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Home health care nurse routing and scheduling problem considering ergonomic risk factors

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ABSTRACT

Home health care routing and scheduling is a complex problem that requires many aspects to be considered simultaneously. One of the important aspects is ergonomics. Home health care nurses are at higher risk of work-related health problems such as musculoskeletal disorders and burnout since they are frequently exposed to physical, mental, and environmental ergonomic risks in their jobs. Therefore, it is essential to integrate ergonomic considerations into the construction of daily schedules for home health care nurses to mitigate these health risks. The purpose of this study is to present a mathematical model that incorporate ergonomic risks. We introduce a set of constraints into our model to prevent nurses from encountering excessive workloads. To assess the workload, we propose a subjective assessment method and employ a fuzzy inference system to calculate nurses' perceived workload levels. We applied our model to a several numerical examples to investigate the impact of workload on the nurse daily schedules. We observed that, at a specified workload level, there may be alternative solutions where the number of patients visited is the same. Therefore, we defined an objective function to maximize patient visits while minimizing nurses' workload levels as much as possible. As a result, our model generates solutions that effectively reduce nurse workloads, leading to more balanced schedules. Thus, our study offers a comprehensive approach to home health care scheduling by incorporating ergonomic considerations, ultimately enhancing both patient care and nurse well-being.

1. Introduction

Home health care (HHC), providing long-term medical services to patients at their homes are in high demand globally [1]. The aging population can be counted main reason for this demand. Older people need care, preferably in their own homes. 9.3 % of the population consists of people aged 65 and over in 2020, and this ratio is expected to increase to 16.0 % in 2050 worldwide [2]. According to a recent study by Kebbler et al. [3], the rapid growth of the elderly population and the emergence of patient-centered care pushed the health care system to move toward home health care. The need for HHC has also been experienced more clearly during the COVID-19 pandemic as a result of the hospital's inability to provide services due to the high number of infected people and infection risk.

HHC offers many benefits, such as decreasing hospital occupancy, reducing health care expenses, and providing more convenient care to patients [4]. However, the HHC system also has generated difficult design and operational problems that need to be addressed. Among these, Home Health Care Routing and Scheduling Problems (HHCRSP) have received a lot of attention lately [5]. This problem

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involves allocating nurses to patients, scheduling working times, and establishing travel routes under some governmental regulations and industry-specific constraints [5]. HHCRSP is a complex problem that requires many aspects to be considered simultaneously. In general, HHCRSP is viewed as a variant of vehicle routing problem, especially with time windows, since patient visits must be scheduled within a specific window [6]. Besides the time window constraints, HHCRSP also involve industry-specific restrictions such as, uncertainty [7–9], continuity of care [8,10], lunch breaks [11,12], flexible starting and ending points [13], synchronization [12,14,15], etc., which make problem more complicated.

In this study, we will consider a practical HHCRSP that incorporates constraints commonly encountered in real-world applications. The first constraint pertains to nurses' skill. The nurses in HHC settings usually performs task that require different skills. Therefore, it is important to assign patients to nurses who have the necessary skills.

The second constraint is related to lunch break. Since nurses work outside of the HHC centers, they usually take a lunch break near the patients' houses either preceding or following visits, at a predetermined time interval. Therefore, the lunch break times should be determined in such a way that the HHC service is not interrupted.

The third important aspect that must be included in HHC scheduling is the workloads of the nurses. Nurses in HHC are frequently exposed to excessive workloads, which leads to work-related illnesses. For instance, work-related musculoskeletal disorders (WMSDs) [16] and burnout [17] are very common among nurses. In the literature, workload assessment is often made based on quantitative factors such as the number of patients visits, the total working hours, travel distance covered by nurses. In this study, we claim that the assessment of workload should be extended to encompass ergonomic risks that prevalent in the nursing profession. These ergonomic risks include physical factors such as lifting patients, bending frequently, awkward posture while providing care, environmental factors such as noise level, lighting conditions in a patient's home environment, and as well as cognitive load and mental stress associated with tasks. However, assessing workloads considering these ergonomic risks can be challenging because HHC nurses work in a variety of settings and usually have different professional and personal experiences that might affect their perception of workloads. To overcome this challenge, we propose a subjective method, allowing nurses to assess their own workloads.

In this study, we will adopt a more nurse-centered approach and attempt to seek answers to the following research questions:

- What strategies can be developed to incorporate workload considerations into scheduling, in order to reduce work-related illnesses among nurses?
- What is the most suitable and practical method for assessing the workload of nurses?

Table 1
Studies dealing with home health care routing and scheduling problem with workloads.

References	Travel time/ Distance/	Number of patients visited	Working time/ Service time	Overtime	Visit load
[26]	+	–	–	–	–
[27]	+	–	–	–	–
[28]	–	+	–	–	–
[29]	+	–	+	–	–
[14]	–	–	+	–	–
[30]	–	–	+	–	–
[7]	+	–	+	–	–
[31]	–	–	+	+	–
[32]	–	+	+	–	–
[33]	–	–	+	–	–
[34]	–	–	+	–	–
[35]	+	–	–	–	–
[36]	+	–	–	–	–
[37]	+	–	–	–	–
[38]	+	–	+	–	–
[39]	–	–	+	–	–
[40]	+	+	–	–	+
[41]	–	–	+	–	–
[8]	–	–	–	+	–
[42]	+	–	–	–	–
[43]	+	–	–	–	–
[44]	–	–	+	–	–
[45]	–	+	–	–	–
[46]	–	–	+	–	–
[47]	–	+	–	–	–
[48]	+	–	+	–	–
[49]	–	–	+	–	–
[50]	–	–	+	–	–
[51]	–	+	–	–	–
[52]	+	–	+	–	–
[53]	–	+	–	–	–
[54]	–	+	–	–	–

To address these research questions, first, we develop a post-task questionnaire designed to collect the perceived workload of the nurses in the context of ergonomic risks and use a fuzzy inference system (FIS) to determine the workload of the nurses. Second, we develop a mathematical model, incorporating a set of constraints we refer to as "workload constraints" to prevent nurses from having excessive workloads. As a result, our aim in this study is to find routes and schedules of the nurses in order to maximize the number of patients visited while considering skill, lunch time, and the workloads of the nurses.

The main contribution of this study can be summarized as follows: To the best of our knowledge, this is the first study to consider ergonomics in HHCRSP. It introduces a novel dimension by incorporating ergonomic considerations into the scheduling and routing process. While previous research has recognized the importance of ergonomics in HHC services, they have not integrated these critical considerations into the scheduling and routing problem. Considering workload in the context of ergonomic risks plays an important role in preventing nurses from experiencing excessive workload, thereby ensuring their well-being and enabling efficient patient care. Moreover, this study suggests a workload assessment method that takes into account the diversity of nurses and their working environments, offering a practical solution suitable for real-world applications.

