SOLVING A BI-OBJECTIVE MANPOWER SCHEDULING PROBLEM CONSIDERING THE UTILITY OF OBJECTIVE FUNCTIONS

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Abstract This paper presents a novel bi-objective manpower scheduling problem that minimizes the penalty incurred by the employees' assignment at lower skill levels than their real skills and maximizes the employees' utility by assigning them at desired skill levels in some shifts/days. Employees are classified in two specialist groups and three skill levels in each specialization. In addition, the presented model executes some essential work regulations. This paper also proposes a solution procedure based on the utility of objective values. Applying this procedure, an effective point is obtained for the given problem. This is the point where both objective functions have the highest utility simultaneously.

Keywords Manpower Scheduling, Workforce Scheduling, Utility, Bi-objective Model

چکیده این مقاله، یک مساله زمانبندی نیروی انسانی دو هدف جدید را ارائه می‌نماید که هدف آن حداقل کردن جریمه حاصل از تخصیص کارکنان در سطوح مهارت پائین‌تر از مهارت واقعی‌شان و حداکثر نمودن مطلوبیت کارکنانی که تمایل به کار کردن در یک سطح مهارت خاص در برخی از شیفت‌ها یا روزها دارند، است. کارکنان به دو گروه متخصص و سه سطح مهارت در هر تخصص طبقه‌بندی می‌شوند. علاوه بر این، مدل ارائه شده برخی از قواعد کاری ضروری را اجرا می‌کند. همچنین در این مقاله، یک رویه حل مبتنی بر مطلوبیت مقادیر هدف پیشنهاد می‌شود. با استفاده از این رویه، یک نقطه موثر برای مدل ارائه شده بدست می‌آید و این همان نقطه‌ای است که در آن هر دو تابع هدف دارای بالاترین مطلوبیت بطور همزمان می‌باشند.

1. INTRODUCTION

Production factors are the economic resources which are used to produce goods and services. One of the most important factors among them is the workforce or manpower. The work division which makes the highest possible efficiency of manpower is called "the proper allocation of human resources". Manpower should be scheduled to attain the proper allocation. Manpower scheduling is a managerial process that contains the analysis of human resources requirement of an organization in variable situations. It makes clear the policies and systems, which satisfy these requirements. The ultimate goal of manpower scheduling is to seek the shift rosters that conform to time-varying demand, so that it controls the costs and satisfies all executive regulations [1]. Since 1970's manpower scheduling has allotted a broad field of research to itself. Apart from the scope of automated operations, all organizations such as: service companies, production companies, etc require manpower. As a general rule, manpower scheduling can be modeled in three categories: a) individual scheduling (e.g., nurse, physician, surgery and the like), b) group scheduling (e.g., crew), and c) personnel scheduling.

Manpower scheduling methods are usually divided into two approaches: cyclic and non-cyclic approaches [2]. Cyclic approaches are defined by fixed series of shifts that are approximately assigned to employees in an equal manner. Non-cyclic methods are generally placed on two groups: 1) the methods which are based on human's experience and the spreadsheets, and 2) optimization methods that can be computerized entirely without so much necessity to human's interference. In case of proper design, the latter will be capable to execute many rules concurrently.

A matter at hand in manpower scheduling is workforce homogeneity or heterogeneity [3]. Homogeneous workforces are those whose available time is equal and necessity to them remains constant during a shift. Most full-time employees in production industries are placed on this group. Heterogeneous workforce is applied to those whose available time is different or necessity to them varies during a shift. Heterogeneous manpower scheduling is also called *tour scheduling*.

Manpower planning not only handles manpower scheduling but also deals with flexible working agreements. Some investigations on this subject are categorized to single-shift scheduling and multiple-shift scheduling [4-13]. In multiple-shift scheduling, each day is divided into several shifts, and scheduling determines which days of planning horizon and which hours of the day each employee is fitted to work.

Another important subject in manpower scheduling is days-off. Azmat et al. [14] categorized days-off scheduling problem to single-shift (one type of activity) and multiple-shift (several types of activities). Each category includes four groups: regular work schedule, compressed work schedule, hierarchical workforce schedule and annual hours schedule. In regular work schedule, each work pattern consists of five workdays and two successive days-off per week [15-17]. The compressed work schedule includes a work pattern with three, four or three-four workdays per week [18-19]. Hierarchical workforce schedule takes different classes of employees with different constraints into consideration [20-22]. Annual hours schedule regards fixed annual total hours per employee and varying work hours per week [14,23]. Costa et al. [24] studied days-off scheduling problem when staff demand alters day-to-day but total number of workdays per each staff is constant.

Workforce scheduling and simultaneous allocation in production environments are one of the topics that have been extensively taken into account by many researchers. Cerulli et al. [25] presented a mathematical model for scheduling and allocating the specific number of workforce. Emmons and Fuh [26] constructed a model to schedule full-time and part-time workforce regarding vacations and weekends. Blochliger [27] provided a tutorial for staff scheduling problems. A problem which is propounded in scheduling is the solution method of presented models. In this connection, Alfares [28] proposed a two-phase algorithm based on mathematical models for manpower scheduling considering cyclic days-off. Lagodimos et al. [29] presented greedy heuristic algorithms. Musliu et al. [30] also stated that there are a number of different approaches in the literature that have been applied to solve workforce scheduling problems. The modeling of scheduling problems as network flow, the combination of management science and artificial intelligence techniques, and mixed approaches joining constraint satisfaction and local improvement algorithms are just some of the approaches have been used so far. In some cases, staff scheduling has been done in non-production environments. Ernst et al. [31] studied staff scheduling models and introduced important subjects in this context. They examined literature reviews, applications, models and algorithms of manpower scheduling and finally suggested some points for the future research. Ingolfsson et al. [32] integrated queuing theory and cost minimization to model the random arrival process and the congestion that comes from a special schedule.

