CENTRAL EUROPEAN REVIEW
OF ECONOMICS AND MANAGEMENT

ISSN 2543-9472; eISSN 2544-0365

Vol. 4, No. 3, 67-87, September 2020

www.cerem-review.eu
www.ojs.wsb.wroclaw.pl

Conflict management in university examination timetabling. A case study of summer school mid-terms

Mustafa Mehmet BAYAR

Ankara Hacı Bayram Veli University, Turkey

Irmak UZUN BAYAR

Hacettepe University, Ankara, Turkey

Abstract:

Aim: This study is on tackling Examination Timetabling Problem (ETP) of the Faculty of Economics And Administrative Sciences (FEAS) of the Ankara HBV University summer school, where the courses of fall and spring semesters are offered simultaneously and regulations on restricting enrollments in inter-department electives or in-department courses of distinct years are relaxed. Thus, the complexity of the nature of the ETP problem is exacerbated. The direct heuristics based on successive assignments that the university normally adopts was proven inadequate for assuming standard regulations hence, another approach we explain in this paper was needed.

Design / Research methods: The ETP was formulated as a Linear Mixed-Integer Program (LMIP) and decomposed into three stages; timetabling exams, room assignment, student allocation. To manage the conflict between the stakeholders of the examination procedure, a lexicographic optimization process based on the priority of the parties was undertaken.

Conclusions / findings: After a recursive timetabling process based on a trial-and-error method a clash-free timetable was generated and, a room assignment plan that minimizes the total number of proctoring duties, usage of higher floor rooms and total crowdedness of rooms respectively was put into action. Therefore no student group experienced any clashing exams, the faculty members saved time that can be spent on research instead, since the room usage was better planned the costs (elevator usage, lighting, air conditioning, the labor of the janitors) were assumed to be decreased.

Correspondence address: Mustafa Mehmet BAYAR, Ankara HBV University, Turkey. E-mail: mehmet.bayar@hbv.edu.tr (Mustafa Mehmet BAYAR), uzunirmak@hotmail.com (Irmak UZUN BAYAR).
Received: 28.01.2020, Revised: 13.06.2020, Accepted: 04.08.2020.
doi: http://dx.doi.org/10.29015/cerem.870

Originality / value of the article: Each examination period bares a different ETP due to its problem-specific nature (number of courses offered, the structure of student enrollments, availability of rooms, etc.). Summer schools provide a more irregular structure that demands special attention, a trial-and-error reformulation of the ETP in our case. In addition, the traditional formulations of the ETP, to the extent we have been able to scan, do not include the minimization of the crowdedness of the rooms. Thus, in creating a more comfortable environment, easier to monitor exams and, ability in handling unexpected dysfunctionalities (broken classroom equipment, etc.) this study is novel.

Limitations of the research: The algorithms to solve an ETP formulated as an LMIP are of high complexity therefore, we are not able to assert the optimality of our suggested solutions acquired within time limitations.

Keywords: examination timetabling, group decision making, lexicographic optimization, linear mixed integer programming

JEL: C44, C61, M12

1. Introduction

Summer school programs are exceptionally irregular for a number of reasons – offering courses of both fall and spring semesters, allowing enrollment in courses of any year simultaneously, the high volume of visiting students (students of universities that do not offer summer schools authorize their students to enroll in summer schools of other universities), etc. Due to the increased complexity and decreased predictability, more conventional approaches to examination timetabling problem (ETP) assuming regularities to eliminate conflicts was proven inadequate to Ankara HBV University's summer school and the 86 courses within offered by the Faculty of Economics and Administrative Sciences (FEAS). Therefore, a novel mixed-integer program formulation for solving the ETP at hand was demanded.

The idea of producing examination timetables using algorithms rather than manual effort dates back to 1964 (Broder 1964), where minimizing conflicts were based on a Monte Carlo procedure to generate a set of selection of assignments. Among the related family of problems on timetabling, Schaerf (1999) provided a classification in his review article (for more surveys on ETP see Carter et al. 1996; Qu et al. 2009 among others). He also defined ETP as "The scheduling for the exams of a set of university courses, avoiding overlap of exams of courses having common students, and spreading the exams for the students as much as possible." (Schaerf 1999).

Until the vertex coloring based heuristic HORHEC (Laporte, Desroches 1984) direct heuristics (successive assignment of exams) was the main course of action. The path we follow in this study – integer linear programming (IP) formulations of ETP – was first introduced by Lawrie (1969). Later, for a related problem – school timetabling – a large scale 0-1 IP formulation (Tripathy 1984) was presented where due to the complexity of the problem, the solution was based on lagrangian relaxation. By time, as the computational power of the computers was improved, an IP was formulated and exact solution was obtained for the related university course timetabling problem (Daskalaki et al. 2004). Daskalaki et al. (2004) also claimed their formulation could be solved even for large departments using solvers available of their time. Conventionally, ETP was based on the knowledge of the number of students enrolled in each course. In that case, the problem at hand is post-enrollment ETP. On the other hand, instructors of the courses as well as the students prefer having the examination timetable as soon as possible. For this reason, Cataldo et al. (2017) proposed an IP to tackle the curriculum-based ETP where the examination timetable was produced without complete information on student enrollments. Sancar Edis and Edis (2019) also studied the curriculum-based ETP and in addition, they introduced a set of constraints to increase the satisfaction of the instructors and the students. Another research (MirHassani 2006) on improving the well-being of the parties affected by the examination timetables focused on maximizing the study time each student has between examinations.

