Two-Stage Multi-Objective University Courses Timetabling Using Genetic Algorithms

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Abstract - In this paper, a University Courses Timetabling (UCTT) optimization model has been developed in MS Excel environment and solved using Evolver solver based on Genetic Algorithms.The proposed model has two stages, which may be used together or individually in accordance with the philosophy of the university. The proposed model was implemented to schedule the courses in the Mechanical Engineering Department of Umm Al-Qura University, and it provided an optimal schedule.

Keyword- UCTT, Optimization, GA, Evolver

1. Introduction

Timetables are organizationalstructures that can be found in various areas of human activity including sports [1], entertainment [2], transport [3], industry [4], and education [5]. In the context of higher education institutions, a timetable can be thought of as an assignment of events (such as lectures, tutorials, or exams) to a finite number of rooms and timeslots in accordance with a set of constraints; some of which will be mandatory, while others may be optional [6]. According to [7], the problem of constructing such timetables can be divided into two categories: exam timetabling problems and course timetabling problems. It is also suggested that course timetabling problems can be further divided into two sub-categories: ‘‘post enrolment-based course timetabling’’, where the constraints of the problem are specified by student enrolment data, and ‘‘curriculum-based course timetabling’’, where constraints are based on curricula specified by the university.T. Müller and H. Rudová[8] have also presented that these sub-categories are closely related, demonstrating how instances of the latter can be transformed into those of the former in many cases.

A Novel Genetic Algorithm Technique for Solving University Course Timetabling Problems [9], Trans Genetic Coloring Approach for Timetabling Problem [10], On improvement of Effectiveness in Automatic University Timetabling Arrangement with Applied Genetic Algorithm [11] are presented.

The CB-CTT problem consists of scheduling lectures of a set of courses into a weekly timetable, where each lecture of a course must be assigned a period and a room in accordance with a given set of constraints are proposed[12].University Course Timetabling Problem is presented in Fig. 1 [13].

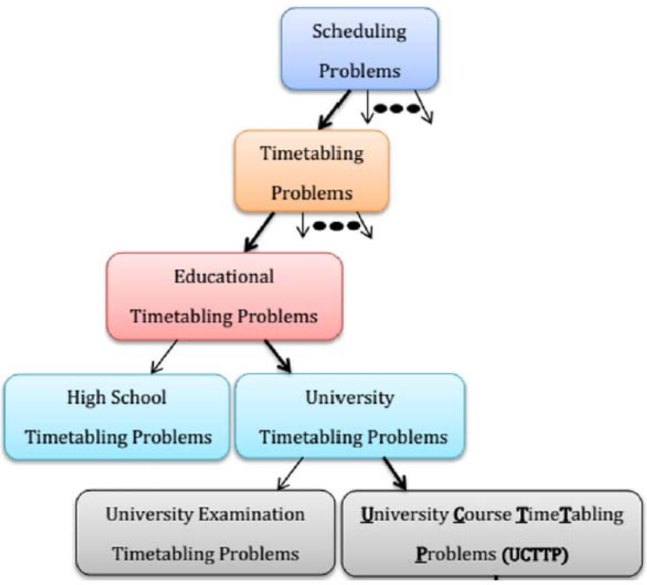

Figure 1. Diagram of University Course Timetabling Problem

Evolver can use any of the following sixsolvingmethods, depending on the type of optimization model. Three of the solving methods (Recipe, Order, and Grouping) make use of entirely differentalgorithms. The other three (Budget, Project, and Schedule) are descendants of these three, addingadditional constraints[14].

The **Schedule** solving method has beenusedin this research to solve the UCTT problem. Eachcourse is assumed to take the same amount of time.

In the **Schedule** solving method, there are eight kinds of constraints between courses:

1) (**With**) two classes must occur in the sametime block.
2) (**Not with**) two classes must not occur in thesame time block.
3) (**Before**) the first class must occur before the second class.
4) (**at**) theclass must occur in the time block ina certain time block.
5) (**Not after**) thefirst class must occur at the same timeor before the second task.
6) (**Not before**) thefirst class must occur at the same timeor after the second class.
7) (**Not at**) theclass must not occur in a certain time block.
8) (**After**) the first class must occur after the second class.