This paper is organized as follows: Section 2 provides an in-depth literature review specifically focusing on workload balancing within the context of HHCRSP. Section 3 offers detailed insights into the mathematical model. Section 4 describes the proposed workload assessment method. Section 5 presents numerical examples to explain our proposed model in detail. Finally, Section 6 concludes the paper with a discussion and future research directions.

2. Literature review

HHC systems involve many challenging optimization problems. Here, we will limit our attention to HHCRSP, especially the studies that consider the workloads of the nurses.

HHCRSP was first studied in the literature by Fernandez et al. [18]. HHCRSP gained more attention after Akjiratikarl et al. [19] conceptualized the problem as an expanded variant of the vehicle routing problem [5]. According to recent reviews, routing and scheduling problems of nurses and patients have gained special interest (for detailed literature information, see Refs. [20–23]). There are a lot of studies that consider HHC specific features, such as patient priority, patient and staff preferences, synchronization, continuity of care, workloads, etc. (for detailed literature information, see Ref. [1]).

Increasing service quality and reducing costs are the main focuses of the HHCRSP. However, ignoring nurse health, which is frequently a secondary concern, can result in significant unintended expenditures for HHC companies and society. In recent years, there have been some studies that include nurse health in the HHCRSP from different perspectives [24,25]. For instance, workload has been integrated as an additional constraint when developing nurse schedules. Table 1 gives some of the studies that consider workload

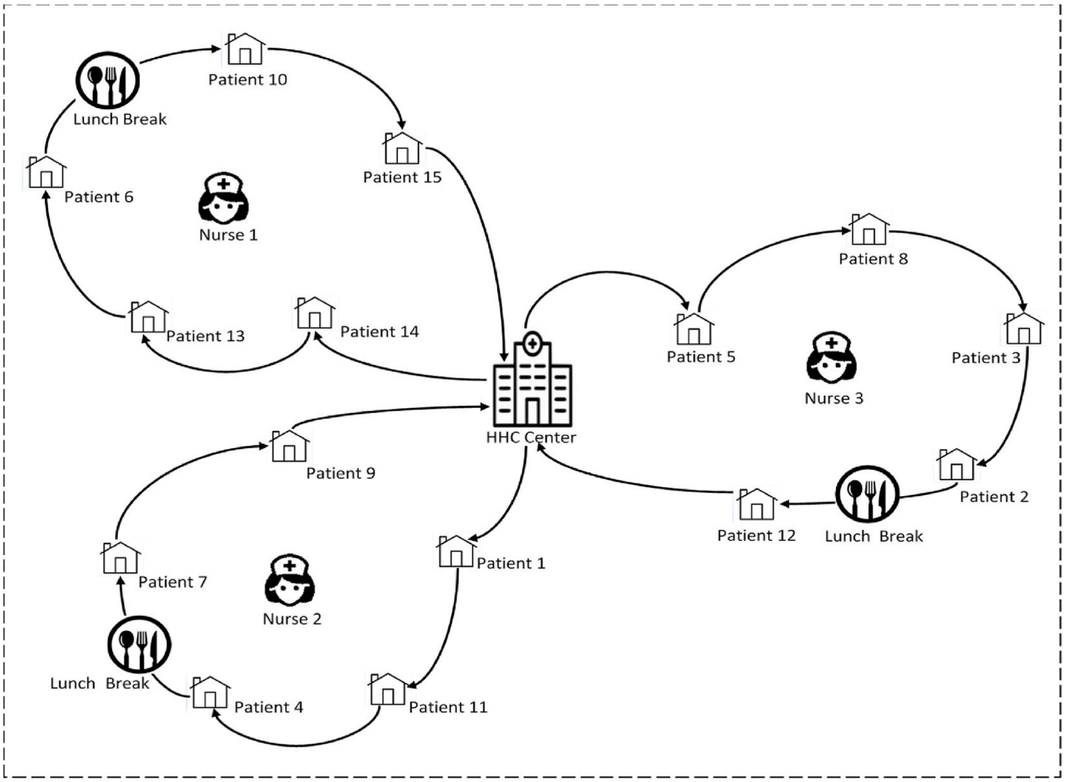

Fig. 1. Graphical illustration of the problem.

in the scheduling proses.

In these studies, workloads have typically been associated with factors such as the travel time or distance, the number of patients visited, working or service time, overtime, and visit load. However, this study extends the concept of the workload by including ergonomic risks as another dimension. While ergonomics risk has been recognized as a significant risk factor in home health care services (see Refs. [55,56]), most of the studies have concentrated on assessing these risks, investigating their connection to health problems and suggest some ergonomic interventions to mitigate these risks. In contrast, our study presents a novel perspective on reducing ergonomic risks. We offer a new mathematical model that creates nurse schedules while considering ergonomic risks, in addition to typical constraints encountered in real-world applications. Our aim in this study is to provide home health care to as many patients as possible without risking the health of nurses.

3. Problem description and mathematical model

In this study, we deal with HHCRSP by incorporating ergonomic risks. We can describe our problem as follows: There are sets of nurses that have different skills. Nurses start their work at the HHC center, work 8 h, and return to HHC center at the end of the shift; overtime is not allowed. Nurses should take a 1-h lunch break within the specified time interval. The goal is to find nurse-patient assignments and routes such that the number of patients visited is maximized while minimizing the total daily workload of the nurses. This problem can be illustrated in Fig. 1. In practice, home care nurse scheduling is often done on a daily basis since the number, treatment requirements, and visit frequencies of patients change constantly. Therefore, we will develop daily schedules for nurses.

Although HHCRSP may involve many constraints depending on the special situations, we will consider common and important constraints in real-life applications such as the time window, lunch break, and workload constraints. Some patients have a certain time window in which they must receive their treatment. For instance, blood sugar levels should be checked before meals, and medications should be given at the prescribed time. Therefore, each patient should be visited within the specified time window. We consider the time window a hard constraint, i.e., a nurse must wait if he or she arrives early at the patient's home, and arrivals after the time window are not allowed.

As a legislative requirement, each nurse must have a 1-h lunch break at certain time intervals. For the sake of simplicity, since we do not know the exact location of nurses when they take a lunch break, we assume that the nurses will go to the nearest facility for lunch or bring their meal and that the 1-h lunch break will include both travel times and meal time.

In addition to these two constraints, we will also consider the workload resulting from ergonomic risks. Thus, we add workload constraints that ensure that each nurse must have a workload below a predetermined level in order to reduce their health risks. In order to calculate the workload of the nurses, we use a subjective assessment method and FIS. A detailed explanation of the workload assessment method is given in Section 4.