In this paper, we broaden the focus on the satisfaction of the parties – i.e., students, instructors, janitors, school administration, etc. – from a different point of view. That is, we focus on managing the conflict between parties while setting standards for achieving an adequate minimum level of pain for all. Furthermore, from the study of Daskalaki et al. (2004) until now, even more improvements are achieved both in the computational power of the CPUs and in the efficiency of algorithms to solve IPs. Thus, we believed an IP formulation and pursuing exact solutions are were plausible and we achieved verification.

Rest of this paper is organized as follows: Section 2 introduces the problem at hand and the three models formulated to tackle it. Then in Section 3, we summarize the output of the optimization process by illustrating samples from the examination timetable and the proctor duties plan. Finally, in Section 4, we summarize the article, interpret the results, point out the novel features of our study and, discuss the limitations and future research.

2. Methods

FEAS holds nine departments and these departments may offer three BSc programs (English Education, 30% English Education, and Turkish Education). In the 2018-2019 Summer semester, FEAS organized a summer school and offered 86 courses that are instructed by 37 lecturers where a total of 2446 students were enrolled in. To illustrate the structure of the courses and the student enrollments please see Table1 and Table2.

Table 1. Number of courses offered by departments and programs

	ECON	BADM	PADM	ETCS	PFIN	IREL	LECO	HLTH	ITRD
Pr1		1				1			
Pr2	17	11	8	11	2	1	5	2	
Pr3		11	3			11			2

ETP is the scheduling for the exams of a set of university courses, avoiding exam conflicts, and spreading the exams for each student group as widely as possible (Schaerf 1999). The fashion we defined each course (thus, each exam) is by both subject and section therefore, we only allow a conflict of exams of the same subject. As for the detecting student groups to fit the ETP definition, summer schools are an exception to school regulations. I.e., students may enroll in courses of any year, elective courses of any department, courses normally offered in fall or spring semesters together. Consequently, identifying student groups and eliminating exam conflicts is not a straightforward routine. Even more, the high volume of visiting students canceled out using the student database to detect the scattered micro-groups. Thus, we separated the date-time assignment phase of the ETP from the room and student allocation phase. So that, announcing a draft examination timetable stripped off the room allocation information to prevent confusion would be possible and then, we could collect conflict reports if there were any. The approach to tackle the aforementioned difficulty is discussed further in sections 2.1.1 and 4.

Table 2. Student enrollments by departments and programs

	ECON	BADM	PADM	ETCS	PFIN	IREL	LECO	HLTH	ITRD
Pr1		14				24			
Pr2	351	382	179	220	204	60	152	42	
Pr3		326	269			201			22

The examination timetable will affect mainly four groups: students, instructors & proctors, janitors, and the FEAS administration. These parties' have conflicting preferences. E.g., the instructors prefer their exams as soon as possible in order to maximize time for grading where the students prefer a timetable that has no clashing exams and provides a reasonable paper spread to maximize their success. In sections 2.1.1, 2.1.2 and, 2.1.3, the conflict between parties are managed via formulated constraints and adopted the goal programming approach.

2.1. Models

The formulation procedure of the ETP problem at hand is three-fold. In the first model, we assigned dates and times to each exam. In model 2, we specify in which room the examinations were to be held on its predetermined date and time. And finally, in model 3, we allocate the students enrolled in each course to the room assigned and decide the minimum number of proctors needed in each room accordingly.

2.1.1. Model 1: Assigning dates and times

Sets and parameters

$C =: \{c | c = 1, \cdots, 86\}$: Set of the 86 courses offered by FEAS at the 2018-2019 Summer School.

$D =: \{d | d = 1, \cdots, 5\}$: Set of days. The examination period was spread over the working days of one week.

$S =: \{s | s = 1, \cdots, 12\}$: Set of time slots in each day that exams may be assigned to. Starting at 8.30a.m. and ending at 8.30p.m., there were 12 one-hour-periods in each day.

$I =: \{i | i = 1, \cdots, 9\}$: Set of the nine departments of FEAS

$P =: \{p | p = 1, \cdots, 3\}$: Set of programs offered by FEAS departments.

$L =: \{l | l = 1, \cdots, 4\}$: Set of years (levels) in the BSc education programs (Freshman, ⋯ , Senior).

