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A course timetabling formulation under circumstances of online education

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Absract

This study addresses the adaptation of the course timetabling problem to the online education system mandated by the Covid-19 pandemic. The seating capacity constraint loses its validity in online education conditions. It is replaced by a bandwidth constraint that restricts the number of instantaneous connections. Overlapping courses in the same time slot increase the number of instant connections and excessive connections cause technical problems. Bandwidth constraint requires the distribution of total connection in a day over all time slots. However, while this is achieved, the time slots should be allocated fairly to the departments.

In this study, a multi-objective mathematical model is proposed that distributes the courses fairly on the day and time slot axis and distributes the total number of connections to time slots in each day as equally possible. The model adopts the maximum difference minimizing approach and requires solving the objectives sequentially according to the order of them.

The model was tested with the real data of the 2020-2021 fall semester of a 7 department faculty. The model has 12084 decision variables and 15567 constraints and an optimal solution gets in approximately 28 minutes.

Results were compared with a decentralized and manually prepared timetable. The comparison shows that the model is superior to the manual timetable in the distribution of courses across the day and time slot. Also, the model can reduce the number of students in the peak time slot by 22% compared to manual scheduling.

1. Introduction

The Covid-19 virus spread to many countries in a short time from Wuhan city in China. With the World Health Organization declaring the pandemic on March 11, 2020, countries tried to prevent the spread by closing borders, stopping international flights, and curfews. The education system has suffered from the measures taken, and most governments have decided to temporarily close schools (United Nations Educational, 2020). Countries with sufficient infrastructure to provide continuity of education activated online options that allow social distancing and self-isolation. Most institutions have transformed their campus-based education model to a synchronous private online format (Kaplan & Haenlein, 2016). Also, administrative tasks such as course and exam timetables have been reconfigured to comply with the circumstances of online education. In this context, the base constraint of *"Classroom capacity can not be less than the number of students of the event to which the classroom is allocated"* is no longer valid because the restrictive factor is not the seating capacity, but the bandwidth. The bandwidth limits the number of instantaneous connected students. Since this number can be affected by many factors such as network load and broadcast quality, it is difficult to define the instantaneous capacity with a certain number as the seating capacity. Hence, the number of simultaneous connections rises as a new constraint on timetabling for large institutions with tens of programs and thousands of students in the circumstances of online education.

Especially in decentralized planning, it is possible that many events belonging to different departments to which numerous students will be connected overlap at the same time. The excessive connection can result in a variety of technical issues, including failed connection, disconnection, and audio or video stream delay. The simplest solution is to distribute events throughout the day rather than overlapping them in a limited time slot. However, this solution raises the question of how time slots are allocated between departments, due to the different attractiveness of time slots. The allocation of time slots becomes a matter of fairness in decentralized planning across departments. It seems that central planning is required to tackle bandwidth-related issues in the circumstances of online education. On the other hand, a balanced distribution of the courses of a grade of a department on the axis of day and time slot supports fair understanding.

In this study, we handle the above-mentioned problem of the course timetabling that appears in online education conditions. This paper proposes a multi-objective integer model that aims to distribute students across time slots, allocating days and time slots fairly to each grade of each department. The model adopts a minimax approach to reach both objectives. For example, minimizing the difference between the maximum and the minimum number of students in time slots ensures that the total number of students per day is distributed as evenly as possible over time slots and prevents accumulation at any given time slot. We tested our model with medium size real data. We compared the results with the course timetable prepared manually in a decentralized manner.

The highlights of the study are as follows; i) It deals with the adaptation of the education system to the pandemic, ii) It offers an automated course timetabling model with a central perspective to the real-world problem, iii) It adopts the minimax approach in modeling, iv) It contains the balanced distribution of all connections throughout time slots and allocating days and time slots fairly to each grade of each department.

The remaining part of the paper proceeds as follows: related studies are introduced in Section 2. Case details and mathematical formulation are presented in Section 3. Section 4 covers computational results. Finally, concluding remarks are presented in Section 5.

