Developing and Implementing Classroom Optimization Model

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Abstract

Scheduling optimization is vital to use resources (classroom) optimally in many organizations. In this research, a model has been developed which maximizes the rate of classroom usage and minimizes the underutilization of the classroom in a short time. The classroom scheduling consists of teachers, the number of students, and classrooms into a fixed set of periods. An optimal schedule could be defined as where no student, teacher, or classroom is utilized more than once at any given period which is defined as penalty here. A model has been developed based on this concept using integer linear programming where the penalty has been minimized. During the development of this model, some basic and local requirements have been considered. After developing the model, it has been solved in two different ways. The model has been solved through iteration which has been done manually. A software has been also made based on those requirements. A complete class schedule has been presented as an output in the software. The classroom utilization has been optimized at a large scale where the percentage utilization increases from 33.33% to 66.66%.

Keywords
Optimization, Scheduling, Integer linear programming, Iteration

1. Introduction

Scheduling is creating a reliable execution of tasks pre-planned for an individual or an entire industrial system. Timetabling is a tough nut to crack as it belongs to the larger area of scheduling and can be defined as daily schedules of class routines, railroads, etc. In these problems type the timeslot, representing the interval needed to perform tasks, is known in advance. Therefore, reducing the schedule length is not generally the main goal, and however other criteria are proposed to estimate the schedule quality. In these schedules, the main goal is to maximize the usage of the resources. The problem of scheduling university courses is defined by the distribution of courses over the five working days of each week for several time periods and the complexity of the classes and their needs. The development of a university schedule to fulfill all the needs meets a wide range of variabilities, including a very critical and extremely difficult job for professors and students. The schedules are manually designed and this is a long-term method because a scheduler has to deal with limitations.

Generally, the classroom assignment problem formulation is to try to assign a set of classes into a collection of rooms. An expenditure is computed for all possible allocation of the classes to the rooms by using basic quality control and allows each time period to be modeled as a unique and individual assignment problem, where polynomial time can be used for resolving (Carter & Tovey, 1992). This is similar to determine a maximum weighted bipartite matching between the set of classes and the set of rooms (Lach & Lu¨bbecke, 2008).

One of the areas of combinatorial optimization is a timetabling problem where many well-known techniques of the computer science fields and the operation research has been approached. Varied surveys on course timetabling (Carter & Laporte, 1998) and automated timetabling (Schaerf, 1999), like others on more specific aspects of the problem, this work has been systematically documented, thus sorting the different categories of the problem and solutions to the solution.

Within the layout, all the classrooms are under the university's register office and have several requirements. Educational timetable issues are aimed at seeking a suitable assignment of courses to the time periods and the rooms, meeting external conditions relevant to the optimization of the classroom.

In this research, a model is proposed that can optimize the unwanted time slot for the teacher and the class and also increase the utilization of the classroom. Some requirements are considered and formulated into integer programming which turns out to be a mathematical model. From the university register office which course will be taken by which faculty member in which room in which time period will be fixed.

The proposed model may be used for any department operating in the described way. Here each constraint is considered as a condition and solves our model manually through iteration. But this is almost impossible to solve the problem manually because it is complicated and time-consuming. So a software is developed using this condition which is less time consuming and more effective than the manual way.

1.1. Objectives

The main purpose of this research is to maximize the rate of infrastructure usage and minimize the inefficiency of the classroom in a short time.

2. Review of Similar Works and State-of-the-art

Educational institution’s classrooms are generally underutilized due to lack of proper planning and less organized class schedules. In an institution, the implementation of such planning is time-consuming and much complicated. These problems address the root structure of the classroom underutilization problem that causes the institution to build up many classrooms and create unnecessary infrastructures that are expensive to maintain. Optimization on such a problem where the number of classrooms to maintain the total curriculum structure intact is calculated and the classes are well distributed throughout the classrooms to ensure the minimum utilized classroom number to lessen the maintenance and operating cost of them.

Three steps such as section number, assigning a faculty member to different sections and schedules of the sections into time slots and classrooms are investigated and congregated in scheduling and decision support system by Z. Houhamdi Et Al (2019) (Houhamdi, et al., n.d.).

The issue of the university schedule is understood as the system of assigning university classes to various time periods from more than five working days of the week and determining the adequacy of the classrooms for the number of students enrolled and the parameters of each course. There really are three main steps here, in practice. Firstly, each department determines the lecturers and the allocation of courses according to their abilities and experience. The coordinating load is considered in this phase, based on the policy of the department. The second stage is that the department must decide the date and time of study on that day based on the availability of the lecturer and the students. Finally, in the third phase, the scheduler must collect all the data from each department to allocate all the courses to suitable classrooms (Thongsanit, 2014).