$Cdep_c$: The department that offers course c

$Cprg_c$: The program course c is offered within

$Ccod_c$: The course code of course c

$Ctyp_c$: Type of course c (1 for electives and 0 for compulsory courses)

$Clvl_c$: The year course c is planned to be offered in the curriculum

$Cstu_c$: Number of students enrolled in course c

Variables

$\vec{\boldsymbol{\tau}} \epsilon \{0,1\}^{D\text{x}S\text{x}C}$: Binary integer variable for assigning date times for each exam (course)

$\overrightarrow{{}^{0}\boldsymbol{\gamma}} \epsilon \mathbb{R}^{D\text{x}S}$: Auxiliary continuous variable, number of conflicting exams on day d and time slot s.

$\overrightarrow{{}^{1}\boldsymbol{\gamma}} \epsilon \mathbb{R}^{D\text{x}S\text{x}P}$: Auxiliary continuous variable, number of conflicting exams of courses of distinct subjects offered by department i within program p on day d and time slot s.

$\overrightarrow{{}^{2}\boldsymbol{\gamma}} \in \mathbb{R}^{D\text{x}S\text{x}P\text{x}L}$	:	Auxiliary continuous variable, number of conflicting exams of courses of distinct subjects offered by department i within program p for year l on day d and time slot s.
$\overrightarrow{{}^{3}\boldsymbol{\gamma}} \in \mathbb{R}^{D\text{x}S\text{x}P}$	:	Auxiliary continuous variable, number of conflicting exams of elective courses offered within programs p on day d and time slot s.
$\overrightarrow{{}^{4}\boldsymbol{\gamma}} \in \mathbb{R}^{D\text{x}S\text{x}P\text{x}L}$	:	Auxiliary continuous variable, number of conflicting exams of elective courses offered within programs p for year l on day d and time slot s.
$\overrightarrow{{}^{5}\boldsymbol{\gamma}} \in \mathbb{R}^{I\text{x}P\text{x}L\text{x}D}$	:	Auxiliary continuous variable, number of exams exceeding one on day d for the regular students in year l registered in department i and program p.
$\overrightarrow{{}^{6}\boldsymbol{\gamma}} \in \mathbb{R}^{D\text{x}S}$	:	Auxiliary continuous variable, number of exams exceeding one on day d for the students registered in department i and program p.

Hard constraints

Each courses' exam must be scheduled to a day and timeslot:

$$\sum_{d,s} \tau_{d,s,c} = 1 \quad , \quad \forall c \tag{1.1}$$

Exams for courses of the same subject must be simultaneous:

$$\tau_{d,s,c} = \tau_{d,s,c'} \quad , \quad \forall d \; \forall s \; \forall c \; \forall c' \; |Ccod_{c'} = Ccod_c \tag{1.2}$$

For each regular student group no more than 2 exams for consecutive days:

$$\sum_{s,c \,\middle|\, \substack{Cdep_c=i \\ Cprg_c=p \\ Clvl_c=l}} \tau_{d,s,c} + \sum_{s,c \,\middle|\, \substack{Cdep_c=i \\ Cprg_c=p \\ Clvl_c=l}} \tau_{d+1,s,c} \leq 2 \quad , \quad \forall i \; \forall p \; \forall l \; \forall d \; |d, d+1 \in D \tag{1.3}$$

For each program no more than 1 exam in consecutive timeslots:

$$\sum_{c \,\middle|\, \substack{Cdep_C=i \\ Cprg_C=p \\ Clvl_C=l \\ Ccod_C \neq Ccod_{c'}}} \tau_{d,s,c'} + \tau_{d,s+1,c} \leq 1 \quad , \quad \forall i \; \forall p \; \forall l \; \forall d \; \forall s \;\; |s, s+1 \in S \qquad (1.4)$$

For each program no more than 1 exam in consecutive timeslots:

$$\sum_{c \,\middle|\, \substack{Cdep_C=i \\ Cprg_C=p \\ Ccod_C \neq Ccod_{c'}}} \tau_{d,s,c'} + \tau_{d,s+1,c} \leq 1 \quad , \quad \forall i \; \forall p \; \forall d \; \forall s \;\; |s, s+1 \in S \;\; \forall c' \; \left| \begin{array}{l} Cdep_c = i \\ Cprg_c = p \end{array} \right. \qquad (1.5)$$

Soft constraints

Minimize exam conflicts:

$$\sum_{c | Ccod_C \neq Ccod_{c'}} \tau_{d,s,c'} + \tau_{d,s,c} \leq 1 + {}^{0}\gamma_{d,s} \quad , \quad \forall d \; \forall s \; \forall c' \qquad (1.6)$$

Minimize exam conflicts for each program:

$$\sum_{c \,\middle|\, \substack{Cdep_C=i \\ Cprg_C=p \\ Ccod_C \neq Ccod_{c'}}} \tau_{d,s,c'} + \tau_{d,s,c} \leq 1 + {}^{1}\gamma_{d,s,p} \quad , \quad \forall i \; \forall p \; \forall d \; \forall s \;\; \forall c' \; \left| \begin{array}{l} Cdep_{c'} = i \\ Cprg_{c'} = p \end{array} \right. \qquad (1.7)$$

