A Mathematical Model for the Optimization of Timetable Scheduling Problem of an Educational Institution

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Abstract

The need to optimize the use of all types of resources is a necessity in educational institutions as well as in any other type of institution. Preparing a course program is a very difficult task considering the resources. Usually, it is a waste of time and energy since it is made by traditional methods and by hand. There are some restrictions that must be followed when preparing the course program. In this study, a binary integer programming model is proposed by placing the timetable, lessons on the appropriate day and time periods and taking into account various constraints. The data are taken from Ibn-i Sina Vocational and Technical Anatolian High School in Nizip district of Gaziantep, Turkey. In the case study, there are 43 lesson hours and 15 classes to be given weekly for high-school level. In the model, it is aimed to assign the number of lessons per week to the days in the most balanced way. The aim of the model is to minimize the number of empty lessons during the day in any classroom in high school timetables during the pandemic period. In the proposed model comparing to the current timetable, the first sessions of the lessons with more than one session are assigned to the first days of the week, and the last sessions to the last days of the week. Thus, students are provided with a more flexible education in the last days of the week under pandemic conditions. Finally, break time is taken into consideration.

Keywords
0-1 Integer Programming, Optimization, Timetabling.

1. Introduction

Scheduling problems are an important approach that should be used in almost every sector today (Köçken et al. 2014). Aircraft departure times, shift schedules of nurses or doctors, shift schedules in factories, course schedules, or exam schedules in educational institutions may be some examples of scheduling problems. In this study, the education time scheduling problem, one of the aforementioned time scheduling types, has been discussed. The education time scheduling problem deals with the assignment of courses belonging to teacher and student groups to classrooms of appropriate capacity at appropriate time intervals in educational institutions and aims to make the best assignments in accordance with the resources, needs, and expectations of the relevant institution (Al-Yakoob and Sherali, 2006). Although there have been a lot of approaches applied in time tabling literature (Taş et al. 2018), 0-1 integer mathematical modeling is used and it is aimed to assign the courses to the appropriate days and time period in this study.

The scheduling problem is a problem encountered in educational institutions in every academic year. While preparing the scheduling, the classes to which the courses will be assigned according to their current situation, the restrictions on the teachers, and the scheduling according to the course time complicate the situation. Due to this complex structure, it is very difficult to find the optimal solution (Altunay and Eren, 2017b). In this study, the scheduling of a vocational high school in the Nizip district of Gaziantep is discussed. While preparing the timetable, a timetable is created considering 28 teachers, 15 classes, and 4 student groups. The distribution of the course hours has been balanced in the proposed approach. The problem is modeled using 0-1 integer programming and solved with the LINGO 14.0 optimization program. After the introduction section, the literature review is given in the second part, the mathematical model is explained in the third part, the data are explained in the fourth part, and the results are given and discussed in the fifth and sixth parts.

2. Literature Review

The course scheduling problem is a type of problem in the literature that has been increasingly studied over the years. Assignment problem is one of the most widely used and solved problems. Time scheduling, which is one of the most frequently encountered types of the assignment problem in the literature, is defined as the problem of assigning resources based on limited time intervals and space constraints (Altunay and Eren, 2017b; Can, 2019). Relevant studies are given in Table 1.

