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Table 3**.** Department details and special cases.

Department	Planning period	Number of nurses	Shift type	Nurse requests and preferences
Plastic Surgery	05 March - 01 April 2012	7	8*16, 16*8, 8*24, 16*24	1st nurse, the responsible nurse 2nd nurse will be on duty on Saturdays of the 1st and 2nd week
Obstetrics and Gynecology	05 November - 02 December 2012	6	8*16, 16*8	1st nurse, the responsible nurse 4th nurse wants to work at night in the weekdays and at day times on weekends 3rd nurse wants to work on Saturday in the 1st week, on Wednesday and Sunday in the 2nd week, on Friday in the 3rd week, on Tuesday and Sunday in the 4th week at 16*8 shifts.
Pediatrics	01 October -28 October 2012	7	8*16, 16*8	1st nurse, the responsible nurse 2nd nurse will work on day shifts in the first three weeks, and at 16*8 shift on Friday in the 4th week 2nd nurse is off duty on Wednesday, Thursday and Friday of the 1st week. 4th week, all workers will work 16 hours less than normal due to festival holiday 6th nurse is off duty until Saturday of the 4th week.
Oncology	03 September - 30 September 2012	13	8*16, 16*8, 8*24, 16*24	1st nurse, the responsible nurse 2nd, 3rd and 5th nurses shall work on day times during weekdays 2nd nurse is on the 4th week leave. 6th nurse spends her annual leave throughout four-week period 8th nurse is on her first two weeks of the annual leave 11th nurse is on annual leave from Monday of the second week up to Wednesday of the 3rd week. 12th nurse is on the third week of her annual leave
Eye Treatment	06 August - 02 September 2012	11	8*16, 16*8, 8*24, 16*24	1st nurse, the responsible nurse 2nd nurse wants to work twice at the 16*8 shift on weekdays 3rd nurse is on annual leave with the exception of Wednesday of the second week 7th nurse works 32 hours a week and can only work at the 8*16 shift. 8th nurse wants to work on Monday and Tuesday in the third week 8th nurse is on her last week of her annual leave. 9th nurse is on the third and fourth week of her annual leave. 10th nurse is the first and second week of her annual leave . Because Monday and Tuesday of the 3rd week fall within festival period, all workers shall work 16 hours less than normal. Because Thursday of the 4th week is an official holiday, all workers shall work 8 hours less than normal times.

Table 4. Nurse demands for the departments.

Department\Days	First Week							Second Week							Third Weed							Fourth Week						
	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su
Plastic Surgery	3	3	3	3	3	1	1	3	3	3	3	3	1	1	3	3	3	3	3	1	1	3	3	3	3	3	1	1
	2	2	2	1	2	1	1	1	2	2	2	2	1	1	1	2	2	2	2	1	1	1	2	2	2	2	1	1
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Obstetrics and Gynecology	3	3	3	2	3	1	1	3	3	3	3	2	1	1	3	3	3	3	2	1	1	3	3	3	3	2	1	1
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Pediatrics	3	3	2	2	2	1	1	3	3	3	3	2	1	1	3	3	3	3	2	1	1	3	3	1	1	2	1	1
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Oncology	5	5	4	4	4	1	1	4	4	5	5	4	1	1	4	5	4	4	4	1	2	4	4	5	4	4	2	3
	2	2	3	3	3	2	2	2	2	2	2	3	2	2	2	2	2	2	2	2	2	2	2	3	2	3	2	2
	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Eye Treatment	3	3	3	3	3	2	2	4	3	4	4	3	2	1	1	1	4	3	3	3	2	3	3	3	2	3	1	1
	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	3	2	2	3	2	1	1	1	1	1	1
	2	2	1	1	2	1	2	2	2	2	2	2	1	1	1	1	1	3	1	2	2	1	1	1	1	1	1	1

Table 5. Parameters used for the recommended ABC algorithm and their solution periods parameters.

		Number of Initial bee	Number of Scout bees	Number of Follower Bees	Iteration	CPU Time (second)			
						First Week	Second Week	Third Weed	Fourth Week
Department	Plastic Surgery	150	15	20	1200	23,68	25,59	25,63	26,24
	Obstetrics and Gynecology	150	15	20	1200	24,98	25,44	25,75	25,55
	Pediatrics	150	15	20	1200	25,02	26,86	26,73	26,59
	Eye Treatment	150	15	20	1200	26,8	28,98	28,72	27,72
	Oncology	150	15	20	1200	28,2	30,22	30,68	31,1

In case of a situation that necessitates penalty, then by taking the data regarding that situation from Table 2, penalty value is calculated and added onto the bee's penalty.