Most manpower scheduling models usually deal with full-time personnel and part-time employees play the role of supplemental workforce in them. Glover et al. [33] presented a heuristic established upon Tabu search to produce the schedules for full-time workforce accompanied by part-timers. Willis et al. [34] used an integer programming approach for a staff scheduling problem in a call center containing both part-time and full-time staff. Schindler et al. [35] took a workforce problem at Pan American World Airways into account. They regarded some constraints for part-timers as well as standard set-covering model constraints. Dowsland [36] applied a Tabu search technique for a nurse scheduling problem and also considered the use of part-timers to satisfy the demand. Bard et al. [37] modeled a staff scheduling problem at the United States Postal Service (USPS) as an integer programming that involves both full-timers and part-timers.

Production or non-production environments generally confront employees with different skill levels. Eitzen et al. [38] recommended a model to generate workforce rosters with non-hierarchical skill levels in CS energy's Swanbank Power Station in the Australian state of Queensland. An important feature of this model that differentiates it from the preceding models is non-hierarchical nature of the skill sets. In fact, their method was an extension of work on hierarchical skill sets by Billonnet [39], Cai and Li [40]. Techawiboonwong et al. [41] presented a model to schedule skilled and unskilled temporary workers. They classified workers into two groups: a) permanent and temporary, b) skilled and unskilled, and then constructed a model by introducing some constraints for work stations.

The proposed models for manpower scheduling have various objective functions. Some of them include minimizing the costs, workforce size, etc, or maximizing job satisfaction, service quality, and the like. In traditional workforce scheduling, the optimal schedule has been determined by minimizing the costs. Job satisfaction is another topic favored by researchers in manpower scheduling lately. Mohan [42] studied part-time personnel scheduling with respect to availability restrictions in order to maximize personnel's job satisfaction.

In recent years, multi-objective manpower scheduling problems have received increased interest from researchers. For instance; Castillo et al. [1] examined manpower scheduling problem regarding two objective functions: minimizing the costs and maximizing the service level. They introduced quality subject in manpower scheduling problem by their innovation. Hertz et al. [43] made a flexible MILP model for multiple-shift workforce planning with several objectives, such as: balancing the workload of employees and minimizing the workforce size.

This paper intends to meditate on bi-objective manpower scheduling problem in another point of view and present a solution procedure using the definition of utility function. Section 2 introduces a manpower scheduling problem which is focused on. A solution method considering the utility of objective functions is recommended in Section 3. Section 4 discusses the computational results. Concluding remarks and suggestions for future research are expressed in the final section of the paper.

2. MATHEMATICAL MODEL

The concerned manpower scheduling problem is applicable in production as well as service environments which operate 24 hours a day in multiple shifts. In this case, each day is divided to three 8-hour shifts. The planning horizon includes 28 days (4 weeks). Employees are categorized into two specializations (maybe some of them have enough expertise to work in both specializations). Employees of each specialization are classified into three skill levels (Senior, Standard and Junior) and each employee can work at his/her real skill level or at any lower skill levels but not more than one skill level simultaneously. Attendance of at least one employee with the highest skill level in any specialization in each shift is mandatory. Employees are not permitted to work in two consecutive shifts. Moreover, they are not allowable to work in more than two shifts on a day. Each of them who works in two non-consecutive shifts on a day should be off for the next day to rest.

The manpower scheduling problem has been formulated as a bi-objective mathematical programming model. The objectives of the presented model are to minimize the employees' assignment at lower skill levels than their real skill and maximize the employees' utility by assigning them at desired skill levels in some shifts/days.

2.1. Notations The following are notations used in the presented model.

2.1.1. Indices

i = Index for the employees, (i = 1, …, I)
k = Index for the days, (k = 1, …, K)
j = Index for the shifts, (j = 1, …, J) ; in this case: (j = 1: Morning, 2: Afternoon, 3: Night)
p = Index for the specializations, (p = 1, …, P)
s = Index for the skill levels in each specialization, (s = 1, …, S); in this case: (s = 1: Senior, 2: Standard, 3: Junior)

2.1.2. Sets

I = Set of employees
K = Set of days in the schedule
J = Set of shifts
P = Set of specializations in the schedule
S = Set of skill levels in each specialization

2.1.3. Data

H_{kj} = Length of shift j on day k
V_{max} = Maximum allowable working hours for an employee during a day
W_{min} = Minimum required working hours for an employee during the planning period
W_{max} = Maximum allowable working hours for an employee during the planning period
L_i = Real skill level of each employee i
pen = A penalty coefficient for assignment at lower skill level in each specialization
b_{kj}^{ps} = Total number of required employees at skill level s of specialization p in shift j on day k
$\overline{K}_i^{ps}$ = The set of special days that employee i with specialization p is interested in working in some shifts of these days at skill level s based on his/her personal reasons
$\overline{J}_{\overline{K}_i^{ps}}$ = The set of special shifts on day k that employee i with specialization p is interested in working at skill level s based on his/her personal reasons
$Comp_{ikj}^{ps}$=1, if employee i with specialization p can be assigned to work at his/her real skill level or at any lower skill level s in shift j on day k; 0, otherwise.
u_{ikj}^{ps} =1, if employee i with specialization p is interested in working in shift j on day k at skill level s based on his/her personal reasons; 0, otherwise.

2.1.4. Decision variables X_{ikj}^{ps} =1, if employee i with specialization p is assigned to work in shift j on day k at skill level s; 0, otherwise.
Q_{ik}^{p} =1, if employee i with specialization p is assigned to work in two non-consecutive shifts (morning & night shifts) on day k; 0, otherwise.

