance measure	HHC
[11]	*NetLogo*	Real-time request of availability of patients	2 simulations of 500 working days, stochastic model, N = 100 for each decision rule	2 case studies (synthetic data, inspired from classical types of French HHC providers)	Statistical significance (confidence interval), evaluation of efficiency, pertinence, scalability, robustness, and implementability	HHC
[13]	*MATLAB*	Assumption: appointments can be made by patients	DP = 20, N = 100, stochastic model	2 scenarios (synthetic data)	Average values of a performance measure	HHC
[14]	-	Update of preferences and management goals	-	-	-	HHC
[18]	*AnyLogic*	-	-	-	-	HHC
[19]	*JDK*	Caregivers and patients submit bids to an auctioneer	-	1 scenario (unknown data source)	-	Dementia (Home) Care
[22]	-	-	Comparison to optimal solution of 8 model configurations (DP = 8), N = 10, stochastic model	8 scenarios (synthetic data at realistic scale)	Average values of a performance measure (bidding solution payment)	HHC
[23]	*AnyLogic*	-	10 repair runs	Assumption: synthetic data	Average value of a performance measure (costs)	HHC
[25]	*JADE*	Information exchange, service requests and offers	-	Two examples of coordination (synthetic data)	-	HHC

Zarour, Zarour, and Khalfi [25] provide an agent-based architecture to support coordination and communication for patients and cooperating providers of services regarding the patient's care. Similar to the previously mentioned contributions from Castelnovo et al. and Itabashi et al., the protocol *contract net* was used to enable coordination like scheduling on an abstract level. Furthermore, the authors defined the agent's communication processes and presented an ontology for information exchange in the considered domain. The implementation is based on *JADE* and for evaluation the authors compared their information system with a similar agent-based support system. Because of missing information regarding the input data of the scenario for comparison, it must be assumed that they used synthetic data. A part of this work (presented in 2010) was already published in 2008 by two of the authors [24].

Beside these 11 approaches, which were selected in the literature review as described in Sect. 3, the ideas presented by **Fraile Nieto, Rodríguez, Bajo, and Corchado** [7] are worth mentioning. The authors applied an abstract MAS architecture to a home care scenario, where agents can offer and request services from other participants. This can be conceived as a part of a management solution. Because of a lack of elaboration in the area of resource scheduling, the publication is not part of the tables. The authors only mention that it could be possible to use this architecture for scheduling medical staff.

Similar to the previously mentioned contributions using the *contract net protocol*, the work of **De Causmaecker, Demeester, Berghe, and Verbeke** [3] provides an agent-based scheduling approach including negotiations for personnel exchange respectively task exchange. In the same year (2005), the authors published another paper to this topic and give further information regarding an implementation and planned experiments [4]. Because both publications are very short, without details, and not linked directly to the domain of home health care, the contribution is not part of the tables here. By looking at an earlier publication from 2004, a connection to the domain of HHC can be established. Here, De Causmaecker et al. [2] analyzed personnel scheduling problems, mention application domains, and propose a classification, where one type of planning refers to home health care.

5 Shortcomings of the Surveyed Approaches

The previous section analyzed the identified contributions with respect to the defined key features. None of the surveyed approaches is satisfactory to support planning and scheduling in operational HHC management regarding flexibility in caregivers' operations, efficiency in the use of resources, and economic viability under present and future conditions.

Shortcomings in the approaches' concepts are mostly related to *outcome*, *spatial aspects*, and *goals*. It can be observed that an *outcome* for the HHC management that is "ready to use" does not exist. Beside theoretical contributions, like frameworks, the publications provide outcomes on a prototype level. Further, *spatial aspects*, such as traffic times or map data, are not sufficiently considered and no real-world traffic data is used. Instead, static travel times are used, not regarded at all, or no distinction in the direction among the nodes is made. Specific optimization goals are pursued in 9 out of 11 publications and only one system allows for the interchangeability of goals. The approach by López-Santana et al. takes cargivers' skills into account and allows for new customer requests during runtime. However, their system focuses only on minimizing travel times of caregivers as well as delays in arrival times at customer locations. Here, generating an optimal solution takes too much time for real-world problems. Similarly, the approach by Xie and Wang only focuses on minimizing service costs and the search for an optimal solution takes too long here as well. The approach by Marcon et al. assigns each caregiver to a set of customers with a corresponding route proposal, which can be adapted later by the caregiver. Following this, a dynamic solution is provided based on a caregiver's local decision. By changing the local decision-making mechanisms, different higher-level objectives can be pursued, e.g., minimizing waiting times. But each caregiver only interacts with his own patients, so interchangeability is not possible. In addition, there is no coordination between caregivers to react on events in order to reach a better joint solution. The remaining surveyed approaches do not provide sufficient dynamic scheduling solutions, but communication platforms and basic coordination solutions.

In the implementation of the surveyed approaches, shortcomings are observed in terms of used *software* and its *accessibility*. Through the use of commercial frameworks, a third-party is included which claims license fees for use. Consequently, a monetary dependency results. Further, a dependency arises in software maintenance and durability. Overall, the applicability of the implementation is strongly limited. Regarding the *accessibility* of the implementations, none of the authors referred to online repositories or websites for downloading the proposed implementations. Because of the inaccessibility of all developed software, the key feature *accessibility* is not part of the tables. Shortcomings in the evaluation of the surveyed approaches arise in all defined key features. First, relevant parts of the parameter space must be identified and systematically investigated. Unfortunately, the *design of experiment* in the publications is mostly on a non-professional level. Second, *input data* in terms of suitable real-world data is not provided sufficiently. Either synthetic data or a brief case study is given. Third, to ensure statistical reliability and the significance of the evaluation results, it is recommended to apply means of *output data analysis*. The greater part of the surveyed approaches uses information about considered performance measures in terms of statistical measurements of central tendencies.

6 Conclusion and Further Work

Operational management processes in terms of planning and scheduling in the domain of home health care systems can be supported by multiagent systems as well as decision support systems using agent-based simulation. This article provides an overview of these approaches. Therefore, we conducted a systematic literature review in which 11 relevant approaches using agent technology were identified. Further, the identified publications were analyzed and shortcomings were detected. The shortcomings comprise aspects of the respective concepts, the provision of implementations and the execution of evaluation processes. In order to cope with an increasing demand in HHC, besides efforts to improve efficiency, additional caregivers must be hired by service providers. However, the availability of skilled caregivers on the labor market is very limited. None of all current agent-based approaches offers a sufficient solution to dealing with a shortage of skilled workers. Furthermore, no learning mechanisms for agents are used to increase efficiency and the handling of the dynamic environment is not sufficient as well. The latter includes coping caregiver outages and delays in operational processes as well as no usage of real-world traffic data.

As the need for management support persists, we are working on a dynamic distributed scheduling solution for the control of operational processes which increases efficiency and improves the use of limited resources to allow for coping with the rising demand.

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