3.1. Assumptions

- There is a fixed number of nurses with different skill levels in the system
- Each patient can be visited only by one nurse
- There are no preferences among patients and nurses
- Service time is known and fixed for each nurse
- Travel times are constant and proportional to distances
- Lunch break includes both travel times and lunchtime
- The workload may change depending on the nurse providing the service

3.2. Sets and indices

V: Set of all nodes {0,1,2, …, n+2} where 0 and $n+2$ represent the HHC center, and $n+1$ represents a fictitious lunch node.
P: Set of patients {1, …, n}, P⊂V.
H: Set of nurses {1,2, …, s}
i, j, k: Node indices
s: Nurse index.

3.3. Parameters

t_i: Time spent in node i (service time for patient nodes, lunch break time for the lunch node)
d_{ij}: The travel time between node i and node j
$[e_i, l_i]$: Time windows for patient i
$[lt_1, lt_2]$: The time window for lunch break
wl_i^s: The amount of workload that nurse s has for patient i
Q: The maximum permitted daily workload for a nurse
b: The maximum number of patients that a nurse can visit in a day.

g_j^s: 1 if nurse *s* has the necessary skills for patient *j*; 0 otherwise
M: A very large number.
ε: A very small number

3.4. Decision variables

$$x_{i,j}^s = \begin{cases} 1, \text{if nurse } s \text{ visits node } j \text{ after node } i \\ 0, \text{otherwise} \end{cases}$$

$$y^s = \begin{cases} 1, \text{if nurse } s \text{ is assigned to at least one patient} \\ 0, \text{otherwise} \end{cases}$$

q^s: Difference between the permitted workload and the nurse's actual workload
a_i^s: Arrival time of nurse *s* to node *i*
w_i^s: Waiting time of nurse *s* at node *i* if she arrives before the time window

3.5. Mathematical model

$$Max \sum_{i \in V} \sum_{j \in P} \sum_{s \in H} x_{i,j}^s + \varepsilon \sum_{s \in H} q^s \tag{1}$$

$$x_{i,j}^s \leq g_j^s \quad \forall i \in V;\ \forall j \in P;\ \forall s \in H \tag{2}$$

$$\sum_{j=1}^{n} x_{0,j}^s = y_s \quad \forall s \in H \tag{3}$$

$$\sum_{i=1}^{n+1} x_{i,n+2}^s = y_s \quad \forall s \in H \tag{4}$$

$$\sum_{i=0}^{n} \sum_{j=1}^{n} x_{i,j}^s \leq b\ y_s \quad \forall s \in H \tag{5}$$

$$\sum_{i=0}^{n} \sum_{s=1}^{m} x_{i,j}^s \leq 1 \quad \forall j \in P \tag{6}$$

$$\sum_{i=0}^{n} x_{i,n+1}^s = y^s \quad \forall s \in H \tag{7}$$

$$\sum_{j=1}^{n+2} x_{n+1,j}^s = y^s \quad \forall s \in H \tag{8}$$

$$\sum_{i=0}^{n+1} x_{i,k}^s = \sum_{j=1}^{n+2} x_{k,j}^s \quad \forall k \in \{1, 2, \ldots, n+1\};\ \forall s \in H \tag{9}$$

$$a_i^s + w_i^s + t_i + d_{ij} \leq a_j^s + M\left(1 - x_{i,j}^s\right) \quad \forall s \in H;\ i, j \in V - \{n+1\} \tag{10}$$

$$a_{n+1}^s + w_{n+1}^s + t_{n+1} + \sum_{k=0}^{n} x_{k,n+1}^s d_{kj} \leq a_j^s + M\left(1 - x_{n+1,j}^s\right)\ \forall s \in H;\ j = \{1, 2, \ldots, n+2\} \tag{11}$$

$$a_i^s + w_i^s \geq e_i y^s \quad \forall s \in H;\ i \in P \tag{12}$$

$$a_i^s \leq l_i \quad \forall s \in H;\ i \in P \tag{13}$$

$$a_{n+1}^s + w_{n+1}^s \geq lt_1\ y_s \quad \forall s \in H \tag{14}$$

$$a_{n+1}^s \leq lt_2 \quad \forall s \in H \tag{15}$$

$$a^{s}_{n+2} \leq 540 \quad \forall s \in H \tag{16}$$

$$\sum_{i \in C} \sum_{j \in N} wl^{s}_{i}\, x^{s}_{i,j} + q^{s} = Q \quad \forall s \in H \tag{17}$$

$$x^{s}_{i,j}, y^{s} \in \{0,1\};\ \forall i,j \in V;\ s \in H;\ q^{s}, a^{s}_{i}, w^{s}_{i} \geq 0;\ \forall i \in P;\ \forall s \in H \tag{18}$$

Equation (1) defines our objective function. In this study, we have two objectives. First objective is to maximize the number of patients provided by HHC, which is represented by the first term in the objective function. The second objective is to reduce the total workload of the nurses, if possible. This objective is defined as the second term in the objective function, which aims to maximize the total differences between the permitted workload and the nurse's actual workloads. Since our primary objective is to maximize the number of patients, we should seek first the optimal solution for this objective. However, we should consider the second objective only if there are alternative solutions for the first objective. To achieve this, we multiply the second term in the objective function by ε. The value of ε should be set a very small so that the second objective does not hinder the first objective. For this problem, the value of ε can be set as $\varepsilon < 1/(sQ)$, where s is the number of nurses, and Q is the permitted workload level. Equation (2) ensures that nurses with the necessary skills are assigned to patients. Equations (3) and (4) ensure that nurses start the work at the HHC center (node *0*) and return to the HHC center (node $n+2$) after 8 h of work. Equation (5) prevents exceeding the maximum number of patients that can be visited during the day. Equation (6) ensures that patients can be visited at most once a day. Equations (7) and (8) ensure that every nurse assigned during the day must take a lunch break. Equation (9) ensures that the nurse who arrives at a node must go to another node. Equations (10) and (11) are used to obtain the arrival time at node *j* from node *i*. The value of M in those constraints can be set as $M > 540$ in the solution of the problem. Equation (12) calculate the waiting times if nurses arrive at patients' homes before the time window. Equation (13) prevents nurses from arriving after the time window. Equations (14) and (15) ensure that each nurse takes a 1-h lunch break during the day. Equation (16) do not permit nurses to work more than 8 h (540 min). Finally, Equation (17) ensure that the total workload that a nurse is exposed to in a day does not exceed the permitted workload and calculate the differences between the permitted workload and the nurses' actual workloads.