2.2. Objective Functions The objectives of the model are related to minimize the employees' assignment at lower skill levels than their real skill and maximize the employees' utility by assigning them at desired skill levels in some shifts/days:

$$\min \sum_i \sum_k \sum_j \sum_p \sum_s [(s - L_i) * X_{ikj}^{ps} * pen] \qquad (1)$$

$$\max \sum_i \sum_{k \in \overline{K}_i^{ps}} \sum_{j \in \overline{J}_{\overline{K}_i^{ps}}} \sum_p \sum_s [u_{ikj}^{ps} * X_{ikj}^{ps}] \qquad (2)$$

2.3. Constraints

- Each employee in any specialization is assigned to work at his/her real skill level or at any lower skill level in each shift per day:

$$X_{ikj}^{ps} \le Comp_{ikj}^{ps} \qquad ;\forall i, k, j, p, s \qquad (3)$$

- Total number of required employees at any skill level of each specialization in each shift per day:

$$\sum_i X_{ikj}^{ps} = b_{kj}^{ps} \qquad ;\forall k, j, p, s \qquad (4)$$

- Upper bound on the total number of daily hours worked by each employee:

$$\sum_p \sum_s \sum_j X_{ikj}^{ps} h_{kj} \le V_{\max} \qquad ;\forall i, k \qquad (5)$$

- Lower and upper bound on the total number of hours worked by each employee during the planning period:

$$W_{\min} \le \sum_p \sum_s \sum_k \sum_j X_{ikj}^{ps} h_{kj} \le W_{\max} \qquad ;\forall i \qquad (6)$$

- There should be at least 8 hours between the end of one shift and the beginning of the next shift for each employee (These constraints imply that each employee can be assigned to work in two non-consecutive shifts on a day):

$$\sum_p \sum_s \Big(\sum_{j \in Morning} X_{ikj}^{ps} + \sum_{j \in Afternoon} X_{ikj}^{ps} \Big) \le 1 \qquad ;\forall i, k \qquad (7)$$

$$\sum_p \sum_s \Big(\sum_{j \in Afternoon} X_{ikj}^{ps} + \sum_{j \in Night} X_{ikj}^{ps} \Big) \le 1 \qquad ;\forall i, k \qquad (8)$$

$$\sum_{p}\sum_{s}\Big(\sum_{j\in Night}X_{ikj}^{ps}+\sum_{j\in Morning}X_{i(k+1)j}^{ps}\Big)\le 1 \qquad ;\forall i,k-\{28\} \qquad (9)$$

$$\sum_{j}\sum_{p}\sum_{s}X_{ikj}^{ps}\le 2 \qquad ;\forall i,k \qquad (10)$$

- Each employee who is assigned to work in two non-consecutive shifts on a day should be off for the next day:

$$Q_{ik}^{p}-\sum_{j\in Morning}\sum_{s}X_{ikj}^{ps}\le 0 \qquad ;\forall i,k,p \qquad (11)$$

$$Q_{ik}^{p}-\sum_{j\in Night}\sum_{s}X_{ikj}^{ps}\le 0 \qquad ;\forall i,k,p \qquad (12)$$

$$Q_{ik}^{p}-\sum_{j\in Morning}\sum_{s}X_{ikj}^{ps}-\sum_{j\in Night}\sum_{s}X_{ikj}^{ps}\ge -1 \qquad ;\forall i,k,p \qquad (13)$$

So, these constraints verify that:

$Q_{ik}^{p}=1$, if employee i with specialization p is assigned to work in two non-consecutive shifts (morning & night shifts) on day k; 0, otherwise.

Then, the rule is verified by adding the following constraint:

$$\sum_{j\in Morning}\sum_{s}X_{ikj}^{ps}+\sum_{j\in Night}\sum_{s}X_{ikj}^{ps}+\sum_{j}\sum_{s}X_{i(k+1)j}^{ps}\le 3-Q_{ik}^{p} \qquad ;\forall i,k-\{28\},p \qquad (14)$$

- There should be at least one specialist with the highest skill level in any specialization in each shift per day:

$$\sum_{i}\sum_{s\in Senior}X_{ikj}^{ps}\ge 1 \qquad ;\forall k,j,p \qquad (15)$$

- Each employee in any specialization can only be assigned to work at one skill level in each shift per day:

$$\sum_{s}X_{ikj}^{ps}\le 1 \qquad ;\forall i,k,j,p \qquad (16)$$

3. SOLUTION PROCEDURE

In the last decades, a number of various methods have been developed to solve multi-objective problems. Some references are [1, 43, 44-47]. In this paper, the presented bi-objective problem is thought of in another point of view and a solution procedure using the definition of utility of objective values is recommended. As a matter of fact, utility is a measure of the desirability of different objective values. It should be noted this solution procedure is applicable for bi-objective problems which have contradiction in objectives and one objective function has to be minimized while the other one has to be maximized.

3.1. The Proposed Algorithm Finding feasible points regarding the utility of objective functions

Step 1. Consider the bi-objective problem (the main problem) as two separate single-objective problems.

Step 2. Call the maximization problem as Problem1 and follow the subsequent steps: **Step 2.1.** Solve Problem 1 by one of the optimization softwares and name the optimized objective value M_1.

Step 2.2. Convert the objective function of Problem 1 to minimization and solve the new Problem 1. Name the resulted optimized objective value m_1.

Step 2.3. Calculate the utility of objective function of Problem 1 as follow:

$$U(objective1)=\frac{objective1(x)-m_1}{M_1-m_1}$$

According to Figure 1, when *objective1(x)* is equal to extreme values m_1 and M_1, objective function acquires minimum and maximum utility, respectively. Otherwise, it varies between 0 and 1 per unit change in *objective 1(x)*.