For a comprehensive survey of formulations and approaches cutting-edge, the reader to the surveys by (Bardadym, 1995), (Burke, et al., 2003), (Carter, 2001), (Petrovic & Burke, 2004) and (Burke & Trick, 2004) are referred.
The solution of the scheduling problem needs a man-machine involvement as seen on Mulvey (Mulvey , 1982). Although this is a major area of concern, the management science/operations research literature has received little systematic attention. Mulvey 's work was to expand the faculty/course scheduling problem-solution strategy, as explained in Dyer and Mulvey (Dyer & Mulvey, n.d.) to include the classroom/time assignment model. In that work of Dyer and Mulvey, They have developed, implemented, and used an integrated data system to assist in the allocation and allocation of faculty resources to the academic department.

Their work, according to them is a natural extension of previous work (Geoffrion, et al., 1972), where they stated that one of the most common difficulties obstructing the successful application of mathematical programming techniques to real problems is the presence of multiple criteria. If there are only two criteria, a widely accepted method is to measure the relevant portion of the tradeoff graph in criterion space analytically and allow the decision-maker to choose the point he favors most (Geoffrion, et al., 1972). Multiple criteria in mathematical programming were also stated by (Johnsen, 1968) and (Roy, November 1971).

In addition to the mathematical model, several authors separate specifications into two main categories; the hard ones included in the constraints and specifying the search space, and the soft ones shown in the objective function in some manner. (Geoffrion, 1970).

A similar scenario for a timetabling issue for universities is solved in (Aubin & Ferland, 1989) by clustering sub-problems. A solving approach for a similar scenario, however with schedules of different lengths is stated in (Ferland & Roy, 1985); in this formulation system classes may last for several periods.

The challenges that the NP-hard class can solve with traditional optimization methods, such as backtracking, restriction logic programming, or evolutionary computation (Grobner, 2003), (Rudova, 2003). Such strategies minimize the overall penalty for breaches of constraints and provide possible, but not optimal solutions (Ghaemi, et al., 2007). Nowadays stochastic techniques have been engaged using genetic algorithms (GAs) to face the scheduling and allocation issue using tabu search in GSA (Sait, et al., 1996) and a force manipulated crossover in GABIND (Mandal, et al., 2000).

In recent years, there have been huge advancements in computer software and hardware. And thus, integer programming and MIP formulations have instead started to be an effective solution to several combinatorial problems (Grobner, 2003). New inventions in information systems, increased tranquility of robust software and the ability to solve relatively large problems in a remarkably short time are the main reasons for making this conventional modeling approach appealing for the solution of practical problems. Two decades ago, the problems solvable by modern IP techniques retained tens of variable decimal, often group-and-bound. Now an issue at special occasions with many thousands or even millions of binary variables is not really an issue. In regards with the scheduling problems, IP models have been described in (Rudova, 2003) for the university timetabling problem and in (Sait, et al., 1996), (Mandal, et al., 2000) For the problem of school scheduling; the solutions developed with business software posed no exact computation of time problems.

3. Methods Towards Development of Model and Software

The classroom scheduling timetable consists of teachers, the number of students, and classrooms into a fixed set of periods. An optimal schedule could be defined as where no student, teacher, or classroom is utilized more than once at any given period which can be defined as penalty. A model is developed based on this concept where we minimize the penalty. During the development of the model, some basic requirements and some local requirements are considered which are discussed here.

Basic Requirements:

- For each course, fixed hours per week must be scheduled (e.g. considered courses with 3 credit hours.)
- Each class is limited to be present one course at a time.
- Each teacher is limited to be present one course at a time.
- Each room is limited to host one course at a time.

Local Requirements:

- All courses scheduled for any class of the day should be in the same room.
- All courses must be allocated either in the morning session or in the afternoon session for each class.
- Empty time between two courses is not allowed for each class.
- The availability of rooms in those special time slots.
- The availability of the teacher in the specific time slots.
- Maximizing the satisfaction degree of the teachers.

After developing the model, it is solved in two different ways. Using trial and error method the model is solved through iteration Which is done manually.

A software is also made based on the model. In the software, Teacher information, Teacher preferences according to their seniority, Number of weekly hours for each course, etc are used as input. Finally, the complete class schedule will be presented as output by the software.

