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# Effects of NSGA-II Algorithm in Compare to Bee Colony Optimization on Nurse Scheduling Problem

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**Abstract**

In this paper, a nurse scheduling problem in work shifts in a medical center and solving the model by Bee Colony Optimization (BCO) has been addressed. First, a multi-objective Mathematical model is presented in which nurses have been allocated based on different capabilities in a 30-day scheduling program considering the soft and hard constraints of the model. Then by reviewing the work regulations of nurses in hospitals of China, two sample problems have been designed and solved with the proposed algorithm. Also, in this paper, a comparison between the results of Bee Colony Optimization (BCO) algorithm and the Non-Dominated Sorting Genetic Algorithm (NSGA-II) has been made, and the results showed that bee colony optimization has a higher capability in discovering and searching in the more solutions infeasible area to find a better solution than the NSGA-II algorithm.

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## 1. Introduction

Workforce scheduling is defined as the allocation of the qualified workforce in order to supply the time-dependent demand for productions or different services while the considered work regulations and stipulations and employee preferences and employer goals are satisfied. Special needs of production and service industries to human resources have to lead to the presentation of varied scheduling models and as a consequence, to more solving techniques.

In the literature, different classifications have been proposed for workforce scheduling problem. For instance, Tien and Kamiyama (1982) divided the general workforce scheduling problem into five sub problems including temporary staff requirements, total staff requirements, recreation and leave, work schedules and shift schedules. Baker (1976) has also divided the workforce scheduling problem into three sub problems including Shift scheduling (time-of-day scheduling), Days-off scheduling (Days-of-Week scheduling) and Tour scheduling which is a combination of the first two sub problems. But a more accurate classification has been proposed by Ernest et al. (2004). They considered multiple modules associated with the process of making a schedule. A part of or all of these modules may be found in making up scheduling in a specific practical environment. Whereas this research

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study is defined in the area of medical services, in following, a brief overview of some of the most critical research in this area is given.

A significant concentration of planning and scheduling in healthcare service systems, especially in hospital sections with acute illnesses is on nurse scheduling. There are two clinical and sumptuary requirements in providing appropriate workforce in different medical parts of a hospital. Plans should provide qualified nurses to cover the demand originated from the number of patients, consider working regulations between permanent and temporary workforce, guarantee that the night shifts and weekend shifts are fairly distributed among employees, consider leave and recreation of employees and try to satisfy the employee preferences as much as possible. Most of the times, scheduling problems have many constraints.

The 1970s and 1980s approaches show some of the problem formulations and their solving techniques. The aim of most of these studies is to provide backup tools in order to reduce hand-made nurse plans. Some of the reviews (Rothe and Wolfe, 1973; Freund and Wanger, 1977; Baker and Marciante, 1975) proposed the determination of workforce and required qualifications problem based on the number of patients and medical requirements. Some others chose mathematical programming (Warner and Prawda, 1972; Trivedi, 1974), branch and border (Ravindran, 1981) or goal programming (Ozkarahan, 1991). Others (Smith, 1976; Bradley and Martin, 1991) used iterative algorithms to generate periodic plans in which nurses reasonably start a sequence of shifts with different time schedules so that the covering and combination of required qualifications are satisfied in each section.

In some of the articles from the 1990s (Jaumard et al., 1998), researchers have worked on the classification of nurse planning systems and reviewing different methods for solving different problem sets. Moreover, more progress in the application of linear programming or mixed integer programming and network optimization techniques for generalizing the nurse plans were made (Millar and Kiragu, 1998; Sattar, 1996). Constraint programming (CP) methods (Eeil et al., 1995) have also been used for modeling complicated regulations related to nursing plans. Above methods have been applied to problems including periodic and non-periodic planning, and these problems involved the rules of a specific hospital. Proposed approaches for hospital applications may require reformulation. Some of the approaches used the combination of innovative methods and modeling techniques for solving complicated nurse scheduling and clinical services. For instance, Nooriafshar (1995) proposed a completed modeling technique by using Artificial Intelligence (AI) for placement of nurse training on the schedule. Randhawa and Sitompul (1993) provided a decision backup system based on a shift pattern generator innovative method for generalizing weekly work schedule. Isken and Hancock (1991) used a refrigerating modeling algorithm for solving a vast covering set for formulating integer programming to generalize schedules with the combination of the permanent and temporary workforce with determined demand in a half-hour period of time over the duration of ten days. Siferd and Benton (1994) used modeling to evaluate the day to day scheduling of the nurses based on decisions that originated from stochastic models of patient's critical situations. Lukman et al. (1991) discussed the generalization of a knowledge-based system in order to generate the weekly schedule of nurses and regulate plans in reaction to daily changes in demand and availability of the workforce. Hosseinabadi and Tirkolaee (2018) proposed a novel method is proposed based on a Gravitational Emulation Local search (GELS) algorithm for task scheduling among agents and load balancing used the combination of forbidden search and integer programming to generate weekly schedules in which a complicated set of shift rules, cost constraints, nurse ranking and preference constraint of employees have been satisfied. Shahraki and et al. (2018) Given that the problem is NP-Hard, Tabu Search (TS) is used to solve the developed model while used a hybrid forbidden search algorithm to gain solutions in a reasonable timeframe for a commercial system in nurse planning. After that, the proposed approach of Burke et al. (1998) has been improved by a set of mimetic algorithms. Aickelin and Dowsland (2004) used NSGA-II algorithm to solve the nurse scheduling problem in a hospital in England. Bellanti et al. (2004) proposed a neighborhood search approach and a greedy procedure to prevent the generation of impractical solutions in nurse scheduling problem and used the forbidden search approach and an iterative Local Search (LS) algorithm to solve the problem. Bard and Pornomo (2005) considered a nurse scheduling problem in which multiple contradictory factors affect the process of decision making and used a columnar generation approach which is a combination of integer programming and meta-heuristic methods to solve this single objective problem. In the proposed model, they (2005) considered personal preferences of nurses and demand for leave in some days of scheduling simultaneously with covering the order of all shifts. For solving the multi-objective optimization problem, the non-dominated sorting genetic algorithm II (NSGA-II) Deb et al. (2002) is employed. Three numerical examples are implemented with the presence of Pareto optimal solution set. In addition, the present results are also compared with those of previous study in the literature to demonstrate the reliability and effectiveness of the proposed approach. Beddoe and Petrovic (2006) presented a new method for making a decision about nurse scheduling and planning and adapted the technique for solving new problems based on a case-based reasoning paradigm (CBR). Gutjahr and Rauner (2007) used Ant Colony Optimization (ACO) algorithm for solving a dynamic nurse scheduling problem in a hospital in Austria. Bard and Purnomo (2007) formulated the periodic nurse scheduling and planning problem while the problem considered the quality of every individual plan in the integer programming form and solved the problem by using an innovative method based on Lagrange liberation. Tsai and Li (2009) generalized a two-step mathematical modeling for a nurse scheduling system in which regulations of hospital management, governmental regulations and preferences of nurses are considered and the problem is solved by using the NSGA-II algorithm. Burke et al (2010) presented a multi-objective model which was a combination of integer programming and Variable Neighborhood Search (VNS) for nurses scheduling and planning problem in modern hospital environments with many constraints. Also, Glass and Knight (2010) concentrated on nurse scheduling and planning problem and analyzed four sample problems from the literature in order to provide an approach to the nature of the problem. They reduced the related solution space of the problem by determining the problem structure and used a mixed integer programming method to find the optimal solution for four sample problems. Topaloglu and Selim (2010) presented a new multi-objective mathematical integers programming model by considering uncertainty in preference goal values of nurses and hospital management and divided the model into three fuzzy goal programming models by using different fuzzy approaches. Burke et al. (2010) also used a Scatter Search (SS) approach for nurse scheduling and planning. Han et al. (2014) proposed an improved NSGA-II for multi-objective LSFS (Lot-streaming flow shop) scheduling problems, in which EDA (Estimation of distribution algorithm) and a mutation operator based on insertion and swap are utilized to replace traditional crossover and mutation operator based on insertion and swap are utilized to replace traditional crossover and mutation operators.

In the field of nurse scheduling, Shahnazari et al. (2012) in another study addressed this problem. In this problem, there are three shifts in a day. Two six-hour morning and afternoon shifts and a 12-hour night shift, also nurses are in three levels of capability, and a higher capability nurse can be assigned to a lower level of capability. For solving the problem, they used waterfall and DE algorithms. M'Hallah and Alkhabbaz (2013) analyzed the nurse scheduling problem in health protection unit of the country of Kuwait. They presented a mix integer mathematical model for their problem in which minimum and maximum allowed hours in each day for nurses and number of consecutive night shifts (two consecutive night shifts are permitted) are considered.

Abdollahi and Ansari (2013) analyzed the nurse scheduling problem in their article and presented a mathematical goal programming for the problem. In their mathematical model, priorities of nurses are considered. They used hospital data as a case study and carried out the modeling process according to existing regulations in ICU unit of the hospital and also used the data of this unit for solving the problem.

Tontarski (2014) analyzed the nurse scheduling problem in his research. He presented a methodology for optimized nurse allocation to work shifts in the planning period. His mathematical model has two shifts every day in which nurses have specific conditions in the process of distribution. He used a modeling technique for implementing the model dynamically and statically. Malmir (2014) used GMDH type neural networks and NSGA-II algorithm to solve a multi-objective optimization problem. Bagherinejad and shoeib (2018) compared the performance of GA and bee in solving covering location problems. Firouzi and Malmir (2016) combined Tabu Search and NSGA-II so solve NP-hard multi-objective problems for the same purpose. Ning et al. (2018) An archive-based multi-objective artificial bee colony optimization algorithm is proposed and compared with the existing multi-objective meta-heuristic algorithms; it uses less control parameters and can be effectively used for solving multi-modal and multi-dimensional optimization problems. Mirjalili et al. (2017) results are verified by comparing MOALO against NSGA-II and MOPSO. The results of the proposed algorithm on the test functions show that this algorithm benefits from high convergence and coverage.

## 2. Methodology

### 2.1. Problem Definition

As mentioned above, this article is devoted to the nurse scheduling model in work shifts. In this problem, the number of nurses is determined, and there are three qualification levels for nurses: Paramedic, Paramedic assistant and nurse. Nurses in all levels of qualification are scheduled in a 28-day period in morning, afternoon and night shifts.