2. Literature Reviews

Within the scope of the university timetabling, various sub-problems appear such as *Course Timetabling, Class-Teacher Timetabling, Student Scheduling, Teacher Assignment, and Classroom Assignmen*t (Carter & Laporte, 1998). Course timetabling problems focus on the planning of a set of teaching events into a decision matrix consisting of days, time, and classrooms with satisfying the hard and soft constraints. The course timetabling problem which is NP-Hard (Thepphakorn & Pongcharoen, 2019), has a wide range of solution approaches. Various meta-heuristics such as Genetic Algorithm (Akkan & Gülcü, 2018), Simulated Annealing (Goh et al., 2019), are suggested for large size problems in the literature. For relatively medium and smaller size problems, exact solution approaches are suggested (Daskalaki & Birbas, 2005; Dimopoulou & Miliotis, 2001).

The literature introduces various variants of the course timetabling model that differ from one institution to another in terms of specific constraints (Schaerf, 1999). Babaei et. al. (2015) reviewed the hard and soft common constraints in the literature, as shown below.

Hard Constraints

- H1- A teacher can not be assigned to more than one classroom in the same time slot.
- H2- A classroom can not be allocated to more than one course in the same time slot.
- H3- A teacher teaches only one course in one classroom in the same time slot.
- H4- One classroom can only be allocated to a group of students and a teacher in the same time slot.
- H5- Some predefined courses are scheduled in a given timeslot.
- H6- The capacity of the classroom cannot be less than the number of students for the course to which it is allocated.

Soft Constraints

- S1- The teacher can suggest a day or time slot priority for the courses which she/he will teach.
- S2- A teacher can request a special classroom for a specific course.
- S3- The timetable should be adjusted in a way that the empty time slots of both teacher and student to be minimized.
- S4- Timetabling should be conducted taking into account the attractiveness of time zones as much as possible.
- S5- The lunch break is either 12–13 or 13–14, usually.
- S6- Time slots start at 8 am and end at 20:30, usually.
- S7- The maximum teaching/ learning hours for teachers/students in a classroom are 4 h.

Hard constraints must be satisfied for a feasible solution whilst soft constraints should be satisfied as much as possible for a quality solution. These constraints may vary depending on the case. For example, in some cases, simultaneous courses are taken into account where H2 is violated (Yoshikawa et al., 1996). Similarly, in the online education setting, S4, S5, and S6 remain whilst H6 loses its validity.

The balanced distribution issue, which stands out in our study, appears in the literature in several ways. Some studies take into account the balanced distribution of students to the sections of courses to minimize the conflicts that may occur (Ramon Alvarez-Valdes et al., 2002; Aubin & Ferland, 1989; Carter, 2001; Palma & Bornhardt, 2020). Some studies have taken into account the balanced distribution of courses throughout the week (Akı, 2020; R. Alvarez-Valdes et al., 1996; Birbas et al., 2009; Colorni et al., 1998; Wright, 1996). The balanced distribution of courses throughout time slots is shown among the soft constraints by Hosny (2019). Dandashi and Al-Mouhamed (2010) propose a heuristic aimed at balancing the course load for time slots. Arratia-Martinez et. al. (2021) achieved a balanced course distribution by minimizing the difference between the maximum and the minimum number of courses in each time slot. Their modeling approach of the balanced course distribution in the study is inspiring for us.

The fair allocation of resources has been the subject of course timetabling problems (Matias et al., 2018; Mühlenthaler & Wanka, 2016). Wanka (2016) compared two approaches (MMF-Max-Min Fairness, JFI-Jain's Fairness Index) which are used to measure the fairness of course timetables. JFI takes a value in the range [0-1]. Approaching 1 indicates that resources are allocated equally among stakeholders, approaching 0 indicates that resources are allocated to a single stakeholder. On the other hand, MMF has an iterative structure. At each iteration, the most disadvantaged stakeholder tries to improve and a fair schedule is obtained at the end of iterations. In our study, with a similar approach to MMF, we aim to minimize the maximum resource use of departments and to allocate resources fairly. Dimopoulou & Miliotis (2004) adopted the fair allocation of resources to departments in central planning.

To the best of our knowledge, our study is the first to discuss the circumstances of online education in the course timetabling problem. In this respect, it has the feature of being the first in the literature.