Penalty points are calculated in the same way both at the initial solution and during evaluation of the follower bees. The penalties of the nurses throughout a weekly schedule are summed up to obtain the bees' or followers' penalties.

Generally, the schedule obtained from the initial solution becomes in a worse condition. To improve such a schedule, neighbor finding is applied around the pioneer bees in order to establish the followers. Neighbor finding is achieved with the following algorithm steps;

(i) Turn up to the number of pioneer bees

(ii) Equalize all the follower bees to the pioneer bees

(iii) Reset the counter

(iv) Turn up to the number of follower bees

(v) Select two nurses randomly

(vi) Make one increment to the counter

(vii) Randomly choose a day

(viii) Select a shift randomly

(ix) Randomly select two nurses

(x) Change the selected shifts for the selected nurses, calculate the follower penalty

(xi) If the new status is better or the counter = 5, then save the follower and increase the number of follower by one. Otherwise return to step 6.

(xii) If the number of followers is reached, increase the number of pioneer by one and return to the 2nd step

(xiii) If the number of pioneer bees is reached, then compare every pioneer bee with its follower bee; designate a good follower bee as a pioneer bee.

After determining bee followers, the bees are compared with respective follower bees and the best bee is chosen as the pioneer bee. After specifying every pioneer bee in this manner, iteration becomes accomplished. Then the loop starts again and the algorithm runs until the required number of iterations is reached. The stopping condition in this study has been defined as the number of iterations. In order to determine the correct number of iterations, the program was run several times with different types of problems.

The model formed has been designed basically for establishing weekly schedules. When the program is run once, the first week solution will have been established. Beside this, the model forms a four week schedule by taking the previous weeks' schedules into consideration. In this way, schedules for a four-week period will have correctly been formed.

4.2. *The software developed for the problem*

To achieve solution to the nurse scheduling problem a user interactive program was prepared on Visual Studio C # software[27]. A useful user guide interface that enables the program user to enter necessary data was formed. While most studies in literature are only capable of offering solutions to certain specific shift models, the developed program in this study allows the user to select any required shift type from the user interface. In addition, the program has been designed in such a way that, through its interface, it allows entrance of penalty values for details such as the number of personnel, demand values, exact and flexible constraints. With these features, the developed program provides a good opportunity for making changes, easily, to the characteristic specifications of the problem. This

flexible feature of the program provides a room for applications with different hospitals and a diverse range of the departments at those hospitals.

At Karadeniz Technical University, Faculty of Medicine, where this study was conducted, the scheduling programs are carried out by responsible personnel of every department. This forms a structure that enables more accurate and quick decision on workers special demands like workers leaves, types of works etc. With the help of its flexible feature, the study enables separate formation of schedules for every department and simplifies their control by the responsible personnel of these departments.

4.3. *Program print outs and evaluation*

The parameters and solution periods used for the ABC algorithm conducted for the hospital departments are given in Table 5. In order to determine suitable parametric values, the program was run several times.

When the table (Table 5) is studied it is found that same parameter values are sufficient for all the departments. This shows that the parameters used were chosen correctly. When the processing time is investigated it is seen that the program used between 23 and 31 seconds to establish a weekly schedule. Such a short processing time increases usability of the program in real life.

The difference between the longest and shortest processing time for a weekly schedule is about 8 seconds. This shows how insignificant the effects of tough conditions or increasing the number of personnel may be to the program. The schedules obtained from the conducted studies and the existing schedules were evaluated based on specified constraints. Table 6 shows the constraints infringing numbers for every department calculated by the developed ABC program. These constraints' infringing numbers are the total of values for a four-week period. As for the schedules applied by the hospital management, the constraint infringing numbers are given in Table.

When Table 3 is studied, it is seen that there is no special constraining conditions, whatsoever, for the plastic surgery department. Higher number of shifts worked at, simplifies the assigning process. Within the planning period, none of the personnel took a leave. If the demand values given in Table 4 are studied, it is observed that the available number of workers is quite sufficient to cover all the demands without necessitating them to work on overtimes. When the values for the plastic surgery department in Table 6 are studied, it is seen that the proposed algorithm sufficiently covers all the exact constraints under the given operating conditions and that 22 flexible constraints are infringed. Corresponding to this, when the values for plastic surgery given in Table 7 are investigated, it is found that, in the existing application, the third exact constraint was infringed twice whereas the sixth exact constraint was infringed once. Besides this, flexible constraints were found to be infringed eighty times. This proves that the proposed ABC algorithm model exhibits better performance than the conventional method provided that extreme conditions are not the case.