2. Problem description

The problemsof UCTT may involvetwo classes of hard and soft constraints. Hard constraints must be satisfied in the problem completely so that the generated solution would be possible without any conflict; no violation is allowed in these constraints. Soft constraints are related to objective function; the objective function is to maximize the number of satisfied soft constraints. Unlike hard constraints, soft constraints are not necessarily required to be satisfied, but as the number of these satisfied constraints increases, the quality of solutions of objective function increases. In the following, a list of hard and soft constraints is presented.Theseconstraintsare taken from literature [15-19].

a. Hard constraints

1. No student is required to attend more than one course at the same time.
2. No lecturer is required to attend more than one course at the same time.
3. Number of courseoccurred at the same time slot donotexceed the available number of teaching rooms.
4. Each course also requires a room capacity.
5. The double booking of rooms is prohibited.
6. Some events cannot be taught in certain timeslots.
7. Precedence constraints –some courses need to be scheduled before or after others.

b. Soft constraints

1. The teacher can have the choice to suggest priority to certain timeslots for her/his courses.
2. A teacher may request a special classroom for a given course.
3. The courses should not be scheduled for evening timeslots, as it is possible.
4. The teaching hours for teachers in a classroom are 2 hours.

3. Model formulation and implementation

The proposed model has beenimplemented to schedule the courses in the Mechanical Engineering Department of Umm Al-Qura University. The problem involves assigning a set of courses to 30 timeslots (5 days, with 6-timeslots per day) as shown in Table 1, which also includes the prioritypenalty (PP) of each slot as specified by the faculty policy. The lower the priority penalty, thenumber is the most prior slot.

The model has beensolved using Evolver solver and runon an Intel® Core™ i3-2310M CPU @2.10 GHz (3 GB of RAM).The GA parameters include; population size N =50, number of generationsG =40,000, probability of crossover Pc = 0.5, and probability of mutation Pm = 0.1.

The slots PPs may be chosen according to the requirements of each university. In this research, the slots PPsare assumed as shown in Table 1.Most priorities are given to the morning slots and priorities are reduced for the later slots. Thursday slots have the lowest priorities.

Table 1. Time slot and priority penalty table

Day	Period	Slots	Priority Penalty	Day	Period	Slots	Priority Penalty	Day	Period	Slots	Priority Penalty	Day	Period	Slots	Priority Penalty	Day	Period	Slots	Priority Penalty
Sunday	1	1	0	Monday	1	7	0	Tuesday	1	13	0	Wednesday	1	19	0	Thursday	1	25	50
	2	2	1		2	8	1		2	14	1		2	20	1		2	26	60
	3	3	2		3	9	2		3	15	2		3	21	2		3	27	70
	4	4	3		4	10	3		4	16	3		4	22	3		4	28	80
	5	5	4		5	11	4		5	17	4		5	23	4		5	29	90
	6	6	5		6	12	5		6	18	5		6	24	5		6	30	100

The list of the courses and the number of students registered in each course as tabulated in Table 2 are some of the model inputs.

