Application of Integer Programming in University Course Scheduling System

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Abstract: *Course scheduling is a crucial component of teaching management in higher education institutions. A reasonable course scheduling system is directly related to the efficient utilization of teaching resources and the improvement of students' learning outcomes. This paper constructs an integer programming model for the multi-resource allocation problem in course scheduling systems and solves the model via MATLAB programming, thus obtaining an optimal course scheduling scheme. Under the premise of strictly abiding by various teaching requirements, the model can realize the optimal allocation of teaching resources and the scientific planning of course scheduling, providing feasible methodological support for the intelligent upgrading and decision-making of university course scheduling systems.*

Keywords: *University Course Scheduling System; Linear Programming; Integer Programming*

1. Introduction

Course scheduling is a complex and critical task in university teaching management.. From the perspective of mathematical modeling, this is not a simple administrative scheduling problem, but a typical, high-dimensional combinatorial optimization problem[1]. This paper takes integer programming theory as the core to construct a mathematical model for the university course scheduling system. University course scheduling is far from being a simple arrangement of course time slots. Essentially, it is a complex combinatorial allocation problem involving multiple dimensions of limited resources such as teachers, courses, time, and classrooms[2]. Its core objective is to formulate a course scheduling scheme that integrates feasibility, rationality and optimality through the optimal scheduling and collaborative allocation of resources under multiple constraints[3].

2. Problem Description and Analysis

Taking the third-semester course scheduling for the major of Information and Computing Science as an example, the theoretical courses of this major are currently arranged in Classrooms 1 to 10 in the teaching area, among which Classrooms 8 and 9 are designated as computer labs, and the playground is numbered as Classroom 10. A total of 10 courses are scheduled for this semester, including Mathematical Analysis, Discrete Mathematics, Probability Theory and Mathematical Statistics, MATLAB Programming, Data Structures and Algorithms, Matrix Analysis, College Physics, Introduction to Mao Zedong Thought, College Physical Education and College English. The weekly class hours of each course are shown in Table 1.

Table 1 Weekly Class Hours of Courses

Course Name	Weekly class hours
Mathematical Analysis	3
Discrete Mathematics	2
Probability Theory and Mathematical Statistics	2
College Physics	2
Introduction to Mao Zedong Thought	2
MATLAB Programming	2
Data Structures and Algorithms	2
College English	1
College Physical Education	1
Matrix Analysis	1

Each of the 10 courses is taught by a dedicated teacher, with one teacher responsible for only one course in this semester. The time slots and classrooms assigned to each course must be free of conflicts, and all courses must complete the required weekly class hours as scheduled. To ensure learning and teaching efficiency, the same course can only be arranged once a day. Theoretical courses are not allowed to be scheduled on the playground, which is the exclusive venue for College Physical Education. Meanwhile, MATLAB programming and college English courses require computer-based teaching and must be arranged in computer labs. Since students have higher concentration and more flexible thinking in the morning, which is more suitable for attending theoretical courses in science, the three professional basic courses of mathematical analysis, discrete mathematics, and probability theory and mathematical statistics are arranged in the morning. At the same time, to balance the courses requiring 2 class hours, they are arranged every other day. In order to meet the weekly class hours of all courses, we try not to arrange the first class in the afternoon and evening classes. Based on the above analysis, we design the course scheduling system.

Essentially, the course scheduling problem falls under the category of resource assignment optimization. Its core logic involves embedding various preset constraints into the system model and achieving optimal allocation of teaching resources through combinatorial optimization algorithms [4]. The specific constraints are divided into hard constraints and soft constraints as follows.

2.1 Hard constraints

a: To ensure all courses can be completed by the end of the semester, the weekly class hours of each course are clearly specified, and all courses must meet the specified weekly class hour requirements.

b: At most one course can be arranged in a specific classroom during a given time period to avoid scheduling conflicts.

c: A designated course can only be arranged in one classroom during a specific time period to prevent classroom scheduling conflicts.

d: When a specific course is taught in a designated classroom, it can only be scheduled in one time slot to avoid time slot conflicts.

e: On any given day, the same course should not be scheduled more than once.

2.2 Soft constraints

a: The playground is exclusively for College Physical Education classes.

b: College Physical Education classes cannot be held during the fifth period.

c: Mathematical Analysis, Discrete Mathematics and Probability Theory and Mathematical Statistics are arranged in the first and second morning periods.

d: Courses with 2 or more weekly class hours are scheduled on alternate days.

e: No classes are scheduled for the fifth period on Friday.

f: Computer labs are exclusively for MATLAB Programming and College English classes.

g: Introduction to Mao Zedong Thought is scheduled in the afternoon, specifically in the third or fourth period.

h: College English cannot be arranged in the first class.