In this section for the nurse scheduling problem, a four-objective model is presented, and the details are as following:

### 2.2. Sets

*I:* Set of nurses
*K*: Set of days
*J:* Set of shifts
*S*: Set of qualification levels
*Ω*: Set of scenarios

### 2.3. Indices

*i:* Index of nurses which *i = 1,2, …, I*
*k:* Index of days which *k = 1,2, …,K*
$\omega$: Index of scenarios $\omega = 1 \ldots \Omega$
*j*: Index of shifts which *j = 1,2,3 (j =1: morning, j=2: afternoon, j=3: night)*
*s*: Index of qualifications level which *s = 1,2,3 (s=1: paramedic, s=2: paramedic assistant, s=3: nurse)*
*LK:* Index of last day of each week during scheduling period
*(lk = 7, …, LK)*; in this model: *(lk=7,14,21,28)*, |*LK*| is equal to the cardinality of *LK* set; in this model |*LK*|*=4*

### 2.4. Parameters

$dh_{max}$: Maximum working hours for each nurse in a day
$h_{kj}$: Length of *j*th shift in *k*th day.
$p_{\omega}$: Probability every scenario happen
$\delta$ : Penalty coefficient for deviation from criterion
$\rho$: Penalty coefficient for deviation from criterion
$wh_{min}$: Lower bound on all hours that a nurse worked during a week
$wh_{max}$: Upper bound on all hours that a nurse worked during a week
$mh_{min}$: Lower bound on all hours that a nurse worked during a scheduling period (1 month)
$mh_{max}$: Upper bound on all hours that a nurse worked during a scheduling period (1 month)
$RN_{kjs\omega}$: Total number of required nurses in *sth* level of qualification in *jth* shift in *kth* day under $\omega$ scenarios
Max-night: maximum number of night shifts that a nurse can work during a scheduling period.
*Penl*: amount of penalty for allocating a nurse to a lower level of qualification
$RSL^{i}_{kjs}$: 1, if ith nurse can work in his/her real level of qualification or a lower level of qualification *s*th in *j*th shift from *k*th day; 0, otherwise.
$k_i$: The days that *i*th nurse prefers not to be allocated to work in all or some shifts.
$j_{k_i}$: The shifts in the day $k_i$ that ith nurse prefers not to be allocated to work.
*LK*: set of last days from all weeks during working schedule.
$d^{1i}_{kj}$: Variation from the days or shifts that ith nurse prefers not to be allocated to work.
$d^{2i}_{k_1}$: Variation from lower bound on all hours that ith nurse worked during a week.
$d^{3i}_{k_1}$: Variation from upper bound on all hours that ith nurse worked during a week.

### 2.5. Decision Variables

$x_{kjs}^{i}$: 1 if nurse *i* is allocated to work in the level of qualification s in shift *j* in day *k; 0* if otherwise
$O_k^i$: 1 if nurse *i* is continuously allocated to work in the morning and afternoon shifts of day *k*; 0 if otherwise.
$F_k^i$: 1 if nurse *i* is allocated to work in the night shift of day *k; 0* if otherwise
$d_{kj\omega}^{+}$: More deviation of the number of nurses from the number of nurses in the days or the shifts we need for the nurse.
$d_{kj\omega}^{-}$: Less deviation of the number of nurses from the number of the nurses in the days or shifts in which we need nurses.
$\mathrm{d}_{\mathrm{kjs}}^{1\mathrm{i}}$: Deviations from the days or shifts that the nurse *i* tends to not assign to work.
$d_{k_{1\omega}}^{2i}$: Deviation from lower bound on the total number of hours worked by nurse i during a week
$d_{k_{1\omega}}^{3i}$: Deviation from upper bound on the total number of hours worked by nurse *i* during a week
$\pi_\omega$: Auxiliary variable
$\mu_\omega$: Auxiliary variable

## 3. Mathematical model

In this section, according to the above definitions, a mathematical model will be presented. First, objective functions and then the constraints of the model will be explained in the following.

Minimizing the cost of allocating a nurse to a level of qualification that is lower than his/her real level of qualification:

Minimizing the cost of allocating a nurse to a level of qualification that is lower than his/her real level of qualification:

$$Z_1 = Min \sum_i \sum_k \sum_j \sum_s \left[ \left( s - RSL^i \right) \times X_{kjs}^i \times Penl \right] \tag{1}$$

Minimizing the summation of variations from days and shifts in which nurses prefer not to be allocated to work:

$$Z_2 = \sum_i \sum_k \sum_j \sum_s d_{kjs}^{1i} \tag{2}$$

Minimizing the number of morning and afternoon shifts that a nurse is continuously allocated to:

$$Z_3 = Min \left( \sum_i \sum_k O_k^i \right) \tag{3}$$

Minimize the deviation from the number of nurses required under any scenario:

$$\mathrm{Z}_4(\omega) = \sum_k \sum_j \sum_s \left( d_{kjs\omega}^{-} + d_{kjs\omega}^{+} \right) \tag{4}$$

$$Min \sum_\omega p_\omega \mathrm{Z}_5(\omega) + \rho \sum_{\acute{\omega}} \left( \mathrm{Z}_5(\acute{\omega}) - \sum_\omega p_\omega Z_5(\omega) + 2\mu_{\acute{\omega}} \right) \tag{5}$$

Minimizing the summation of variations from lower and upper bounds on all hours that a nurse worked during a week.

$$Z_5 = Min \sum_{i} \sum_{k_1=1}^{|LK|} (d_{k_1}^{2i} + d_{k_1}^{3i}) \tag{6}$$

$$Min \sum_{\omega} p_{\omega} \mathrm{Z}_4(\omega) + \delta \sum_{\acute{\omega}} \left( \mathrm{Z}_4(\acute{\omega}) - \sum_{\omega} p_{\omega} \mathrm{Z}_4(\omega) + 2\pi_{\acute{\omega}} \right) \tag{7}$$

### 3.1. Constraints

#### 3.1.1. Hard Constraint

The Maximum number of working hours that a nurse can work each day:

$$\sum_{j} \sum_{s} h_{kj}\, x_{kjs}^{i} \leq dh_{max} \qquad ; \forall\ i, k \tag{8}$$

The Minimum number of working hours that a nurse can work in a 1-month scheduling period:

$$\sum_{k} \sum_{j} \sum_{s} h_{kj} x_{kjs}^{i} \geq mh_{min} \qquad ; \forall\ i \tag{9}$$

The Maximum number of working hours that a nurse can work in a 1-month scheduling period:

$$\sum_{k} \sum_{j} \sum_{s} h_{kj} x_{kjs}^{i} \leq mh_{max} \qquad ; \forall\ i \tag{10}$$

The Total number of required nurses in every level of qualification in every shift of every day:

$$\sum_{i} x_{kjs}^{i} + d_{kjs\omega}^{-} - d_{kjs\omega}^{+} = RN_{kjs\omega} \qquad ; \forall\ k, j\ , \forall \omega \in \Omega \tag{11}$$

Every nurse cannot work in an upper level of qualification of everyday shifts.

$$\sum_{s} x_{kjs}^{i} \leq 1 \qquad ; \forall\ i.j.k \tag{12}$$

Every nurse can work in his/her level of qualification of lower than his/her real level of qualification.

$$x_{kjs}^{i} \leq RSL_{kjs}^{i} \qquad ; \forall i.k.j.s \tag{13}$$

Consecutive night shifts are not allowed:

$$\sum_{k=k_1}^{k_1+1} \sum_{s} x_{k(j\in 3)s}^{i} \leq 1 \qquad ; \forall\ i.k_1 \in [1.\dots.K-1] \tag{14}$$

The Maximum number of night shifts that a nurse can work in a 1-month scheduling period:

$$\sum_{k} \sum_{s} x_{k(j\in 3)s}^{i} \leq max - night \qquad ; \forall\ i \tag{15}$$

The night shift of morning shift or afternoon shift and night shift in a day and also night shift and morning shift in the next day is not allowed, i.e. nurses cannot work more than 12 hours in a day or 12 hours continuously.

$$\sum_{s}\sum_{j\in 1} x_{kjs}^{i} + \sum_{s}\sum_{j\in 3} x_{kjs}^{i} \leq 1 \quad ;\forall\, i.k \tag{16}$$
$$\sum_{s}\sum_{j\in 2} x_{kjs}^{i} + \sum_{s}\sum_{j\in 3} x_{kjs}^{i} \leq 1 \quad ;\forall\, i.k \tag{17}$$
$$\sum_{s}\sum_{j\in 3} x_{kjs}^{i} + \sum_{s}\sum_{j\in 1} x_{(k+1)js}^{i} \leq 1 \quad ;\forall\, i.k \tag{18}$$
$$\sum_{j}\sum_{s} x_{kjs}^{i} \leq 2 \quad ;\, \forall\, i.k \tag{19}$$

If a nurse continuously works a morning shift and an afternoon shift and a night shift or a night shift in a working day, he/she should take the next day off from work.

About continuous morning and afternoon shift, we have:

$$O_k^i - \sum_{s} x_{k1s}^{i} \leq 0 \quad ;\forall i.k \tag{20}$$
$$O_k^i - \sum_{s} x_{k2s}^{i} \leq 0 \quad ;\forall i.k \tag{21}$$
$$O_k^i - \sum_{s} x_{k1s}^{i} - \sum_{s} x_{k2s}^{i} \geq -1 \quad ;\forall i.k \tag{22}$$

These three constraints guarantee that:

$O_k^i$ = 1, if nurse i is continuously allocated to work a morning and afternoon shift in day *k*. *0*, if otherwise.

Then, this rule can be validated by adding the following constraint:

$$\sum_{s} x_{k1s}^{i} + \sum_{s} x_{k2s}^{i} + \sum_{j}\sum_{s} x_{(k+1)js}^{i} + O_k^i \leq 3 \;\; ;\forall i.k \in \{1.\dots.29\} \tag{23}$$

About night shift we also have:

$$F_k^i - \sum_{s} x_{k3s}^{i} = 0 \quad ;\forall i.k \tag{24}$$

This constraint guarantees that:

$F_k^i$ = 1, if nurse i is allocated to work in the night shift of day *k*; 0, if otherwise.