3. Problem Description

To prevent the spread of the Covid-19 virus, Turkish higher education paused for 3 weeks on March 16, 2020 (Council of Higher Education, 2020). Universities with sufficient infrastructure shifted to a synchronous private online format, which is a paced format that is very similar to the campus-based education model, on March 23, 2020. In this context, the university, which provided data, chose Moodle (Moodle, 2018) which is an open-source education platform. The platform is integrated with the student information system, ensuring the synchronization of all required academic components such as courses, students, and teachers. The platform is private to registered students and courses take place synchronously and are recorded. Course timetables have been reconfigured to comply with the circumstances of online education. Before the pandemic, each department prepared its course timetable manually by using the classrooms allocated to it. With this habit, online course timetable was also prepared in a decentralized manner. This caused overlaps of the courses belonging to different departments, especially during the midday hours (13:00-14:00). The excessive connection request caused failure to connect, disconnection or delays in audio and video stream.

With the model proposed in this study, we aim to prevent the problems that arise with decentralized planning, taking into account the online conditions. We test the behavior of the model with real data of a faculty with 7 departments, 198 courses, and 1898 students. Time slots start 8:00 and end 17:00, lunch break is 12:00-13:00, each slot consists of 1 hour, and 8 slots in total are available. No preference is taken from students or teachers regarding course placement. The soft and hard constraints in the problem are as follows.

Hard Constraints

- A teacher or student cannot attend more than one lesson in one time period.
- A group of students can attend a maximum of two lessons per day.
- Lunchtime (12–13) must be free.
- The same group of students can not have more than two courses in a day.
- The courses of the same group of students can not be consecutive in a day.

Soft Constraints

- The number of connected students in time slots should be as balanced as possible.
- Days and time slots should be allocated to departments as fairly as possible.
- Courses should be distributed throughout the week.

3.1. Mathematical Model

Sets and Indices

T: Time Slots t: indices of T

t^f, t^l, t^m: refer to the first and last element of T, and lunchtime, respectively.

D: Planning Period d: indices of D

B: Departments b: indices of B

G: Grades g: indices of G

C: Courses c: indices of C

L: Lecturers l: indices of L

C^l: Courses of the lecturer l

C^b: Courses of the department b

$C^{b,g}$: Courses of the grade g of the department b

Parameters

H^c: Duration of the course c

E^c: The # of enrolled in course c

Decision Variables

x_{cdt} :1 if course c is placed in time slot t at day d, 0 otherwise

xt_{ct} :1 if course c is placed in time slot t, 0 otherwise

xd_{cd} :1 if course c is placed at day d, 0 otherwise

bgd_{bg}^{max} : The maximum number of courses per day of the grade g of the department b

bgd_{bg}^{min} : The minimum number of courses per day of the grade g of the department b

bgt_{bg}^{max} : The maximum number of courses belonging to the department b placed in time slot t

bgt_{bg}^{min} : The minimum number of courses belonging to the department b placed in time slot t

con_d^{max} : The maximum number of connections in any time slot of day d

con_d^{min} : The minimum number of connections in any time slot of day d

Objective Function

$$Min\ Z_1 = \sum_{b\in B}\sum_{g\in G}(bgd_{bg}^{max} - bgd_{bg}^{min}) \tag{1}$$

$$Min\ Z_2 = \sum_{b\in B}\sum_{g\in G}(bgt_{bg}^{max} - bgt_{bg}^{min}) \tag{2}$$

$$Min\ Z_3 = \sum_{d\in D}(con_d^{max} - con_d^{min}) \tag{3}$$

Our model has a multi-objective structure. $Z1$ minimizes the difference between the maximum and the minimum number of courses in a day for each grade of each department. $Z2$ minimizes the difference between the maximum and the minimum number of courses in a time slot for each grade of each department. $Z3$ minimizes the difference between the maximum and the minimum number of connections in a time slot for each day. $Z1$ and $Z2$ are related to the balanced distribution of the courses on the axis of the day and time slot. In this way, students and departments can have a fair resource allocation. $Z3$ is concerned with the distribution of the total number of daily connections over time slots. Technical problems can be minimized by distributing connection requests daily to all time slots.

