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A COURSE TIMETABLING FORMULATION UNDER PANDEMIC CONSIDERATIONS

M. Edib GURKAN[1*], Ahmet Bahadır ŞİMŞEK[2]

[1] Department of Management Information Systems, Karabuk University, Karabuk, Turkey
[2] Health Care Management Department, Faculty of Health Sciences, Gumushane University, Turkey

Keywords
University Course Timetabling, Pandemic, Hybrid Education, Multi-Objective Mathematical Model.

Abstract
The covid-19 pandemic has significantly affected the education sector and raised the new operational challenges that spring from the necessity of planning courses in a way to ensure community safety. Accordingly, many higher education institutions provide guidelines regarding the measures to be implemented in education operations. As such, timetabling of the courses is required to be carried out in line with these guidelines. To address this need, this study introduces a multi-objective mathematical model for a university course timetabling problem under the pandemic-related considerations. In particular, the proposed mathematical model aims to minimize the total number of online courses and sections while considering the balanced distribution of the courses over time slots and days. We test the effectiveness of the proposed model using real-life data. The results show that the proposed approach is able to create an optimal timetable in a reasonable time that addresses the objectives of the faculty administration and satisfies the pandemic-related requirements. The study contributes to the literature by introducing new pandemic constraints and inspires managers facing pandemic guidelines.

PANDEMİ KOŞULLARI ALTINDA DERS ÇİZELGEMESİ FORMÜLASYONU

Anahtar Kelimeler
Üniversite Ders Çizelgeleme, Pandemi, Hibrit Eğitim, Çok Amaçlı Matematiksel Model.

Öz
Covid-19 pandemisi eğitim sektörünü önemli ölçüde etkilemiş ve derslerin toplum güvenliğini sağlayacak şekilde planlanması gerekliliğinden kaynaklanan yeni operasyonel zorlukları gündeme getirmiştir. Bu sebeple, birçok yükseköğretim kurumu, eğitim faaliyetlerinde uygulanacak önlemlere ilişkin rehberler sunmaktadır ve ders programlarının, bu rehberler göz önüne alınarak hazırlanması gerekmektedir. Bu ihtiyacı karşılamak için bu çalışmada, pandemi ile ilgili endişeleri kapsayan bir üniversite ders çizelgeleme problemi için çok amaçlı bir matematiksel model sunulmaktadır. Önerilen matematiksel model ile çevrimiçi olarak sunulması planlanan derslerin ve kapasite kısıtı sebebiyle oluşturulan şubelerin sayısı, mevcut dersleri günler ve ders saatlerine mümkün mertebe dengeli dağıtma hedefini de göz önüne alarak en düşük düzeye indirgemeyi amaçlamaktadır. Önerilen modelin etkinliği gerçek yaşam verileri kullanılarak test edilmektedir. Sonuçlar, önerilen yaklaşımın fakülte yönetiminin hedeflerine hitap eden ve pandemi ile ilgili gereksinimleri karşılayan optimal bir zaman çizelgesini makul bir sürede oluşturabildiğini göstermektedir. Çalışma pandemiyle ilgili yeni kısıtları tanıtarak literatüre katkı sağlamakta ve pandemi rehberleriyle yüzleşen yöneticilere ilham kaynağı olmaktadır.

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Yazar Kimliği / Author ID (ORCID Number)
M. E. Gurkan, 0000-0003-1961-0215
A. B. Şimşek, 0000-0002-7276-2376

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* İlgili yazar / Corresponding author: edibgurkan@karabuk.edu.tr, +90-370-418-6508

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M. Edib GURKAN[1†], Ahmet Bahadır Şimşek[2]
[1] Department of Management Information Systems, Karabuk University, Karabuk, Turkey
[2] Health Care Management Department, Faculty of Health Sciences, Gumushane University, Turkey

Highlights

- The university course timetabling problem along with the pandemic considerations is considered.
- A multi-objective mathematical model is proposed to obtain course timetables satisfying pandemic-related requirements.
- The efficiency of the proposed model against a manually prepared timetable is investigated on real-life data.

Purpose and Scope

This study aims to provide an approach to assigning university courses to classrooms and time slots considering the pandemic-related requirements.

Design/methodology/approach

The problem addressed in this study is formulated as a multi-objective integer programming model, which allows for minimizing the total number of online courses and sections while distributing the courses over a week and time slots as balanced as possible.

Findings

The numerical tests conducted on the real-life data show that the proposed approach provides a more balanced timetable compared to the manually created timetable. We also observe that the proposed approach ensures following the face-to-face education model as much as possible while adhering to the pandemic rules.

Practical implications

Manually generating course timetables is a challenging and highly time-consuming task that is mainly conducted by the academic staff. The proposed approach promises to create an automated timetable and, thus, alleviates the workload of the academic staff in the faculty administration.

Originality

This study contributes to the literature by addressing a university course timetabling problem under pandemic regulations.

1. Introduction

Following the recognition of Covid-19 as a pandemic by WHO (World Health Organization, 2020), the measures taken against the spread of the virus have helped to contain the pandemic but negatively affected social and economic life (Shen et al., 2020). The education sector, which brings high risk for virus transmission, had to temporarily stop face-to-face education to hedge against the pandemic. Fortunately, it soon shifted to an online setting and ensured the continuity of education. Along with the increase in the vaccination rate and the awareness of the public, the measures have been gradually relaxed, and the education sector returned to face-to-face education in line with the pandemic prevention guidelines.