Then, this rule can be validated by adding the following constraint:

$$\sum_{s} x_{k3s}^{i} + \sum_{j}\sum_{s} x_{(k+1)js}^{i} + F_k^i \leq 2 \quad ;\forall i.k \in \{1.\dots.29\} \tag{25}$$

A nurse cannot take four consecutive days off from work:

$$\sum_{k=l}^{l+4}\sum_{j}\sum_{s} x_{ljs}^{i} \geq 1 \qquad ;\forall i, l \in \{1.\dots.26\} \qquad (26)$$

In every shift of every day, there should be at least one nurse with the highest level of qualification:

$$\sum_{i} x_{kj(s\in 1)}^{i} \geq 1 \qquad ;\ \forall\ k, j \qquad (27)$$

### 3.1.2. Soft Constraint

Nurses prefer not to be allocated to work on the days and shifts that they determined not to work before.

$$x_{kjs}^{i} + d_{kjs}^{1i} = RSL_{kjs}^{i} \qquad ;\forall i, k \in k_i, j \in j_{k_i}, s \in S \qquad (28)$$

$$d_{kj}^{1i} \geq 0 \qquad ;\forall i. k \in k_i. j \in j_{k_i} \qquad (29)$$

These limitations are added to the model for positive deviation from the mean:

$$Z_4(\acute{\omega}) - \sum_{\omega} p_{\omega} Z_4(\omega) + \pi_{\acute{\omega}} \geq 0 \qquad \forall \acute{\omega} \in \Omega \qquad (30)$$

$$Z_5(\acute{\omega}) - \textstyle\sum_{\omega} p_{\omega} Z_5(\omega) + \mu_{\acute{\omega}} \geq 0 \qquad \forall \acute{\omega} \in \Omega \qquad (31)$$

Lower and upper bound on all hours that a nurse worked during a week:

$$\sum_{k=7k_1-6}^{7k_1}\sum_{j}\sum_{s} h_{kj} x_{kjs}^{i} + d_{k_1\omega}^{2i} \geq wh_{min} \qquad ;\forall i, k_1 \in \{1, \dots, |LK|\}, \forall \omega \in \Omega \qquad (32)$$

$$\sum_{k=7k_1-6}^{7k_1}\sum_{j}\sum_{s} h_{kj} x_{kjs}^{i} - d_{k_1\omega}^{3i} \leq wh_{max} \qquad ;\forall i, k_1 \in \{1, \dots, |LK|\}, \forall \omega \in \Omega \qquad (33)$$

$$d_{k_1}^{2i} \geq 0 \qquad ;\forall i. k_1 \in \{1.\dots.|LK|\} \qquad (34)$$

$$d_{k_1}^{3i} \geq 0 \qquad ;\forall i. k_1 \in \{1.\dots.|LK|\} \qquad (35)$$

$$x_{kjs}^{i} \in \{0, 1\} \qquad ;\forall i. j. k. s \qquad (36)$$

$$O_k^i \in \{0, 1\} \qquad ;\forall i. k \qquad (37)$$

$$F_k^i \in \{0, 1\} \qquad ;\forall i. k \qquad (38)$$

## 4. Solving method

In this paper, Bee Colony Optimization has been used in order to solve the proposed model and the results gained from this algorithm have been compared with the results of the NSGA-II algorithm based on multiple objective problem indexes Vahdani et al. (2019) In this section structure of the proposed Bee Colony Optimization (BCO) has been explained.

### 4.1. Bee Colony Algorithm

Bee Colony Algorithm (BCA) which is proposed by Pham et al. (2005) is an innovative group algorithm that imitates the food-seeking behavior of honey bees. In this paper, honey bee colony algorithm has been used in order to optimize the optimum combination of the factors that affect learning. This algorithm requires multi-variable functions. In the following, first the behavior of honey bees will be viewed, and then the Bee Colony algorithm will be explained.

Bee colony starts to search for food by sending the scout bees, so that a stochastic search for promising food resources can be performed. Bees can fly long distances (14 kilometers) and in different directions to exploit food resources, and by this sequence, the exploitation of many food resources will be guaranteed. During the search process, some bees in the colony are always considered as scout bees. If the quality of the gathered ambrosia from a resource is more than a threshold value, the scout bee will save the supply and will draw the attention of the other bees by performing a waggle dance. The waggle dance is vital for communications in the colony and includes all of the necessary information outside of the hive. Bees in the hive choose the food resources based on the knowledge gained from the waggle dance of scout bees. Therefore, more bees will visit the promising food resource, which leads to an efficient food seeking process. Dispatching more bees to a promising food resource continues until the fitness of that food resource is above the threshold value.

Pseudo-code of the proposed structure of BCA is as follows:

*{Initialization:*
*Initialize the algorithm parameter.*
*Generate N feasible solution as initial population.*
*While criterion is met*
*Calculate the fitness for each solution in current population.*
*Select the best bees and their location as p1 set.*
*Select the other bees and their location as p2 set.*
*Apply neighborhood search operator on p1 set,*
*Assign some bees to obtained solutions and calculate their fitness.*
*Apply random neighborhood search operator on p2.*
*Calculate their fitness.*
*Select the N best bees of each location.*
*Update pareto archive.*
*Select N solution as population of next generation.*
*End while*
*Return the best solution.*
*}*

In fact, in BCA, there is a crowd of bees in which every bee is on a food resource (solution). Bees will be divided into two groups P1 and P2. P1 moves toward better food resources (solution) by using neighborhood search. P2 will search for food resources in a stochastic manner, and it is continued until the optimum food resource (solution) is found. Also, we can show a general flowchart of this HBA to make it a better solution for the next stage.

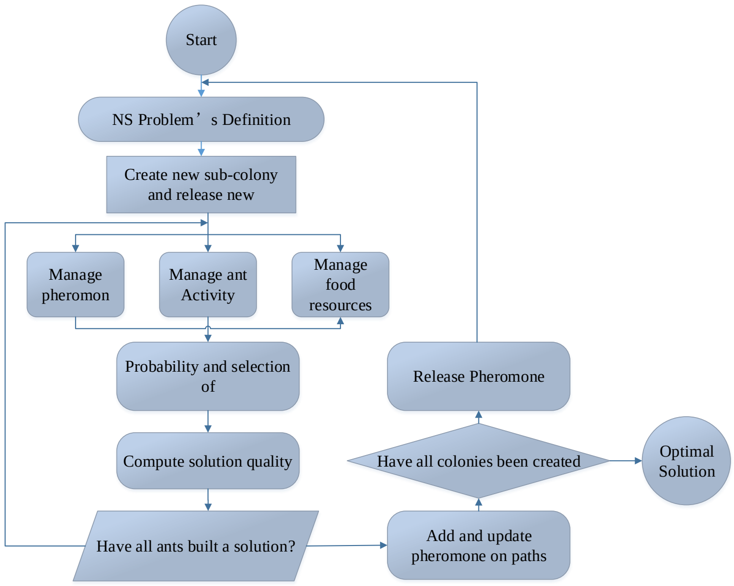


**Fig.1.** Flowchart of HBA.

### 4.2. Solution representation method

In all meta-heuristic algorithms, due to the need for a feasible solution, it is required to save the feasible solution in a specific structure which is called solution representation method. A feasible solution to the problem in this article is represented by a two-dimensional matrix in which the rows of the matrix are equal to the number of nurses, and the columns are similar to the multiplication of the number of days in the scheduling and number of shifts in every day of schedule. Elements of the matrix represent the level of qualification that the allocated workforce in the day and the shift has. For instance, in the under-study problem, if the value of an element in (3, 11) is equal to two, it means that the third workforce in day six and morning shift is allocated to qualification number two.

### 4.3. Solution initialization method

In this study, in order to initialize a high-quality solution, a parallel neighborhood search with multiple starts has been used. The designed parallel neighborhood search method in this work includes three neighborhood search structures which apply to a solution at the same time. This method first starts with a feasible initial solution. Method of generating a feasible solution is as follows:

1. For every day *i*, the first shift for every qualification equal to demand is chosen randomly among the nurses who can work.

1.1. For scheduling the rest of the days and shifts except the first shift of day *i*, the method is as follows:

For every qualification until the satisfaction of the demand, from the nurses who can work (the nurse, who is allocated less till now, is chosen and assigned).

Besides, when choosing a nurse for qualification, the analysis starts from the nurses whose

Level of skill is closer to the case that is under canvassing.

2. Increment *i* and go to step 1

Designed structures for neighborhood search of the solution are as following:

#### 4.3.1. First neighborhood search operator

The working mechanism of this operator is: It chooses one of the nurses randomly and tries to cancel the allocations of the selected nurse in some days (by considering the constraints) and gives the canceled allocation days to a nurse who has the qualifications but is not allocated.

#### 4.3.2. Second neighborhood search operator

The working mechanism of this operator: It randomly chooses a nurse. In all shifts, if a nurse is allocated to a level below his/her qualification level, it tries to assign the nurse to shifts which are closer to his/her qualification level. If it is possible, the allocation of this nurse is cancelled and the canceled allocation will be allocated to a qualified nurse or the assignment of this nurse will be substituted with a nurse who has the closer level of qualification.

#### 4.3.3. Third neighborhood search operator

In this operator, a nurse and the index of one of his/her allocation days will be generated randomly. If the selected day is among the days which the nurse prefers to leave, the allocation of that nurse, by considering the constraints will be canceled and the canceled allocation will be given to another qualified nurse with the higher level of preference.

In order to generate the initial solution, first, *N* (size of population) initial feasible solutions will be generated randomly, and all of these solutions will be entered to the parallel neighborhood search structure and the outputs from parallel neighborhood search which are N solutions, are considered as the initial solution. The structure of the parallel search is as follows:

**Step 0**. Set the counter to zero.

**Step 1**. Give the input solution (s) to the first neighborhood structure and label the output as s1.

**Step 2**. Give the input solution (s) to the second neighborhood structure and label the output as s2.

**Step 3**. Give the input solution (s) to the third neighborhood structure and label the output as s3.

**Step 4**. Among s1, s2, s3 and s, substitute the highest quality solution with s.

**Step 5**. Increment the counter.

**Step 6**. If the counter reaches its maximum value, go to Step 7, otherwise, go to Step 1.

**Step 7**. Report s as output and go to Step 8.

**Step 8**. End.

In each iteration, conditions for a solution to be accepted are that the solution with the maximum Euclidean distance with the best solution will be added to the solution population.