Table 2. Courses ID and no. of students

ID	Course code	# St.	ID	Course code	# St.	ID	Course code	# St.
1	804151-G1	20	28	804302-G2	38	55	804201-G3	38
2	804151-G2	22	29	804302-G3	34	56	804201-G4	40
3	804344-G1	42	30	804336-G1	32	57	804201-G5	13
4	804344-G2	26	31	804343-G1	20	58	804201-G6	39
5	804344-G3	31	32	804343-G2	23	59	804201-G7	37
6	804344-G4	28	33	804343-G3	20	60	804201-G8	38
7	804344-G5	44	34	804343-G4	15	61	804331-G1	12
8	804301-G1	45	35	804343-G5	41	62	804331-G2	45
9	804301-G2	37	36	804351-G1	21	63	804453-G1	45
10	804301-G3	27	37	804351-G2	18	64	804453-G2	43
11	804461-G1	21	38	804370-G1	46	65	804465-G1	28
12	804461-G2	34	39	804370-G2	44	66	804465-G2	23
13	804466-G1	38	40	804424-G1	40	67	804465-G3	27
14	804466-G2	33	41	804424-G2	51	68	804469-G1	40
15	804306-G1	46	42	804416-G1	45	69	804234-G1	17
16	804306-G2	25	43	804416-G2	24	70	804234-G2	36
17	804306-G3	41	44	804416-G3	25	71	804234-G3	66
18	804306-G4	24	45	804420-G1	47	72	804234-G4	23
19	804308-G1	34	46	804420-G2	37	73	804253-G1	26
20	804308-G2	25	47	804420-G3	38	74	804253-G2	39
21	804333-G1	37	48	804446-G1	31	75	804253-G3	44
22	804333-G2	27	49	804446-G2	37	76	804253-G4	18
23	804469-G1	36	50	804446-G3	31	77	804253-G5	16
24	804319-G1	37	51	804451-G1	39	78	804334-G1	15
25	804319-G2	42	52	804451-G2	16	79	804434-G1	37
26	804469-G1	48	53	804201-G1	27	80	804434-G2	51
27	804302-G1	32	54	804201-G2	33	81	804434-G3	30

The students'list of each course is the second input of the model. Table 3 is a sample of students'lists of some courses.

Table 3.Students 'listsof each course (sample)

Engineering Graphics		Engineering Economics				
Group (1)	Group (2)	Group (1)	Group (2)	Group (3)	Group (4)	Group (5)
4300000	4300020	4300042	4300080	4300111	4300148	4300179
4300001	4300021	4300043	4300081	4300112	4300149	4300180
4300002	4300022	4300044	4300082	4300113	4300150	4300181
4300003	4300023	4300045	4300083	4300114	4300151	4300182
4300004	4300024	4300046	4300084	4300115	4300152	4300183
4300005	4300025	4300047	4300085	4300116	4300153	4300184
4300006	4300026	4300048	4300086	4300117	4300154	4300185
4300007	4300027	4300049	4300087	4300118	4300155	4300186
4300008	4300028	4300050	4300088	4300119	4300156	4300187
4300009	4300029	4300051	4300089	4300120	4300157	4300188
4300010	4300030	4300052	4300090	4300121	4300158	4300189
4300011	4300031	4300053	4300091	4300122	4300159	4300190
4300012	4300032	4300054	4300092	4300123	4300160	4300191
4300013	4300033	4300055	4300093	4300124	4300161	4300192
4300014	4300034	4300056	4300094	4300125	4300162	4300193
4300015	4300035	4300057	4300095	4300126	4300163	4300194

The optimization process is completed in two stages. The first stage is formulated to optimize the time slot for each course, while the second stage is formulated to optimize the location of each course. So, the first stage is calledthe time stage, and the second stage is calledthe location stage.

a. Time stage

Time stage consists of three steps as follows:

1. Student overlap
2. Lecturer overlap
3. Model Not-With (NW) constraints

1. Student overlap matrix

To ensure that no student has more than one lecture at the same time, the model is designed to compare the courses group's lists automatically to determine the student overlap matrix. Table 4 shows a part of 81*81 student overlap matrix.

Table 4. Student overlap matrix (sample)

ID	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1																		
2									NW	NW								
3																		NW
4							NW											
5																		
6																		
7																		
8																		

2. Lecturer overlap matrix

To ensure that no lecturer has more than one lecture at the same time, after entering lecturers responsible forteaching each group as shown in Table 5, the model will analyze it automatically to determine the lecturer overlap matrix. Table 6 shows a part of 81*81 lecturer overlap matrix.