Table 1. Literature review

Reference	Problem	Methodology	Case
Andrew and Collins (1971)	Determination of the annual teaching schedule by assigning faculty to courses and other activities on the basis of their responses to course preference questionnaires.	Integer programming	Graduate School of Management at UCLA.
Akkoyunlu (1973)	The problem is formulated in terms of costs associated with features of the timetable, including the interaction between courses.	Linear programming	University timetable.
Badri (1996)	The model seeks to maximize faculty course preferences in assigning faculty members to courses; and then, maximize faculty time preferences in allocating courses to time blocks.	Two-stage multi-objective programming	Faculty-course-time assignments.
Dimopoulou and Miliotis (2001)	This paper reports the design and implementation of a PC-based computer system to aid the construction of a combined university course–examination timetable.	Integer programming	The Athens University of Economics and Business.
Daskalaki et al. (2004)	In this paper, a two-stage relaxation procedure that solves efficiently the integer programming formulation of a university timetabling problem is presented. The relaxation is performed in the first stage and concerns the constraints that warrantee consecutiveness in multi-period sessions of certain courses. These constraints, which are computationally heavier than the others, are recovered during the second stage and a number of sub-problems, one for each day of the week, are solved for local optima.	Integer programming	Engineering department.
Al-Yakoob and Sherali (2006)	This paper presents mathematical programming models for assigning faculty members to classes including, among typical academic class scheduling issues, certain specialized central policies.	Integer programming	Kuwait University.
Ismayilova et al. (2007)	The problem of constructing timetables for educational institutions is a classical combinatorial problem that requires finding a schedule to determine which courses will be given in which classrooms, by which instructors and during which time slots.	0-1 integer programming	Numerical example.
Méndez-Díaz et al.(2016)	Post enrollment course timetabling problem.	Integer programming	A private university in Buenos Aires, Argentina.
Ranga Prabodanie (2017)	The decision variables are defined with fewer dimensions to economize the model size of large scale problems and to improve modeling efficiency. Binary matrices are used to incorporate the relationships between the courses and students, and the courses and teachers.	0-1 integer programming	A university faculty which conducts various degree programs.
Jamali et al. (2018)	This paper aims to increase satisfaction degree of instructors by maximizing their preferences to teach in their desired day and timeslot, as well as providing more times to do researches.	0-1 integer programming	A govermental university in Tehran,Iran.
Küçükyelkenci Alper (2019)	The important aspect of this study is to solve a mathematical programming model for the university timetabling problem and incorporating Analytic Hierarchy Process to calculate the weights of instructor and student preferences to handle the objective function.	0-1 integer programming	Timetabling problem at Çankaya University.
Odeniyi et al. (2020)	The aim of this work is to develop an effective solution approach (model and algorithm) which provides boundless use and high quality solution to the school timetabling problem. The overall idea is to overcome the problem of low solution quality (slow convergence speed), which is a common problem when using simulated annealing.	Mixed integer linear programming, simulated annealing and genetic algorithm	A high school in Nigeria

3. Mathematical Model

A 0-1 integer programming method is adapted and applied in this study. The models of Süre (2015) and Altunay and Eren (2017a) are modified. The variables, constraints and parameters related to the problem are described below.

Indices

i lessons $i \in I = \{1,\dots, 220\}$

j days $j \in J = \{1,\dots, 5\}$

k lesson hours k ∈ *K* = {1,… .., 5}

Parameters and sets

A_i lessons set according to the classrooms,
B_i the set of lessons given by the teachers,
M_i how many times *i.* lesson is taken per week,
N_i fixed and unchangeable *i.* lesson hours on day *j* and lesson hours *k*,
O_i *i.* lesson appointment no more than once or twice a day.

Decision variables

X_{ijk}= {1; *i*. lesson, *j*. day, *k*. lesson house if assigned to lesson hours / 0; otherwise.

Objective Function

$$MaxZ = \sum_{i=1}^{132}\sum_{j\in\{1,2,3\}}^{j\in\{1,2,3\}}\sum_{k=1}^{5}X(i,j,k) + \sum_{i=1}^{132}\sum_{j\in\{4,5\}}^{j\in\{4,5\}}\sum_{k\in\{4\}}^{k\in\{4\}}X(i,j,k) + \sum_{i=133}^{220}\sum_{j\in\{1,2\}}^{j\in\{1,2\}}\sum_{k=1}^{5}X(i,j,k) + \sum_{i=1}^{132}\sum_{j\in\{3,4,5\}}^{j\in\{3,4,5\}}\sum_{k\in\{4\}}^{k\in\{4\}}X(i,j,k) \quad (1)$$

The objective function (1) is maximized to assign the 9th, 10th, 11th, and 12th classes to the number of blocks made in the tables, respectively.

$$\sum_{j=1}^{5}\sum_{k=1}^{5}X(i,j,k) = Mi \qquad for\ i \in Mi, j \in J, k \in K \quad (2)$$
$$\sum_{i=1}^{Bi}X(i,j,k) \leq 1 \qquad for\ i \in Bi, j \in J, k \in K \quad (3)$$
$$\sum_{i=1}^{Ai}X(i,j,k) \leq 1 \qquad for\ i \in Ai, j \in J, k \in K \quad (4)$$
$$\sum_{i=1}^{Oi}X(i,j,k) \leq 1 \qquad for\ i \in Oi, j \in J, k \in K \quad (5)$$
$$\sum_{i=1}^{Oi\in\{202,212\}}X(i,j,k) \leq 2 \qquad for\ i \in Oi \in \{202,212\}, j \in J, k \in K \quad (6)$$
$$X(i,j,k) = 1 \qquad for\ i \in Ni, j \in J, k \in K \quad (7)$$
$$Xijk \in \{0,1\} \qquad for\ i \in I, j \in J, k \in K \quad (8)$$