### 4.4. Fitness function calculation method

In order to calculate the fitness function, first the solutions will be leveled based on Deb regulation [51], and the crowd distance criteria for each solution will be calculated for the level of solution, that depends on the level at which the answer is. Then for each solution, CS criteria will be calculated as follows which denotes the amount of fitness for each solution.

$$cs = \frac{crowding\ distance}{rank}$$

In the above formula, crowding distance denotes the crowd distance and rank is depends on the level at which the answer is**.**

### 4.5. Local search (P1 group of bees)

To solve the under-study problem, a new method has been designed based on local search. The input of this method is the crowd solution of group p1. This method operates based on neighborhood search. In other words, the mentioned method considers a set of solutions as input and tries to reach the best neighborhood solutions by improving each of these solutions.

To design the mentioned method, in this article a Variable Neighborhood Search (VNS) is used. Variable neighborhood search is created by the combination of multiple neighborhood search operators which, in this study, the number of neighborhood search operators in VNS is three.

Variable neighborhood search method in this study includes three Neighborhood Search Structures (NSS). Each of the structures includes local search operators which have been explained in the initialization section.

Each of the operators is used in a specific structure which is called Neighborhood Search Structure (NSS). In this study, the designed neighborhood search structure is as following:

```
NSS type k,
{for i=1 to nom do
      n_s=local search k th(current solution)
     Current solution=acceptance procedure
 endfor
Return current solution.
 }
```

This structure is the same for all three local search operators. Here, acceptance criteria are designed by using non-dominate relationships, and the dominant solution will be selected. Now, if both solutions have the same quality, the solution which has the most Euclidean distance with the best solution so far will be chosen.

Three neighborhood search structures are combined in the form of variable neighborhood search which is shown as follows.

As mentioned previously, VNS structure is made up of the combination of these three operators. VNS structure is as follows:

The pseudo-code of our VNS is as follows:

*{For each input solution*

*K=1*

*While stopping criterion is met do*

*New solution=Apply NSS type k*

*If new solution is better then*

*K=1*

*Else*

*K=k+1*

*If k=4 then*

*K=1*

*Endif*

*Endif*

*Endwhile*

*}*

### 4.6. Stochastic neighborhood search (p2 group of bees)

Stochastic search in Bee Colony Optimization is for the second group of bees which randomly search for food resource (solution). In order to implement the stochastic search in this study, a number of i between 1and 3 is generated randomly. Also, the $i_{th}$ local search operator will be applied to the solution; if the new solution is better it will be substituted for the current solution.

### 4.7. Pareto archive updating

Since the contradiction between objectives in multi-objective problems, a unified solution in which all goals are optimized in does not exist, a set of dominant solutions (solutions closer to the optimum) are considered as the optimum solution. Here, because of using a method which is based on a Pareto archive for solving the model, existing quality of the solutions available in the files has a vital role. Therefore, in this study, the archive will be updated repeat of Bee Colony Optimization. In order to update the Pareto archive, all of the existing solutions in the Pareto archive and freshly generated solutions will be put into a pool of solutions and then leveled. Subsequently, all of the first level solutions will be considered as new Pareto archive.

## 5. Computational results

In this study, a mathematical model for nurse scheduling problem in work shift is proposed as multi-objective problems. Due to the nature and the complexity of the problem (NP-Hard), a meta-heuristic algorithm has been generalized. In order to evaluate the performance analysis of the model and the proposed algorithm, two sample problems have been solved by the proposed generalized algorithm. In the following, computational results of solving the model by NSGA-II and BCA that have been coded in CPLEX R2009a on a personal computer with 4 GB RAM and 2.27 GHz CPU with two cores will be explained and discussed in detail.

**5.1. Comparison criteria**

To evaluate the performance of the proposed algorithm, three criteria have been used: quality, monotonousness and variation.

Quality criterion: this criterion is equal to the number of Pareto solutions (non-dominated).

Monotonousness criterion: this criterion, analyzes the monotonousness of the distribution of Pareto solutions in the solutions boundary. This criterion is defined as follows:

$$s = \frac{\sum_{i=1}^{N-1} \left| d_{mean} - d_i \right|}{(N-1) \times d_{mean}} \tag{39}$$

In the following equation, $d_i$ denotes the Euclidean distance between two non-dominated adjoining solutions and $d_{mean}$ indicates the mean of $d_i$ values.

Variation criterion: this criterion is used in order to determine the amount of non-dominated solutions found from the optimum boundary. The definition of variation criterion is as follows:

$$D = \sqrt{\sum_{i=1}^{N} \max(\left\| x_t^i - y_t^i \right\|)} \tag{40}$$

In the above equation, $\left\| x_t^i - y_t^i \right\|$ denotes the Euclidean distance between two adjoining solutions $x_t^i$ and $y_t^i$ on the optimum boundary.

In this article, two sample problems are designed to solve, in which the values of the parameters and characteristics of the issues are based on the data gained from a hospital in China. In these sample problems, first, the problem number 1 with 18 nurses and then the second problem with 90 nurses will be analyzed. This section of the article includes the introduction of these sample problems are presented as Table 1 Which is proposed general characteristics of sample problem while around eighteen nurses are shifted as Table 2.

Also in Table 3, the required number of nurses in each shift and each day in scheduling period for an 18-person section are illustrated. in Table A1 and A2 in Appendix present nurse characteristics in five 90-person sections and required number of each skill level of employees per shift of every day during the planning period, a total of 5 sections of 90 people, respectively.

**Table 1.** General Characteristics of the sample problem

| | |
|---|---|
| **30 days** | Planning horizons |
| 3 shifts<br>Shift 1: morning, shift 2: afternoon, shift 3: night | Number of shifts |
| 3 levels of qualifications<br>Qualification 1: nurse, qualification 2: paramedic, qualification number 3: paramedic assistant | Number of qualification levels |
| Morning and afternoon: 6 hours<br>Night: 12 hours | Duration of each shift |
| 12 hours | Maximum allowed working hours in every day for each individual during a week |
| 12 hours | Minimum allowed working hours in every day for each individual during a week |
| 42 hours | Maximum allowed working hours for each individual during a scheduling period |
| 132 hours | Minimum allowed working hours for each individual during a scheduling period |
| 180 hours | Maximum allowed working hours for each individual during a scheduling period |
| 15 money units | Penalty coefficient for allocating each individual in a lower level of qualification than his/her real level |
| 15 shifts | Maximum allowed night shifts in a schedule |

**Table 2.** Characteristic of nurses in an 18-person section

| Nurse number | Actual level of qualification | Preferred days for leaving |
|---|---|---|
| **1** | nurse | - |
| **2** | nurse | 29 |
| **3** | nurse | 28,29 |
| **4** | nurse | - |
| **5** | nurse | - |
| **6** | nurse | 24,25,26 |
| **7** | nurse | 9,10,11,12 |
| **8** | nurse | 26 |
| **9** | nurse | 16,17,18 |
| **10** | nurse | - |
| **11** | nurse | 7,14 |
| **12** | paramedic | 1,2,3,4 |
| **13** | paramedic | 22 |
| **14** | paramedic | 19,20,21,22 |
| **15** | paramedic | - |
| **16** | paramedic | - |
| **17** | paramedic assistant | - |
| **18** | paramedic assistant | - |

**Table 3.** Required number of nurses in each shift and each day in scheduling period for an 18-person section

| day | shift | nurse | paramedic | Paramedic assistant |
|---|---|---|---|---|
| - | morning | 3 | 0 | 1 |
| 1,2,15,28 | afternoon | 2 | 1 | 1 |
| - | night | 2 | 1 | 0 |
| - | morning | 2 | 1 | 0 |
| 6,10,13,20,22,27 | afternoon | 2 | 1 | 0 |
| - | night | 2 | 1 | 0 |
| 3,4,5,7,8,9,11,12 | morning | 4 | 0 | 1 |
| 14,16,17,18,19,21 | afternoon | 2 | 1 | 1 |
| 23,24,25,26,29,30 | night | 2 | 1 | 0 |

**Table 4.** Number of required nurses in each level of qualification in each shift of each day in a scheduling period in five 90-person sections.

| day | shift | nurse | paramedic | Paramedic assistant |
|---|---|---|---|---|
| **-** | morning | 15 | 0 | 5 |
| **1،2،15،28** | afternoon | 10 | 5 | 5 |
| **-** | night | 10 | 5 | 0 |
| **-** | morning | 10 | 5 | 0 |
| **6،10،13،20،22،27** | afternoon | 10 | 5 | 0 |
| **-** | night | 10 | 5 | 0 |
| **3،4،5،7،8،9،11،12** | morning | 20 | 0 | 5 |
| **14،16،17،18،19،21** | afternoon | 10 | 5 | 5 |
| **23،24،25،26،29،30** | night | 10 | 5 | 0 |

## 6. Results of solving the sample problem

In this article, three sample problems have been solved by bee colony algorithm and NSGA-II algorithm. The results are as follows:

**Table 5.** Results from solving sample problem 1.

<table>
<tr><td rowspan="2">Objective function values</td><td colspan="2">Objective 1</td><td colspan="2">Objective 2</td><td>Objective 3</td><td>Objective 4</td></tr>
<tr><td colspan="2">2790</td><td colspan="2">1</td><td>5</td><td>0</td></tr>
<tr><td rowspan="3">Comparison criteria values</td><td colspan="3">BCO algorithm</td><td colspan="3">NSGA-II algorithm</td></tr>
<tr><td>Quality</td><td>Variation</td><td>Monotonousness</td><td>Quality</td><td>Variation</td><td>Monotonousness</td></tr>
<tr><td>70.08</td><td>109.6</td><td>1.11</td><td>29.92</td><td>57.7</td><td>0.64</td></tr>
</table>

**Table 6.** Results from solving sample problem 2.

| Objective function values | Objective 1 | | Objective 2 | | Objective 3 | Objective 4 |
|---|---|---|---|---|---|---|
| | 1125 | | 65 | | 5 | 90 |
| Comparison criteria values | BCO algorithm | | | NSGA-II algorithm | | |
| | Quality | Variation | Monotonousness | Quality | Variation | Monotonousness |
| | 100 | 977.2 | 0.77 | 0 | 229.3 | 0.45 |

**Table 7.** Runtime comparison.

| Problem | NSGA-II algorithm | Bee colony algorithm |
|---|---|---|
| **18 Nurses** | 50 seconds | **400 seconds** |
| **90 Nurses** | 120 seconds | **970 seconds** |