Minimize exam conflicts for each program and each year

$$\tau_{d,s,c'} + \sum_{c \,|\, Cdep_C=i,\ Cprg_C=p,\ Clvl_C=l,\ Ccod_C \neq Ccod_{c'}} \tau_{d,s,c} \leq 1 + {}^{2}\gamma_{d,s,p,l}, \quad \forall i\ \forall p\ \forall d\ \forall s\ \forall c' \,|\, Cdep_{c'} = i,\ Cprg_{c'} = p,\ Clvl_{c'} = l \tag{1.8}$$

Minimizing clashing electives throughout FEAS:

$$\tau_{d,s,c'} + \sum_{c \,|\, Cprg_C=p,\ Ctyp_C=1,\ Ccod_C \neq Ccod_{c'}} \tau_{d,s,c} \leq 1 + {}^{3}\gamma_{d,s,p}, \quad \forall p\ \forall d\ \forall s\ \forall c' \,|\, Cprg_{c'} = p,\ Ctyp_{c'} = 1 \tag{1.9}$$

Minimizing clashing electives throughout FEAS (year based):

$$\tau_{d,s,c'} + \sum_{c \,|\, Cprg_C=p,\ Clvl_C=l,\ Ctyp_C=1,\ Ccod_C \neq Ccod_{c'}} \tau_{d,s,c} \leq 1 + {}^{4}\gamma_{d,s,p,l}, \quad \forall p\ \forall l\ \forall d\ \forall s\ \forall c' \,|\, Cprg_{c'} = p,\ Clvl_{c'} = l,\ Ctyp_{c'} = 1 \tag{1.10}$$

For each regular student group no more than 1 exam a day:

$$\sum_{s,c \,|\, Cdep_C=i,\ Cprg_C=p,\ Clvl_C=l} \tau_{d,s,c} \leq 1 + {}^{5}\gamma_{i,p,l,d}, \quad \forall i\ \forall p\ \forall l\ \forall d \tag{1.11}$$

For each program no more than 1 exam a day:

$$\sum_{s,c \,|\, Cdep_C=i,\ Cprg_C=p} \tau_{d,s,c} \leq 1 + {}^{6}\gamma_{i,p,d}, \quad \forall i\ \forall p\ \forall d \tag{1.12}$$

Objectives

In order to meet the seven goals, we first minimize the auxiliary variables employed in constraints 1.6 to 1.12 within an additive function. And then, we focus on minimizing the number of exams assigned to the undesired timeslots as a second priority objective. Due to the minimized number of students having exams during rush hours or evening hours, the number of proctors required and course instructors supervising examinations are also minimized:

Priority 1 Objective:

$$Min\left(\begin{array}{c}\sum_{d,s} {}^{0}\gamma + \sum_{d,s,p} {}^{1}\gamma + \sum_{d,s,p,l} {}^{2}\gamma + \sum_{d,s,p} {}^{3}\gamma + \\ \sum_{d,s,p,l} {}^{4}\gamma + \sum_{i,p,l,d} {}^{5}\gamma + \sum_{i,p,l,d,s} {}^{6}\gamma\end{array}\right) \quad (1.13)$$

Priority 2 Objective:

$$Min\left(\sum_{d,c}\left(\begin{array}{c}\tau_{d,0,c} \cdot 9. Cstu_c + \tau_{d,9,c} \cdot Cstu_c + \\ \tau_{d,10,c} \cdot 3 \cdot Cstu_c + \tau_{d,11,c} \cdot 9 \cdot Cstu_c\end{array}\right)\right) \quad (1.14)$$

2.1.2. Model 2: Assigning rooms

During the examination period, the summer school did not take pause. Consequently, the rooms designated for examinations were even more limited. Using predetermined timetables produced by optimizing model 1, in model 2 we assigned each examination to the rooms. The reason for separating the room assignment from the timetabling process is not being able to identify the complete collection of sets of student groups that did not enroll in common courses. Thus, we first announced a timetable without room information to both collect data for clashing courses and, prevent further confusion due to room changes.

Additional sets and parameters

$T =: \{(d,s,c) | d \in D, s \in S, c \in C, \tau_{d,s,c} = 1\}$: Set of day-timeslot-course combinations from the basic timetable (Model 1 results)

K : Set of courses that require multiple consecutive timeslots

$R =: \{r | r = 1, \cdots, 16\}$: Set of the 16 rooms designated for midterm examinations by the FEAS administration.