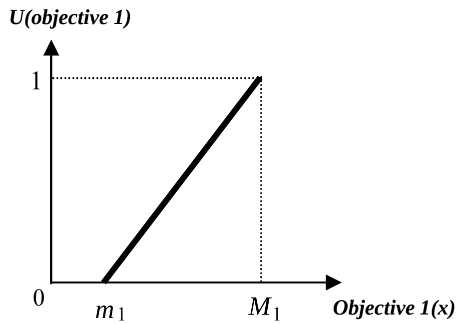

Figure 1. The utility function of Problem 1

Step 3. Call the minimization problem as Problem 2 and follow the subsequent steps: **Step 3.1.** Solve Problem 2 by one of the optimization softwares and name the optimized objective value m_2. **Step 3.2.** Convert the objective function of Problem 2 to maximization and solve the new Problem 2. Name the resulted optimized objective value M_2. **Step 3.3.** Calculate the utility of objective function of Problem 2 as follow:

$$U(objective\ 2)=1-\frac{objective\ 2(x)-m_2}{M_2-m_2}$$

According to Figure 2, when *objective2(x)* is equal to extreme values m_2 and M_2, objective function acquires maximum and minimum utility, respectively. Otherwise, it varies between 0 and 1 per unit change in *objective2(x)*.

Give notice to this matter, m_1, M_1, m_2 and M_2 may obtain positive, zero or negative values. Moreover, M_1 and M_2 may be infinite. This algorithm does not examine infinite values. In some cases, maximum and minimum values of an objective function are

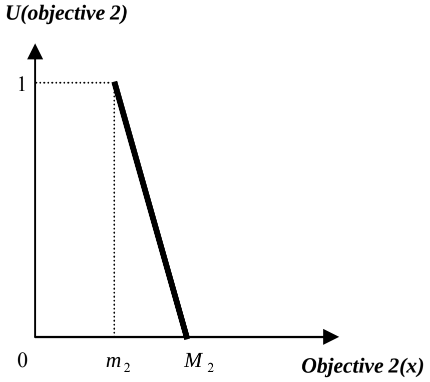

Figure 2. The utility function of Problem 2

the same. Given this situation, the utility function of considered objective function is converted to a single-point which is always equivalent to 1.

Step 4. Initially, set $t_1 = 0$ and $t_2 = 0$.

Step 5. Calculate the proper reduction amount in utility of each objective functions as follow:

$$\Delta U_{1t_1} = \frac{t_1 * |\Delta Obj_1|}{Max_1 - Min_1}$$

$$\Delta U_{2t_2} = \frac{t_2 * |\Delta Obj_2|}{Max_2 - Min_2}$$

where ΔObj_1 and ΔObj_2 are assumed to be unit change amount in *objective1(x)* and *objective2(x)*, respectively. Then, compute the reduced utility values as below:

$$U(Obj_{1t_1}) = 1 - \Delta U_{1t_1}$$

$$U(Obj_{2t_2}) = 1 - \Delta U_{2t_2}$$

Change t_2 from 0 to $\frac{Max_2 - Min_2}{|\Delta Obj_2|}$ in above formulas. In each iteration, note the value of $U(Obj_{1t_1})$, $U(Obj_{2t_2})$, Obj_{1t_1}, Obj_{2t_2} and add the equations ***objective 1(x)=*** Obj_{1t_1} and ***objective2(x)=*** Obj_{2t_2} to the constraints of main problem. Solve the obtained problem that has no objective function. Two cases may occur: a) there is a feasible solution in this iteration and take notice of it, b) there is no feasible solution. **Step 6.** $t_1 = t_1 + 1$. If $t_1 \le \frac{Max_1 - Min_1}{|\Delta Obj_1|}$, go to Step 5; else, all possible situations have been checked and stop.

Step 7. Among the achieved feasible solutions, select the answer that has the highest utility. This choice depends on DM's point of view about objective functions.

4. COMPUTATIONAL RESULTS

In order to examine the performance of proposed solution procedure, a numerical example is presented in this section. Some characteristics of the example are summarized in Table 1. The number of employees is considered 24 persons. In this instance, each employee has just one specialization and employees of each specialization are classified into three skill levels (Senior, Standard and Junior). The planning period is 28 days (4 weeks). Table 2 shows the specialization and real skill level of each employee.

Apart from the junior skill level of the first specialization in a morning shift of all days, the number of required employees at any skill level of each specialization is one person in all shifts of planning horizon's days. The required number of junior employees of the first specialization in a morning shift of all days is two persons. According to problem's assumptions, each employee can be assigned to work at his/her real skill level or at any lower skill levels in his/her specialization but not more than one skill level simultaneously. Hence, senior employees are capable to work at standard or junior level and standard employees have ability to work at junior level of his/her specialization.

Some employees are interested in working at a special skill level in some shifts/all shifts of some days. Table 3 demonstrates the shifts that these employees have requested to be assigned at their desired skill levels.

Regarding above information, the presented bi-objective manpower scheduling problem is solved by the Lingo 9 software in accordance with the steps of proposed algorithm and the results are expressed in Tables 4 and 5.

In this case, the DM is interested in obtaining the feasible solution in which both objective functions have the highest utility at the same time. Therefore, it is not mandatory to check all situations and as soon as to reach the highest utility simultaneously, the algorithm can be stopped. Table 5 summarizes all examined situations. 1(13)-0.9375(2,100,000):N at t_1=0 and t_2=1 indicates that the first objective function has the utility value of 1 at the objective value of 13, the second objective function has the utility value of 0.9375 at the objective value of 2,100,000, and a non-feasible solution in this iteration. For instance, the DM chooses a feasible solution including $U(Obj_1)$= 0.92308 at Obj_1=12 and $U(Obj_2)$= 0.9375 at Obj_2=2,100,000. Table 6 shows the shift-assignment of employees in a selected solution by the DM. In some shifts, employees have been allotted to lower skill levels than their real skill. For example, (1:3) in the sixth day and the morning shift implies that an employee with ID=1 has been assigned to work in the morning shift of the sixth day of planning period at a junior skill level of his/her specialization.

The selected feasible solution is an effective (a dominant) point for the proposed bi-objective manpower scheduling problem. Getting far from this point causes the situation of one of objective functions to get worse.