The pandemic prevention guidelines regulate two important dynamics of higher education in which the transmission risk is high, (i) campus life and (ii) educational tasks. The regulations associated with the campus life cover the measures such as hygiene, arrangements to comply with social distancing rules, and ventilation for common areas, whilst the regulations regarding educational tasks include measures related to the course and exam schedules. From the perspective of individual protection from the virus, the difference between them can be highlighted as follows. While a student has the option to stay away from the risky indoor areas in common use such as gymnasium and library, s/he does have to be in indoor areas where educational tasks, i.e., lessons and exams, are carried out. This difference reveals the importance of complying with the regulations regarding educational tasks. Some of these are as follows: reducing the duration of courses and exams, using a certain percentage of classroom capacity, and conducting some courses in an online setting. Although regulations have been defined in the pandemic prevention guideline, it has not been defined how to combine various planning

† Corresponding author: edibgurkan@karabuk.edu.tr, +90-370-418-6508

components such as the planning horizon, time slots, classroom capacities, number of lecturers and supervisors to implement the regulations. This situation directs managers who are faced with pandemic guidelines to innovative and effective solutions. While it is difficult to prepare schedules that satisfy all stakeholders (student, teacher, and administration) even before the pandemic, it is much more difficult to achieve this by considering the regulations related to the pandemic. In this study, the course timetabling problem, which is an important task of higher education institutions, is handled by considering the pandemic regulations.

The university course timetabling problem (UCTP) aims to assign a variety of courses to a given number of classrooms and time slots considering several constraints which can be categorized into two sets (Mirhassani and Habibi, 2013). The first set consists of constraints that must be satisfied to obtain a feasible timetable (called hard constraints), whilst the second set consists of constraints that must be satisfied as much as possible (called soft constraints). The UCTP is a challenging task that is repeatedly encountered by higher education institutions in each academic semester (Bellio et al., 2014). Manually searching for a solution to UCTP that will satisfy stakeholders is an error-prone, time-consuming process and results in a non-optimal solution. To that end, generating timetables via employing automized support systems has become a common practice in especially large educational institutions (Dorneles et al., 2014).

The context of the UCTP may differentiate from one university to another since they all have different requirements and objectives while scheduling the courses. Therefore, the research effort on UCTP can be categorized into two major streams. The first stream focuses on developing the computationally efficient solution methods for the respective problem. UCTP falls within the class of NP-hard problems (Thepphakorn and Pongcharoen, 2019). This implies that this problem cannot be solved optimally in polynomial time for large-sized problem instances. There exists a rich literature on UCTP in which a variety of metaheuristic approaches, such as adaptive large neighborhood search algorithm (Kiefer et al., 2017), tabu search algorithm (Lü and Hao, 2010), genetic algorithm (Akkan and Gülcü, 2018), harmony search algorithm (Al-Betar & Khader, 2012), are proposed to solve large-sized problems. The studies within this stream of research concentrate on developing methods to find a close-to-optimal timetable within a reasonable time.

The second stream provides mathematical models that satisfy the case-specific needs of managers and aims to obtain optimal solutions for small or medium-sized real-world applications. This study falls within the second stream of research. The related literature has recently attracted a notable interest since the rapid advancements in information technologies have directly increased the computational capability of off-the-shelf solvers. Therefore, many researchers make use of integer programming models to solve the UCTP addressing the specific necessities and restrictions related with the educational institution under consideration. For instance, Mokhtari et al. (2021) consider the timetabling problem in an Iranian university in which the travel time between classrooms should be of concern while scheduling the courses. Colajanni and Daniele (2021) provide a mathematical model introducing novel constraints associated with lecturers' preferences, daily classroom stability and capacity utilization of the classrooms. Arratia-Martinez et al. (2021) tackle with the determining timetable for a department in a Mexican university and address the case where the course assignments are made considering the area of expertise of the lecturers. Şimşek (2021) investigates the UCTP over a case of online education arising in Turkish university and aims to present a timetable which does not suffer from the technical problems related to the density in the number of connections. Note that the literature also consists of numerous works considering different specific real-world features including lecturers' movement between classrooms (Kaviani et al., 2013), courses with repetitive sessions (Daskalaki and Birbas, 2005), gender issues (Al-Yakoob and Sherali, 2007) and balanced workload among lecturers (Domenech and Lusa, 2016).