$Rcpe_r$: Seating capacity of room r for examination

$Rflo_r$: The floor room r is on

U : Booking rate for rooms, default value is 0,95

Variables

$\vec{\boldsymbol{x}} \in \{0,1\}^{T \times R}$: Binary integer variable for assigning rooms for each exam (course) on the predetermined timetable

$\vec{\boldsymbol{\alpha}} \in \mathbb{R}^C$: Auxiliary continuous variable, a measure of spaciousness in rooms assigned for course c.

Hard constraints

Room can be occupied for at most 1 exam at a time:

$$\sum_{c|(d,s,c)\in T} x_{d,s,c,r} \leq 1 \quad , \quad \forall d \ \forall s \ \forall r \qquad (2.1)$$

At least 1 room must be dedicated for each exam on the predetermined time:

$$\sum_{r,(d,s)|(d,s,c)\in DSC} x_{d,s,c,r} \geq 1 \quad , \quad \forall c \qquad (2.2)$$

The total seating capacity of the dedicated rooms must be greater than or equal to the number of students enrolled:

$$\sum_{r,(d,s)|(d,s,c)\in T} x_{d,s,c,r} \cdot U \cdot Rcpe_r \geq Cstu_c \quad , \quad \forall c \qquad (2.3)$$

Rooms can be occupied for at most one course on consecutive timeslots:

$$\sum_{c|(d,s,c)\in T} x_{d,s,c,r} + \sum_{c'|(d,s+1,c')\in T} x_{d,s+1,c',r} \leq 1 \quad , \quad \forall r \ \forall d \ \forall s \ |s, s+1 \in S \qquad (2.4)$$

If a room is occupied for a long exam, the room cannot be occupied for any courses for the next 2 timeslots:

$$\sum_{c \left| \substack{(d,s,c)\in T \\ c\in K} \right.} x_{d,s,c,r} + \sum_{c' | (d,s+2,c')\in T} x_{d,s+2,c',r} \leq 1 , \quad \forall r \ \forall d \ \forall s \ | s, s+2 \in S \qquad (2.5)$$

Soft constraint

α is a measure of the spaciousness of dedicated rooms

$$Cstu_c \cdot \alpha_c \leq \sum_{r,(d,s)|(d,s,c)\in DSC} x_{d,s,c,r} \cdot Rcpe_r , \quad \forall c \qquad (2.6)$$

Objectives

In FEAS, we assigned rooms on the lower floors to minimize movement, operations, and maintenance costs. This way we minimized total distance covered by students and proctors as well as minimizing elevator usage, air conditioning and, housekeeping activities. Then, in the second stage, we maximized spaciousness in rooms so that, students could concentrate better and proctors could manage the exams more easily. Also, minimizing crowdedness eliminates problems faced due to broken or missing classroom materials:

Priority 1 Objective:

$$Min\left(\sum x_{d,s,c,r} \cdot (4 + Rflo_r)\right) \qquad (2.7)$$

Priority 2 Objective:

$$Min\left(\sum -\alpha_c\right) \qquad (2.8)$$

2.1.3. Model 3: Allocating students

An additional set

Set of day-timeslot-course-room combinations from the complete timetable (Model 2 results):

$$E =: \left\{(d,s,c,r) \middle| d \in D, s \in S, c \in C, r \in R, x_{d,s,c,r} = 1\right\}$$

Variables

$\overrightarrow{\boldsymbol{x'}} \epsilon \mathbb{Z}_+{}^E$	:	Integer variable, number of students enrolled in course c assigned to room r on the predetermined day and timeslot
$\vec{\boldsymbol{y}} \epsilon \mathbb{Z}_+{}^{D\text{x}S\text{xRxI}}$	:	Integer variable, minimum number of proctors that work for department i required on day d and timeslot s for room r
$\overrightarrow{{}^{\boldsymbol{0}}\boldsymbol{\beta}} \epsilon \mathbb{R}^{D\text{x}S\text{x}R}$	:	Auxiliary continuous variable, room usage rate over the 60% level
$\overrightarrow{{}^{\boldsymbol{1}}\boldsymbol{\beta}} \epsilon \mathbb{R}^{I}$	:	Auxiliary continuous variable, minimum number of personnel required for proctoring duties of department i

Hard constraints

Assign no more student than the seating capacity:

$$\sum\nolimits_{c|(d,s,c,r)\in E} x'_{d,s,c,r} \leq Rcpe_r \cdot U \quad , \quad \forall d \ \forall s \ \forall r \qquad (3.1)$$

No student enrolled in can be left unseated:

$$\sum\nolimits_{(d,s,r)|(d,s,c,r)\in E} x'_{d,s,c,r} = Cstu_c \quad , \quad \forall c \qquad (3.2)$$

For every 40 students seated add 1 more proctor:

$$\sum\nolimits_{c\left|\substack{(d,s,c,r)\in E \\ Cdep_c=i}\right.} x'_{d,s,c,r} \div 40 \leq y_{d,s,r,i} \quad , \quad \forall i \ \forall d \ \forall s \ \forall r \qquad (3.3)$$