## 7. Conclusions

As mentioned earlier, in this article an investigation has been carried out on a nurse scheduling problem in working shifts. A four-objective mathematical model is proposed which has been designed based on the reasonable regulations of one of the hospitals in China. Also, to solve the model, bee colony algorithm has been implemented based on a Pareto Archive. In order to address the model, two sample problems with 18 and 90 nurses, three work shifts and three levels of qualifications in a 30-day scheduling period have been designed. Sample problems have been solved by using Bee Colony Algorithm (BCA), and the results that have been gained from this algorithm have been compared with the results of the NSGA-II algorithm. The results of the comparisons showed that bee colony algorithm has a higher capability in finding optimal and close to optimal solutions in comparison with the NSGA-II algorithm. Also, the result showed that bee colony algorithm in comparison with the NSGA-II algorithm searches in the broader area of the solution space has a higher variation. In comparing the runtime and monotonousness criterion, the performance of the NSGA-II algorithm is better than Bee Colony Optimization. In fact, it can be used to provide sufficient coordinates in the new ideas section for future research discussions including modeling the behavior of other beings against bees such as ants, birds and bats with this feature, all of which aims to optimize and help research and solve multiple algorithm problems. Also, considering the different algorithms against the overall comparison with the bee colony, we find it important to combine two or more of the possible algorithms to better serve the optimization and optimize the problem. Moreover, with a large number of nurses in the medical service and their observance of their work, and non-interference and their satisfaction, and to evaluate the correct implementation of work and work during service, better comparison between algorithms. With this in mind, a new approach with other methods such as more advanced algorithms such as colonial algorithms, meta-heuristic algorithms and fire and spin algorithms for the problems ahead, a better combination of algorithms and a more effective and consistent solution for future research in various fields has been proposed.

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**Conflicts of Interest**
The authors declare no conflict of interest.

## Appendix A.

**Table A1**. Nurse Characteristics in five 90-person sections.

| Nurse number | Actual level of qualification | Preferred days for leaving |
|---|---|---|
| 1 | nurse | - |
| 2 | nurse | 29 |
| 3 | nurse | 28,29 |
| 4 | nurse | - |
| 5 | nurse | - |
| 6 | nurse | 24,25,26 |
| 7 | nurse | 9,10,11,12 |
| 8 | nurse | 26 |
| 9 | nurse | 16,17,18 |
| 10 | nurse | - |
| 11 | nurse | 7,14 |
| 12 | nurse | 3,4,5 |
| 13 | nurse | 22 |
| 14 | nurse | 18,19,20,21 |
| 15 | nurse | - |
| 16 | nurse | - |
| 17 | nurse | - |
| 18 | nurse | - |
| 19 | nurse | 24,25 |
| 20 | nurse | 25 |
| 21 | nurse | - |
| 22 | nurse | - |
| 23 | nurse | - |
| 24 | nurse | 22 |
| 25 | nurse | 12,13,14 |
| 26 | nurse | 2021,22 |
| 27 | nurse | 5,6,7 |
| 28 | nurse | 2,3 |
| 29 | nurse | 17,18,19 |
| 30 | nurse | - |
| 31 | nurse | 11,12 |
| 32 | nurse | - |
| 33 | nurse | 23,24,25,26 |
| 34 | nurse | 2 |
| 35 | nurse | - |
| 36 | nurse | - |
| 37 | nurse | 4,5,6,7 |

| Nurse number | Actual level of qualification | Preferred days for leaving |
|---|---|---|
| 38 | nurse | 7,8,9 |
| 39 | nurse | _ |
| 40 | nurse | 26,27,28 |
| 41 | nurse | - |
| 42 | nurse | 10,14 |
| 43 | nurse | _ |
| 44 | nurse | 13,14,15 |
| 45 | nurse | 1,2,3,4 |
| 46 | nurse | 4,5 |
| 47 | nurse | - |
| 48 | nurse | 22,23,24 |
| 49 | nurse | 6,7 |
| 50 | nurse | - |
| 51 | nurse | 1,2,3 |
| 52 | nurse | - |
| 53 | nurse | - |
| 54 | nurse | - |
| 55 | nurse | - |
| 56 | paramedic | 23,24 |
| 57 | paramedic | 7,8,9,10 |
| 58 | paramedic | - |
| 59 | paramedic | - |
| 60 | paramedic | 22 |
| 61 | paramedic | - |
| 62 | paramedic | - |
| 63 | paramedic | 19،20،21 |
| 64 | paramedic | - |
| 65 | paramedic | 14،15،16 |
| 66 | paramedic | - |
| 67 | paramedic | 1،2،3،4 |
| 68 | paramedic | - |
| 69 | paramedic | 11،12 |
| 70 | paramedic | - |
| 71 | paramedic | - |
| 72 | paramedic | - |
| 73 | paramedic | - |
| 74 | paramedic | 25،26،27 |
| 75 | paramedic | - |
| 76 | paramedic | 19،20،21،22 |
| 77 | paramedic | - |
| 78 | paramedic | - |
| 79 | paramedic | 6،7،8،9 |
| 80 | paramedic | 21 |
| 81 | assistant paramedic | 19،20،21،22 |
| 82 | assistant paramedic | 16،17،18 |
| 83 | assistant paramedic | - |
| 84 | assistant paramedic | 22 |

| Nurse number | Actual level of qualification | Preferred days for leaving |
|---|---|---|
| 85 | assistant paramedic | 1،2،3،4 |
| 86 | assistant paramedic | - |
| 87 | assistant paramedic | - |
| 88 | assistant paramedic | 7،14 |
| 89 | assistant paramedic | _ |
| 90 | assistant paramedic | _ |

**Table A2.** Required number of each skill level of employees per shift of every day during the planning period, a total of 5 sections of 90 people.

| Day | Scenario | Shift | Nurse | Practical Nurse | Practical Nurse assistant |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 15 | 0 | 5 |
| 1 | 1 | 2 | 10 | 5 | 5 |
| 1 | 1 | 3 | 20 | 5 | 0 |
| 2 | 1 | 1 | 15 | 5 | 0 |
| 2 | 1 | 2 | 15 | 10 | 5 |
| 2 | 1 | 3 | 10 | 5 | 5 |
| 3 | 1 | 1 | 15 | 5 | 5 |
| 3 | 1 | 2 | 15 | 0 | 5 |
| 3 | 1 | 3 | 10 | 10 | 5 |
| 4 | 1 | 1 | 20 | 10 | 0 |
| 4 | 1 | 2 | 20 | 10 | 5 |
| 4 | 1 | 3 | 20 | 5 | 5 |
| 5 | 1 | 1 | 15 | 0 | 5 |
| 5 | 1 | 2 | 10 | 0 | 0 |
| 5 | 1 | 3 | 10 | 5 | 5 |
| 6 | 1 | 1 | 20 | 5 | 5 |
| 6 | 1 | 2 | 10 | 5 | 5 |
| 6 | 1 | 3 | 10 | 0 | 0 |
| 7 | 1 | 1 | 20 | 5 | 5 |
| 7 | 1 | 2 | 20 | 0 | 0 |
| 7 | 1 | 3 | 10 | 0 | 5 |
| 8 | 1 | 1 | 15 | 10 | 0 |
| 8 | 1 | 2 | 10 | 0 | 0 |
| 8 | 1 | 3 | 15 | 5 | 0 |
| 9 | 1 | 1 | 15 | 5 | 5 |
| 9 | 1 | 2 | 20 | 0 | 5 |
| 9 | 1 | 3 | 10 | 10 | 5 |
| 10 | 1 | 1 | 20 | 5 | 0 |
| 10 | 1 | 2 | 10 | 0 | 0 |
| 10 | 1 | 3 | 10 | 10 | 0 |
| 11 | 1 | 1 | 10 | 5 | 5 |
| 11 | 1 | 2 | 15 | 0 | 5 |
| 11 | 1 | 3 | 10 | 0 | 0 |
| 12 | 1 | 1 | 10 | 10 | 5 |
| 12 | 1 | 2 | 20 | 10 | 5 |
| 12 | 1 | 3 | 10 | 5 | 5 |

| Day | Scenario | Shift | Nurse | Practical Nurse | Practical Nurse assistant |
|---|---|---|---|---|---|
| 13 | 1 | 1 | 10 | 0 | 5 |
| 13 | 1 | 2 | 10 | 0 | 5 |
| 13 | 1 | 3 | 10 | 5 | 0 |
| 14 | 1 | 1 | 15 | 5 | 5 |
| 14 | 1 | 2 | 20 | 0 | 5 |
| 14 | 1 | 3 | 20 | 0 | 5 |
| 15 | 1 | 1 | 15 | 5 | 0 |
| 15 | 1 | 2 | 20 | 0 | 0 |
| 15 | 1 | 3 | 15 | 0 | 5 |
| 16 | 1 | 1 | 10 | 10 | 0 |
| 16 | 1 | 2 | 20 | 0 | 5 |
| 16 | 1 | 3 | 20 | 10 | 5 |
| 17 | 1 | 1 | 10 | 0 | 0 |
| 17 | 1 | 2 | 20 | 10 | 5 |
| 17 | 1 | 3 | 10 | 10 | 0 |
| 18 | 1 | 1 | 15 | 10 | 0 |
| 18 | 1 | 2 | 15 | 10 | 0 |
| 18 | 1 | 3 | 20 | 10 | 0 |
| 19 | 1 | 1 | 15 | 5 | 5 |
| 19 | 1 | 2 | 15 | 5 | 0 |
| 19 | 1 | 3 | 15 | 10 | 5 |
| 20 | 1 | 1 | 20 | 5 | 5 |
| 20 | 1 | 2 | 20 | 10 | 0 |
| 20 | 1 | 3 | 15 | 5 | 5 |
| 21 | 1 | 1 | 10 | 10 | 0 |
| 21 | 1 | 2 | 10 | 10 | 5 |
| 21 | 1 | 3 | 20 | 10 | 0 |
| 22 | 1 | 1 | 10 | 5 | 5 |
| 22 | 1 | 2 | 10 | 0 | 0 |
| 22 | 1 | 3 | 10 | 5 | 0 |
| 23 | 1 | 1 | 15 | 5 | 5 |
| 23 | 1 | 2 | 20 | 10 | 5 |
| 23 | 1 | 3 | 10 | 5 | 5 |
| 24 | 1 | 1 | 15 | 0 | 0 |
| 24 | 1 | 2 | 10 | 0 | 0 |
| 24 | 1 | 3 | 10 | 10 | 0 |
| 25 | 1 | 1 | 20 | 5 | 0 |
| 25 | 1 | 2 | 15 | 0 | 5 |
| 25 | 1 | 3 | 10 | 0 | 5 |
| 26 | 1 | 1 | 20 | 10 | 5 |
| 26 | 1 | 2 | 20 | 0 | 0 |
| 26 | 1 | 3 | 15 | 0 | 5 |
| 27 | 1 | 1 | 10 | 5 | 0 |
| 27 | 1 | 2 | 20 | 5 | 0 |
| 27 | 1 | 3 | 10 | 5 | 5 |
| 28 | 1 | 1 | 10 | 10 | 0 |
| 28 | 1 | 2 | 10 | 0 | 5 |