Constraints

$\sum_{d\in D} xd_{cd} = 1$	$\forall\ c \in C$	(4)
$\sum_{t\in T} xt_{ct} = H^c$	$\forall\ c \in C$	(5)
$x_{cdt} = xd_{cd} * xt_{ct}$	$\forall\ c \in C, d \in D, t \in T$	(6)

$$\sum_{c \in C^{bg}} x_{cdt} \leq 1 \qquad \forall b \in B, g \in G, d \in D, t \in T \tag{7}$$

$$\sum_{c \in C^{l}} x_{cdt} \leq 1 \qquad \forall d \in D, t \in T, l \in L \tag{8}$$

$$\sum_{c \in C^{bg}} xd_{cd} \leq 2 \qquad \forall b \in B, g \in G, d \in D \tag{9}$$

$$\sum_{c \in C} xt_{ct^m} = 0 \tag{10}$$

$$x_{cdt} + \sum_{c' \in C^{bg}: c' \neq c} x_{c'dt+1} \leq 1 \qquad \forall b \in B, g \in G, c \in C^{bg}, d \in D, t \in T: t \neq t^l \tag{11}$$

$$\begin{aligned} & xt_{ct^f} + xt_{ct^f + t'} \leq 0 && \forall c \in C, t' \in \{1 \dots H^c\} \\ & -xt_{ct} + xt_{ct+1} - xt_{ct+t'} \leq 0 && \forall c \in C, t \in T \setminus \{t^f, t^l\}, \; t' \in \{1 \dots H^c\}: t + t' \leq t^l \\ & xt_{ct^l} + xt_{ct^l - t'} \leq 0 && \forall c \in C, t' \in \{1 \dots H^c\} \end{aligned} \tag{12}$$

$$\begin{aligned} & \sum_{c \in C^{bg}} xd_{cd} \leq bgd_{bg}^{max} \\ & \sum_{c \in C^{bg}} xd_{cd} \geq bgd_{bg}^{min} \end{aligned} \qquad \forall b \in B, g \in G, d \in D \tag{13}$$

$$\begin{aligned} & \sum_{c \in C^{bg}} xt_{ct} \leq bgt_{bg}^{max} \\ & \sum_{c \in C^{bg}} xt_{ct} \geq bgt_{bg}^{min} \end{aligned} \qquad \forall b \in B, g \in G, t \in T \tag{14}$$

$$\begin{aligned} & \sum_{c \in C} E^c * x_{cdt} \leq con_d^{max} \\ & \sum_{c \in C} E^c * x_{cdt} \geq con_d^{min} \end{aligned} \qquad \forall d \in D, t \in T: t \neq t^m \tag{15}$$

Constraint 4 provides courses to be placed in just one day. Constraint 5 makes sure courses occupy as many slots as needed. Constraint 6 relates the day and time slot decision given in constraints 4 and 5 for the courses with each other. Constraints 7 and 8 prevent a student group and teacher from having more than one course in one time slot, respectively. Constraint 9 avoids a group of students from having more than two courses in a day. Constraint 10 keeps the lunch break free. Constraint 11 avoids the courses of a student group from being consecutive in a day. Constraint group 12 allows courses that require more than one time slot to be placed consecutively. Constraint group 13 and 14 determine the maximum and the minimum number of courses of a student group on any given day, and in any given time slot, respectively. Constraint group 15 defines the maximum and the minimum number of connections per day in any time slot. Constraint groups 13, 14, and 15 together with the objective functions gain the efficiency of bounding the solution.

4. Implementation

As a solution approach, we have adopted the lexicographic method, which includes solving the objectives sequentially in cases where the objectives can be ranked in the order of importance. The tasks of the objectives can be briefly summarized as follows. $Z1$ and $Z2$ determine how many courses will be on which day and in which time slot. On the other hand, $Z3$ decides which course should be placed in which day and time slot taking into account the number of students of each course, to distribute the total number of students over time slots. In this case, $Z1$ and $Z2$ act as a guide for $Z3$. When the objectives are optimized simultaneously, $Z1$ and $Z2$ can not fulfill their guiding task, since $Z3$ will dominate the Pareto optimal solution. Therefore, $Z1$ and $Z2$ are solved together due to they are on the same scale, and then $Z3$ should be optimized as a single objective. It supports the ranking of objectives as $Z1 = Z2 > Z3$. The relationship of the objectives can be observed in Figure 1. Point A represents the solution that occurs when all objectives are optimized simultaneously, whilst point B shows the solution formed by optimizing Z1 + Z2 first and then Z3.