4. Workload assessment method

The workload is defined as the amount of mental and physical effort required by the work. Although the definition is simple, determining the workload is difficult since it involves many aspects. One important aspect that could increase the workload is ergonomic risks. Workload caused by ergonomic risks can be grouped into three categories physical, environmental, and mental. Physical workload usually occurs from tasks such as pushing, lifting, awkward postures, etc. Every task, whether physical or cognitive, involves some degree of mental processing that results in mental workloads. Environmental workload is related to poor working conditions, such as noise, inadequate lighting, etc., which will affect workers' health.

Some of the ergonomic risks that HHC nurses encounter during transportation and at the patient's home are listed below [57–62].

- Physical activities like lifting, pushing, pulling, standing for a long time, etc.
- Inappropriate thermal conditions
- Noise
- Inadequate lighting
- Chemical and biological hazards
- Poor hygiene conditions
- Negative attitudes of patients and their relatives
- Traffic problems or accidents

The excessive workload can interfere with nurses' physical and cognitive abilities and affect both their performance and health [63]. Therefore, the schedules must be constructed to avoid nurses having excessive workloads as much as possible.

In order to construct a schedule based on workloads, we should first assess workloads due to ergonomic risk factors. Several methods are available for workload assessment. These methods can be classified as observational, objective, or subjective. Observational methods are generally used to determine the physical workloads of the workers. The most popular observational methods are Rapid Entire Body Assessment (REBA), Rapid Upper Limb Assessment (RULA), Ovako Working Posture Analysis (OWAS), Occupational Repetitive Actions (OCRA), Strain Index (SI) and National Institute for Occupational Safety and Health (NIOSH) Lifting Equation. In the objective methods, the workload can be assessed based on physiological indicators such as heart rate, blood pressure, skin conductivity, eye movements, brain activity, etc. [64]. Subjective methods are based on the analysis of feedback supplied by employees through interviews or post-task questionnaires [65]. Subjective approaches can be used in a wide range of situations since they allow for the simultaneous examination of various aspects. Some of the subjective workload assessment techniques that are commonly used are NASA Task Load Index (NASA-TLX), Subjective Workload Assessment Technique (SWAT), Instantaneous Self Assessment (ISA), Workload profile (WP), Harper Scale, and Rating of Perceived Exertion (RPE).

Since there is no method that fits all circumstances, it is important to select an appropriate workload assessment method that incorporates tasks, workers, and their working environment. The workload assessment in HHC is more difficult since nurses work in a variety of environments throughout the day. Furthermore, nurses' personal and professional characteristics may influence their perception of workload. For example, one nurse may find a task to be more difficult than others or may prefer a patient based on a previous visit. Therefore, we use a subjective workload method to account for variations in both the environment and among nurses as well as nurse-patient compatibility.

In this study, FIS approach is used to determine the workloads of nurses due to ergonomic risk factors during patient visits. The fuzzy logic approach, developed by Zadeh [66], is used in modelling uncertainty in decision-making and has been applied to complex real-life systems. Home health care involves uncertainties in terms of task, input, and environment, which require fuzzy definitions (for detailed literature information, see Ref. [67]). Task uncertainty pertains to the level of difficulty and variability in the work that needs to be accomplished; input uncertainty pertains to the lack of predictability in both the quantity and nature of a task, such as the unpredictability of the condition of a new patient; and environmental uncertainty pertains to physical and social factors that must be considered in decision-making [68].

In the HHCRSP literature, the fuzzy logic approach has been employed to integrate the uncertainties associated with factors such as demand, travel time, time windows, and service duration into the HHCRSP [69–71]. Fuzzy logic is also used to assess workloads considering ergonomic risk factors [72–78]. Chen et al. [72] developed the Ergonomic Workload Stress Index (EWSI) model, which estimates the ergonomic workload stress level using fuzzy set theory. Linguistic variables (heavy, hot, high, etc.) were used to define the stress caused by environmental, mental, and physical demands at the workplace. The Analytic Hierarchy Process (AHP) was also used to obtain weightings for each component since people perceive and respond to stress differently. Jung and Jung [76] developed a model similar to EWSI that includes linguistic variable sets and used AHP to assess the overall workload level (OWL). They compared the results of the developed model with the results of NASA-TLX. Azadeh et al. [78] developed an adaptive intelligent algorithm for forecasting and improving the mental workload of operators with questionnaires designed to determine the subjective perception of operators against factors related to health, safety, environment, and ergonomics. Artificial Neural Networks (ANN) and Adaptive Network Based Fuzzy Inference System (ANFIS) are used in the algorithm.

The FIS method is a collection of procedures that use fuzzy logic to produce output based on inputs. The general structure of the FIS is shown in Fig. 2. Fuzzification is the first step, in which crisp inputs are transformed into fuzzy inputs. Fuzzy outputs are produced by the inference engine using knowledge base, which contains a rule base (fuzzy rules) and database (membership functions). Finally, fuzzy outputs are transformed back into crisp output during the defuzzification stage.

In this study, we used the Fuzzy Logic Toolbox in MATLAB to implement FIS. Fuzzy Logic Toolbox is a powerful tool that offers some advantages like intuitive modeling, robustness, flexibility, and speed. The steps of designing FIS with Fuzzy Logic Toolbox involve (i) choosing the type of FIS, (ii) specifying the properties of FIS, (iii) defining the input and output variables and their ranges and membership functions, and (iv) constructing the rule base.

There are two types of fuzzy inference systems that can be implemented in the Fuzzy Logic Toolbox: Mamdani-type [79] and Sugeno-type [80]. Mamdani-type FIS is often preferred when output membership functions need to be defined as fuzzy sets [81]. We used the Mamdani-type inference system, which has three input variables and one output variable, as shown in Fig. 3. Triangular membership functions are employed for defining both input and output variables. The properties of the FIS are given in Table 2.