| Day | Scenario | Shift | Nurse | Practical Nurse | Practical Nurse assistant |
|---|---|---|---|---|---|
| 28 | 1 | 3 | 10 | 10 | 0 |
| 29 | 1 | 1 | 15 | 5 | 0 |
| 29 | 1 | 2 | 15 | 0 | 5 |
| 29 | 1 | 3 | 15 | 5 | 5 |
| 30 | 1 | 1 | 15 | 10 | 0 |
| 30 | 1 | 2 | 20 | 10 | 5 |
| 30 | 1 | 3 | 10 | 0 | 0 |
| 1 | 2 | 1 | 20 | 10 | 5 |
| 1 | 2 | 2 | 20 | 5 | 0 |
| 1 | 2 | 3 | 10 | 0 | 0 |
| 2 | 2 | 1 | 20 | 0 | 5 |
| 2 | 2 | 2 | 20 | 10 | 0 |
| 2 | 2 | 3 | 20 | 0 | 0 |
| 3 | 2 | 1 | 20 | 5 | 5 |
| 3 | 2 | 2 | 20 | 10 | 0 |
| 3 | 2 | 3 | 20 | 5 | 0 |
| 4 | 2 | 1 | 20 | 10 | 0 |
| 4 | 2 | 2 | 10 | 0 | 5 |
| 4 | 2 | 3 | 15 | 5 | 0 |
| 5 | 2 | 1 | 10 | 0 | 5 |
| 5 | 2 | 2 | 10 | 10 | 5 |
| 5 | 2 | 3 | 15 | 5 | 5 |
| 6 | 2 | 1 | 15 | 0 | 5 |
| 6 | 2 | 2 | 10 | 5 | 5 |
| 6 | 2 | 3 | 15 | 0 | 5 |
| 7 | 2 | 1 | 10 | 5 | 5 |
| 7 | 2 | 2 | 10 | 5 | 5 |
| 7 | 2 | 3 | 10 | 5 | 0 |
| 8 | 2 | 1 | 15 | 10 | 0 |
| 8 | 2 | 2 | 10 | 10 | 0 |
| 8 | 2 | 3 | 10 | 0 | 0 |
| 9 | 2 | 1 | 15 | 10 | 5 |
| 9 | 2 | 2 | 15 | 10 | 5 |
| 9 | 2 | 3 | 20 | 5 | 0 |
| 10 | 2 | 1 | 10 | 10 | 0 |
| 10 | 2 | 2 | 20 | 0 | 0 |
| 10 | 2 | 3 | 10 | 5 | 5 |
| 11 | 2 | 1 | 10 | 5 | 0 |
| 11 | 2 | 2 | 10 | 10 | 0 |
| 11 | 2 | 3 | 10 | 0 | 5 |
| 12 | 2 | 1 | 20 | 0 | 5 |
| 12 | 2 | 2 | 10 | 5 | 5 |
| 12 | 2 | 3 | 10 | 5 | 5 |
| 13 | 2 | 1 | 20 | 0 | 0 |
| 13 | 2 | 2 | 10 | 10 | 0 |
| 13 | 2 | 3 | 10 | 0 | 0 |
| 14 | 2 | 1 | 20 | 0 | 5 |

| Day | Scenario | Shift | Nurse | Practical Nurse | Practical Nurse assistant |
|---|---|---|---|---|---|
| 14 | 2 | 2 | 20 | 0 | 5 |
| 14 | 2 | 3 | 15 | 10 | 0 |
| 15 | 2 | 1 | 10 | 5 | 0 |
| 15 | 2 | 2 | 15 | 5 | 0 |
| 15 | 2 | 3 | 20 | 0 | 5 |
| 16 | 2 | 1 | 15 | 10 | 5 |
| 16 | 2 | 2 | 20 | 5 | 5 |
| 16 | 2 | 3 | 20 | 10 | 5 |
| 17 | 2 | 1 | 15 | 10 | 0 |
| 17 | 2 | 2 | 20 | 10 | 5 |
| 17 | 2 | 3 | 15 | 5 | 5 |
| 18 | 2 | 1 | 10 | 10 | 5 |
| 18 | 2 | 2 | 10 | 5 | 0 |
| 18 | 2 | 3 | 20 | 0 | 5 |
| 19 | 2 | 1 | 10 | 10 | 5 |
| 19 | 2 | 2 | 10 | 5 | 0 |
| 19 | 2 | 3 | 10 | 0 | 0 |
| 20 | 2 | 1 | 20 | 0 | 0 |
| 20 | 2 | 2 | 10 | 10 | 0 |
| 20 | 2 | 3 | 10 | 10 | 0 |
| 21 | 2 | 1 | 15 | 10 | 0 |
| 21 | 2 | 2 | 15 | 5 | 0 |
| 21 | 2 | 3 | 15 | 5 | 5 |
| 22 | 2 | 1 | 15 | 10 | 5 |
| 22 | 2 | 2 | 20 | 0 | 0 |
| 22 | 2 | 3 | 15 | 0 | 0 |
| 23 | 2 | 1 | 10 | 0 | 0 |
| 23 | 2 | 2 | 10 | 0 | 5 |
| 23 | 2 | 3 | 10 | 5 | 0 |
| 24 | 2 | 1 | 20 | 0 | 0 |
| 24 | 2 | 2 | 15 | 5 | 0 |
| 24 | 2 | 3 | 20 | 5 | 5 |
| 25 | 2 | 1 | 15 | 0 | 5 |
| 25 | 2 | 2 | 15 | 0 | 5 |
| 25 | 2 | 3 | 10 | 10 | 0 |
| 26 | 2 | 1 | 20 | 10 | 5 |
| 26 | 2 | 2 | 10 | 0 | 0 |
| 26 | 2 | 3 | 10 | 10 | 0 |
| 27 | 2 | 1 | 15 | 10 | 0 |
| 27 | 2 | 2 | 10 | 5 | 5 |
| 27 | 2 | 3 | 20 | 0 | 5 |
| 28 | 2 | 1 | 15 | 10 | 5 |
| 28 | 2 | 2 | 10 | 0 | 0 |
| 28 | 2 | 3 | 15 | 10 | 0 |
| 29 | 2 | 1 | 20 | 5 | 5 |
| 29 | 2 | 2 | 20 | 5 | 0 |
| 29 | 2 | 3 | 15 | 0 | 5 |

| Day | Scenario | Shift | Nurse | Practical Nurse | Practical Nurse assistant |
|---|---|---|---|---|---|
| 30 | 2 | 1 | 15 | 5 | 5 |
| 30 | 2 | 2 | 10 | 10 | 0 |
| 30 | 2 | 3 | 10 | 0 | 5 |
| 1 | 3 | 1 | 20 | 0 | 5 |
| 1 | 3 | 2 | 10 | 0 | 0 |
| 1 | 3 | 3 | 10 | 0 | 0 |
| 2 | 3 | 1 | 15 | 10 | 5 |
| 2 | 3 | 2 | 15 | 0 | 5 |
| 2 | 3 | 3 | 20 | 5 | 0 |
| 3 | 3 | 1 | 20 | 10 | 0 |
| 3 | 3 | 2 | 10 | 10 | 5 |
| 3 | 3 | 3 | 10 | 0 | 0 |
| 4 | 3 | 1 | 20 | 10 | 0 |
| 4 | 3 | 2 | 10 | 10 | 0 |
| 4 | 3 | 3 | 10 | 5 | 5 |
| 5 | 3 | 1 | 15 | 10 | 0 |
| 5 | 3 | 2 | 10 | 10 | 5 |
| 5 | 3 | 3 | 10 | 5 | 0 |
| 6 | 3 | 1 | 15 | 10 | 5 |
| 6 | 3 | 2 | 10 | 10 | 5 |
| 6 | 3 | 3 | 15 | 0 | 0 |
| 7 | 3 | 1 | 10 | 10 | 0 |
| 7 | 3 | 2 | 10 | 5 | 5 |
| 7 | 3 | 3 | 15 | 0 | 5 |
| 8 | 3 | 1 | 10 | 5 | 5 |
| 8 | 3 | 2 | 10 | 0 | 0 |
| 8 | 3 | 3 | 20 | 0 | 0 |
| 9 | 3 | 1 | 10 | 5 | 5 |
| 9 | 3 | 2 | 20 | 10 | 5 |
| 9 | 3 | 3 | 15 | 5 | 5 |
| 10 | 3 | 1 | 15 | 5 | 0 |
| 10 | 3 | 2 | 20 | 0 | 0 |
| 10 | 3 | 3 | 20 | 5 | 0 |
| 11 | 3 | 1 | 15 | 0 | 5 |
| 11 | 3 | 2 | 15 | 10 | 5 |
| 11 | 3 | 3 | 15 | 0 | 0 |
| 12 | 3 | 1 | 20 | 0 | 0 |
| 12 | 3 | 2 | 20 | 0 | 5 |
| 12 | 3 | 3 | 10 | 5 | 5 |
| 13 | 3 | 1 | 15 | 5 | 0 |
| 13 | 3 | 2 | 15 | 0 | 5 |
| 13 | 3 | 3 | 15 | 10 | 5 |
| 14 | 3 | 1 | 10 | 0 | 5 |
| 14 | 3 | 2 | 20 | 10 | 0 |
| 14 | 3 | 3 | 20 | 10 | 5 |
| 15 | 3 | 1 | 10 | 0 | 5 |
| 15 | 3 | 2 | 15 | 5 | 0 |