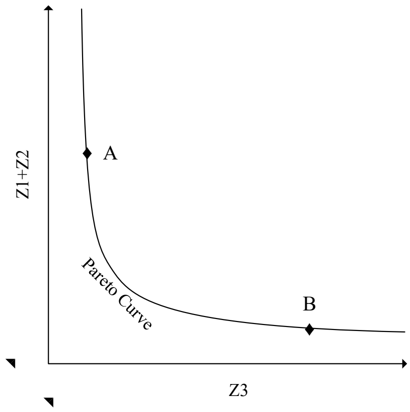

Figure 1. Positions of Objectives on the Pareto Curve

We run the model in the Python/Gurobi modeling environment on a 3,5 GHz i5-8250U processor and a 12 GB RAM. Our model includes 12084 decision variables and 15567 constraints. The solution of the model takes 1690 seconds (about 28 min). We benefited from two features of Gurobi in the implementation of the model. i) Ability to solve the objectives in multi-objective optimization models in the specified order. ii) Ability to handle quadratic constraints (see constraint 6).

We compared the automated timetable with the manual by two indicators: i) the distribution of the courses in the day and time slots, ii) the distribution of the number of students in the time slots. The base comparison metric is the standard deviation, and the smaller it means the better the distribution is.

Table 1. Distribution of Courses by Days

Automated									Manual								
		Days									Days						
Dep.	**Grade**	**1**	**2**	**3**	**4**	**5**	**Mean**	**Std. Dev.**	**Dep.**	**Grade**	**1**	**2**	**3**	**4**	**5**	**Mean**	**Std. Dev.**
1	1	1	2	2	1	1	1,4	0,490	1	1	3	1	1	2	0	1,4	1,020
1	2	1	1	2	2	1	1,4	0,490	1	2	1	2	2	1	1	1,4	0,490
1	3	1	1	2	2	1	1,4	0,490	1	3	1	3	2	1	0	1,4	1,020
1	4	1	1	2	1	1	1,2	0,400	1	4	0	0	1	3	2	1,2	1,166
2	1	1	2	1	1	2	1,4	0,490	2	1	2	1	2	1	1	1,4	0,490
2	2	1	1	2	2	2	1,6	0,490	2	2	3	2	1	0	2	1,6	1,020
2	3	2	2	2	1	1	1,6	0,490	2	3	3	2	1	1	1	1,6	0,800
2	4	1	1	1	1	2	1,2	0,400	2	4	2	0	0	0	4	1,2	1,600
3	1	2	2	1	1	2	1,6	0,490	3	1	3	1	1	3	0	1,6	1,200

3	2	1	2	2	2	2	1,8	0,400	3	2	3	2	2	2	0	1,8	0,980
3	3	2	1	2	1	1	1,4	0,490	3	3	3	2	0	2	0	1,4	1,200
3	4	1	1	1	1	1	1	0,000	3	4	0	2	2	0	1	1	0,894
4	1	2	2	2	1	1	1,6	0,490	4	1	2	2	2	2	0	1,6	0,800
4	2	2	1	2	1	2	1,6	0,490	4	2	3	1	2	1	1	1,6	0,800
4	3	2	2	1	2	2	1,8	0,400	4	3	1	1	2	3	2	1,8	0,748
4	4	2	2	2	1	2	1,8	0,400	4	4	0	1	2	3	3	1,8	1,166
5	1	1	1	2	1	1	1,2	0,400	5	1	2	2	0	1	1	1,2	0,748
5	2	1	1	2	1	2	1,4	0,490	5	2	1	2	2	1	1	1,4	0,490
5	3	1	1	2	1	1	1,2	0,400	5	3	2	1	1	1	1	1,2	0,400
5	4	0	1	1	1	1	0,8	0,400	5	4	0	1	1	1	1	0,8	0,400
6	1	1	2	1	2	1	1,4	0,490	6	1	2	2	1	2	0	1,4	0,800
6	2	1	2	1	2	2	1,6	0,490	6	2	2	0	2	2	2	1,6	0,800
6	3	1	2	1	1	2	1,4	0,490	6	3	2	1	1	2	1	1,4	0,490
6	4	1	1	1	2	1	1,2	0,400	6	4	0	1	1	2	2	1,2	0,748
7	1	1	2	1	1	2	1,4	0,490	7	1	2	2	1	2	0	1,4	0,800
7	2	1	2	2	2	1	1,6	0,490	7	2	2	0	2	2	2	1,6	0,800
7	3	2	1	1	1	2	1,4	0,490	7	3	2	1	1	2	1	1,4	0,490
7	4	2	1	1	1	1	1,2	0,400	7	4	0	1	1	2	2	1,2	0,748
						Mean	**1,414**	**0,440**							**Mean**	**1,414**	**0,825**