Table 5. Lecturer-course table (sample)

Courses (ID)	1	2	3	4	5	6	7	8	9	10	11	12
Lecturer Code	L01	L01	L01	L01	L01	L01	L01	L02	L02	L03	L02	L02
Courses (ID)	13	14	15	16	17	18	19	20	21	22	23	24
Lecturer Code	L03	L03	L04	L04	L04	L04	L05	L06	L05	L05	L27	L26
Courses (ID)	25	26	27	28	29	30	31	32	33	34	35	36
Lecturer Code	L26	L25	L25	L25	L25	L10	L24	L24	L24	L16	L16	L23
Courses (ID)	37	38	39	40	41	42	43	44	45	46	47	48
Lecturer Code	L23	L22	L22	L22	L22	L21	L21	L21	L20	L20	L20	L19
Courses (ID)	49	50	51	52	53	54	55	56	57	58	59	60
Lecturer Code	L19	L18	L17	L17	L14	L14	L14	L16	L16	L16	L15	L15
Courses (ID)	61	62	63	64	65	66	67	68	69	70	71	72
Lecturer Code	L14	L14	L13	L13	L12	L12	L12	L11	L10	L09	L09	L08
Courses (ID)	73	74	75	76	77	78	79	80	81			
Lecturer Code	L07	L07	L07	L07	L07	L06	L06	L07	L07			

Table 6. Lecturer overlap matrix(sample)

(ID)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	NW	NW	NW	NW	NW	NW									
2		NW	NW	NW	NW	NW									
3			NW	NW	NW	NW									
4				NW	NW	NW									
5					NW	NW									
6						NW									
7															
8								NW		NW	NW				
9										NW	NW				
10												NW	NW		

3. Model “not-with” constraints determination

The Not-With constraints shown in Table 7 are resulted automatically in the modelfor the courses that have a student or lecturer overlap.

Table 7.Model NW Constraints

ID 1	Rel.	ID 2	ID 1	Rel.	ID 2	ID 1	Rel.	ID 2	ID 1	Rel.	ID 2	ID 1	Rel.	ID 2
1	NW	2	6	NW	53	21	NW	34	29	NW	72	39	NW	69
1	NW	25	8	NW	61	21	NW	74	30	NW	32	39	NW	70
1	NW	26	10	NW	11	23	NW	56	30	NW	39	39	NW	77
1	NW	29	10	NW	51	24	NW	81	30	NW	44	40	NW	45
1	NW	32	10	NW	54	25	NW	28	30	NW	50	41	NW	48
1	NW	33	10	NW	79	25	NW	30	30	NW	52	41	NW	72
1	NW	34	11	NW	79	25	NW	39	30	NW	77	43	NW	63
1	NW	35	12	NW	24	25	NW	50	30	NW	78	43	NW	72
2	NW	10	13	NW	55	25	NW	52	31	NW	39	44	NW	46
2	NW	11	14	NW	65	25	NW	77	31	NW	70	45	NW	48
2	NW	79	15	NW	34	26	NW	43	32	NW	35	45	NW	57
3	NW	19	15	NW	37	27	NW	38	32	NW	63	48	NW	57
3	NW	45	16	NW	68	27	NW	46	32	NW	80	50	NW	52
3	NW	48	16	NW	69	27	NW	78	33	NW	36	50	NW	77
3	NW	57	19	NW	43	28	NW	30	33	NW	72	51	NW	54
3	NW	64	19	NW	45	28	NW	39	34	NW	37	52	NW	77
4	NW	8	19	NW	48	28	NW	50	36	NW	49	53	NW	72
4	NW	42	19	NW	57	28	NW	52	37	NW	66	58	NW	72
4	NW	55	20	NW	31	28	NW	77	38	NW	72	59	NW	61
4	NW	62	20	NW	39	29	NW	31	38	NW	78	60	NW	71

The output of first stageisthe optimal slot numberfor each course, which satisfies two objectives of minimizing both the penalty of priority and the excess number of classes asshown in Table 8. Limiting the number of classes at each slot by an available number of rooms, which is equal to four in this case, by reducing the excess classes’ number which is calculated by subtracting the number of the available rooms from the number of scheduled classes. Table 9 shows the resulted optimal solution, in which there are no required excess rooms in any time slot.