In Eq. (2), it is aimed to assign the number of blocks (lesson assignment limitation). It is prevented that the lessons given by the teachers do not come to the same time period on the same day (Eq. 3). In the next constraint, it is taken into account that more than one lesson does not coincide with the same day and time period according to the course requirements of a classroom (Eq. 4).Courses taught with sessions should not be assigned more than 1 in the same day. This constraint is guaranteed with Eq. (5). TLAL course is taught as 3 + 2 in face-to-face education of 12th classes. Constraints are written on the model to be assigned a maximum of 2 times a day, as a result, it is determined that the first 3-hour course is assigned consecutively (Eq. 6). It is aimed to assign fixed days for the 12th classes for the vocational training course in businesses for Wednesday, Thursday and Friday (Eq. 7). Eq. (8) is the last constraint that explains that it is a 0-1 integer modeling.

4. Data Collection

There are classes between eight (08:30) and seventeen (17:45) on five days during the week (In formal education). There are 15 classrooms available for the school. The number of students who will take the course is known by the principal and vice principals and divided into classes. Lessons in the school's lesson plan; Timetable-based compulsory, elective and area courses are divided into categories. Place and time assignments of some courses to be included in the course schedule can be determined before the weekly course schedule is created. The vice principals who organize the timetabling ask them to contact the teachers before the semester starts and inform them on which days and hours they do not want, depending on the special timetabling of the lessons they will give. There are 4 student groups at the school (9, 10, 11, and 12). The courses and weekly course hours of all classrooms are explained in Table 2. They have 43 lesson hours per week; the 12th classroom has 42 hours. One lesson hour is guidance lessons, and it is not added to the model. For 12th classes, VTIB-1 and VTIB-2 coded courses are among the courses that students receive internship at the hospital. Education and development in the profession is aimed by observation by the responsible nurse. Due to the pandemic conditions, internships are not possible, so suggestions and things to be considered in the profession are now provided with distance education. Lessons are shared among health care teachers, and the lessons are kept constant according to the days and left flexible according to the teachers' free time.

Table 2. Course's name and weekly course hours

Courses(9th classes)	Weekly Course Hours	Courses(11th classes)	Weekly Course Hours
PD	2	PE	2
SOA	2	MATH	2
PE	2	HIST	2
HIST	2	NABH	4
CHEM	2	AA	2
TLAL	5	PCP	2
BPP	5	FL	6
ANTM	4	ID	2
RCAE	2	PRAR	2
GEO	2	PHLSP	2
ENG	5	RCAE	2
BIO	2	FA	2
PHYSC	2	TLAL	5
MATH	6	BIO	2
Courses (10th classes)	**Weekly Course Hours**	SD	2
PE	2	PHYSC	2
MATH	5	ENG	2
HIST	2	**Courses (12th classes)**	**Weekly Course Hours**
CHEM	2	ENG	2
OP	2	TLAL	5
ANTM	4	RCAE	2
TLAL	5	CIH	2
PP	6	SOA	1
GEN	2	HP	2
SOA	1	MATH	2
PHLSP	2	TRHIST	2
RCAE	2	VTIB-1	8
GEO	2	VTIB-2	16
ENG	2		
BIO	2		
PHYSC	2		

5. Results and Discussion

Using the model and data given above, the case study has been solved in the LINGO 14.0 package program. According to the course codes, the output of the numerical results, that is, the lessons that received 1 equivalent according to the 0-1 integer program formed the course schedule.