Table 2. Distribution of Courses by Time Slots

Automated												**Manuel**											
		Time Slots												**Time Slots**									
Dep.	**Grade**	**1**	**2**	**3**	**4**	**6**	**7**	**8**	**9**	**Mean**	**Std. Dev.**	**Dep.**	**Grade**	**1**	**2**	**3**	**4**	**6**	**7**	**8**	**9**	**Mean**	**Std. Dev.**
1	1	0	0	2	2	1	2	2	2	1,4	0,857	1	1	0	2	1	2	2	0	2	2	1,4	0,857
1	2	1	2	2	1	2	1	1	2	1,5	0,500	1	2	0	0	2	2	2	2	2	2	1,5	0,866
1	3	2	0	0	1	2	1	2	1	1,1	0,781	1	3	0	0	1	1	3	2	2	0	1,1	1,053
1	4	1	1	1	1	1	1	1	0	0,9	0,331	1	4	0	2	1	1	0	1	2	0	0,9	0,781
2	1	1	2	1	1	2	2	1	1	1,4	0,484	2	1	1	2	2	0	2	2	2	0	1,4	0,857
2	2	1	1	1	2	0	1	2	2	1,3	0,661	2	2	0	1	2	2	0	0	3	2	1,3	1,090
2	3	2	1	1	0	2	0	1	2	1,1	0,781	2	3	0	1	1	2	2	2	1	0	1,1	0,781
2	4	1	1	1	1	0	1	0	1	0,8	0,433	2	4	0	2	0	2	0	1	0	1	0,8	0,829
3	1	2	2	1	0	2	1	1	2	1,4	0,696	3	1	0	2	1	2	2	2	1	0	1,3	0,829
3	2	1	1	2	0	1	1	2	1	1,1	0,599	3	2	1	1	2	0	0	1	2	2	1,1	0,781
3	3	2	2	1	2	1	1	0	1	1,3	0,661	3	3	2	2	3	0	0	1	1	1	1,3	0,968
3	4	1	0	1	1	1	1	1	1	0,9	0,331	3	4	1	0	1	1	1	1	1	1	0,9	0,331
4	1	1	2	1	1	2	2	1	1	1,4	0,484	4	1	0	2	2	1	2	2	2	0	1,4	0,857
4	2	2	1	1	1	1	0	2	1	1,1	0,599	4	2	2	2	0	0	2	1	2	0	1,1	0,927
4	3	1	1	2	2	2	2	0	1	1,4	0,696	4	3	0	2	2	2	2	2	0	1	1,4	0,857
4	4	1	2	0	2	1	1	1	2	1,3	0,661	4	4	1	2	0	2	1	1	1	2	1,3	0,661
5	1	1	1	2	1	0	1	2	1	1,1	0,599	5	1	2	0	2	0	0	2	2	1	1,1	0,927
5	2	1	1	1	1	1	1	1	1	1,0	0,000	5	2	1	2	0	1	1	1	2	0	1,0	0,707
5	3	0	1	2	2	1	1	1	1	1,1	0,599	5	3	0	2	2	2	0	0	2	1	1,1	0,927
5	4	1	0	0	1	1	1	0	0	0,5	0,500	5	4	2	0	0	0	1	1	0	0	0,5	0,707