After determining the hard and soft constraints, it is necessary to establish an integer programming model for the course scheduling system of higher education institutions.

3. Model Assumptions and Symbol Definitions

3.1 Model Assumptions

a: Disregarding the impact of holidays on course scheduling, it is assumed that the teaching week is continuous.

b: Assuming there are no classes on Saturdays and Sundays, classes are only scheduled on weekdays.

c: Assuming that the scheduled classes fully comply with the timetable and there are no special reasons for class adjustments.

d: Suppose a teacher only teaches one course this semester.

e: Assuming that the two classes, Class 231 and Class 232, who have accepted the course schedule, will have the same courses this semester, and the two classes will be combined for classes.

f: Assuming there are 10 available classrooms, the designated purposes of the classrooms are as follows:

Due to the diverse types of courses, classrooms of different sizes and equipped with various facilities are set up to meet the curriculum needs and are numbered for easy distinction. Mathematical Analysis, Discrete Mathematics, and Probability and Mathematical Statistics are three professional basic courses, with only two classes from the Information Science major attending them together. A classroom of moderate size is sufficient, and the classroom numbers are set as follows r_1, r_2, r_3 . Considering classroom size and distance, the classroom numbers for Data Structures and Algorithms and Matrix Analysis are set as follows r_4, r_5 . University Physics and Introduction to Mao Zedong Thought are two public compulsory courses, which are attended by students from other majors in addition to the Information Science major. Due to their large class sizes, large classrooms are required. Assuming that the Information Science major takes priority in classroom arrangement and other influences are not considered, the classroom numbers for these two courses are set as follows r_6, r_7 . College English and MATLAB Programming require classes in computer labs, and the classroom numbers are set as follows r_8, r_9 . Due to the curriculum requirements, College Physical Education classes must be held on the playground, and the classroom number is set as follows r_{10} .

g: Assuming that the school teaching time slots and the number of classes per day remain unchanged, the weekly class schedule is as follows 5 days in total, from Monday to Friday; 5 classes per day, with 2 classes in the morning, 2 classes in the afternoon, and 1 class in the evening. The weekly class schedule is as follows 8:30-10:00, 10:20-11:50, 13:30-15:00, 15:20-16:50, 18:30-20:00, with 5 classes per week.

3.2 Set and Symbol Descriptions

a: Course collection $T = \{t_i\}, t_i = i, i \in \{1, 2, 3, \ldots 10\}$;

b: Teachers gather $L = \{l_i\}, l_i = i, i \in \{1, 2, 3, \ldots 10\}$;

c: Gather at a specific time each day $S=\{s_{\mathrm{j}}\}, s_j=j, j\in\{1,2,3,4,5\}$;

d: Collection of weekly days $D=\{d_i\}, d_i=i, i\in\{1,2,3,4,5\}$;

e: Collection of time periods $DS=\{d_i s_j\}, i\in\{1,2,...,5\}, j\in\{1,2,...,5\}$;

f: Collection of classrooms $R=\{r_i\}, r_i=i, i\in\{1,2,3,...,10\}$,where classroom 10 serves as the playground;

g: $x_{t_i,\mathrm{d}_i\mathrm{s}_j,r_i}$ Indicate r_i whether the course is scheduled $d_i s_j$ in the r_i during the specified classroom;

h: During the specifiedclassroom $C=\{C_1,C_2\}$;

i: n_{t_i} Indicate the t_i number of class periods per week for the ith course.

Table 2 Course Code Table

Course Code	Course Name	teacher
t_1	Mathematical Analysis	l_1
t_2	Discrete Mathematics	l_2
t_3	Probability Theory and Mathematical Statistics	l_3
t_4	University Physics	l_4
t_5	Introduction to Mao Zedong Thought	l_5
t_6	MATLAB programming	l_6
t_7	Data Structures and Algorithms	l_7
t_8	College English	l_8
t_9	College Physical Education	l_9
t_{10}	Matrix Analysis	l_{10}

4. Model establishment

4.1 Decision variables

$$x_{t,ds,r}=\begin{cases}0 & Course\ t\ is\ not\ scheduled\ in\ classroom\ r\ during\ time\ period\ ds\\ 1 & Course\ t\ is\ scheduled\ in\ classroom\ r\ during\ time\ period\ ds\end{cases}$$