Table 8.Slot number and PP for the first six course (First Objective)

ID	1	2	3	4	5	6
Course code	804151-G1	804151-G2	804344-G1	804344-G2	804344-G3	804344-G4
Slot No.	11	2	7	14	23	9
PP	4	1	0	1	4	2

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Table 9.The excess number of classes (Second Objective)

Slots	Sched. classes	Excess classes	Slots	Sched. classes	Excess classes	Slots	Sched. classes	Excess classes
1	4	0	11	2	0	21	4	0
2	4	0	12	3	0	22	4	0
3	4	0	13	4	0	23	4	0
4	4	0	14	4	0	24	1	0
5	2	0	15	4	0	25	0	0
6	3	0	16	2	0	26	0	0
7	4	0	17	2	0	27	0	0
8	4	0	18	2	0	28	0	0
9	4	0	19	4	0	29	0	0
10	4	0	20	4	0	30	0	0
						Sum	81	0

b. Location stage

The location state consists of two steps as follows:

1. Room NW matrix
2. Course location and schedule.

1. Room NW matrix

The objective of this stage is to reduce the number of excess students in the teaching rooms. It mustensure that there is no more than one lecture in the same room at the same time. Table 10 shows the NW relationships between courses at the same slot.

Table 10. Room NW matrix(sample)

ID/ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1															
2															
3												NW			
4									NW						
5															
6															
7															
8															

2. Course location and schedule.

The resulted room number assigned for each course table is shown in Table 11.

Table 11. Course location (sample)

ID	1	2	3	4	5	6
Course code	804151-G1	804151-G2	804344-G1	804344-G2	804344-G3	804344-G4
#St	20	22	42	26	31	28
Slot No.	11	2	7	14	23	9
Room No.	4	4	4	4	3	3
Room Capacity	70	70	70	70	35	35
Excess students	0	0	0	0	0	0

The final schedule of the program is shown in table 12,wherein it is noticed that there are no lectures on Thursday because of its higher PP.

Table 12. Courses schedule.

Day	Room	Period					
		1	2	3	4	5	6
Sunday	**Room 1**	804466-G1	804253-G2	804308-G2	804201-G7		804351-G1
	Room 2	804370-G2	804306-G3	804453-G1	804370-G1		
	Room 3	804343-G4	804343-G2	804351-G2	804461-G2	804334-G1	804302-G1
	Room 4	804416-G1	804151-G2	804465-G3	804434-G2	804253-G3	804424-G2
Monday	**Room 1**	804420-G3	804469-G1	804469-G1	804234-G4		
	Room 2	804306-G1	804201-G6	804469-G1	804343-G5		804331-G2
	Room 3	804416-G2	804336-G1	804344-G4	804253-G5	804253-G4	804343-G1
	Room 4	804344-G1	804420-G1	804201-G8	804308-G1	804151-G1	804424-G1
Tuesday	**Room 1**	804319-G1	804343-G3	804201-G1	804301-G2		
	Room 2	804465-G1	804446-G3	804234-G2		804451-G2	804302-G3
	Room 3	804301-G3	804434-G3	804253-G1	804201-G2		
	Room 4	804201-G4	804344-G2	804302-G2		804201-G5	804420-G2
Wednesday	**Room 1**	804465-G2	804333-G1	804466-G2	804416-G3	804331-G1	
	Room 2	804453-G2	804319-G2	804306-G4	804201-G3	804234-G3	
	Room 3		804306-G2	804461-G1	804446-G1	804344-G3	
	Room 4	804301-G1	804451-G1	804333-G2	804344-G5	804446-G2	804434-G1
Thursday	**Room 1**						
	Room 2						
	Room 3						
	Room 4						

The quality of the solution may be improved by repeating the optimization process without restoring the adjustable cells. The relation between achieved objective, processing time (PT) and the number of iterations for different number of trials for each run is represented in Table 13.Fig. 2 shows that increasing the number of trial for each run increases the quality of the solution by getting better values of the objective and decreases the number of iterations required to get the best solution. The solution does not change after six or seven iterations at most.