The pandemic guideline prepared by the Turkish Higher Education Council (Council of Higher Education, 2021) gives priority to maintaining social distance and ventilating indoor environments. While preparing the course timetables, reducing the classroom capacity utilization rate and leaving at least one empty slot between the courses assigned to the same classroom satisfy both priorities. However, these practices would result in a capacity bottleneck while scheduling the courses. A prominent way to bypass this issue for any course is to divide the enrolled students into multiple subgroups or sections, where the corresponding course is provided to each section separately. This is referred to as course sectioning which may be insufficient to cope with the capacity problem as it will increase the workload of the lecturers and the number of courses to be scheduled. Fortunately, hybrid education, which combines online and face-to-face educations, is allowed in the pandemic guideline, on the condition of prioritizing the face-to-face education. Herein, the managers may decide to move the courses that cannot be carried out face-to-face, even though sectioning, to the online environment. The usage of online education option is the only way to deal with the capacity bottleneck. In order to put the theoretical solution into practice, the questions listed below must be answered. (i) which courses will be conducted online?, (ii) which courses will be divided into sections?, (iii) how will the classrooms be planned to allow ventilation. Further, the following question might be addressed, which arises from the natural structure of the course timetabling problem,

(iv) how will the courses be evenly distributed over the days and time slots without overlapping the courses of the same lecturer and students?

In this study, we address UCTP in the presence of pandemic regulations centered around mitigating the risk of virus transmission. In particular, we introduce a multi-objective integer model attempting to answer the above-mentioned questions of managers that are specific to pandemic conditions. The pandemic-oriented requirements and objectives are adopted from the pandemic guideline prepared by Council of Higher Education in Turkey (Council of Higher Education, 2021). To be able to show the benefits of the automated university course timetable, we first compare the proposed mathematical modelling approach without the pandemic considerations against the manually prepared timetable. This is done using medium-sized real-life data generated by a Turkish university. Then, we solve the complete model and discuss the results of the proposed approach based on the previously obtained data.

The remainder of the paper is organized as follows. The following section is devoted to defining the rules to be satisfied in the automated timetable and providing an overview of the problem under consideration. Section 3 presents the mathematical notation and introduces a mathematical model for the UCTP under pandemic requirements. Section 4 applies the proposed formulation to a case study in a Turkish university and discusses our numerical findings. Section 5 finalizes the paper by providing the concluding remarks.

2. Problem Description

This section first focuses on providing the details of the UCTP arises in a Turkish university and then presents the requirements to adapt it to the Covid-19 pandemic. We consider a course timetabling problem of a faculty that involves five different undergraduate programs, each of which allowing for eight semesters of curricula. There are more than 11000 enrolled students and 132 different courses in the faculty under consideration. Each semester involves 15 weeks and two types of courses offered in all of these programs; mandatory and elective. In one of the programs, belonging to the Department 1, fourth-grade students have to follow an internship program, covering four days of each week. The first course takes place at 08:00 whereas the last one starts at 17:00. A single time slot lasts 50 minutes and there is 10 minutes break between any consecutive slots. There should not be any course assignment between 12:00 and 13:00 since this slot is defined as the lunch break. The courses are taught only on weekdays and the first-grade students have to be enrolled in the introductory courses provided online by the university administration on Thursdays before noon. Put in other words, there should not be any course scheduled to weekends and to the time interval between 08:00 and 12:00 on Thursdays. There are 4 different sized classrooms, 14 in total, that can be used by any of the departments in the faculty. The faculty administration aims to obtain a feasible timetable that distributes the courses as balanced as possible within a week and time slots.

The course timetable under the abovementioned circumstances is originally created manually. More specifically, at the beginning of any semester, faculty administration specifies the classrooms to be used by each department in order to prevent possible overlaps within courses. The lecturer of each course is also predefined. Each department assigns a research assistant to allocate the department courses to the classrooms. Once all the departments generate their timetables, the faculty coordinator checks whether the resulting course timetable is feasible. S/he makes the necessary revisions in the timetable if there are any violations against the faculty requirements. Finally, the course timetable is announced to the students through the faculty website when the faculty coordinator completes the verification stage. This manual process takes two weeks on average. Here, we propose a mathematical model to generate an automated timetable which is promising in reducing the overwhelming effort of academic staff and better serving the purpose of faculty administration. The following rules should be satisfied in the resulting automated course timetable;

- Each course must be assigned to a classroom,
- The number of time slots assigned to a course must be equal to the total credit hours of the corresponding course,
- A lecturer cannot teach more than one course in any given time slot,
- There can only be a single course held in any given classroom and time slot,
- The mandatory courses of the students at the same level of education within any department cannot be overlapped,
- Time slots covering the time interval 12:00 and 13:00 must be defined as lunch break in each day,
- Courses cannot be assigned to the weekend period,
- Courses of the fourth grade students in Department 1 have to be scheduled to a single day,
- The first grade courses cannot be assigned between the time interval 08:00 and 12:00 on Thursdays,
- It is not allowed to allocate a course to a classroom unless the number of enrolled students is less than the

classroom capacity,
- The courses should be distributed as balanced as possible within a week and time slots.

Prior to the reopening of the universities in the 2021-2022 academic year, Council of Higher Education in Turkey has released a guideline to cope with the ongoing pandemic in universities (Council of Higher Education, 2021). Building upon this, we are motivated in introducing a few new rules that have a direct influence on the course timetabling. As such, these new rules should be considered while scheduling the courses. Then, the requirements given below should be met to produce a feasible timetabling in a pandemic environment;

- The education should be face-to-face if the institution has enough resources,
- The capacity of the classrooms should be adjusted considering the social distancing rules,
- To be able to refreshen the air inside the classrooms, there should not be consecutive courses assigned to the corresponding classroom,
- The course should be divided into the sections if the number of enrolled students is higher than the adjusted capacities,
- The total number of sections should be as least as possible.