TABLE 1. Some characteristics of problem instance

Planning horizon (day)	28
No. of shifts	3
No. of employees	24
No. of specializations	2
No. of skills	3
Length of each shift (hour)	8
Maximum allowable working hours for an employee during a day (hour)	16
Minimum required working hours for an employee during the planning period (hour)	168
Maximum allowable working hours for an employee during the planning period (hour)	192
A penalty coefficient for assignment at lower skill level in each specialization (Rial/person)	100000

TABLE 2. The specialization and real skill level of each employee

Employee's ID	*Specialization*	*Real skill level*
1,2,3,4	1	Senior (1)
5,6,7,8	2	Senior (1)
9,10,11,12	1	Standard (2)
13,14,15,16	2	Standard (2)
17,18,19,20	1	Junior (3)
21,22,23,24	2	Junior (3)

TABLE 4. The values obtained by the proposed algorithm

m_1	0 (person)	m_2	2,000,000 (Rial)
M_1	13 (person)	M_2	3,600,000 (Rial)
ΔObj_1	1(person)	$^\wedge Obj_2$	100,000 (Rial)
$Max_1 - Min_1$	13 (person)	$Max_2 - Min_2$	1,600,000 (Rial)
t_1	0,1,…,13	t_2	0,1,…,16

TABLE 3. The List of employees that have tendency to work at a special skill level in some shifts/days

Employee's ID	*Skill*	*Day*	*Shift*
1	1-2-3	1	Morning (1)- Afternoon (2)- Night (3)
1	2-3	2	Morning (1)- Afternoon (2)- Night (3)
1	2-3	3	Morning (1)- Afternoon (2)- Night (3)
1	2-3	4	Morning (1)- Afternoon (2)- Night (3)
1	2-3	5	Morning (1)- Afternoon (2)- Night (3)
1	2-3	6	Morning (1)- Afternoon (2)- Night (3)
1	2-3	7	Morning (1)- Afternoon (2)- Night (3)
1	1	10	Morning (1)
10	2-3	17	Morning (1)- Afternoon (2)- Night (3)
13	2	22	Morning (1)
16	2	16	Night (3)
19	3	1	Afternoon (2)
21	3	22	Night (3)

TABLE 5. Utility and objective values in all iterations ($U_1(Obj_{1t1})$ - $U_2(Obj_{2t2})$:feasible/non-feasible)

t_2 \ t_1	0	1	2	3
0	1(13) - 1(2,000,000):N	0.92308(12) - 1(2,000,000):N	0.84615(11) - 1(2,000,000):F	0.76923(10) - 1(2,000,000):F
1	1(13) - 0.9375(2,100,000):N	0.92308(12) - 0.9375(2,100,000):F	0.84615(11) - 0.9375(2,100,000):F	0.76923(10) - 0.9375(2,100,000):F
2	1(13) - 0.8750(2,200,000):F	0.92308(12) - 0.8750(2,200,000):F	0.84615(11) - 0.8750(2,200,000):F	0.76923(10) - 0.8750(2,200,000):F
3	1(13) - 0.8125(2,300,000):F	0.92308(12) - 0.8125(2,300,000):F	0.84615(11) - 0.8125(2,300,000):F	0.76923(10) - 0.8125(2,300,000):F
4	1(13) - 0.7500(2,400,000):F	0.92308(12) - 0.7500(2,400,000):F	0.84615(11) - 0.7500(2,400,000):F	0.76923(10) - 0.7500(2,400,000):F
5	1(13) - 0.6875(2,500,000) :F	0.92308(12) - 0.6875(2,500,000):F	0.84615(11) - 0.6875(2,500,000):F	0.76923(10) - 0.6875(2,500,000):F
6	1(13) - 0.6250(2,600,000):F	0.92308(12) - 0.6250(2,600,000):F	0.84615(11) - 0.6250(2,600,000):F	0.76923(10) - 0.6250(2,600,000):F
7	1(13) - 0.5625(2,700,000):F	0.92308(12) - 0.5625(2,700,000):F	0.84615(11) - 0.5625(2,700,000):F	0.76923(10) - 0.5625(2,700,000):F
8	1(13) - 0.5000(2,800,000):F	0.92308(12) - 0.5000(2,800,000):F	0.84615(11) - 0.5000(2,800,000):F	0.76923(10) - 0.5000(2,800,000):F
9	1(13) - 0.4375(2,900,000):F	0.92308(12) - 0.4375(2,900,000):F	0.84615(11) - 0.4375(2,900,000):F	0.76923(10) - 0.4375(2,900,000):F
10	1(13) - 0.3750(3,000,000):F	0.92308(12) - 0.3750(3,000,000):F	0.84615(11) - 0.3750(3,000,000):F	0.76923(10) - 0.3750(3,000,000):F
11	1(13) - 0.3125(3,100,000):F	0.92308(12) - 0.3125(3,100,000):F	0.84615(11) - 0.3125(3,100,000):F	0.76923(10) - 0.3125(3,100,000):F
12	1(13) - 0.2500(3,200,000):F	0.92308(12) - 0.2500(3,200,000):F	0.84615(11) - 0.2500(3,200,000):F	0.76923(10) - 0.2500(3,200,000):F
13	1(13) - 0.1875(3,300,000):F	0.92308(12) - 0.1875(3,300,000):F	0.84615(11) - 0.1875(3,300,000):F	0.76923(10) - 0.1875(3,300,000):F
14	1(13) - 0.1250(3,400,000):F	0.92308(12) - 0.1250(3,400,000):F	0.84615(11) - 0.1250(3,400,000):F	0.76923(10) - 0.1250(3,400,000):F
15	1(13) - 0.0625(3,500,000):F	0.92308(12) - 0.0625(3,500,000):F	0.84615(11) - 0.0625(3,500,000):F	0.76923(10) - 0.0625(3,500,000):F
16	1(13) - 0(3,600,000):F	0.92308(12) - 0(3,600,000):F	0.84615(11) - 0(3,600,000):F	0.76923(10) - 0(3,600,000):F