Assign at least 2 proctors for each room occupied for an exam:

$$\sum_i y_{ds,r,i} \geq 2 \quad , \quad \forall d \ \forall s \ \forall r \left| \sum_{c|(d,s,c,r)\epsilon E} x_{d,s,c,r} \right. \qquad (3.4)$$

Minimum number of required proctoring personnel for each department:

$$\sum_r y_{ds,r,i} \leq {}^1\beta_i \quad , \quad \forall i \ \forall d \ \forall s \qquad (3.5)$$

Soft constraint

More than 60% occupation rate is not desired:

$$\sum\nolimits_{c|(d,s,c,r)\in E} x'_{d,s,c,r} \div Rcpe_r \leq 0.6 + {}^0\beta_{d,s,r} \quad , \quad \forall d \ \forall s \ \forall r \qquad (3.6)$$

Objectives

In model 3, room usages rates over the 60% levels, total number of proctoring personnel required and, total number of proctoring duties were minimized together in an additive manner:

$$Min\left(\sum {}^{0}\beta_{d,s,r} + \sum {}^{1}\beta_{i} + \sum y_{d,s,r,i}\right) \tag{3.7}$$

3. Results

3.1. Data preparation

ETP is a problem of high complexity. Thus, we introduced a family of subsets of courses that our formulations loop over. Consequently, we reduced the complexity that may have led to the availability of the exact solutions. In addition, before proceeding to each next model, we restructured the sets to shrink the volume. E.g.: T instead of D,S and, C that reduce the cardinality from 5160 to 86 (98.33% reduction).

3.2. Model outputs

We solved the models in the Gurobi Optimizer (2019) v9.0.0 on an i7-7700HQ device with 16 GB of memory.

3.2.1. Basic timetable

Course-date-time information is the basic timetable and a sample fragment of the basic timetable is shown in Table 3. According to the basic timetable; 877 students (a student may be counted more than once as she/he is enrolled in multiple courses) are scheduled on the undesired hours, Deviations from desired values can be summarized as follows: $\overrightarrow{\boldsymbol{\gamma_0}} \cdot \vec{\mathbf{1}} = 26$, $\overrightarrow{\boldsymbol{\gamma_1}} \cdot \vec{\mathbf{1}} = 3$, $\overrightarrow{\boldsymbol{\gamma_2}} \cdot \vec{\mathbf{1}} = 2$, $\overrightarrow{\boldsymbol{\gamma_3}} \cdot \vec{\mathbf{1}} = 3$, $\overrightarrow{\boldsymbol{\gamma_4}} \cdot \vec{\mathbf{1}} = 2$, $\overrightarrow{\boldsymbol{\gamma_5}} \cdot \vec{\mathbf{1}} = 6$, $\overrightarrow{\boldsymbol{\gamma_6}} \cdot \vec{\mathbf{1}} = 39$.

Table 3. A fragment of the basic examination timetable

	Mon.	Tue.	Wed.	Thu.	Fri.
08:30	**ISLE218** Sec2 - Yr2 **ISLE218** Sec1 - Yr2	**IKTI402** Sec1 - Yr4	**ISLE304** Sec1 - Yr3	**KAMU202** Sec2 - Yr2 **KAMU202** Sec1 - Yr2	**ISLE110** Sec2 - Yr1 **ISLE110** Sec1 - Yr1
09:30	**ISLE407** Sec1 - Yr4	**EKON309** Sec1 - Yr3	**IKTI102** Sec1 - Yr1	**CALI402** Sec1 - Yr4	**EKON401** Sec1 - Yr4 **ISLE203** Sec1 - Yr3
10:30	**KAMU209** Sec1 - Yr2	**BUAD403** Sec1 - Yr4 **ISLE403** Sec1 - Yr4	**KAMU407** Sec1 - Yr4	**KAMU105** Sec1 - Yr1 **ISLE312** Sec1 - Yr3 **KAMU105** Sec1 - Yr1	**ULUS411** Sec1 - Yr4

3.2.2. Complete timetable

Table 4 illustrates a piece from the complete examination timetable, where Course, instructor, department-program, and number of students assigned with the room usage rates.

Spaciousness metrics, α_cs, are distributed within the range $[1.053, 4.167]$ with a mean of 1.499 and a standard deviation of 0.603. The 16 rooms available for are on the second, third, and fourth floors. The mean value of the floors of the rooms used, $\overline{x_{d,s,c,r} \cdot Rflo_r}$, is 2.392 and the standard deviation is 0.706.