In the following section, we aim to introduce our multi-objective mathematical model to solve the problem satisfies the rules given above.

3. Mathematical Model

In this section, we first present the notation to be used in establishing the mathematical model in Table 1 and then, provide the details of the proposed formulation.

Table 1. Notation to be used in the mathematical model

	Definitions
Indices and Sets	
$c \in C$	Courses, $C = \{c_1, c_2, \dots, c_{\|C\|}\}$
$k \in K$	Physical Classrooms, $K = \{k_1, k_2, \dots, k_{\|K\|}\}$
$f \in F$	Online Classrooms, $F = \{f_1, f_2, \dots, f_{\|F\|}\}$
$r \in R$	Classrooms, $R = F \cup K$
$lc \in L$	Lecturers, $L = \{lc_1, lc_2, \dots, lc_{\|L\|}\}$
$s \in S$	Time slots, $S = \{s_1, s_2, \dots, s_{\|S\|}\}$
$n \in N$	Days, $N = \{n_1, n_2, \dots, n_{\|N\|}\}$
$d \in D$	Departments, $D = \{d_1, d_2, \dots, d_{\|D\|}\}$
$z \in Z$	Grades, $Z = \{z_1, z_2, \dots, z_{\|Z\|}\}$
Parameters	
ρ_c^{cr}	Total number of credits of course c
ρ_c^{lc}	Lecturer of the course c
ρ_c^{en}	Total number of enrolled students in course c
ρ_c^{d}	Department under which the course c is taught
ρ_c^{z}	The grade in which the course c is taught
ρ_c^{s}	The lecturers' time slot preference with respect to the course c
ρ_c^{n}	The lecturers' day preference with respect to the course c
ρ_c^{ct}	Type of the course c (i.e., mandatory, elective)
ξ_r^{cp}	Maximum capacity of a classroom r
ω	The capacity utilization rate
Decision Variables	
$\zeta_{c,r}$	Binary variable indicates whether the course c is scheduled to the classroom r, or not.
$\varphi_{c,n}$	Binary variable indicates whether the course c is scheduled to the day n, or not.
$\tau_{c,s}$	Binary variable indicates whether the course c is scheduled to the time slot s, or not
$\alpha_{c,r,n}$	Binary variable indicates whether the course c is scheduled to the classroom r on day n, or not.
o_C	Binary variable indicates whether the course c is scheduled online, or not.
$\beta_{c,r,s}$	Binary variable indicates whether the course c is scheduled to the classroom r in time slot s, or not.
$\gamma_{c,n,s}$	Binary variable indicates whether the course c is scheduled on day n in time slot s, or not.
$\phi_{c,r,n,s}$	Binary variable indicates whether the course c is scheduled to the classroom r in time slot s on day n, or not.
$k_{d,z}^{max}$	Maximum number of courses scheduled to a time slot of grade z at department d.
$w_{d,z}^{max}$	Maximum number of courses scheduled to a day of grade z at department d.
y_c	Total number of sections belong to course c.

Having provided the full notation to be used in our model, we are now ready to present the formulation of the problem under consideration. Following the goals of the faculty administration and Covid-19 guideline prepared by Council of Higher Education in Turkey, we focus on three objectives while scheduling the courses. Below, Eq. (1) minimizes the sum of online courses provided. This objective also enforces not to scheduling online courses if there are available resources for complete face-to-face education. The second objective minimizes the total number of sections created due to the capacity restriction caused by newly introduced Covid-19 rules. Thus, the workload of the lecturers' aspired to be reduced by avoiding redundant sectioning of the courses. The functions in Eq. (3) and Eq. (4) jointly serve the purpose of distributing the courses over the days and time slots as balanced as possible.

$$\min z_1 \qquad \sum_{c\in C} o_c \tag{1}$$

$$\min z_2 \qquad \sum_{c\in C} y_c \tag{2}$$

$$\min z_3 \qquad \sum_{d\in D}\sum_{z\in Z} k_{d,z}^{max} \tag{3}$$

$$\min z_4 \qquad \sum_{d\in D}\sum_{z\in Z} w_{d,z}^{max} \tag{4}$$

Constraints (5) guarantee that there cannot be any course scheduled to the time slots covering an interval 08:00 and 12:00 for first grade students (z_1).

$$\sum_{c\in C:\, \rho_c^z = z_1} \gamma_{c,n_4,s} = 0 \qquad \forall s \in \{s_1, s_2, s_3, s_4\} \tag{5}$$

For the sake of brevity, let us now introduce a new set M including the courses belongs to the department d_1 at grade z_4. Then, constraints (6) enforce that each course offered to fourth grade students (z_4) in department d_1 is scheduled on a single day.

$$\sum_{c\in M} \varphi_{c,n} = \varphi_{c',n} * |M| \qquad \forall c' \in M, n \in N \tag{6}$$

Constraints (7) ensure that each course can only be assigned to a single physical classroom and constraints (8) confirm that online courses can only be taught in online rooms. Constraint (9) compel each course to be assigned to either a physical or an online classroom. Constraint (10) guarantee that the course *c* is scheduled within a week as much as the total number of sections belong to corresponding course. Constraints (11) provide the logical relationship between the credits of any course and the number of time slots it is assigned.