Cont'd TABLE 5. Utility and objective values in all iterations ($U_1(Obj_{1t1})$ - $U_2(Obj_{2t2})$:feasible/non-feasible)

t_2 \ t_1	4	5	6	7
0	0.69231(9) - 1(2,000,000):F	0.61538(8) - 1(2,000,000) :F	0.53846(7) - 1(2,000,000):F	0.46154(6) - 1(2,000,000):F
1	0.69231(9) - 0.9375(2,100,000):F	0.61538(8) - 0.9375(2,100,000):F	0.53846(7) - 0.9375(2,100,000):F	0.46154(6) - 0.9375(2,100,000):F
2	0.69231(9) - 0.8750(2,200,000):F	0.61538(8) - 0.8750(2,200,000):F	0.53846(7) - 0.8750(2,200,000):F	0.46154(6) - 0.8750(2,200,000):F
3	0.69231(9) - 0.8125(2,300,000):F	0.61538(8) - 0.8125(2,300,000):F	0.53846(7) - 0.8125(2,300,000):F	0.46154(6) - 0.8125(2,300,000):F
4	0.69231(9) - 0.7500(2,400,000):F	0.61538(8) - 0.7500(2,400,000):F	0.53846(7) - 0.7500(2,400,000):F	0.46154(6) - 0.7500(2,400,000):F
5	0.69231(9) - 0.6875(2,500,000):F	0.61538(8) - 0.6875(2,500,000):F	0.53846(7) - 0.6875(2,500,000):F	0.46154(6) - 0.6875(2,500,000):F
6	0.69231(9) - 0.6250(2,600,000):F	0.61538(8) - 0.6250(2,600,000):F	0.53846(7) - 0.6250(2,600,000):F	0.46154(6) - 0.6250(2,600,000):F
7	0.69231(9) - 0.5625(2,700,000):F	0.61538(8) - 0.5625(2,700,000):F	0.53846(7) - 0.5625(2,700,000):F	0.46154(6) - 0.5625(2,700,000):F
8	0.69231(9) - 0.5000(2,800,000):F	0.61538(8) - 0.5000(2,800,000):F	0.53846(7) - 0.5000(2,800,000):F	0.46154(6) - 0.5000(2,800,000):F
9	0.69231(9) - 0.4375(2,900,000):F	0.61538(8) - 0.4375(2,900,000):F	0.53846(7) - 0.4375(2,900,000):F	0.46154(6) - 0.4375(2,900,000):F
10	0.69231(9) - 0.3750(3,000,000):F	0.61538(8) - 0.3750(3,000,000):F	0.53846(7) - 0.3750(3,000,000):F	0.46154(6) - 0.3750(3,000,000):F
11	0.69231(9) - 0.3125(3,100,000):F	0.61538(8) - 0.3125(3,100,000):F	0.53846(7) - 0.3125(3,100,000):F	0.46154(6) - 0.3125(3,100,000):F
12	0.69231(9) - 0.2500(3,200,000):F	0.61538(8) - 0.2500(3,200,000):F	0.53846(7) - 0.2500(3,200,000):F	0.46154(6) - 0.2500(3,200,000):F
13	0.69231(9) - 0.1875(3,300,000):F	0.61538(8) - 0.1875(3,300,000):F	0.53846(7) - 0.1875(3,300,000):F	0.46154(6) - 0.1875(3,300,000):F
14	0.69231(9) - 0.1250(3,400,000):F	0.61538(8) - 0.1250(3,400,000):F	0.53846(7) - 0.1250(3,400,000):F	0.46154(6) - 0.1250(3,400,000):F
15	0.69231(9) - 0.0625(3,500,000):F	0.61538(8) - 0.0625(3,500,000):F	0.53846(7) - 0.0625(3,500,000):F	0.46154(6) - 0.0625(3,500,000):F
16	0.69231(9) - 0(3,600,000):F	0.61538(8) - 0(3,600,000):F	0.53846(7) - 0(3,600,000):F	0.46154(6) - 0(3,600,000):F

Cont'd TABLE 5. Utility and objective values in all iterations ($U_1(Obj_{1t1})$ - $U_2(Obj_{2t2})$:feasible/non-feasible)

t_2 \ t_1	8	9	10	11
0	0.38462(5) - 1(2,000,000):F	0.30769(4) - 1(2,000,000):F	0.23077(3) - 1(2,000,000):F	0.15385(2) - 1(2,000,000):F
1	0.38462(5) - 0.9375(2,100,000):F	0.30769(4) - 0.9375(2,100,000):F	0.23077(3) - 0.9375(2,100,000):F	0.15385(2) - 0.9375(2,100,000):F
2	0.38462(5) - 0.8750(2,200,000):F	0.30769(4) - 0.8750(2,200,000):F	0.23077(3) - 0.8750(2,200,000):F	0.15385(2) - 0.8750(2,200,000):F
3	0.38462(5) - 0.8125(2,300,000):F	0.30769(4) - 0.8125(2,300,000):F	0.23077(3) - 0.8125(2,300,000):F	0.15385(2) - 0.8125(2,300,000):F
4	0.38462(5) - 0.7500(2,400,000):F	0.30769(4) - 0.7500(2,400,000):F	0.23077(3) - 0.7500(2,400,000):F	0.15385(2) - 0.7500(2,400,000):F
5	0.38462(5) - 0.6875(2,500,000):F	0.30769(4) - 0.6875(2,500,000):F	0.23077(3) - 0.6875(2,500,000):F	0.15385(2) - 0.6875(2,500,000):F
6	0.38462(5) - 0.6250(2,600,000):F	0.30769(4) - 0.6250(2,600,000):F	0.23077(3) - 0.6250(2,600,000):F	0.15385(2) - 0.6250(2,600,000):F
7	0.38462(5) - 0.5625(2,700,000):F	0.30769(4) - 0.5625(2,700,000):F	0.23077(3) - 0.5625(2,700,000):F	0.15385(2) - 0.5625(2,700,000):F
8	0.38462(5) - 0.5000(2,800,000):F	0.30769(4) - 0.5000(2,800,000):F	0.23077(3) - 0.5000(2,800,000):F	0.15385(2) - 0.5000(2,800,000):F
9	0.38462(5) - 0.4375(2,900,000):F	0.30769(4) - 0.4375(2,900,000):F	0.23077(3) - 0.4375(2,900,000):F	0.15385(2) - 0.4375(2,900,000):F
10	0.38462(5) - 0.3750(3,000,000):F	0.30769(4) - 0.3750(3,000,000):F	0.23077(3) - 0.3750(3,000,000):F	0.15385(2) - 0.3750(3,000,000):F
11	0.38462(5) - 0.3125(3,100,000):F	0.30769(4) - 0.3125(3,100,000):F	0.23077(3) - 0.3125(3,100,000):F	0.15385(2) - 0.3125(3,100,000):F
12	0.38462(5) - 0.2500(3,200,000):F	0.30769(4) - 0.2500(3,200,000):F	0.23077(3) - 0.2500(3,200,000):F	0.15385(2) - 0.2500(3,200,000:F
13	0.38462(5) - 0.1875(3,300,000):F	0.30769(4) - 0.1875(3,300,000):F	0.23077(3) - 0.1875(3,300,000):F	0.15385(2) - 0.1875(3,300,000):F
14	0.38462(5) - 0.1250(3,400,000):F	0.30769(4) - 0.1250(3,400,000):F	0.23077(3) - 0.1250(3,400,000):F	0.15385(2) - 0.1250(3,400,000):F
15	0.38462(5) - 0.0625(3,500,000):F	0.30769(4) - 0.0625(3,500,000):F	0.23077(3) - 0.0625(3,500,000):F	0.15385(2) - 0.0625(3,500,000):F
16	0.38462(5) - 0(3,600,000):F	0.30769(4) - 0(3,600,000):F	0.23077(3) - 0(3,600,000):F	0.15385(2) - 0(3,600,000):F