The inputs of FIS are the perceived workload of nurses due to environmental, physical, and mental risk factors, which are obtained from a post-task questionnaire (see Appendix 1). Nurses assess their level of discomfort caused by each ergonomic risk factor during their visits using the linguistic variables “none”, “low”, “moderate” or “high”. The post-task questionnaire consists of 17 questions,

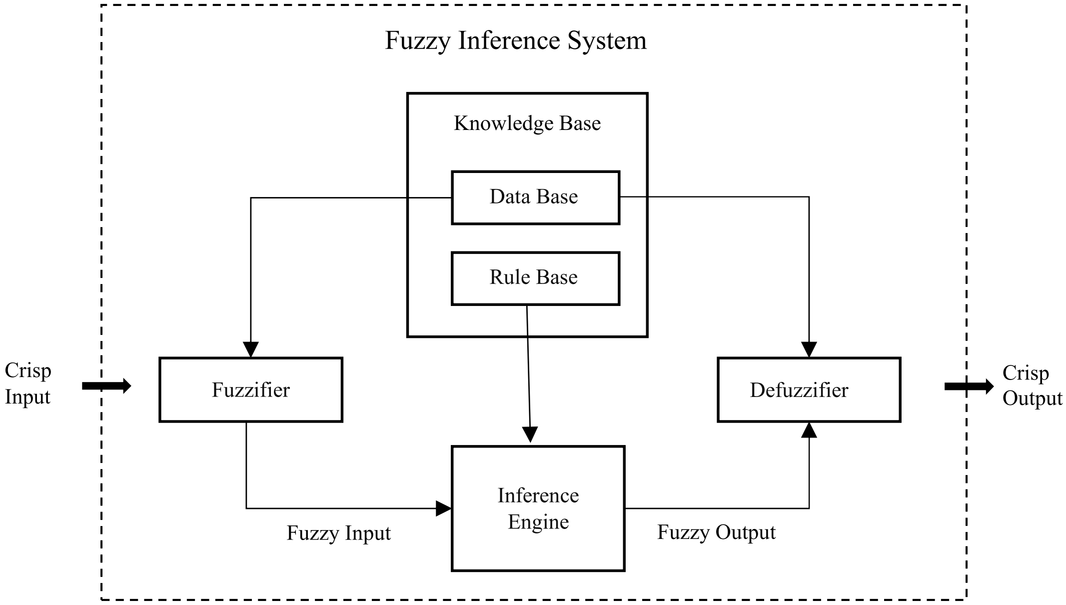

Fig. 2. Fuzzy inference system.

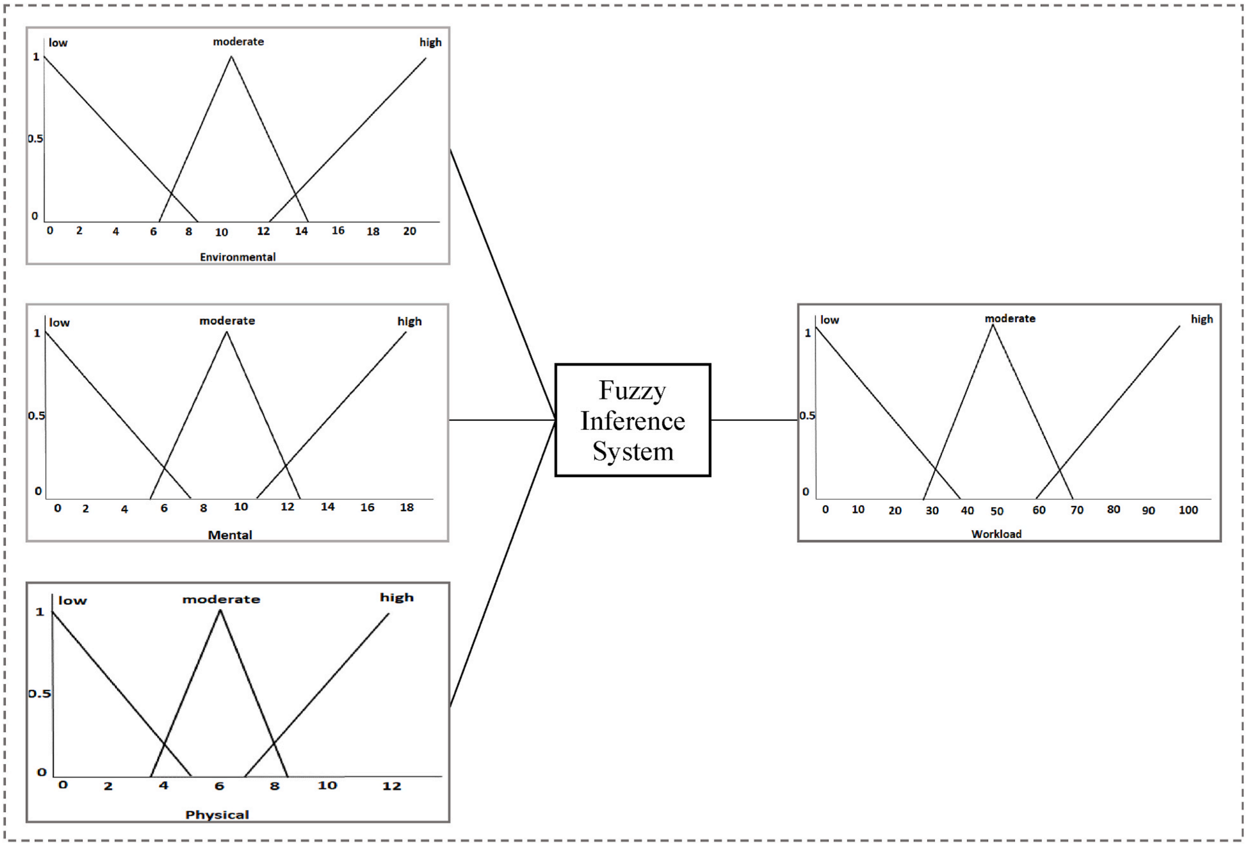

Fig. 3. The fuzzy inference system developed in MATLAB.

Table 2
The properties of Fuzzy Inference System.

Properties of FIS	Method
Decision method for fuzzy logic operators AND (intersection)	Min
Decision method for fuzzy logic operators OR (union)	Max
Implication method	Min
Aggregation method	Max
Defuzzification	Centroid (Center of gravity)

including seven environmental, six mental, and four physical risk factors. Each risk factor takes a score between 0 and 3 corresponding to linguistic variables, so the combined scores for environmental, mental, and physical inputs range between [0–21], [0–18], and [0–12], respectively. Finally, the workload scores between 0 and 100 are produced by FIS as an output. The parameters of the triangular membership functions are given in Table 3.

In the third step of the FIS, the rule structure is constructed, which defines the relations between inputs and output. Various methods can be used to construct the rule structure in the FIS. The most common method is to construct a single rule structure based on expert opinion [82]. However, in our case, because nurses possess varying levels of expertise and distinct character traits, they may perceive workload differently. As a result, we will construct distinct rule structures for each nurse to account for these individual

Table 3
Parameters for input variables and output variable.

Inputs/Output	Ranges corresponding to linguistic variables		
	Low	Moderate	High
Environmental	0-0-8.5	6.5-10.5-14.5	12.5-21-21
Mental	0-0-7.5	5.5-9-12.5	10.5-18-18
Physical	0-0-5	3.5-6-8.5	7-12-12
Workload	0-0-40	30-50-70	60-100-100

variances. The rule structure has 27 if-then rules since there are three input variables, each with three levels (low, moderate, and high). The outputs that show the perceived workload level are determined by nurses according to input variables. Table 4 present a sample rule structure for a nurse. For instance, in the rule structure given in Table 4, the nurse states that if the environmental factor is "moderate", the mental factor is "low", and the physical factor is "moderate" (Rule 5), then the perceived workload level is "moderate".