Investigation on values given for the second department in Table 3 reveals that this department possesses more constraining special cases than the first department does. The fact that there are only two working shifts in the department plus inclusion of special demands of the nurses in the schedule cause slight toughening of the department. Table 4 also indicates that the existing number of personnel in the second department is capable of covering the nurses' demands without having overtimes. As for the case of infringed constraints listed in Table 6, it is seen that the proposed algorithm has had only one exact constraint infringed while flexible constraints have been infringed twenty four times. Table 7 shows the values for the second department where by the existing method has undergone exact constraint infringement four times and flexible constraints sixty five times.

As for the remaining 3rd, 4th and 5th departments, when Table 3 is studied it is found that special cases are progressively increasing and that scheduling procedures become more complex. Table 6, shows that even under these tough conditions the proposed algorithm still exhibits better performance by maintaining all the exact constraints for the 3rd and 5th departments but infringing four exact constraints for the 4th department. On the contrary, when Table 7 is investigated, it is found that in the applied schedule 3, 16 and 5 exact constraints were infringed in the 3rd, 4th and 5th departments respectively. By comparing these two situations, it is

clearly seen that the proposed algorithm forms more quality schedules even under difficult conditions than the existing schedule. The result tables (Table 6 and Table 7) show that the proposed algorithm is capable of forming more improved schedules for all the five departments as compared with the normally applied system. As it is also seen from Table 6, the total of infringed exact constraints is 5 and the total number of infringed flexible constraints is 208; but the total number of exact constraints infringed in the applied schedules (Table 7) is 31 while that of the flexible constraints within that system is 457. These results confirm that, under various operating conditions, the proposed algorithm runs effectively and establishes suitable nurse schedules in a quick manner.

Table 6. Number of infringed constraints in the schedules formed with the proposed ABC algorithm.

No	Department	Hard Constraints (1, 2,…,10)										Soft Constraints (11, 12,…,15)				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Plastic Surgery	0	0	0	0	0	0	0	0	0	0	0	0	6	4	12
2	Obstetrics and Gynecology	0	0	0	0	0	0	0	0	1	0	3	0	5	1	15
3	Pediatrics	0	0	0	0	0	0	0	0	0	0	0	2	4	4	16
4	Eye Treatment	0	0	0	0	0	0	1	1	0	2	15	3	9	6	23
5	Oncology	0	0	0	0	0	0	0	0	0	0	21	4	11	5	34

Table 7. Number of infringed constraints in the schedules prepared by the hospital management.

No	Department	Hard Constraints (1, 2,…,10)										Soft Constraints (11, 12,…,15)				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Plastic Surgery	0	0	2	0	0	1	0	0	0	0	39	0	6	4	31
2	Obstetrics and Gynecology	0	0	1	0	0	0	0	0	3	0	33	0	8	3	21
3	Pediatrics	0	0	3	0	0	0	0	0	0	0	24	4	4	3	20
4	Eye Treatment	0	0	2	0	3	3	0	0	4	4	60	3	11	7	33
5	Oncology	0	0	1	0	2	2	0	0	0	0	83	4	15	6	35

5. Results and Suggestions

In this study, Artificial Bee Colony (ABC) algorithm has been proposed for the Nurse Scheduling Problems (NSP) which is termed as a NP-difficult problem in literature. In order for the proposed algorithm to work a user interface model was developed on a PC by using a flexible C# programming language.

This is the first study that uses ABC algorithm to deal with the NSP. In order to evaluate the performance of the proposed ABC algorithm, real data obtained from five departments of the hospital belonging to Karadeniz Technical University, Faculty of Medicine were used. Shift schedules were formed by using the data and the results obtained from the algorithm were compared with the existing applied method.

The constraints and penalty points considered during scheduling, literature studies and face to face contacts made with hospital personnel were specified based on the real situations. The obtained results indicated that algorithm exhibits improved performance under all conditions by substantially covering both exact and flexible constraints, forming more improved schedules than the existing method and that the new method is faster too. Consequently; this study has shown that ABC algorithm is a suitable method for NSP.

Future studies may include parameter analysis and hybrid methodologies to speed up the model even further and enhancing the solution quality. Moreover; the same data may be used and the proposed algorithm

may be compared and contrasted with other intuitive methods like Genetic Algorithm, Variable Neighbor Search, and Tabu Search

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