Table 13.Effect of no. of iterations and trial on the objective and processing time.

		No. of Trials									
		10000		20000		30000		40000		50000	
		Obj.	PT (Sec.)	Obj.	PT (Sec.)	Obj.	PT (Sec.)	Obj.	PT (Sec.)	Obj.	PT (Sec.)
Iteration	1	398	214	530	468	300	453	331	708	326	799
	2	314	274	250	460	193	470	190	667	192	856
	3	250	402	197	460	185	469	180	670	180	850
	4	245	298	192	446	185	509	180	679	180	780
	5	235	219	189	458	181	599	179	633	180	810
	6	235	260	189	465	181	514	175	658	180	800
	7	235	230	189	460	181	537	175	661	180	841

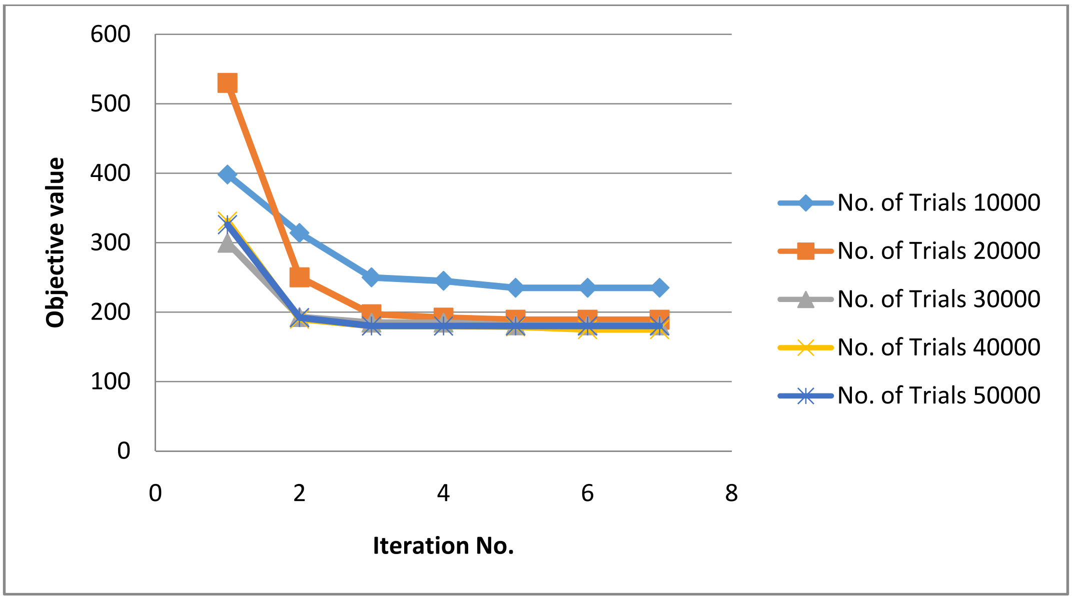

Figure 2.Effect of no. of iterations and trial on the objective value.

4. Conclusion

The University Courses Timetabling (UCTT) optimization proposed model has beenbuilt in MS Excel environment and solved using Evolver solver based on Genetic Algorithms. The model has beenimplemented in Umm Al-Qura University.

The proposed model has two stages, which may be used together or individually in accordance with the philosophy of the university.Some universities are assigning initially the time slot for all courses and ask their students to register and the registration system preventsoccurring of any conflict of time for both lecturers and students.In this case, there is no need ofthe firststage.

The quality of the solution may be improved by repeating the optimization process without restoring the adjustable cells.