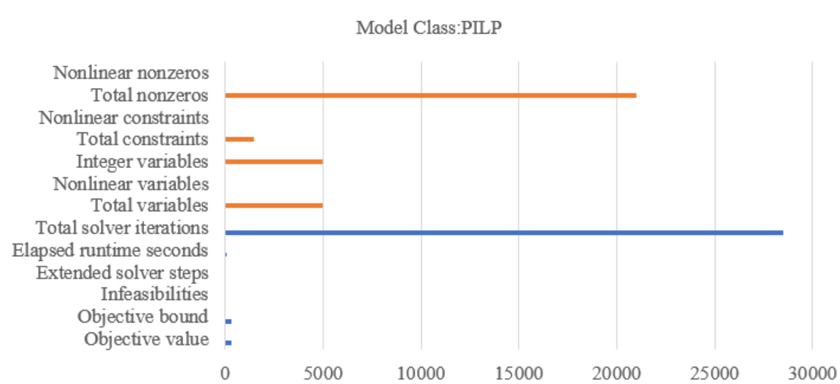

Figure 1. Global optimal solution

Appropriate codes are written in the LINGO 14.0 optimization package program, and the results are obtained according to the number of course blocks and the time frame separately. 4 student groups are divided into 2 groups according to the number of blocks. The first group is 9 classes and the other group is 6 classes. 23x9 = 207, 22x6 = 132 so the optimized result should be 339 in total. As a result of the appropriate coding, the number of 339 is obtained and the results are approved by the school administration. The objective value is 339; 28,486 iterations are applied, solved in 4. 31 seconds, the total number of variables is 4,948, of which 4,948 are integers. The total number of constraints is 1,476 (Figure 1). The appropriate assignment results according to the lesson numbers in the model are given in Table 3.

Table 3. The obtained assignments

X143	1	X2824	1	X5351	1	X7832	1	X10753	1	X13921	1	X17325	1	X20511	1
X212	1	X2832	1	X5424	1	X7854	1	X10815	1	X13954	1	X17334	1	X20623	1
X352	1	X2854	1	X5514	1	X7922	1	X10825	1	X14051	1	X17351	1	X20722	1
X454	1	X2933	1	X5623	1	X8044	1	X10842	1	X14142	1	X17453	1	X20825	1
X531	1	X3022	1	X5634	1	X8114	1	X10944	1	X14241	1	X17541	1	X20931	1
X625	1	X3143	1	X5644	1	X8123	1	X11051	1	X14353	1	X17652	1	X20932	1
X635	1	X3212	1	X5715	1	X8135	1	X11131	1	X14412	1	X17744	1	X20933	1
X644	1	X3351	1	X5825	1	X8212	1	X11213	1	X14511	1	X17821	1	X20934	1
X714	1	X3411	1	X5921	1	X8334	1	X11341	1	X14531	1	X17922	1	X21041	1
X723	1	X3432	1	X6041	1	X8415	1	X11435	1	X14552	1	X17933	1	X21042	1
X741	1	X3444	1	X6132	1	X8425	1	X11521	1	X14643	1	X17943	1	X21043	1
X824	1	X3525	1	X6224	1	X8443	1	X11633	1	X14744	1	X18032	1	X21044	1
X832	1	X3535	1	X6244	1	X8542	1	X11753	1	X14822	1	X18111	1	X21051	1
X951	1	X3552	1	X6254	1	X8615	1	X11812	1	X14913	1	X18254	1	X21052	1
X1015	1	X3614	1	X6314	1	X8623	1	X11831	1	X15014	1	X18315	1	X21053	1
X1111	1	X3634	1	X6322	1	X8632	1	X11841	1	X15112	1	X18425	1	X21054	1
X1142	1	X3724	1	X6331	1	X8753	1	X11933	1	X15221	1	X18551	1	X21114	1
X1153	1	X3842	1	X6443	1	X8822	1	X12025	1	X15342	1	X18614	1	X21212	1
X1234	1	X3913	1	X6453	1	X8921	1	X12121	1	X15351	1	X18721	1	X21221	1
X1321	1	X3921	1	X6534	1	X9013	1	X12244	1	X15444	1	X18752	1	X21222	1
X1413	1	X3954	1	X6613	1	X9035	1	X12251	1	X15522	1	X18811	1	X21325	1
X1422	1	X4023	1	X6723	1	X9111	1	X12315	1	X15613	1	X18931	1	X21424	1
X1433	1	X4115	1	X6742	1	X9134	1	X12324	1	X15633	1	X19032	1	X21513	1
X1534	1	X4231	1	X6751	1	X9141	1	X12352	1	X15654	1	X19042	1	X21623	1
X1641	1	X4241	1	X6833	1	X9212	1	X12413	1	X15752	1	X19053	1	X21711	1
X1722	1	X4253	1	X6912	1	X9225	1	X12422	1	X15831	1	X19122	1	X21815	1
X1823	1	X4333	1	X7011	1	X9243	1	X12432	1	X15915	1	X19243	1	X21931	1
X1915	1	X4422	1	X7035	1	X9354	1	X12542	1	X16032	1	X19312	1	X21932	1
X2033	1	X4513	1	X7052	1	X9444	1	X12623	1	X16143	1	X19423	1	X21933	1
X2043	1	X4635	1	X7133	1	X9524	1	X12743	1	X16223	1	X19533	1	X21934	1
X2053	1	X4712	1	X7242	1	X9631	1	X12811	1	X16234	1	X19613	1	X22041	1
X2111	1	X4821	1	X7341	1	X9752	1	X12914	1	X16253	1	X19634	1	X22042	1
X2121	1	X4842	1	X7424	1	X9833	1	X13034	1	X16311	1	X19641	1	X22043	1
X2151	1	X4852	1	X7552	1	X9914	1	X13154	1	X16425	1	X19715	1	X22044	1
X2213	1	X4931	1	X7613	1	X10051	1	X13235	1	X16541	1	X19824	1	X22051	1
X2225	1	X4943	1	X7631	1	X10154	1	X13332	1	X16624	1	X19944	1	X22052	1
X2314	1	X4953	1	X10322	1	X10214	1	X13425	1	X16723	1	X20054	1	X22053	1
X2435	1	X5015	1	X10434	1	X10224	1	X13534	1	X16813	1	X20112	1	X22054	1
X2512	1	X5025	1	X10543	1	X10252	1	X13614	1	X16931	1	X20213	1		
X2544	1	X5154	1	X7651	1	X10611	1	X13633	1	X17024	1	X20214	1		
X2552	1	X5211	1	X7711	1	X10623	1	X13723	1	X17042	1	X20224	1		
X2642	1	X5332	1	X7721	1	X10712	1	X13824	1	X17112	1	X20315	1		
X2731	1	X5341	1	X7753	1	X10732	1	X13915	1	X17214	1	X20421	1		