6	1	0	0	2	2	1	2	1	2	1,3	0,829	6	1	0	0	2	2	2	2	0	2	1,3	0,968
6	2	2	2	2	2	0	1	1	2	1,5	0,707	6	2	2	2	2	2	0	0	2	2	1,5	0,866
6	3	1	1	1	1	1	1	1	1	1,0	0,000	6	3	1	1	1	1	1	1	1	1	1,0	0,000
6	4	1	1	1	1	1	1	1	1	1,0	0,000	6	4	1	1	1	1	1	1	1	1	1,0	0,000
7	1	1	1	1	1	1	2	2	1	1,3	0,433	7	1	0	2	1	0	2	2	2	1	1,3	0,829
7	2	1	2	2	2	2	1	1	1	1,5	0,500	7	2	1	2	2	2	2	1	2	0	1,5	0,707
7	3	1	1	1	1	1	1	1	1	1,0	0,000	7	3	0	1	2	1	1	0	2	1	1,0	0,707
7	4	1	1	1	1	1	1	1	1	1,0	0,000	7	4	1	1	1	0	0	1	2	2	1,0	0,707
									Mean	**1,156**	**0,490**										**Mean**	**1,152**	**0,763**

Table 3. Distribution of Time Slots Allocated to Departments

	Automated Time Slots									
Dep.	**1**	**2**	**3**	**4**	**6**	**7**	**8**	**9**	**Mean**	**Std. Dev**
1	4	3	5	5	6	5	6	5	**4,9**	**0,927**
2	5	5	4	4	4	4	4	6	**4,5**	**0,707**
3	6	5	5	3	5	4	4	5	**4,6**	**0,857**
4	5	6	4	6	6	5	4	5	**5,1**	**0,781**
5	3	3	5	5	3	4	4	3	**3,8**	**0,829**
6	4	4	6	6	3	5	4	6	**4,8**	**1,090**
7	4	5	5	5	5	5	5	4	**4,8**	**0,433**
Mean	**4,4**	**4,4**	**4,9**	**4,9**	**4,6**	**4,6**	**4,4**	**4,9**		
Std. Dev	**0,904**	**1,050**	**0,639**	**0,990**	**1,178**	**0,495**	**0,728**	**0,990**		

	Manuel Time Slots									
Dep.	**1**	**2**	**3**	**4**	**6**	**7**	**8**	**9**	**Mean**	**Std. Dev**
1	0	4	5	6	7	5	8	4	**4,9**	**2,260**
2	1	6	5	6	4	5	6	3	**4,5**	**1,658**
3	4	5	7	3	3	5	5	4	**4,5**	**1,225**
4	3	8	4	5	7	6	5	3	**5,1**	**1,691**
5	5	4	4	3	2	4	6	2	**3,8**	**1,299**
6	4	4	6	6	4	4	4	6	**4,8**	**0,968**
7	2	6	6	3	5	4	8	4	**4,8**	**1,785**
Mean	**2,7**	**5,3**	**5,3**	**4,6**	**4,6**	**4,7**	**6,0**	**3,7**		
Std. Dev	**1,666**	**1,385**	**1,030**	**1,400**	**1,761**	**0,700**	**1,414**	**1,161**		

Tables 1 and 2 present the distribution of the courses of each grade of each department in automated and manual timetabling by day and time slot. Table 3 shows the distribution of time slots allocated to the departments in automated and manual timetabling. When the rows in three tables are examined one by one, it is seen that generally, the automated timetable has a lower deviation, and a few of them show equal deviations. There is only one example where the manual timetable shows less deviation with a small margin, which is the distribution of time slots allocated to department 6 in table 3 (highlighted in gray). The finding from the comparison is that automated timetabling can distribute courses more equitably than manual timetabling. Achieving a similar result is difficult with a decentralized and manual approach. Optimization of Z1 and Z2 with a centralized approach realizes fair allocation of resources to stakeholders.