$t\in T, ds\in DS, r\in R.$

4.2 Objective Function

$$Min\sum_{t_i=1}^{10}\sum_{d_i=1}^{5}\sum_{r_i=1}^{10}(x_{t_i,d_3,r_i}+x_{t_i,d_5,r_i})\quad t_i\in T, d_i\in D, r_i\in R.$$

Objective Function Explanation. Combining the optimization requirements of teaching effectiveness, the objective function is set to minimize the number of courses scheduled for the third and fifth classes in the weekday schedule. That is, during the scheduling process, priority is given to arranging courses in the first, the second, and the fourth class periods. By solving this objective function to obtain the optimal scheduling solution, it is possible to reduce students' class schedules during periods prone to fatigue, thereby improving overall learning efficiency.

4.3 Constraint Conditions

4.3.1 Hard constraints

$$\sum_{d_i=1}^{5}\sum_{s_j=1}^{5}\sum_{r_i=1}^{10}x_{t_i,d_is_j,r_i}=n_{t_i},\ t_i\in T, \tag{4.1}$$

$$\sum_{t_i=1}^{10}x_{t_i,d_is_j,r_i}\le 1,\ d_is_j\in DS, r_i\in R, \tag{4.2}$$

$$\sum_{r_i=1}^{10}x_{t_i,d_is_j,r_i}\le 1,\ t_i\in T, d_is_j\in DS, \tag{4.3}$$

$$\sum_{t_i=1}^{10}\sum_{r_j=1}^{10}x_{t_i,d_is_j,r_i}\le 1,\ d_is_j\in DS, \tag{4.4}$$

$$\sum_{s_j=1}^{5}\sum_{r_i=1}^{10}x_{t_i,d_is_j,r_i}\le 1,\ t_i\in T, d_i\in D. \tag{4.5}$$

Expression (4.1) represents the number of courses that students in this major are required to complete within this semester, as well as the number of classes per week that must meet the requirements of the training program and school regulations. Expression (4.2) indicates that to prevent scheduling conflicts, only one course is arranged to be taught in a designated classroom during a specific time period. Expression (4.3) states that within the teaching time slots of the schedule, a specific course can only be arranged in one classroom to avoid classroom scheduling conflicts. Expression (4.4) signifies that when a course is taught in a specific classroom, it can only be scheduled during a certain time period to prevent scheduling conflicts in terms of time. Expression (4.5) means that when scheduling on any working day, a course that has already been arranged for that day can only be scheduled once and must not be repeatedly scheduled.

4.3.2 Soft constraints

$$x_{t_9,d_is_j,10}=1,\ d_is_j\in DS, \tag{4.6}$$

$$x_{9,d_is_j,r_i}=1, d_i\in\{1,2,...,5\}, s_j\notin\{5\}, r_i\in\{10\}, \tag{4.7}$$

$$x_{t_i,d_is_j,r_i}=0, t_i\in\{1,2,3\}, s_j\in\{3,4,5\}, d_i\in D, r_i\in R, \tag{4.8}$$

$$x_{t_i,d_is_j,r_i}\cdot x_{t_i,(d_{i+1}s_j),r_i}=0, t_i\in\{1,2,3,...,7\}, d_i\in\{1,2,3,4\}, s_j\in S, r_i\in R, \text{ and } x_{t_i,d_is_j,r_i}\neq x_{t_i,d_{i+1}s_j,r_i}, \tag{4.9}$$