Table 4. A fragment of the complete examination timetable

	Mon. - 11:30	Mon. - 12:30	Mon. - 13:30	Mon. - 14:30	Mon. - 15:30
room: A202	**ISLE315** Dr. M. Baş BADM -Pr2 (44 / 68) [88 %]		**IKTI302** Dr. T. Dağlaroğlu ECON -Pr2: (47 / 47) [94 %]		**IKTI405** Dr. M. Mert ECON -Pr2 (23 / 23) [46 %]
room: A203		**ULUS309** Dr. F. Taşdemir IREL -Pr3: (24 / 24) [48 %]		**EKON101** Dr. F. Emirmahmutoğlu ETCS -Pr2 (30 / 89) [60 %]	

room: A204	**ISLE315** Dr. M. Baş BADM -Pr2 (24 / 68) [60 %]				
room: A305	**KAMU420** Dr. İ. Keleş PADM -Pr2 (58 / 58) [83 %]			**EKON101** Dr. F. Emirmahmutoğlu ETCS -Pr2 (59 / 89) [84 %]	

3.2.3. Guidelines for proctoring duties

Table 5. A fragment of the total proctoring duties plan (Friday)

	ECON	**BADM**	**PADM**	**ETCS**	**PFIN**	**IREL**	**LECO**	**HLTH**	**ITRD**
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Fri. - 08:30	1	5				2			
Fri. - 09:30	2		2		1	1			
Fri. - 10:30			1			1			
Fri. - 11:30		2							
Fri. - 12:30	1					1			
Fri. - 13:30		3		2			1		
Fri. - 14:30		1	3						
Fri. - 15:30					1		1		
Fri. - 16:30	2	5	2	1	4				
Fri. - 17:30			1					1	
Fri. - 18:30	3			1					
Fri. - 19.30						1		1	
${}^{1}\beta_i$	4	5	4	4	4	3	2	2	1
$\sum_{d,s,r} y_{d,s,r,i}$	42	62	34	26	15	33	16	5	5
$\vec{\boldsymbol{y}} \cdot \vec{\boldsymbol{1}}$	238								

After a tri-phase optimization process, we obtained the total proctoring duties plan. That is, we recommended a minimum number of proctoring personnel required, number of proctors required on each date-timeslot-room combination and, minimized total number of proposed proctoring duties but we did not produce a proctoring schedule and left that micro-planning activity to the departments of FEAS. Table5 present fragment information on the number of proctors required on each timeslot for each department.

[1] β_is are the recommended minimum number of proctoring personnel required for department i. Totally, 29 proctors were assigned 238 duties, and the department of business administration had the busiest schedule with 62 duties.

4. Discussion

In this study, we addressed a summer school application of the examination-timetabling problem. The nature of the problem bore relaxed regulations that are, courses of both fall and spring semesters were available and, students may enroll in any elective throughout FEAS. Furthermore, students from other universities (visiting students) were allowed to register for the summer school. Challenging these complexities, our goal was to produce a timetable that benefitted all parties affected (students, proctors, instructors, housekeeping personnel and, FEAS administration) that had conflicting interests. We aimed to manage these conflicts by categorizing the formulated goals of each party into priority levels and then tackling them employing lexicographic goal programming.

For the aforementioned groups that were to be affected by the examination timetable, we first informally collected a prior data set of feelings and memories of disturbance associated with previous examination periods and made a list of preferences accordingly. E.g., students preferred no more than two exams in consecutive days, administration dictated the rooms were not to be shared for multiple exams and, there were undesired hours (administration did not want to pay overtime, students and proctors would both like to avoid tardiness). Then, before proceeding to model 2 (during the trial-and-error re-timetabling process), based on the observation that many alternative timetables were easily produced, additional unmentioned or newly discovered preferences (assigning rooms on the lower floors so that, housekeeping activity for a smaller area were made, operating costs were decreased, total distance traveled by students and proctors were minimized) surfaced.

In the formulation of our model, we tried each goal as a hard constraint separately and classified those made our model infeasible as soft constraints. And then, according to a priority plan discussed with the administration, we introduced the preferences as hard constraints, soft constraints, and objective functions in the lexicographic optimization process. Thus, we integrated all of the preferences in our model to produce a desirable decision for all.

Minimizing γ_0s, we ruled out the possibility that the basic timetable required more rooms than the available 16. Also, we maintained orderly operations at the examination coordination office, where the exam papers were handed over to proctors and then collected back. $\gamma_1, \gamma_2, \gamma_3$, and γ_4s are metrics of possible examination conflict in both compulsory and elective courses. γ_5 and, γ_6s relate to the possibility of multiple exams on the same day and thus, smaller values allowed study time between examinations and influenced success.

The multiplicative inverse of the α_cs, can be interpreted as a crowdedness metric, $1/\alpha_c$ s. The crowdedness data is ranged between 24% and 95% with a mean of 73.8% and a standard deviation of 19.1%. That is, on average we managed to keep 26% of the capacity idle so, monitoring students became easier and classrooms were airier especially during long exams. On the other hand, 5880 students took their exams on the second floor where 1405 and 1418 took theirs on the fourth and the third floors respectively. Therefore, student, proctor, and instructor movements were minimized together with elevator usage. In addition, we did not assign any exams to three rooms to further save janitors' housekeeping activities, air-conditioning and lighting costs.