| Day | Scenario | Shift | Nurse | Practical Nurse | Practical Nurse assistant |
|---|---|---|---|---|---|
| 15 | 3 | 3 | 10 | 5 | 0 |
| 16 | 3 | 1 | 20 | 5 | 0 |
| 16 | 3 | 2 | 20 | 5 | 5 |
| 16 | 3 | 3 | 20 | 5 | 5 |
| 17 | 3 | 1 | 10 | 5 | 0 |
| 17 | 3 | 2 | 15 | 0 | 5 |
| 17 | 3 | 3 | 10 | 5 | 5 |
| 18 | 3 | 1 | 10 | 5 | 0 |
| 18 | 3 | 2 | 20 | 5 | 5 |
| 18 | 3 | 3 | 15 | 0 | 0 |
| 19 | 3 | 1 | 10 | 10 | 0 |
| 19 | 3 | 2 | 20 | 10 | 0 |
| 19 | 3 | 3 | 15 | 5 | 0 |
| 20 | 3 | 1 | 20 | 10 | 5 |
| 20 | 3 | 2 | 10 | 5 | 5 |
| 20 | 3 | 3 | 10 | 10 | 5 |
| 21 | 3 | 1 | 15 | 0 | 5 |
| 21 | 3 | 2 | 10 | 0 | 5 |
| 21 | 3 | 3 | 10 | 5 | 0 |
| 22 | 3 | 1 | 20 | 0 | 5 |
| 22 | 3 | 2 | 20 | 5 | 0 |
| 22 | 3 | 3 | 10 | 0 | 5 |
| 23 | 3 | 1 | 20 | 5 | 0 |
| 23 | 3 | 2 | 15 | 5 | 0 |
| 23 | 3 | 3 | 10 | 10 | 5 |
| 24 | 3 | 1 | 15 | 0 | 5 |
| 24 | 3 | 2 | 10 | 5 | 5 |
| 24 | 3 | 3 | 15 | 0 | 0 |
| 25 | 3 | 1 | 15 | 10 | 5 |
| 25 | 3 | 2 | 20 | 5 | 0 |
| 25 | 3 | 3 | 15 | 0 | 5 |
| 26 | 3 | 1 | 10 | 10 | 5 |
| 26 | 3 | 2 | 15 | 0 | 5 |
| 26 | 3 | 3 | 15 | 10 | 0 |
| 27 | 3 | 1 | 15 | 10 | 5 |
| 27 | 3 | 2 | 15 | 0 | 5 |
| 27 | 3 | 3 | 20 | 0 | 5 |
| 28 | 3 | 1 | 10 | 10 | 0 |
| 28 | 3 | 2 | 15 | 10 | 0 |
| 28 | 3 | 3 | 20 | 0 | 5 |
| 29 | 3 | 1 | 15 | 5 | 0 |
| 29 | 3 | 2 | 10 | 0 | 5 |
| 29 | 3 | 3 | 20 | 5 | 5 |
| 30 | 3 | 1 | 15 | 0 | 0 |
| 30 | 3 | 2 | 15 | 0 | 5 |
| 30 | 3 | 3 | 20 | 10 | 0 |

**Table A3.** Allocating nurses to the qualifications in shifts of days in scheduling period for a problem with 90 nurses.

| **Allocation**<br>**In parenthesis numbers denote: day, shift and level of qualification from left to right** | **Nurse number** |
|---|---|
| (1:M:1), (2:N:1), (4:A:1), (5:N:1), (8:M:1), (9:A:1), (10:A:1), (11:A:1), (12:N:1), (15:M:1), (16:A:1), (17:A:1), (18:A:1), (19:A:1), (21:M:1), (22:M:1), (23:A:1), (24:A:1), (25:A:1), (26:A:1), (28:M:1), (29:M:1), (30:M:1), | 1 |
| (1:M:1), (2:N:1), (4:A:1), (5:A:1), (7:M:1), (8:M:1), (9:M:1), (10:M:1), (11:A:1), (12:A:1), (14:M:1), (15:M:1), (16:A:1), (17:A:1), (18:A:1), (19:A:1), (20:N:1), (23:A:1), (24:A:1), (25:A:1), (26:A:1), (27:N:1), (30:M:1), | 2 |
| (1:N:1), (3:N:1), (5:N:1), (7:N:1), (10:N:1), (13:M:1), (14:M:1), (15:A:1), (16:M:1), (17:N:1), (19:N:1), (21:N:1), (24:N:1), (26:N:1), (29:M:1), (30:A:1), | 3 |
| (1:A:1), (2:N:3), (4:N:1), (7:M:1), (8:M:1), (9:M:1), (10:N:1), (12:N:1), (14:N:1), (17:M:1), (18:M:1), (19:N:1), (22:A:1), (23:M:1), (24:M:1), (25:M:1), (26:N:1), (29:M:1), (30:M:1), | 4 |
| (1:A:1), (2:N:2), (4:N:1), (7:M:1), (8:M:1), (9:M:1), (10:A:1), (11:N:3), (14:M:1), (15:M:1), (16:M:1), (17:M:1), (18:N:1), (21:M:1), (22:M:1), (23:M:1), (24:M:1), (25:N:1), (28:M:1), (29:M:1), (30:M:1), | 5 |
| (1:M:1), (2:M:1), (3:M:1), (3:A:1), (5:M:1), (6:M:1), (7:M:1), (8:A:1), (9:A:1), (11:M:1), (12:M:1), (13:M:1), (14:M:1), (15:A:1), (16:N:1), (18:N:1), (21:M:1), (22:A:1), (23:N:1), (25:N:1), (28:M:1), (29:A:1), (30:A:1), | 6 |
| (1:N:1), (3:N:1), (6:M:1), (7:A:1), (8:A:1), (9:N:1), (11:N:1), (14:A:1), (15:N:1), (17:N:1), (20:M:1), (21:M:1), (22:N:1), (24:N:1), (27:M:1), (28:A:1), (29:A:1), (30:N:1), | 7 |
| (2:M:1), (3:M:1), (4:M:1), (5:M:1), (6:A:1), (7:A:1), (8:N:1), (11:M:1), (12:M:1), (13:A:1), (14:A:1), (15:N:1), (18:M:1), (19:M:1), (20:M:1), (21:A:1), (22:N:1), (25:M:1), (26:M:1), (27:M:1), (28:A:1), (29:N:1), | 8 |
| (2:M:1), (3:M:1), (4:M:1), (5:M:1), (6:A:1), (7:N:1), (9:N:1), (12:M:1), (13:A:1), (14:N:1), (16:N:1), (19:M:1), (20:A:1), (21:A:1), (23:M:1), (24:M:1), (25:M:1), (26:M:1), (27:A:1), (28:N:1), (30:N:1), | 9 |
| (2:A:1), (3:M:1), (4:M:1), (5:M:1), (6:N:1), (8:N:1), (11:M:1), (12:M:1), (13:N:1), (16:M:1), (17:M:1), (18:M:1), (19:M:1), (20:A:1), (21:N:1), (23:N:1), (26:M:1), (27:A:1), (28:N:1), | 10 |
| (2:A:1), (3:A:1), (4:M:1), (5:A:1), (6:N:1), (9:M:1), (10:M:1), (11:M:1), (12:A:1), (13:N:1), (16:M:1), (17:M:1), (18:M:1), (19:M:1), (20:N:1), (23:M:1), (24:M:1), (25:M:1), (26:M:1), (27:N:1), (29:N:1), | 11 |
| (1:M:1), (2:N:1), (4:A:1), (5:N:1), (8:M:1), (9:A:1), (10:A:1), (11:A:1), (12:N:1), (15:M:1), (16:A:1), (17:A:1), (18:A:1), (19:A:1), (21:M:1), (22:M:1), (23:A:1), (24:A:1), (25:A:1), (26:A:1), (28:M:1), (29:M:1), (30:M:1), | 12 |
| (1:M:1), (2:N:1), (4:A:1), (5:A:1), (7:M:1), (8:M:1), (9:M:1), (10:M:1), (11:A:1), (12:A:1), (14:M:1), (15:M:1), (16:A:1), (17:A:1), (18:A:1), (19:A:1), (20:N:1), (23:A:1), (24:A:1), (25:A:1), (26:A:1), (27:N:1), (30:M:1), | 13 |
| (1:N:1), (3:N:1), (5:N:1), (7:N:1), (10:N:1), (13:M:1), (14:M:1), (15:A:1), (16:M:1), (17:N:1), (19:N:1), (21:N:1), (24:N:1), (26:N:1), (29:M:1), (30:A:1), | 14 |
| (1:A:1), (2:N:3), (4:N:1), (7:M:1), (8:M:1), (9:M:1), (10:N:1), (12:N:1), (14:N:1), (17:M:1), (18:M:1), (19:N:1), (22:A:1), (23:M:1), (24:M:1), (25:M:1), (26:N:1), (29:M:1), (30:M:1), | 15 |
| (1:A:1), (2:N:2), (4:N:1), (7:M:1), (8:M:1), (9:M:1), (10:A:1), (11:N:3), (14:M:1), (15:M:1), (16:M:1), (17:M:1), (18:N:1), (21:M:1), (22:M:1), (23:M:1), (24:M:1), (25:N:1), (28:M:1), (29:M:1), (30:M:1), | 16 |
| (1:M:1), (2:M:1), (3:M:1), (3:A:1), (5:M:1), (6:M:1), (7:M:1), (8:A:1), (9:A:1), (11:M:1), (12:M:1), (13:M:1), (14:M:1), (15:A:1), (16:N:1), (18:N:1), (21:M:1), (22:A:1), (23:N:1), (25:N:1), (28:M:1), (29:A:1), (30:A:1), | 17 |
| (1:N:1), (3:N:1), (6:M:1), (7:A:1), (8:A:1), (9:N:1), (11:N:1), (14:A:1), (15:N:1), (17:N:1), (20:M:1), (21:M:1), (22:N:1), (24:N:1), (27:M:1), (28:A:1), (29:A:1), (30:N:1), | 18 |