$$\sum_{k\in K} \zeta_{c,k} = 1 - o_c \qquad \forall c \in C \tag{7}$$

$$\sum_{f\in F} \zeta_{c,f} = o_c \qquad \forall c \in C \tag{8}$$

$$\sum_{r\in R} \zeta_{c,r} = 1 \qquad \forall c \in C \tag{9}$$

$$\sum_{n\in N} \varphi_{c,n} = y_c \qquad \forall c \in C \tag{10}$$

$$\sum_{s\in S} \tau_{c,s} = \rho_c^{cr} \qquad \forall c \in C \tag{11}$$

Constraints (12)-(15) relate the decision variables between each other. More specifically, constraints (12) combine the classroom and day decisions on any course into a single decision variable. Similarly, constraints (13) determine the scheduled time slot and classroom regarding the course *c*. Constraints (14) calculate the value of variables showing that the day and time slot decisions of each course. Finally, constraints (15) build a relationship between the (12) and (13) and define variables indicating the time, classroom and day decision for each course.

$$\alpha_{c,r,n} = \zeta_{c,r} * \varphi_{c,n} \qquad \forall c \in C, r \in R, n \in N \qquad (12)$$

$$\beta_{c,r,s} = \zeta_{c,r} * \tau_{c,s} \qquad \forall c \in C, r \in R, s \in S \qquad (13)$$

$$\gamma_{c,n,s} = \varphi_{c,n} * \tau_{c,s} \qquad \forall c \in C, n \in N, s \in S \qquad (14)$$

$$\phi_{c,r,n,s} = \alpha_{c,r,n} * \beta_{c,r,s} \qquad \forall c \in C, r \in R, n \in N, s \in S \qquad (15)$$

The following constraints ensure that at most one course can be assigned to a classroom *r* on any day *n* in time slot *s*.

$$\sum_{c \in C} \phi_{c,r,n,s} \leq 1 \qquad \forall r \in R, n \in N, s \in S \qquad (16)$$

Before proceeding any further, let us remind that the earliest and latest time slots in any day is s_1 and $s_{|S|}$, respectively. The constraints (17)-(19) make sure that the time slots assigned to any course must be consecutively.

$$\tau_{c,s_1} - \tau_{c,s_1+k} \leq 0 \qquad \forall c \in C, k \in [1, \rho_c^{cr}] \qquad (17)$$

$$\tau_{c,s_{|S|}} - \tau_{c,s_{|S|}-k} \leq 0 \qquad \forall c \in C, k \in [1, \rho_c^{cr}] \qquad (18)$$

$$-\tau_{c,k} + \tau_{c,k+1} - \tau_{c,k+i} \leq 0 \qquad \forall c \in C, k \in \left(s_1, s_{|S|}\right), i \in [1, \rho_c^{cr}]: k + i \leq s_{|S|} \qquad (19)$$

Classrooms can be utilized as much as the capacity utilization rate (ω). The constraints given below guarantee that the total number of students assigned to a course cannot exceed the 60 % of the corresponding classroom capacity. These constraints are essential in following the social distancing rules of the university.

$$\sum_{r \in R} \omega * \xi_r^{cp} * y_c * \zeta_{c,r} \geq \rho_c^{en} * (1 - o_c) \qquad \forall c \in C \qquad (20)$$

Constraints (21) make sure that a lecturer can teach only one lecture at most on a specific day and time slot. Constraints (22) avoid the potential overlap within mandatory courses belonging to a grade at any department. Finally, constraints (23) define a lunch break for each day.

$$\sum_{c \in C:\, \rho_c^{lc} = 1} \gamma_{c,n,s} \leq 1 \qquad \forall lc \in L, n \in N, s \in S \qquad (21)$$

$$\sum_{\substack{c \in C:\, \rho_c^d = d, \\ \rho_c^z = z, \\ \rho_c^{ct} = m}} \gamma_{c,n,s} \leq 1 \qquad \forall d \in D, z \in Z, n \in N, s \in S \qquad (22)$$

$$\sum_{c \in C:\rho_c^s = 0} \tau_{c,s_4} = 0 \qquad (23)$$

Constraints (24) and (25) respectively calculate the total number of courses offered within a day and in any time slot on a specific day.

$$\sum_{\substack{c \in C:\, \rho_c^d = d, \\ \rho_c^z = z}} \varphi_{c,n} \leq w_{k,d}^{max} \qquad \forall d \in D, z \in Z, n \in N \qquad (24)$$

$$\sum_{\substack{c \in C:\, \rho_c^d = d, \\ \rho_c^z = z}} \tau_{c,s} \le k_{k,d}^{max} \qquad \forall d \in D, z \in Z, s \in S \qquad (25)$$

The following constraints specify the preferences of the lecturers. Constraints (26) indicate the day preference of the lecturer who gives the course c. The time preference with respect to any course is ensured by (27). Constraints (28) provide the relationship between (26) and (27), and combine these variables into a decision variables representing the time and day preferences correspond to each course.