The research assistants (RA) in FEAS are assigned proctoring duties; therefore, 29 of the RAs were not let on leave and were exempted from the final examinations proctoring duties (if applicable). So, the disturbance of the research activity was kept minimal.

In contrast to conventional regulation-based and student-group-oriented formulation, we employed a trial-and-error approach and separated the date-timeslot assignment (basic timetabling) phase from room assignment in order to collect reports on clashing courses. We are the first to consider classroom crowdedness (usage rate over 60%) which eliminated broken or missing classroom material problems, eased proctoring duties and, spacious and improved concentration that hopefully contributed to overall student success.

This paper offers a novel perspective via separating the ETP formulation and reprocessing datasets before each step, which is contrary to the traditional holistic optimization process but reduced complexity of the problem at hand and allowed a greater possibility to reach exact solutions. Research on ETP generally focuses on student welfare we broadened the focus to all parties. In addition, the minimization of classroom crowdedness is a unique detail.

5. Limitations

ETP is a modification of the course timetabling problem that is proven to be of high complexity (NP-Complete) (Even et al. 1975). Thus, we broke the formulation down into three models. Separating basic timetabling from room allocation may have led to sub-optimality. The reason for this main limitation is the lack of complete knowledge of student clusters enrolled in common courses. This misinformation is caused by the inclusion of the visiting students that are not integrated into the FEAS Student Database. Moreover, we believe distributing students to designated rooms and deciding the number of proctors required accordingly is separable from the ETP and did not cause further gap from the ideal results. Lastly, separating basic timetabling from room assignment made it possible to discover hidden preferences that may compensate for a possible optimal solution that does not cover the whole preference criteria.

A second limitation of this research is, we set runtime limitations to the optimization solver. Consequently, it is possible that we produced a suboptimal examination timetable. Yet, agility (ability to react to reports on clashing courses) was paramount to FEAS administration. Given agility is not a mathematically formulated constraint in our models, it is infrangible.

6. Summary and conclusion

In the present article, we offered a novel approach to tackle the ETP for cases where student groups are not available. Our formulations also included a policy for assigning proctoring duties. The formulation of the ETP in this study is three-fold: date-time assignment, room assignment, and student allocation. Through the formulation, we implemented data processing steps to create smaller subsets to loop over and thus, reduced complexity.

Future research may extend this work by employing different multiple objective decision-making (MODM) approaches, proving student allocation is separable from the ETP, and investigating additional approaches to reduce complexity.

References

Broder S. (1964), Final examination scheduling, "Communications of the ACM", vol. 7 no. 8, pp. 494-498.

Carter M.W., Laporte G., Lee S.Y. (1996), Examination timetabling. Algorithmic strategies and applications, "Journal of the Operational Research Society", vol. 47 no. 3, pp. 373-383.

Cataldo A., Ferrer J.C., Miranda J., Rey P.A., Sauré A. (2017), An integer programming approach to curriculum-based examination timetabling, "Annals of Operations Research", vol. 258 no. 2, pp. 369-393.

Daskalaki S., Birbas T., Housos E. (2004), An integer programming formulation for a case study in university timetabling, "European Journal of Operational Research", vol. 153 no. 1, pp. 117-135.

Even S., Itai A., Shamir A. (1975), On the complexity of time table and multi-commodity flow problems, in: 16th Annual Symposium on Foundations of Computer Science (SFCS 1975), pp. 184-193, https://www.computer.org/csdl/proceedings-article/focs/1975/542800184/12OmNx76TVv [05.09.2020].

Gurobi Optimization I. (2019), Gurobi optimizer reference manual, http://www. gurobi. Com [05.09.2020].

Laporte G., Desroches S. (1984), Examination timetabling by computer, "Computers & Operations Research", vol. 11 no. 4, pp. 351-360.

Lawrie N.L. (1969), An integer linear programming model of a school timetabling problem, "The Computer Journal", vol. 12 no. 4, pp. 307-316.

MirHassani S.A. (2006). Improving paper spread in examination timetables using integer programming, "Applied Mathematics and Computation", vol. 179 no. 2, pp. 702-706.

Qu R., Burke E.K., McCollum B., Merlot L.T., Lee S.Y. (2009), A survey of search methodologies and automated system development for examination timetabling, “Journal of Scheduling”, vol. 12 no. 1, pp. 55-89.

Sancar Edis R., Edis E.B. (2019), Gerçek bir sınav çizelgeleme problemi için iki aşamalı çözüm yaklaşımı (A two-phase solution approach for a real-life examination timetabling problem), “Pamukkale University Journal of Engineering Sciences”, vol. 25 no. 1, pp. 71-81.

Schaerf A. (1999), A survey of automated timetabling, “Artificial Intelligence Review”, vol. 13 no. 2, pp. 87-127.

Tripathy A. (1984), School timetabling – a case in large binary integer linear programming, “Management Science”, vol. 30 no. 12, pp. 1473-1489.