Finally, in the defuzzification stage, the crisp workloads are obtained from the input variables using the rule base. Fig. 4 shows a sample screenshot of the MATLAB rule viewer to demonstrate the defuzzification process. The workload score of 83 is obtained when the environmental input is 15, the mental input is 14, and the physical input is 5.

5. Numerical investigations

In this section, we explain our proposed method using a hypothetical problem. For this purpose, we consider a small problem. Suppose that there are 3 nurses who must visit at most 15 patients in a day. The hypothetical problem is based on the following assumptions and criteria:

- X and Y coordinates for patients are generated randomly in the range of [0, 100]. The home health care center is located at the center with coordinates of [48,48].
- The distances between the nodes are measured by using Euclidean distances. Distances and travel times (in minutes) are assumed to be equal.
- For each patient, the service times (in minutes) are generated randomly in the range of [1,28] and time windows in the range of [0, 540].
- Nurses begin work at 8:00 a.m. and work for 8 h a day. They must take a 1-h lunch break starting at 11:00 and ending at 13:00. They return to the HHC center at the end of the day.
- The perception of nurses' workloads may change for each patient depending on the ergonomic risk factors as well as other factors.
- Nurses may have different skills; thus, nurses who have the required skills for the treatment must be assigned to the patients.

The parameters of the problem are given in Tables 5–7. Table 5 gives the patients' house coordinates, service times, and time windows. Table 6 gives the possible patient-nurse assignments determined based on the treatment needs. "1" indicates that the nurse has the skills for the treatment.

Since the perceived workloads of the nurses may change depending on their response to the ergonomic risk factors, we use subjective workload methods. The workloads of nurses are determined from the responses to the post-task questionnaires obtained from the previous visit. We evaluate this data with FIS and produce the workload levels in the interval [0, 100] for each patient, with 0 indicating no workload and 100 indicating a high workload. Table 7 shows a hypothetical workload level generated by FIS model. We

Table 4
A sample rule structure.

	If			Than
Rule No	Environmental factors	Mental factors	Physical factors	Workload
1	Low	Low	Low	Low
2	Moderate	Low	Low	Low
3	High	Low	Low	Moderate
4	Low	Low	Moderate	Low
5	Moderate	Low	Moderate	Moderate
6	High	Low	Moderate	Moderate
7	Low	Low	High	Low
8	Moderate	Low	High	Moderate
9	High	Low	High	High
10	Low	Moderate	Low	Low
11	Moderate	Moderate	Low	Moderate
12	High	Moderate	Low	Moderate
13	Low	Moderate	Moderate	Low
14	Moderate	Moderate	Moderate	Moderate
15	High	Moderate	Moderate	High
16	Low	Moderate	High	Moderate
17	Moderate	Moderate	High	Moderate
18	High	Moderate	High	High
19	Low	High	Low	Moderate
20	Moderate	High	Low	Moderate
21	High	High	Low	High
22	Low	High	Moderate	Moderate
23	Moderate	High	Moderate	High
24	High	High	Moderate	High
25	Low	High	High	Moderate
26	Moderate	High	High	High
27	High	High	High	High

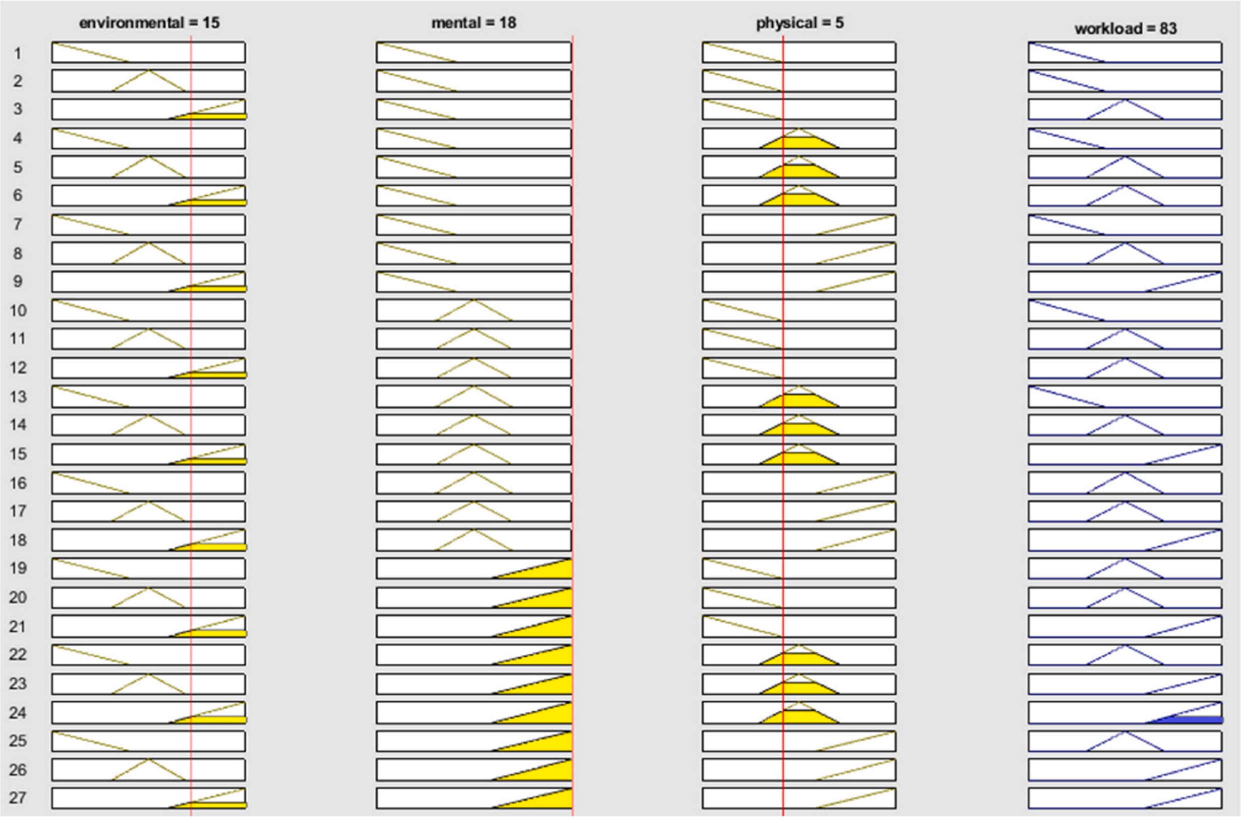

Fig. 4. The screenshot of the fuzzy logic toolbox rule viewer.