$$\varphi_{c,\rho_c^d} = 1 \qquad \forall c \in C \qquad (26)$$

$$\tau_{c,\rho_c^s} = 1 \qquad \forall c \in C \qquad (27)$$

$$\gamma_{c,\rho_c^d,\rho_c^d} = 1 \qquad \forall c \in C \qquad (28)$$

Constraints (29) express that there cannot be consecutive courses assigned to any classroom r in a day and finalizes the proposed model. As such, these constraints imply that there is enough time to refreshen the air in the classroom until the next lecture starts.

$$\phi_{c,r,n,s} + \sum_{c' \in C: c' \neq c} \phi_{c',r,n,s+1} \le 1 \qquad \forall n \in N, r \in R, s \in \{s_1, \dots, s_{|S-1|}\}, c \in C \qquad (29)$$

For the ease of readability, we provide the complete mathematical model in the following. Thus, the course timetable considering pandemic circumstances can be generated once the formulation given below is solved.

$$\begin{aligned} \min \quad & (1)\text{-}(4) \\ & (7)\text{-}(29), \\ \text{subject to} \quad & \zeta_{c,r}, \varphi_{c,n}, \tau_{c,s}, \alpha_{c,r,n}, \beta_{c,r,s}, \gamma_{c,n,s}, \phi_{c,r,n,s}, k_s^{max}, w_{d,z}^{max}, \\ & y_c \in \{0,1\}, o_c \in \{0,1\}, r \in R, s \in S, n \in N, d \in D, z \in Z. \end{aligned} \qquad (30)$$

4. Numerical Results

This section discusses the numerical findings obtained via solving the proposed mathematical model formulation. Here, we first aim to assess the quality of the automated timetable as compared to its manual counterpart. To that end, we use the data set provided for the fall semester of 2021. Note that the manual timetabling corresponding to the semester under consideration has been created without considering the pandemic-related requirements. Accordingly, we solve the proposed mathematical model by excluding the pandemic-oriented constraints and objectives to achieve a fair comparison. Our second goal in this numerical study is to check how the automated timetable deals with the circumstances in which the scarce resources due to the pandemic-related requirements are of concern.

We use Gurobi v9.0.1 solver on an Intel Core i5-8250U CPU with 12 GB RAM to conduct all the numerical experiments. The proposed formulation is solved using a lexicographic approach under which each objective is optimized sequentially following its priority order. The priority order of the objectives is as follows; $z_1 > z_2 > z_3 > z_4$. In what follows, we present and discuss our numerical results.

4.1. Automated vs Manual Timetable

We present the automated and manual timetable based on the distribution of the courses within faculty over the days Table 2. Remind that our aim is to distribute the courses as balanced as possible and lower deviation is the basic indicator of the balanced timetable. If we take a detailed look at the results in Table 2, we observe that the proposed mathematical model yields a timetable in which the average number of the courses ranging from 1.21 to 1.53 whereas that of the manual timetable ranges from 1.05 to 1.84. Further, automated timetable results in lower deviation as compared to the manual timetable in most of the days. These findings imply that the automated timetable distributes courses over days more balanced.

Table 2. Distribution of the courses over days

D	*Z*	Automated					Manual				
		N					*N*				
		1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
1	1	2	1	1	1	1	2	2	2	0	0
1	2	3	3	2	2	1	3	2	3	0	3
1	3	2	2	1	2	2	2	2	2	3	0
1	4	0	0	0	3	0	0	3	0	0	0
2	1	1	1	1	1	1	1	2	1	1	0
2	2	1	2	2	1	0	2	1	0	1	2
2	3	1	1	2	1	2	1	2	2	1	1
2	4	1	2	2	2	0	2	2	2	1	0
3	1	1	1	1	1	1	2	2	1	0	0
3	2	1	2	2	1	1	1	2	1	2	1
3	3	1	2	1	2	2	2	2	1	2	1
3	4	2	0	2	2	2	1	2	1	2	2
4	1	1	1	1	1	1	2	2	0	1	0
4	2	2	0	1	2	2	2	2	1	1	1
4	3	1	3	2	2	3	2	2	2	2	3
4	4	2	2	2	2	1	1	2	2	2	2
5	1	1	1	1	0	1	2	0	1	0	1
5	2	2	2	1	1	1	2	2	1	1	1
5	3	2	1	1	2	1	1	1	1	2	2
	Mean	**1.42**	**1.42**	**1.37**	**1.53**	**1.21**	**1.63**	**1.84**	**1.26**	**1.16**	**1.05**
	Std.Dev.	**0.67**	**0.88**	**0.58**	**0.68**	**0.77**	**0.67**	**0.59**	**0.78**	**0.87**	**1.00**

Table 3 presents the corresponding timetables based on the distribution of courses over time slots. It can be observed that the mean of the first time slot in the manual timetable is 0.26. This shows that the first time slot is rarely used while allocating the courses in the manual timetable. Also, the most used time slot having a mean of 3.42. The mean values in the automated timetable, on the other hand, ranges from 1.00 to 3.05. Accordingly, the automated timetable yields lower standard deviations in most of the time slots and provides a more balanced distribution of the courses over time slots when compared to its manual counterpart.