Table 4. Distribution of the # of Students by Days and Time Slots

				Automated							
				Time Slots							
Days	**1**	**2**	**3**	**4**	**6**	**7**	**8**	**9**	**Sum**	**Mean**	**Std. Dev.**
1	390	400	390	400	395	400	390	390	3155	**394,4**	**4,635**
2	405	405	410	410	405	405	405	405	3250	**406,3**	**2,165**
3	470	470	475	465	466	480	465	480	3771	**471,4**	**5,872**
4	390	400	390	395	390	395	405	405	3170	**396,3**	**5,995**
5	375	375	375	376	380	375	380	380	3016	**377,0**	**2,345**
Sum	2030	2050	2040	2046	2036	2055	2045	2060	16362		
				Manuel							
				Time Slots							
Days	**1**	**2**	**3**	**4**	**6**	**7**	**8**	**9**	**Sum**	**Mean**	**Std. Dev.**
1	276	538	541	437	456	484	613	338	3684	**460,4**	**103,520**
2	233	425	431	351	373	397	512	268	2992	**374,0**	**84,409**
3	223	454	484	365	417	409	514	273	3139	**392,4**	**94,484**
4	352	562	535	435	503	484	619	350	3840	**480,0**	**89,989**
5	205	395	359	321	342	342	437	305	2707	**338,4**	**63,936**
Sum	1290	2374	2350	1909	2092	2117	2695	1535	16362		

Table 4 shows the distribution of students by days and time slots. While the maximum number of students in a time slot is 480 in the automated timetable, it is 619 in the manual timetable (highlighted in yellow). Automation has reduced the connection load by 22% during the peak time slot. This means that the technical problems that may arise during the peak time slot are significantly reduced. On the other hand, the deviation in a time slot for each day is low in automated timetabling compared to manual timetabling. This also means that idle capacity is reduced and is making efficient use of bandwidth.

5. Conclusion

This study handles the adaptation of the education system, which has affected the Covid-19 pandemic, to new conditions. Institutions with sufficient infrastructure to ensure social distance and self-isolation and the continuity of education have switched to a synchronous private online. The course and exam timetabling, which is one of the important tasks of the education system, has also been adapted to online education conditions. The new conditions have introduced the "bandwidth" constraint that requires a central point of view. This constraint can be explained as follows. Overlapping of many events in the same time slot increases the number of instant connections and this causes many technical problems. Bandwidth, which is difficult to express with exact numbers such as seating capacity, limits the number of instantaneous connections. Events in a day should be spread over time slots to use the bandwidth effectively. However, while ensuring this, it is necessary to make sure that time slots are allocated fairly between departments.

In this study, we propose a multi-objective mathematical model, which adopts a min-max approach to the mentioned course-timetabling problem. Objectives can be addressed under two headings: the fair allocation of time slots to the departments and the distribution of the daily total connections over time slots. The ordered relationship between objectives requires solving the model sequentially. The model has been tested with the real data of a faculty for the fall semester 2020-2021. Results were compared with a decentralized and manually prepared timetable.

The findings show that automated timetabling can better distribute courses around the day and time slot axis than the manual timetable. In addition, the maximum load in the peak time slot was reduced by 22%. Centralized automated planning allows the institution to use its resources more effectively, minimize idle capacity, and minimize technical problems that may occur during events. Although the study deals with the course timetabling in online education conditions, the same approach can be adopted for the exam-timetabling problem. Overlapping exams that require numerous students to be online can cause many problems due to bandwidth, and undoubtedly connection problems can aggrieve many students. Again, with the effect of the pandemic, the planning of sessions in many online academic activities such as congresses and symposiums can be evaluated within this framework. The total number of connections in parallel sessions can be balanced by taking the session preferences they want to attend from the participants. On the other hand, the results can be compared by modeling the problem as goal programming. In this way, important outputs can be obtained that appeal to different managerial perspectives.

As the study's main limitation, it can be shown that the constraints such as student and teacher preferences that exist in the literature are not included. Due to the nature of our case, many constraints do not exist, but different institutions may have more complex rules. In such cases, since the complexity of the mathematical model will increase, the optimal solution may not be obtained in a reasonable time. And also for relatively larger problems, it may be necessary to resort to heuristic solution methods.

Conflicts of Interest

The authors declared that there is no conflict of interest.

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