5.1 The Improvements

In order not to reduce the interest of students in lessons under pandemic conditions, it is aimed to prepare a more intense course in the first days of the week and a more flexible structure towards the last days of the week. Since not giving the lunch break creates a loss of motivation for the students, a break is applied (Eren, 2017). In Table 4, according to the courses taken by the classes, for example, the code of the Biology course (BIO) in the 9A classroom is 12, in the 9B classroom it is 26. Each branch is numbered with a different numerical code and the confusion is tried to be removed. All lessons are added as a constraint to the model, where the class is distinguished according to the teacher who teaches the lesson (Süre, 2015). Explanation of the proposed model: Time slots are reduced in half and handled separately. In Table 5, for example, the total lesson hour, which was 10 hours on Monday, is reduced to 5, and each block is adjusted to equal 2 hours.Considering the time period separately while creating the model has minimized the complex structure and no sequential constraint is added for the block lessons. For lessons that have only one lesson per day, the chance to extend the lesson is given within the time period according to the teacher's request. Thus, it is ensured that the students did not experience loss for the lesson subjects that are not taught. In Table 6, time periods are given. Intermediate times have been added so that students can focus on the lessons. In Table 7, lessons taught for two hours in a single session are planned to be assigned one time, 2 + 2 lessons in two sessions two times, lessons taught in three sessions 2 + 2 + 1 or 2 + 2 + 2 three times. Number of block assignments per week for Grades 9 and 10: Monday, Tuesday, Wednesday 5, Thursday, Friday 4. Number of block assignments per week for Grades 11 and 12: Monday, Tuesday 5, Wednesday, Thursday, Friday 4. Thus, 339 courses should be assigned in the total model. The objective function is created accordingly.

Table 4. Numeric codes of all classes

Course Codes	**9A**	**9B**	**9C**	**9D**	**9E**	**9F**	**Course Codes**	**10A**	**10B**	**10C**
PD	1	15	29	43	57	71	PE	85	101	117
SOA	2	16	30	44	58	72	MATH	86	102	118
PE	3	17	31	45	59	73	HIST	87	103	119
HIST	4	18	32	46	60	74	CHEM	88	104	120
CHEM	5	19	33	47	61	75	OP	89	105	121
TLAL	6	20	34	48	62	76	ANTM	90	106	122
BPP	7	21	35	49	63	77	TLAL	91	107	123
ANTM	8	22	36	50	64	78	PP	92	108	124
RCAE	9	23	37	51	65	79	GEN	93	109	125
GEO	10	24	38	52	66	80	SOA	94	110	126
ENG	11	25	39	53	67	81	PHLSP	95	111	127
BIO	12	26	40	54	68	82	RCAE	96	112	128
PHYSC	13	27	41	55	69	83	GEO	97	113	129
MATH	14	28	42	56	70	84	ENG	98	114	130
							BIO	99	115	131
							PHYSC	100	116	132