| | |
|---|---|
| (2:M:1), (3:M:1), (4:M:1), (5:M:1), (6:A:1), (7:A:1), (8:N:1), (11:M:1), (12:M:1), (13:A:1), (14:A:1), (15:N:1), (18:M:1), (19:M:1), (20:M:1), (21:A:1), (22:N:1), (25:M:1), (26:M:1), (27:M:1), (28:A:1), (29:N:1), | 19 |
| (2:M:1), (3:M:1), (4:M:1), (5:M:1), (6:A:1), (7:N:1), (9:N:1), (12:M:1), (13:A:1), (14:N:1), (16:N:1), (19:M:1), (20:A:1), (21:A:1), (23:M:1), (24:M:1), (25:M:1), (26:M:1), (27:A:1), (28:N:1), (30:N:1), | 20 |
| (2:A:1), (3:M:1), (4:M:1), (5:M:1), (6:N:1), (8:N:1), (11:M:1), (12:M:1), (13:N:1), (16:M:1), (17:M:1), (18:M:1), (19:M:1), (20:A:1), (21:N:1), (23:N:1), (26:M:1), (27:A:1), (28:N:1), | 21 |
| (2:A:1), (3:A:1), (4:M:1), (5:A:1), (6:N:1), (9:M:1), (10:M:1), (11:M:1), (12:A:1), (13:N:1), (16:M:1), (17:M:1), (18:M:1), (19:M:1), (20:N:1), (23:M:1), (24:M:1), (25:M:1), (26:M:1), (27:N:1), (29:N:1), | 22 |
| (1:N:1), (3:N:1), (5:N:1), (7:N:1), (10:N:1), (13:M:1), (14:M:1), (15:A:1), (16:M:1), (17:N:1), (19:N:1), (21:N:1), (24:N:1), (26:N:1), (29:M:1), (30:A:1), | 23 |
| (1:M:1), (2:N:1), (4:A:1), (5:A:1), (7:M:1), (8:M:1), (9:M:1), (10:M:1), (11:A:1), (12:A:1), (14:M:1), (15:M:1), (16:A:1), (17:A:1), (18:A:1), (19:A:1), (20:N:1), (23:A:1), (24:A:1), (25:A:1), (26:A:1), (27:N:1), (30:M:1), | 24 |
| (1:A:1), (2:N:2), (4:N:1), (7:M:1), (8:M:1), (9:M:1), (10:A:1), (11:N:1), (14:M:1), (15:M:1), (16:M:1), (17:M:1), (18:N:1), (21:M:1), (22:M:1), (23:M:1), (24:M:1), (25:N:1), (28:M:1), (29:M:1), (30:M:1), | 25 |
| (1:A:1), (2:N:3), (4:N:1), (7:M:1), (8:M:1), (9:M:1), (10:N:1), (12:N:1), (14:N:1), (17:M:1), (18:M:1), (19:N:1), (22:A:1), (23:M:1), (24:M:1), (25:M:1), (26:N:1), (29:M:1), (30:M:1), | 26 |
| (1:M:1), (2:N:1), (4:A:1), (5:N:1), (8:M:1), (9:A:1), (10:A:1), (11:A:1), (12:N:1), (15:M:1), (16:A:1), (17:A:1), (18:A:1), (19:A:1), (21:M:1), (22:M:1), (23:A:1), (24:A:1), (25:A:1), (26:A:1), (28:M:1), (29:M:1), (30:M:1), | 27 |
| (1:M:1), (2:M:1), (3:M:1), (3:A:1), (5:M:1), (6:M:1), (7:M:1), (8:A:1), (9:A:1), (11:M:1), (12:M:1), (13:M:1), (14:M:1), (15:A:1), (16:N:1), (18:N:1), (21:M:1), (22:A:1), (23:N:1), (25:N:1), (28:M:1), (29:A:1), (30:A:1), | 28 |
| (1:N:1), (3:N:1), (6:M:1), (7:A:1), (8:A:1), (9:N:1), (11:N:1), (14:A:1), (15:N:1), (17:N:1), (20:M:1), (21:M:1), (22:N:1), (24:N:1), (27:M:1), (28:A:1), (29:A:1), (30:N:1), | 29 |
| (2:M:1), (3:M:1), (4:M:1), (5:M:1), (6:A:1), (7:A:1), (8:N:1), (11:M:1), (12:M:1), (13:A:1), (14:A:1), (15:N:1), (18:M:1), (19:M:1), (20:M:1), (21:A:1), (22:N:1), (25:M:1), (26:M:1), (27:M:1), (28:A:1), (29:N:1), | 30 |
| (2:M:1), (3:M:1), (4:M:1), (5:M:1), (6:A:1), (7:N:1), (9:N:1), (12:M:1), (13:A:1), (14:N:1), (16:N:1), (19:M:1), (20:A:1), (21:A:1), (23:M:1), (24:M:1), (25:M:1), (26:M:1), (27:A:1), (28:N:1), (30:N:1), | 31 |
| (2:A:1), (3:M:1), (4:M:1), (5:M:1), (6:N:1), (8:N:1), (11:M:1), (12:M:1), (13:N:1), (16:M:1), (17:M:1), (18:M:1), (19:M:1), (20:A:1), (21:N:1), (23:N:1), (26:M:1), (27:A:1), (28:N:1), | 32 |
| (2:A:1), (3:A:1), (4:M:1), (5:A:1), (6:N:1), (9:M:1), (10:M:1), (11:M:1), (12:A:1), (13:N:1), (16:M:1), (17:M:1), (18:M:1), (19:M:1), (20:N:1), (23:M:1), (24:M:1), (25:M:1), (26:M:1), (27:N:1), (29:N:1), | 33 |
| (1:N:1), (3:N:1), (5:N:1), (7:N:1), (10:N:1), (13:M:1), (14:M:1), (15:A:1), (16:M:1), (17:N:1), (19:N:1), (21:N:1), (24:N:1), (26:N:1), (29:M:1), (30:A:1), | 34 |
| (1:M:1), (2:N:1), (4:A:1), (5:A:1), (7:M:1), (8:M:1), (9:M:1), (10:M:1), (11:A:1), (12:A:1), (14:M:1), (15:M:1), (16:A:1), (17:A:1), (18:A:1), (19:A:1), (20:N:1), (23:A:1), (24:A:1), (25:A:1), (26:A:1), (27:N:1), (30:M:1), | 35 |
| (1:A:1), (2:N:2), (4:N:1), (7:M:1), (8:M:1), (9:M:1), (10:A:1), (11:N:3), (14:M:1), (15:M:1), (16:M:1), (17:M:1), (18:N:1), (21:M:1), (22:M:1), (23:M:1), (24:M:1), (25:N:1), (28:M:1), (29:M:1), (30:M:1), | 36 |
| (1:A:1), (2:N:3), (4:N:1), (7:M:1), (8:M:1), (9:M:1), (10:N:1), (12:N:1), (14:N:1), (17:M:1), (18:M:1), (19:N:1), (22:A:1), (23:M:1), (24:M:1), (25:M:1), (26:N:1), (29:M:1), (30:M:1), | 37 |
| (1:M:1), (2:N:1), (4:A:1), (5:N:1), (8:M:1), (9:A:1), (10:A:1), (11:A:1), (12:N:1), (15:M:1), | 38 |

| | |
|---|---|
| (16:A:1), (17:A:1), (18:A:1), (19:A:1), (21:M:1), (22:M:1), (23:A:1), (24:A:1), (25:A:1), (26:A:1), (28:M:1), (29:M:1), (30:M:1), | |
| (1:M:1), (2:M:1), (3:M:1), (3:A:1), (5:M:1), (6:M:1), (7:M:1), (8:A:1), (9:A:1), (11:M:1), (12:M:1), (13:M:1), (14:M:1), (15:A:1), (16:N:1), (18:N:1), (21:M:1), (22:A:1), (23:N:1), (25:N:1), (28:M:1), (29:A:1), (30:A:1), | 39 |
| (1:N:1), (3:N:1), (6:M:1), (7:A:1), (8:A:1), (9:N:1), (11:N:1), (14:A:1), (15:N:1), (17:N:1), (20:M:1), (21:M:1), (22:N:1), (24:N:1), (27:M:1), (28:A:1), (29:A:1), (30:N:1), | 40 |
| (2:M:1), (3:M:1), (4:M:1), (5:M:1), (6:A:1), (7:A:1), (8:N:1), (11:M:1), (12:M:1), (13:A:1), (14:A:1), (15:N:1), (18:M:1), (19:M:1), (20:M:1), (21:A:1), (22:N:1), (25:M:1), (26:M:1), (27:M:1), (28:A:1), (29:N:1), | 41 |
| (2:M:1), (3:M:1), (4:M:1), (5:M:1), (6:A:1), (7:N:1), (9:N:1), (12:M:1), (13:A:1), (14:N:1), (16:N:1), (19:M:1), (20:A:1), (21:A:1), (23:M:1), (24:M:1), (25:M:1), (26:M:1), (27:A:1), (28:N:1), (30:N:1), | 42 |
| (2:A:1), (3:M:1), (4:M:1), (5:M:1), (6:N:1), (8:N:1), (11:M:1), (12:M:1), (13:N:1), (16:M:1), (17:M:1), (18:M:1), (19:M:1), (20:A:1), (21:N:1), (23:N:1), (26:M:1), (27:A:1), (28:N:1), | 43 |
| (2:A:1), (3:A:1), (4:M:1), (5:A:1), (6:N:1), (9:M:1), (10:M:1), (11:M:1), (12:A:1), (13:N:1), (16:M:1), (17:M:1), (18:M:1), (19:M:1), (20:N:1), (23:M:1), (24:M:1), (25:M:1), (26:M:1), (27:N:1), (29:N:1), | 44 |
| (1:M:1), (2:N:1), (4:A:1), (5:N:1), (8:M:1), (9:A:1), (10:A:1), (11:A:1), (12:N:1), (15:M:1), (16:A:1), (17:A:1), (18:A:1), (19:A:1), (21:M:1), (22:M:1), (23:A:1), (24:A:1), (25:A:1), (26:A:1), (28:M:1), (29:M:1), (30:M:1), | 45 |
| (1:A:1), (2:N:3), (4:N:1), (7:M:1), (8:M:1), (9:M:1), (10:N:1), (12:N:1), (14:N:1), (17:M:1), (18:M:1), (19:N:1), (22:A:1), (23:M:1), (24:M:1), (25:M:1), (26:N:1), (29:M:1), (30:M:1), | 46 |
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| (1:M:1), (2:N:1), (4:A:1), (5:A:1), (7:M:1), (8:M:1), (9:M:1), (10:M:1), (11:A:1), (12:A:1), (14:M:1), (15:M:1), (16:A:1), (17:A:1), (18:A:1), (19:A:1), (20:N:1), (23:A:1), (24:A:1), (25:A:1), (26:A:1), (27:N:1), (30:M:1), | 48 |
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