Table 5
Patient information.

Patient No	Coordinates	Service time (min.)	Time window (min.)
1	(21, 19)	20	(0–120)
2	(83, 30)	21	(0–540)
3	(19, 45)	22	(0–540)
4	(43, 20)	22	(0–540)
5	(27, 71)	30	(0–540)
6	(21, 82)	28	(0–120)
7	(53, 39)	23	(0–540)
8	(89, 71)	28	(0–540)
9	(77, 32)	24	(0–540)
10	(94, 30)	29	(0–540)
11	(84, 19)	23	(0–540)
12	(89, 21)	15	(300–540)
13	(9, 83)	24	(0–540)
14	(98, 37)	26	(0–540)
15	(21, 20)	24	(0–540)

assume that each new patient initially has a moderate workload level of 50, which will be updated after each visit based on the data gathered from a post-task questionnaire.

To compare the performance of our model, we will evaluate two distinct cases. In Case 1, we incorporate workload constraints, whereas in Case 2, we intentionally exclude these constraints. To construct workload constraints first the permitted workload level for the nurses must be set. For the sake of simplicity, we can determine the permitted workload according to the number of patients visited. Suppose that each nurse is allowed to visit at most five patients who have a moderate workload. According to our workload assessment method, a moderate workload corresponds to score of 50; thus, we can set the permitted workload score as 250. These two models were solved with General Algebraic Modelling System (GAMS) 23.5.1 using Cplex Version 12.2.0.0 solver. For conducting the computational experiments, a computer with an Intel i5-4460 processor, 8 GB of RAM, and a 3.20 GHz core was employed. Instances given in Table 10 were solved using NEOS Server.

Table 6
Possible patient-nurse assignments.

Patient No	Nurse 1	Nurse 2	Nurse 3
1	1	1	1
2	1	1	1
3	1	0	1
4	1	1	1
5	1	1	1
6	1	1	1
7	1	1	1
8	0	1	1
9	1	1	1
10	1	0	1
11	1	1	1
12	1	0	1
13	1	1	1
14	1	1	1
15	1	1	1

Table 7
Workloads of nurses.

Patient No	Nurse 1	Nurse 2	Nurse 3
1	60	73	50
2	74	43	14
3	50		38
4	28	50	76
5	91	31	12
6	29	42	24
7	70	82	50
8	–	50	55
9	50	53	97
10	55	–	25
11	83	56	20
12	30	–	39
13	5	50	32
14	74	33	26
15	91	21	90

The optimal routes, patient-nurse assignments, and workloads of the nurses obtained in the solutions for Case 1 and Case 2 are presented in Tables 8 and 9, respectively. In the optimal solutions, all patients are visited, and each nurse attends to five patients for both cases. However, when comparing the workloads between the two cases, significant differences emerge. The workloads of Nurses 1 and 2 in Case 2 exceed the permitted workload level (see Table 9). Furthermore, the average workload and mean absolute deviation (MAD) of the workloads are lower in Case 1, indicating that nurses have less and more evenly distributed workloads. These results demonstrate that our approach not only reduces the workload level of the nurses but also generates more balanced schedules among them. This is an important in real-life applications, because there may be disagreement among nurses about excessive or uneven distribution of workload.

In order to show the effect of the workload constraints, we also consider some larger problem instances. Some studies have shared the data sets related to HHCRSP in the literature [37,83–86]. However, we cannot use these data sets in our case since they are constructed to cover different aspects of the problem; thus, we created six problem instances randomly with the problem sizes given in Table 10.

All the instances were solved both with and without considering the workload constraints with a CPLEX solver in GAMS software. We obtained the optimal solutions for the first two instances in Case 1 and all instances in Case 2, and the solutions that were within 1.25 % of the optimal solutions for the last four instances in Case 1. Table 11 shows the number of patients visited, the average workload, the MAD of workload, and the number of nurses who exceed the permitted workload level for two cases. The nurses deliver

Table 8
The optimal solution of the model with workload constraints.

Nurses	Patient visit sequence	Workload
1	1-12-13-6-4	152
2	5-8-9-14-15	188
3	7-10-11-2-3	147
	Average workload	162.33
	MAD	17.11

Table 9
The optimal solution of the model without workload constraints.

Nurses	Patient visit sequence	Workload
1	14, 13, 6, 10, 15	254
2	1, 11, 4, 7, 9	314
3	5, 8, 3, 2, 12	158
	Average workload	242
	MAD	56

Table 10
Problem instances.

Instance No	Number of Patients	Number of Nurses
1	20	3
2	30	5
3	40	7
4	50	9
5	60	11
6	70	13

HHC services to all the patients in all instances, i.e., our primary objective is achieved. However, when we compare the cases in terms of workload, the average workload, MAD of workload, and the number of nurses exceeding the permitted workload are significantly decreased when the workload constraints are included in the model. For instance, the average workload is 48.61, MAD is 15.76, and there is no nurse that exceeds the permitted workload in the last instance of the Case 1, whereas the average workload is 293.54, MAD is 65.26, and 9 out of 13 nurses exceed the permitted workload in Case 2.

As a result, our model enables nurses to provide the same level of HHC services while both lowering their workload and providing a more balanced workload, which may help reduce the risk of work-related illnesses.

6. Sensitivity analysis

In this section, we perform a sensitivity analysis to observe the effect of varying workload on the nurse schedule, which is the primary focus of our research. Specifically, our aim to assess how many patients can be visited under specified workload levels. This information is important in practical application since the admission of new patient to the system may be made on this information. To perform sensitivity analysis, we consider the numerical example presented in Section 5, which includes 3 nurses and 15 patients and the maximum permitted workload of 250. Table 12 shows the outcomes of sensitivity analysis for different permitted workload levels, ranging from 250 to 100.

As we decrease the permitted workload levels, the number of patients visited decreases slightly. This suggests that the model is less sensitive to workload variations. As expected, when the permitted workload level is decreased, a more balanced schedule is obtained. Furthermore, it's worth noting that, this problem might have multiple optimal solutions where the same number of patients is visited. This gives decision-makers the flexibility to choose the alternative schedule that offer more balanced workloads. Our model primarily ensures that nurses do not have excessive workloads, but it doesn't guarantee perfect balance among them. For instance, when considering Scenarios 4 and 5, both involving 14 patients visited. Scenario 5 should be preferred due to its lower permitted workload level and a more evenly distributed workload. These results show that further analysis may be necessary for setting appropriate workload limits for nurses.