Table 3. Distribution of the courses over time slots

D	Z	Automated									Manual								
		S									*S*								
		1	**2**	**3**	**4**	**6**	**7**	**8**	**9**	**10**	**1**	**2**	**3**	**4**	**6**	**7**	**8**	**9**	**10**
1	1	0	1	2	2	2	2	2	2	2	0	2	2	2	3	3	1	1	1
1	2	3	3	3	2	3	3	2	3	3	0	1	4	4	4	4	3	3	2
1	3	2	3	3	1	2	2	2	3	3	1	2	3	3	4	4	2	1	1
1	4	1	1	0	0	1	1	0	1	1	0	0	1	1	1	1	0	1	1
2	1	0	2	2	2	2	2	2	1	1	0	1	1	1	3	4	3	1	0
2	2	1	3	3	2	0	2	3	3	1	0	3	3	3	1	2	3	2	1
2	3	1	3	3	2	3	4	4	1	0	1	3	3	2	2	4	4	2	0
2	4	2	3	3	1	1	2	4	3	2	1	3	3	2	3	3	4	1	1
3	1	1	2	2	1	1	1	2	2	2	0	1	1	1	2	2	3	2	2
3	2	3	3	3	0	2	2	2	2	2	0	2	2	2	2	3	3	3	2
3	3	3	4	4	1	1	2	4	3	2	0	3	3	3	0	0	5	5	5
3	4	4	4	4	0	0	1	4	4	3	0	3	3	3	2	2	5	3	3
4	1	2	2	2	0	2	2	3	1	1	0	2	2	2	0	0	3	3	3
4	2	3	4	4	1	1	3	3	2	0	1	2	2	1	0	0	5	5	5
4	3	3	5	5	2	5	5	6	1	1	0	6	6	6	0	0	5	5	5
4	4	4	4	4	0	3	3	5	2	2	0	4	4	4	0	0	5	5	5
5	1	2	2	2	0	0	0	2	2	2	0	1	2	2	1	0	2	2	2
5	2	2	3	3	1	1	1	4	3	3	0	2	2	2	5	5	5	0	0
5	3	2	3	3	1	1	2	4	3	2	1	3	3	2	3	3	4	1	1
	Mean	**2.05**	**2.89**	**2.89**	**1.00**	**1.63**	**2.11**	**3.05**	**2.21**	**1.74**	**0.26**	**2.32**	**2.63**	**2.42**	**1.89**	**2.11**	**3.42**	**2.42**	**2.11**
	Std.Dev.	**1.15**	**1.02**	**1.07**	**0.79**	**1.22**	**1.12**	**1.36**	**0.89**	**0.91**	**0.44**	**1.30**	**1.18**	**1.23**	**1.52**	**1.68**	**1.43**	**1.57**	**1.71**

Considering that manual scheduling is the result of about two weeks of effort with the participation of a research assistant from each department, it is noticed that automated scheduling can produce time-effective as well as higher-quality schedules.

4.2. Automated Timetable with Pandemic Considerations

This subsection presents the results of the complete mathematical model provided in Section 3 and the results prove that with the proposed model, managers can answer the questions faced by the pandemic guide. Table 4 shows the total number of online and face-to-face courses scheduled for each department. The results demonstrate that it is not possible to obtain a feasible timetable for the faculty under consideration by allowing only for face-to-face education and aiming to follow the pandemic-related rules. This results in the appearance of online courses in the automated timetable. We observe that the total number of online classrooms corresponds to almost half of the physical classrooms scheduled over a week in the automated timetable. The variability in the ratio of online/face-to-face courses between departments is due to the difference in the number of enrollments. From this perspective, it is seen that departments 4 and 2 are relatively more affected by the capacity bottleneck due to the high number of students. Table 4 shows that the rate of hybrid education between departments within the same faculty is variable. Considering that the online education has pros and cons compared to face-to-face education, the criticism that the faculty management does not treat the departments fairly may appear. However, it is clear that there is no more acceptable way to ensure continuity of education in accordance with the pandemic guideline.

Table 4. Total number of online and face-to-face courses scheduled for each department

D	Online Courses	Face-to-face Courses
1	8	21
2	13	12
3	7	21
4	15	20
5	0	18
Total	43	92

Table 5. Total number of single and multi-section courses offered by departments

D	Single	Multi
1	16	13
2	23	2
3	12	16
4	28	4
5	16	2
Total	95	37

Table 5 summarizes the course sectioning decisions obtained from the automated timetable. Keeping in mind that the priority order $z_1 > z_2$, it is observed that the automated timetable first considers to sectioning the course instead of allocating the corresponding course to the online program. This illustrates that the results of the proposed approach coincides with the pandemic-related goals of the Council of Higher Education in Turkey (see e.g., Council of Higher Education, 2021). As such, almost one-third of the total courses are sectioned. Also, we notice that the total number of sections of any course is two at most. This implies that allocating the course to the online program is always a more reasonable decision than dividing the corresponding course into more than two sections in our case.