Cont'd TABLE 5. Utility and objective values in all iterations ($U_1(Obj_{1t1})$ - $U_2(Obj_{2t2})$:feasible/non-feasible)

t_2 \ t_1	12	13
0	0.07692(1) - 1(2,000,000):F	0(0) - 1(2,000,000):F
1	0.07692(1) - 0.9375(2,100,000):F	0(0) - 0.9375(2,100,000):F
2	0.07692(1) - 0.8750(2,200,000):F	0(0) - 0.8750(2,200,000):F
3	0.07692(1) - 0.8125(2,300,000):F	0(0) - 0.8125(2,300,000):F
4	0.07692(1) - 0.7500(2,400,000):F	0(0) - 0.7500(2,400,000):F
5	0.07692(1) - 0.6875(2,500,000):F	0(0) - 0.6875(2,500,000):F
6	0.07692(1) - 0.6250(2,600,000):F	0(0) - 0.6250(2,600,000):F
7	0.07692(1) - 0.5625(2,700,000):F	0(0) - 0.5625(2,700,000):F
8	0.07692(1) - 0.5000(2,800,000):F	0(0) - 0.5000(2,800,000):F
9	0.07692(1) - 0.4375(2,900,000):F	0(0) - 0.4375(2,900,000):F
10	0.07692(1) - 0.3750(3,000,000):F	0(0) - 0.3750(3,000,000):F
11	0.07692(1) - 0.3125(3,100,000):F	0(0) - 0.3125(3,100,000):F
12	0.07692(1) - 0.2500(3,200,000):F	0(0) - 0.2500(3,200,000):F
13	0.07692(1) - 0.1875(3,300,000):F	0(0) - 0.1875(3,300,000):F
14	0.07692(1) - 0.1250(3,400,000):F	0(0) - 0.1250(3,400,000):F
15	0.07692(1) - 0.0625(3,500,000):F	0(0) - 0.0625(3,500,000):F
16	0.07692(1) - 0(3,600,000):F	0(0) - 0(3,600,000):F

TABLE 6. A shift schedule selected by DM at $U(Obj_1=12)=0.92308$ and $U(Obj_2=2,100,000)=0.9375$ (ID:Skill)