$$x_{t_i,d_5s_5,r_i}=0, t_i\in T, r_i\in R, \tag{4.10}$$

$$x_{t_i,d_is_j,r_i}=1, t_i\in\{6,8\}, d_is_j\in DS, r_i\in\{8,9\}, \tag{4.11}$$

$$x_{t_5,d_is_j,r_i}=1, s_i\in\{3,4\}, d_i\in D, r_i\in R, \tag{4.12}$$

$$x_{t_8,d_is_j,r_i}=0, s_j=1, d_i\in D, r_i\in R. \tag{4.13}$$

Expression (4.6) indicates that only physical education classes can be arranged on the playground, and other courses must not be arranged there; expression (4.7) indicates that College Physical Education classes must not be arranged in the fifth class period; expression (4.8) indicates that the three professional basic courses, namely Mathematical Analysis, Discrete Mathematics, and Probability and Mathematical Statistics, should be arranged in the first and second class periods in the morning; expression (4.9) indicates that if a course has two or more class periods within a week, it should be arranged on alternate days within the week, with the same course not being arranged on consecutive days; expression (4.10) indicates that no classes should be arranged in the fifth class period on Friday; expression (4.11) indicates that only courses such as MATLAB Programming and College English should be taught in the computer room, while others should be normally arranged in classrooms or on the playground; expression (4.12) indicates that Introduction to Mao Zedong Thought should only be arranged in the third or fourth class periods, and according to the research and analysis of this topic, it should be preferentially arranged in the fourth class period; expression (4.13) indicates that College English should not be arranged in the first class period within the scheduled class periods.

5. Result Presentation and Analysis

The established integer programming model is solved by the following MATLAB program.

```
C=10;D=5;P=5;R=10;U=10;
Hours=[3 2 2 2 2 2 2 1 1 1];
teacherOf=1:10;
courseNames=["Mathematical
Analysis","Discrete
Mathematics","Probability Theory and
Mathematical Statistics","University
Physics","Introduction to Mao Ze dong
Thought","MATLAB
Programming","Data Structure and
Algorithm","College
English","University Sports","Matrix
Analysis"];
nX=C*D*P*R; nY=C*R; n=nX+nY;
f=zeros(n,1);
intcon=1:n;
lb=zeros(n,1); ub=ones(n,1);
A=[]; b=[]; Aeq=[]; beq=[];
idx=@(c,d,p,r) sub2ind([C D P
R],c,d,p,r);
idy=@(c,r) nX + sub2ind([C R], c, r);
for c=1:C
row=zeros(1,n);
for d=1:D
for p=1:P
for r=1:R
```

```
row(idx(c,d,p,r))=1;
end
end
end
Aeq=[Aeq;row];beq=[beq;Hours(c)];
end
for c=1:C
for d=1:D
row=zeros(1,n);
for p=1:P
for r=1:R
row(idx(c,d,p,r))=1;
end
end
A=[A;row];b=[b;1];
end
end
for d=1:D
for p=1:P
row=zeros(1,n);
for r=1:R
for c=1:C
row(idx(c,d,p,r))=1;
end
end
A=[A;row]; b=[b;1];
end
end
for d=1:D
for p=1:P
for u=1:U
row=zeros(1,n);
for c=1:C
if teacherOf(c)==u
for r=1:R
row(idx(c,d,p,r))=1;
end
end
end
A=[A;row];b=[b;1];
end
end
end
for c=1:7
for d=1:D-1
row=zeros(1,n);
for p=1:P
for r=1:R
row(idx(c,d,p,r))=1;
row(idx(c,d+1,p,r))=row(idx(c,d+1,p,r))
+1;
end
end
A=[A;row]; b=[b;1];
end
end
for r=1:R
row=zeros(1,n);
for c=1:C
row(idx(c,5,5,r))=1;
end
Aeq=[Aeq;row];beq=[beq;0];
end
for d=1:D
for r=1:R
A=[A;zeros(1,n)]; b=[b;0];
A(end,idx(9,d,5,r))=1;
end
```

```
end
for d=1:D
for r=1:R
A=[A;zeros(1,n)]; b=[b;0];
A(end,idx(8,d,1,r))=1;
end
end
for d=1:D
for p=[1 2 5]
for r=1:R
A=[A;zeros(1,n)]; b=[b;0];
A(end,idx(5,d,p,r))=1;
end
end
end
for d=1:D
for p=3:5
for r=1:R
for c=[1 2 3]
A=[A;zeros(1,n)]; b=[b;0];
A(end,idx(c,d,p,r))=1;
end
end
end
end
for d=1:D
for p=1:P
for r=[8 9]
for c=setdiff(1:C,[6 8])
A=[A;zeros(1,n)]; b=[b;0];
A(end,idx(c,d,p,r))=1;
end
end
end
end
for d=1:D
for p=1:P
for r=setdiff(1:R,[8 9])
for c=[6 8]
A=[A;zeros(1,n)]; b=[b;0];
A(end,idx(c,d,p,r))=1;
end
end
end
end
for d=1:D
for p=1:P
for r=10
for c=setdiff(1:C,9)
A=[A;zeros(1,n)]; b=[b;0];
A(end,idx(c,d,p,r))=1;
end
end
end
end
for d=1:D
for p=1:P
for r=setdiff(1:R,10)
A=[A;zeros(1,n)]; b=[b;0];
A(end,idx(9,d,p,r))=1;
end
end
end
for c=1:C
for r=1:R
row=zeros(1,n);
for d=1:D
for p=1:P
```

```
row(idx(c,d,p,r))=1;
end
end
row(idy(c,r))=-Hours(c);
A=[A;row]; b=[b;0];
end
end
eligible=[1 2 3 4 5 7 10];
for k=1:numel(eligible)
c=eligible(k);
row=zeros(1,n);
for r=setdiff(1:R,[8 9 10])
row(idy(c,r))=-1;
end
A=[A;row]; b=[b;-2];
end
roomCap=4;
for r=setdiff(1:R,[8 9 10])
row=zeros(1,n);
for d=1:D
for p=1:P
for c=1:C
row(idx(c,d,p,r))=1;
end
end
end
A=[A;row]; b=[b;roomCap];
end
options=optimoptions('intlinprog','Displ
ay','iter','RelativeGapTolerance',1e-4,'Ma
xTime',300);
[xfull,~,exitflag]=intlinprog(f,intcon,A,b,
Aeq,beq,lb,ub,options);
if exitflag<=0
disp('No feasible schedule');return;
end
x=xfull(1:nX);
y=xfull(nX+1:end);
X=reshape(x,[C D P R]);
days=["Mon","Tue","Wed","Thu","Fri"];
for d=1:D
fprintf('Day %s:\n',days(d));
for p=1:P
printed=false;
for r=1:R
c=find(X(:,d,p,r)>0.5,1);
if ~isempty(c)
fprintf(' Period %d: %s in R%d
(T%d)\n',p,courseNames(c),r,c);
printed=true;
break;
end
end
if ~printed
fprintf(' Period %d: Free\n',p);
end
end
end
```