Table 6. Distribution of the courses over days under Pandemic Planning

D	*Z*	*N*				
		1	**2**	**3**	**4**	**5**
1	1	2	1	1	1	2
1	2	3	3	4	4	3
1	3	1	2	3	3	3
1	4	3	0	3	0	0
2	1	2	0	2	1	1
2	2	1	1	0	2	2
2	3	2	1	2	1	1
2	4	2	1	1	2	2
3	1	2	2	2	0	1
3	2	1	3	2	2	3
3	3	3	1	2	3	3
3	4	3	3	2	3	3
4	1	1	1	1	1	1
4	2	1	2	1	2	1
4	3	3	2	3	3	2
4	4	3	1	1	3	3
5	1	2	1	2	0	1
5	2	0	2	1	2	2
5	3	1	1	2	1	2
	Mean	**1.89**	**1.47**	**1.84**	**1.79**	**1.89**
	Std.Dev.	**0.91**	**0.88**	**0.93**	**1.15**	**0.91**

Table 7. Distribution of the courses over time slots under Pandemic Planning

D	*Z*	*S*								
		1	**2**	**3**	**4**	**6**	**7**	**8**	**9**	**10**
1	1	0	1	2	2	2	2	2	2	2
1	2	3	3	3	2	3	3	2	3	3
1	3	1	3	3	2	3	3	2	2	2
1	4	1	1	1	1	1	1	0	0	0
2	1	1	2	2	1	2	2	2	1	1
2	2	1	3	3	2	2	2	3	1	1
2	3	0	3	3	3	1	3	4	3	1
2	4	3	3	3	0	0	1	4	4	3
3	1	1	2	2	1	2	2	2	1	1
3	2	0	2	3	3	1	2	3	3	2
3	3	2	4	4	2	1	3	4	3	1
3	4	1	4	4	3	2	4	4	2	0
4	1	2	2	2	0	1	1	3	2	2
4	2	3	4	4	1	0	2	3	3	1
4	3	4	6	6	2	4	4	5	1	1
4	4	2	4	4	2	2	2	5	3	3
5	1	1	2	2	1	1	1	2	1	1
5	2	0	3	3	3	1	2	4	3	2
5	3	1	3	3	2	1	3	4	3	1
	Mean	**1.42**	**2.89**	**3.00**	**1.74**	**1.58**	**2.26**	**3.05**	**2.16**	**1.47**
	Std.Dev.	**1.14**	**1.17**	**1.08**	**0.91**	**0.99**	**0.91**	**1.23**	**1.04**	**0.88**

A striking finding in Table 5 is that departments 2 and 4 have relatively few multi-section courses. When Tables 4 and 5 are evaluated together, it is apparent that many of the courses of both departments are conducted online, and among the remains, those that cannot be conducted in a single section are multi-sections. Another inference is that the tables complement each other. A department with many online courses has fewer multi-section courses and vice versa. The most important factor in whether a course is multi-section or not is the capacity of the classrooms. The fact that the existing classrooms are not homogeneous and that the already low capacity of some classrooms is reduced further due to the utilization rate makes low-capacity classrooms useless. Table 5 also indicates that the scarcity of capacity as a result of the pandemic guideline significantly affect sectioning decisions and thus, poses a challenge for planning.

Another issue that should be brought to the fore regarding sectioning is the increase in the workload of lecturers. Workloads are limited and charged by legal regulations. The pandemic guideline causes an increase in the workload of lecturers, but does not remark on the regulations regarding workloads. Multi-section courses were minimized with the objective z_2 to reduce the dissatisfaction caused by excessive workload, albeit for a temporary period. In this way, effective use of classrooms is ensured.

Table 6 and Table 7 report the distribution of courses over days and time slots, respectively. It can be seen from these tables that the courses are distributed as balanced as possible even under pandemic environment, where the limited capacity of classrooms is of concern and scheduling courses consecutively on any day is not allowed.

5. Conclusion

This study addresses a university course timetabling problem under the pandemic considerations in which the capacities of the classrooms are downsized whereas the face-to-face education model is aspired to be maintained as much as possible. To solve this problem, we propose a multi-objective modelling approach, building upon the pandemic guideline released by the Council of Higher Education in Turkey (Council of Higher Education, 2021), that handles each objective sequentially based on its priority. In particular, the proposed mathematical model concerns with minimizing the total number of online courses and sections while distributing the courses over a week and time slots as balanced as possible. We test the effectiveness of the proposed modelling approach against manually prepared timetable using a real-life data of a faculty provided for the fall semester of 2021. This comparison is made without pandemic-related objectives and constraints since the manual timetable ignores the pandemic concerns. We show that the proposed modelling approach yields more balanced timetable against its manual counterpart and solves the problem in a reasonable time. Also, we run the complete model adopting the previously obtained data. The results demonstrate that the proposed approach is able to ensure following the face-to-face education model as much as possible while adhering the pandemic rules and balancing the courses within week and time slots.

The solution time required to solve the proposed model and thus, generate an optimal timetable is around a couple of hours. However, the corresponding model would become more complex to be solved to optimality when institution-specific requirements incorporated into the problem. Therefore, one might explore the heuristic solution approaches for the problem under consideration. Also, faculty administration might consider enrolling students with the same service course under different departments' curricula in a single online course to deal with the capacity bottleneck arising from the pandemic regulations. The proposed mathematical model does not consider such a rule; thus, extending the model to this type of pandemic-related setting would be interesting in solving a practical problem. Improving a decision support tool integrated with the proposed mathematical model and investigating the impacts of the automated timetable on both students and academic staff would also be another direction for future research.

Conflict of Interest

No conflict of interest was declared by the authors.

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