Shift / Day	*Morning (1)*	*Afternoon (2)*	*Night (3)*
1	(1:1), (7:1), (11:2), (12:2), (14:2), (17:3), (18:3), (21:3),	(2:1), (5:1), (10:2), (13:2), (19:3), (22:3),	(1:1), (6:1), (9:2), (16:2), (18:3), (24:3)
2	(2:1), (8:1), (11:3), (12:2), (13:2), (17:3), (21:3),	(4:1), (5:1), (10:2), (16:2), (20:3), (22:3),	(3:1), (6:1), (9:2), (11:3), (12:2), (14:2), (23:3),
3	(1:2), (4:1), (5:1), (15:2), (17:3), (20:3), (21:3),	(2:1), (7:1), (9:2), (12:3), (13:2), (22:3),	(3:1), (6:1), (10:2), (16:2), (18:3), (21:3),
4	(1:2), (2:1), (7:1), (12:3), (15:2), (17:3), (24:3)	(4:1), (6:1), (9:2), (13:2), (19:3), (23:3),	(3:1), (8:1), (11:2), (16:2), (20:3), (24:3)
5	(5:1), (9:2), (15:2), (18:3), (19:3), (21:3),	(1:2), (2:1), (3:1), (7:1), (13:2), (20:3), (23:3),	(4:1), (5:1), (9:3), (10:2), (16:2), (22:3),
6	(1:3), (3:1), (8:1), (11:2), (15:2), (17:3), (24:3)	(4:1), (7:1), (10:2), (16:2), (20:3), (22:3),	(2:1), (6:1), (12:2), (12:2), (14:2), (19:3), (23:3),
7	(4:1), (5:1), (9:3), (11:2), (15:2), (18:3), (24:3)	(3:1), (8:1), (10:2), (13:2), (20:3), (23:3),	(1:2), (2:1), (5:1), (12:2), (14:2), (17:3), (21:3),
8	(3:1), (6:1), (9:3), (10:2), (15:2), (19:3), (22:3),	(4:1), (8:1), (11:2), (13:2), (20:3), (24:3)	(2:1), (7:1), (9:2), (12:3), (16:2), (22:3),
9	(3:1), (6:1), (11:2), (15:2), (17:3), (18:3), (23:3),	(4:1), (8:1), (10:2), (13:2), (19:3), (24:3)	(2:1), (7:1), (12:2), (16:2), (17:3), (21:3),
10	(1:1), (6:1), (11:2), (13:2), (19:3), (20:3), (24:3)	(2:1), (5:1), (9:2), (12:2), (14:2), (18:3), (23:3),	(3:1), (7:1), (10:2), (15:2), (19:3), (22:3),
11	(2:1), (8:1), (11:2), (13:2), (17:3), (18:3), (23:3),	(3:1), (6:1), (9:2), (12:2), (14:2), (20:3), (22:3),	(1:1), (7:1), (10:3), (12:2), (16:2), (23:3),
12	(2:1), (5:1), (11:2), (13:2), (17:3), (18:3), (21:3),	(4:1), (6:1), (10:2), (15:2), (19:3), (22:3),	(2:1), (7:1), (12:2), (12:2), (14:2), (18:3), (24:3)
13	(4:1), (6:1), (9:3), (11:2), (15:2), (17:3), (21:3),	(1:1), (8:1), (12:2), (14:2), (20:3), (23:3),	(3:1), (7:1), (10:2), (15:2), (19:3), (22:3),
14	(1:1), (8:1), (11:2), (14:2), (17:3), (18:3), (23:3),	(3:1), (6:1), (12:2), (16:2), (19:3), (22:3),	(2:1), (7:1), (9:2), (13:2), (20:3), (24:3)
15	(1:1), (5:1), (12:2), (15:2), (17:3), (18:3), (23:3),	(3:1), (8:1), (11:2), (14:2), (20:3), (21:3),	(2:1), (7:1), (10:2), (13:2), (19:3), (23:3),
16	(4:1), (5:1), (9:2), (14:2), (17:3), (20:3), (24:3)	(3:1), (7:1), (10:2), (15:2), (18:3), (22:3),	(2:1), (5:1), (11:2), (16:2), (19:3), (21:3),
17	(4:1), (7:1), (9:2), (14:2), (17:3), (18:3), (24:3)	(3:1), (8:1), (10:2), (16:2), (19:3), (23:3),	(2:1), (6:1), (12:2), (15:2), (20:3), (21:3),
18	(3:1), (5:1), (9:2), (11:3), (14:2), (18:3), (23:3),	(4:1), (8:1), (12:2), (16:2), (20:3), (24:3)	(1:1), (6:1), (10:2), (13:2), (19:3), (21:3),
19	(4:1), (8:1), (11:2), (15:2), (18:3), (20:3), (24:3)	(1:1), (6:1), (12:2), (13:2), (17:3), (22:3),	(3:1), (5:1), (9:2), (14:2), (18:3), (21:3),
20	(1:1), (8:1), (11:3), (12:2), (13:2), (17:3), (24:3)	(4:1), (5:1), (10:2), (14:2), (20:3), (22:3),	(2:1), (7:1), (12:2), (16:2), (19:3), (21:3),
21	(4:1), (8:1), (9:2), (14:2), (17:3), (20:3), (24:3)	(1:1), (5:1), (11:2), (13:2), (18:3), (22:3),	(4:1), (7:1), (10:2), (15:2), (19:3), (24:3)
22	(1:1), (5:1), (12:2), (13:2), (17:3), (18:3), (23:3),	(3:1), (6:1), (10:2), (14:2), (20:3), (22:3),	(2:1), (8:1), (9:2), (16:2), (19:3), (21:3),
23	(3:1), (5:1), (12:2), (14:2), (17:3), (18:3), (22:3),	(4:1), (8:1), (9:3), (10:2), (16:2), (23:3),	(1:1), (6:1), (11:2), (15:2), (19:3), (24:3)
24	(3:1), (8:1), (9:2), (16:2), (17:3), (20:3), (22:3),	(4:1), (6:1), (12:2), (14:2), (18:3), (23:3),	(2:1), (5:1), (10:2), (15:2), (19:3), (24:3)
25	(4:1), (7:1), (12:2), (16:2), (17:3), (18:3), (21:3),	(1:1), (8:1), (9:2), (15:2), (19:3), (23:3),	(3:1), (6:1), (12:2), (13:2), (20:3), (24:3)
26	(4:1), (8:1), (10:2), (16:2), (18:3), (19:3), (21:3),	(3:1), (7:1), (11:2), (15:2), (20:3), (23:3),	(2:1), (5:1), (9:2), (14:2), (17:3), (22:3),
27	(4:1), (7:1), (11:2), (16:2), (19:3), (20:3), (23:3),	(1:1), (5:1), (12:2), (13:2), (18:3), (21:3),	(2:1), (8:1), (10:2), (15:2), (19:3), (22:3),
28	(1:1), (6:1), (11:3), (12:2), (16:2), (17:3), (21:3),	(2:1), (7:1), (9:2), (14:2), (20:3), (24:3)	(4:1), (6:1), (11:2), (12:3), (13:2), (21:3),

5. CONCLUDING REMARKS

In this paper, a novel bi-objective manpower scheduling problem that is appropriate for production and service environments was introduced. The considered objectives has minimized the penalty incurred by the employees' assignment at lower skill levels than their real skill and maximized the employees' utility by assigning them at desired skill levels in some shifts/days. Also, a solution procedure on the basis of utility of objective values was proposed. Solving the given problem by proposed procedure, a feasible solution that is an effective point for presented bi-objective model was obtained. Getting far from the acquired effective point makes the situation of one of objective functions to get worse.

In this study, the utilty of objective values was considered as a linear function. Since the utility function can have various forms, it can be taken as a non-linear function into account according to DM's desire.

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