The optimal course scheduling scheme is obtained based on the optimal solution, as shown in Table 3.

Table3 Optimal Course Schedule

Time period	Monday	Tuesday	Wednesday	Thursday	Friday
Section 1	Mathematical Analysis r_1	Probability Theory and Mathematical Statistics r_3	Free	Discrete Mathematics r_2	Probability Theory and Mathematical Statistics r_3
Section 2	MATLAB Programming r_9	Discrete Mathematics r_2	Mathematical Analysis r_1	Free	Mathematical Analysis r_1
Section 3	University Physics r_6	Matrix Analysis r_5	University Sports r_{10}	Free	Introduction to Mao Ze dong Thought r_7
Section 4	College English r_8	Introduction to Mao Ze dong Thought r_7	Free	Data Structure and Algorithm r_4	University Physics r_6
Section 5	Data Structure and Algorithm r_4	Free	MATLAB Programming r_9	Free	Free

Rational arrangement of core courses: Professional basic courses are prioritized in the morning schedule. Mathematical Analysis is arranged in the first and second morning periods for two of its weekly class hours, and Discrete Mathematics and Probability Theory and Mathematical Statistics are also mainly scheduled in the morning. This is consistent with the teaching principle of arranging core theoretical courses during students' cognitive peak, which helps improve learning efficiency.

Standardized use of teaching venues: College Physical Education is strictly arranged on the playground and does not occupy the morning or evening periods of core theoretical courses; MATLAB Programming and College English are exclusively held in computer labs, which meets the practical operation and computer-aided teaching requirements of the two courses.

Balanced curriculum distribution: Most courses (especially those with weekly class hours $\geqslant 2$) are arranged on alternate days, avoiding excessive concentration of courses on a single day, reducing students' learning burden and facilitating their knowledge digestion and review.

Humanized scheduling design: No courses are arranged in the fifth period on Fridays, reserving time for students to hold class meetings or conduct independent learning, which reflects the integration of curriculum optimization and student-oriented teaching management.

6. Conclusion

Aiming at the complexity of multi-resource allocation and the diversity of constraints in university course scheduling systems, this paper establishes a course scheduling optimization model based on integer programming. By reasonably setting hard and soft constraints, and comprehensively considering multiple dimensions such as teachers, courses, classrooms, and time, the model is solved using MATLAB programming software to obtain a feasible optimal course scheduling plan. The scheme effectively avoids resource conflicts in the scheduling process, improves the efficiency of teaching resource utilization and the rationality of course arrangement, and provides a scientific mathematical method and practical reference for the intelligent construction of university teaching management.

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