The proposed model has beenimplemented to schedule the courses in the Mechanical Engineering Department of Umm Al-Qura University, and it provided an optimal schedule.

References

[1] G. Kendall, S. Knust, C. C. Ribeiro, and S. Urrutia, "Scheduling in sports: An annotated bibliography," Computers & Operations Research, vol. 37, pp. 1-19, 2010.
[2] J. Eliashberg, Q. Hegie, J. Ho, D. Huisman, S. J. Miller, S. Swami, et al., "Demand-driven scheduling of movies in a multiplex," International Journal of Research in Marketing, vol. 26, pp. 75-88, 2009/06/01/ 2009.
[3] A. Caprara, M. Fischetti, and P. Toth, "Modeling and solving the train timetabling problem," Operations research, vol. 50, pp. 851-861, 2002.
[4] I. Blöchliger, "Modeling staff scheduling problems. A tutorial," European Journal of Operational Research, vol. 158, pp. 533-542, 2004.
[5] R. Lewis, "A survey of metaheuristic-based techniques for university timetabling problems," OR spectrum, vol. 30, pp. 167-190, 2008.
[6] D. Corne, P. Ross, and H. Fang, "Evolving timetables," The practical handbook of genetic algorithms, vol. 1, pp. 219-276, 1995.
[7] B. McCollum, A. Schaerf, B. Paechter, P. McMullan, R. Lewis, A. J. Parkes, et al., "Setting the research agenda in automated timetabling: The second international timetabling competition," INFORMS Journal on Computing, vol. 22, pp. 120-130, 2010.
[8] T. Müller and H. Rudová, "Real-life curriculum-based timetabling," Practice and Theory of Automated Timetabling (PATAT 2012), pp. 57-72, 2012.
[9] O. M. K. Alsmadi, S. Za'er, D. I. Abu-Al-Nadi, and A. Algsoon, "A novel genetic algorithm technique for solving university course timetabling problems," in Systems, Signal Processing and their Applications (WOSSPA), 2011 7th International Workshop on, 2011, pp. 195-198.
[10] G. Asham, M. M. Soliman, and A. Ramadan, "Trans genetic coloring approach for timetabling problem," Artificial Intelligence Techniques Novel Approaches & Practical Applications, IJCA, pp. 17-25, 2011.
[11] P. Khonggamnerd and S. Innet, "On improvement of effectiveness in automatic university timetabling arrangement with applied genetic algorithm," in Computer Sciences and Convergence Information Technology, 2009. ICCIT'09. Fourth International Conference on, 2009, pp. 1266-1270.

[12] L. Di Gaspero, B. McCollum, and A. Schaerf, "The second international timetabling competition (ITC-2007): Curriculum-based course timetabling (track 3)," Citeseer2007.
[13] H. Babaei, J. Karimpour, and A. Hadidi, "A survey of approaches for university course timetabling problem," Computers & Industrial Engineering, vol. 86, pp. 43-59, 2015.
[14] Palisade. (2010). Guide to Using Evolver. Available: www.crystalballservices.com
[15] H. Asmuni, "Fuzzy methodologies for automated university timetabling solution construction and evaluation," University of Nottingham, 2008.
[16] M.-R. Feizi-Derakhshi, H. Babaei, and J. Heidarzadeh, "A survey of approaches for University course timetabling problem," in Proceedings of 8th International Symposium on Intelligent and Manufacturing Systems, Sakarya University Department of Industrial Engineering, Adrasan, Antalya, Turkey, 2012, pp. 307-321.
[17] C. Gotlieb, "The construction of class-teacher timetables," in Proc. IFIP Congress, 1963, pp. 73-77.
[18] J. Henry Obit, "Developing novel meta-heuristic, hyper-heuristic and cooperative search for course timetabling problems," University of Nottingham, 2010.
[19] T. A. Redl, "A study of university timetabling that blends graph coloring with the satisfaction of various essential and preferential conditions," Rice University, 2004.

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