7. Managerial insights

Effective nurse scheduling is a vital component of successfully managing HHC operation. Optimizing the nurse scheduling, with a focus the skills and workloads of the nurses is crucial for ensuring high-quality patient care and a motivated, well-supported nursing team. This study offers valuable insights into how such optimization can be applied in real-world scenarios.

First, the subjective workload assessment method presented in this study can be easily implemented in the dynamic environment of home health care services, resulting in a more reliable assessment of workloads.

Second, our model generates schedules that assign nurses to patients based on their skills and maintain an acceptable workload level, while also providing a convenient lunch break for each nurse.

8. Conclusion and further research

HHC nurses are exposed to physical, mental and environmental ergonomic risk factors. As a result, home health care nurses often encounter health problems such as work-related musculoskeletal diseases and burnout syndrome. Since HHC nurses work in a wide variety of settings, ergonomic risks cannot be eliminated by ergonomic interventions. One method to eliminate these risks is to

Table 11
Average and ranges of the workloads.

Instance size	Case 1: with workload constraints				Case 2: without workload constraints			
	No. Patient visited	Ave. workload	MAD of workload	No. Nurse exceeding permitted workload	No. Patient visited	Ave. workload	MAD of workload	No. Nurse exceeding permitted workload
(20 × 3)	20	219.00	5.33	0	20	302.00	48.00	2
(30 × 5)	30	212.66	28.32	0	30	313.20	55.84	5
(40 × 7)	40	72.71	33.18	0	40	244.71	68.16	2
(50 × 9)	50	52.44	14.37	0	50	295.33	62.26	6
(60 × 11)	60	67.72	35.70	0	60	263.82	84.56	6
(70 × 13)	70	48.61	15.76	0	70	293.54	65.26	9

Table 12
The result of the sensitivity analysis.

Scenario No	Permitted workload level	No. Patients visited	Actual Workloads			Average. workload
			Nurse 1	Nurse 2	Nurse 3	
1	250	15	152	188	147	162.33
2	225	15	152	188	147	162.33
3	200	15	152	188	147	162.33
4	175	14	152	157	109	139.33
5	150	14	142	135	147	141.33
6	125	12	92	104	109	101.66
7	100	11	92	71	97	86.66

distribute the workload due to ergonomic risk factors among the nurses as evenly as possible.

In this study, our aim is to determine the routes and schedules of HHC nurses considering the workloads depending on ergonomic risks in order to reduce workload-related risks among nurses. As far as we know, this is the first study to take ergonomic aspects into account in HHCRSP. We constructed a mathematical model that ensures nurses have a workload less than a predetermined workload level. Our primary goal is to maximize the number of patients visited. However, we observed that, at a specified workload level, the problem may be alternative solutions where the number of patients visited is the same. In order to utilize these alternative solutions and achieve a lower workload level, we adjusted the objective function to maximize patient visits while minimizing nurses' workload levels as much as possible.

To determine the workload of nurses, we offered a subjective workload assessment method and let nurses determine their own workloads. This approach is more practical since it considers both individual differences among nurses and the wide range of working conditions in the HHC system. A post-task questionnaire was designed to collect the perceived workload experienced by HHC nurses as a result of some ergonomic risk factors during their visits, and the FIS mechanism was used to assess the workloads.

We applied our model to several problem instances by varying the number of patients and nurses (15 × 3, 20 × 3, 30 × 5, 40 × 7, 50 × 9, 60 × 11, 70 × 13) to investigate the impact of workload on the nurse daily schedules. We observed a significant reduction in both average workloads (33 %, 27 %, 32 %, 70 %, 82 %, 74 %, 83 %, respectively) and mean absolute deviations (69 %, 89 %, 49 %, 51 %, 77 %, 58 %, 76 %) when workload constraints were considered. These results demonstrate that our approach not only reduces the workload level of the nurses but also generates more balanced schedules among them, potentially lowering the risk of work-related illnesses. The sensitivity analysis on workload constraints shows that the permitted workload levels can be lowered without decreasing the number of patients visited, since the problem may have potential alternative solutions. Therefore, the most appropriate workload level can be determined by consecutively solving the problem and setting the maximum workload level among nurses obtained from the previous solution as the permitted workload level.

The purpose of this study is to emphasize the importance of ergonomics in HHC nurse scheduling problems and to present a practical approach for determining workloads associated with ergonomic risks. However, this study comes with several limitations that warrant further investigations.

Firstly, our study focuses on generating daily schedules for nurses. Although our model reduces the daily workloads of nurses, it does not guarantee a balanced workload. Future research could explore the development of new models designed specifically to achieve workload balance, which may involve the incorporation of nonlinear constraints into the model.

Secondly, there may be an imbalance among nurses when weekly or monthly workloads are considered. Thus, multiple time periods should be considered to overcome this problem. However, this may lead the other challenging problems such as estimating the future demands for HHC since the number of patients in the system various constantly.

Thirdly, although our study considers common constraints such as time windows, nurses' skill levels, workloads, and lunch breaks, it's important to recognize that HHC services are subject to additional industry-specific constraints, such as ensuring continuity of care and synchronized visits by two or more nurses. Extending the model to encompass these constraints could enhance its practical applicability.

Fourthly, we used a subjective method to assess nurses' workloads, which may introduce bias into the assessment. To achieve a more realistic workload assessment, this subjective method could be complemented with objective approaches.

Finally, heuristic methods can be used to solve this problem since it is NP-hard.

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The data that has been used is uploaded as supplementary material.

Ethical statement

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CRediT authorship contribution statement

Zehra Durak: Writing - original draft, Investigation, Formal analysis, Conceptualization. **Ozcan Mutlu:** Writing - review & editing, Supervision, Project administration, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

List of abbreviations

AHP	Analytic Hierarchy Process
ANFIS	Adaptive Network Based Fuzzy Inference System
ANN	Artificial Neural Networks
EWSI	Ergonomic Workload Stress Index
FIS	Fuzzy Inference System
HHC	Home Health Care
HHCRSP	Home Health Care Routing And Scheduling Problems
ISA	Instantaneous Self Assessment
MAD	Mean Absolute Deviation
NIOSH	National Institute For Occupational Safety And Health
NASA-TLX	Nasa Task Load Index
OWAS	Ovako Working Posture Analysis
OCRA	Occupational Repetitive Actions
OWL	Overall Workload Level
REBA	Rapid Entire Body Assessment
RULA	Rapid Upper Limb Assessment
RPE	Rating Of Perceived Exertion
SI	Strain Index
SWAT	Subjective Workload Assessment Technique
WMSDs	Work-related Musculoskeletal Diseases
WP	Workload Profile

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e23896.

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