Course Codes	**11A**	**11B**	**11C**	**11D**	**Course Codes**	**12A**	**12B**
PE	133	150	167	184	ENG	201	211
MATH	134	151	168	185	TLAL	202	212
HIST	135	152	169	186	RCAE	203	213
NABH	136	153	170	187	CIH	204	214
AA	137	154	171	188	SOA	205	215
PCP	138	155	172	189	HP	206	216
FL	139	156	173	190	MATH	207	217
ID	140	157	174	191	TRHIST	208	218
PRAR	141	158	175	192	VTIB-1	209	219
PHLSP	142	159	176	193	VTIB-2	210	220
RCAE	143	160	177	194			
FA	144	161	178	195			
TLAL	145	162	179	196			
BIO	146	163	180	197			
SD	147	164	181	198			
PHYSC	148	165	182	199			
ENG	149	166	183	200			

Table 5. Number of blocks according to weekly course hours

9th, 10th	**1**	**2**	**3**	**4**	**5**
Monday	-	-	-	-	-
Tuesday	-	-	-	-	-
Wednesday	-	-	-	-	-
Thursday	-	-	-	-	
Friday	-	-	-	-	
11th,12th	**1**	**2**	**3**	**4**	**5**
Monday	-	-	-	-	-
Tuesday	-	-	-	-	-
Wednesday	-	-	-	-	
Thursday	-	-	-	-	
Friday	-	-	-	-	

Table 6. Time periods

Time Periods	1		2		3		4		5	
Hours	08.30 - 09.00	09.10 - 09.40	09.50 - 10.20	10.30 - 11.00	11.10 - 11.40	12.50 - 13.20	13.30 - 14.00	14.10 - 14.40	14.50 - 15.20	15.30 - 16.00

Table 7. Number of blocks according to weekly course hours-all classes

Lesson Name and Weekly lesson hours 9th classes	Number of blocks	Lesson Name and Weekly lesson hours 10th classes	Number of blocks
PD-2	1	PE-2	1
SOA-2	1	MATH-5	2+2+1-3
PE-2	1	HIST-2	1
HIST-2	1	CHEM-	1
CHEM-2	1	OP-2	1
TLAL-5	2+2+1 - 3	ANTM-4	2+2-2
BPP-5	2+2+1-3	TLAL-5	2+2+1-3
ANTM-4	2	PP-6	2+2+2-3
RCAE-2	1	GEN-2	1
GEO-2	1	SOA-1	1
ENG-5	2+2+1-3	PHLSP-2	1
BIO-2	1	RCAE-2	1
PHYSC-2	1	GEO-2	1
MATH-6	2+2+2-3	ENG-2	1
		BIO-2	1
		PHYSC-2	1
Lesson Name and Weekly lesson Hours 11th classes	**Number of blocks**	**Lesson Name and Weekly lesson Hours 12th classes**	**Number of blocks**
PE-2	1	ENG-2	1
MATH-	1	TLAL-5	2+2+1-3
HIST-2	1	RCAE-2	1
NABH-6	2+2-2	CIH-2	1
AA-2	1	SOA-1	1
PCP-2	1	HP-2	1
FL-6	2+2+2-3	MATH-2	1
ID-2	1	TRHIST-2	1
PRAR-2	1	VTIB-1-8	4
PHLSP-2	1	VTIB-2-16	8
RCAE-2	1		
FA-2	1		
TLAL-5	2+2+1-3		
BIO-2	1		
SD-2	1		
PHYSC-2	1		
ENG-2	1		

6. Conclusion

The lesson scheduling problem is a difficult optimization problem that is frequently encountered in the literature and tried to be solved by using various methods. Although there are many studies on course scheduling in the literature, the problem has common constraints and objectives, as well as the constraints and objectives of the relevant institution. For this reason, the encountered lesson scheduling problem should be well analyzed and modeled. In the study, the problem is handled step by step and a solution is tried to be obtained with a mathematical approach. Many timetables have been prepared under pandemic conditions, and since there is confusion, an appropriate model has been presented considering the first and the last ones. When the constraint of sequencing is added, it is seen that the suitable solution is not obtained because the size of the model is too large, and it is tried to be made simpler and more understandable. In addition, developing a web-based decision support system can be a subject for future research.

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