4. Modeling the University Timetabling Optimization Problem

A mathematical model and a software is developed based on the requirements. The mathematical model constructs a timetable in the optimal way and increases the utilization of classrooms and the software develops a routine based on the model. The models are as follows:

4.1. Mathematical Model: Optimizing Classrooms Considering Various Constraints

In this section, some notations which are used in the model are introduced:
Let,
R = A group of rooms {1, …, r}.
C = A group of courses {1, …, c}.
n_c = Number of hours scheduled for teaching per week.
$n_{c_{min}}$ and $n_{c_{max}}$ gradually, the minimum and the maximum number of daily teaching hours.
T = A set of time periods {1, …, t}. (50 minutes, all are the same length)
D = The days of a week available for teaching {1, …, d}. A day d is divided into two sessions. t_m and t_{af} respectively, morning session and afternoon session.
A = A set of teachers {1, …, a}. For any $a \in A$, $C_a \subset C$ is the subset of courses taken by the teacher *a*.
k_a = Maximum amount of weekly teaching days allowed for the teacher *a.*
S = A set of classes (a group of students following the same course) {1, …, s}. The class *s* should attend $C_s \subset C$ course.
k_s = Maximum amount of daily teaching hours allowed for any class *s.*
P_{ct} = If the course *c* is allocated at the time period *t,* a penalty will occur. Generally P_{ct} measures the "undesirability" of time period *t* for teacher *a* and class *s*.
k_p = Maximum amount of teaching hours a course can hold daily.

Here, the problem requirements are discussed in detail:

i. The sum of the penalties means all the undesirability should be minimized, i.e., the satisfaction degree of the teachers and also increase the utilization of the classroom is aimed to maximize.
ii. Each course $c \in C$: n_c hours a week must be allocated.
iii. Each room $r \in R$: at time $t \in T$ in room *r* more than one course cannot be hosted.
iv. Each teacher $a \in A$: at time $t \in T$ more than one course cannot be taught by the teacher *a.*
v. Each class $s \in S$: at time $t \in T$ more than one course cannot be attended by class *s*.
vi. A teacher $a \in A$ in a week cannot work more than k_a days.
vii. More than k_s teaching hours in a day cannot be attended by any class.
viii. "Consecutive" timetable should be arranged for each class, vacancy between any of the two courses is not allowed.
ix. If a course $c \in C$ is allocated in day $d \in D$, it must take between $n_{c_{min}}$ and $n_{c_{max}}$ hours.
x. All hours of a course $c \in C$ scheduled in a day $d \in D$ must be fixed in the same room $r \in R$.
xi. A day *d* is divided between two sessions (morning session and afternoon sessions). In the day *d* all the courses of a class *s* must be allocated either in the morning session or in the afternoon session.

Now an integer programming formulation is defined for the classroom optimization problem. Three binary variables are introduced here:
x_{ctr} = 1, if course $c \in C$ at time $t \in T$ is allocated in room $r \in R$, x_{ctr} = 0 otherwise;
y_{cd} = 1, if course $c \in C$ is ascertained to the day $d \in D$, otherwise 0;
z_{ds} = 1, if $d \in D$ is a teaching day for teacher $s \in S$, otherwise 0.

With these variables, the formulation meets all the requirements. The formulation is:

Objective function,

$$\text{Minimization,} \quad \sum_{c\in C}\sum_{t\in T} P_{ct} \sum_{r\in R} x_{ctr} \quad \ldots \quad (1)$$

Constraints,

$$\sum_{r\in R}\sum_{t\in T} x_{ctr} = n_c, c \in C \quad \ldots \quad (2)$$

$$\sum_{c\in C} x_{ctr} \le 1, \qquad r \in R, t \in T \quad \ldots \quad (3)$$

$$\sum_{c\in Ca}\sum_{r\in R} x_{ctr} \le 1, \qquad a \in A, t \in T \quad \ldots \quad (4)$$

$$\sum_{c\in Cs}\sum_{r\in R} x_{ctr} \le 1, \quad s \in S, t \in T \quad \ldots \quad (5)$$

$$\sum_{r\in R} x_{ctr} \le z_{ds}, \quad c \in C_a, s \in S, d \in D, t_m \le t < t_{m+1} \quad \ldots \quad (6)$$

$$\sum_{d\in D} z_{ds} \le k_a, \quad \text{a} \in \text{A} \quad \ldots \quad (7)$$

$$\sum_{c\in C_s}\sum_{r\in R}\sum_{t_m\le t<t_{m+1}} x_{ctr} \le k_s, \qquad s \in S, d \in D \quad \ldots \quad (8)$$

$$\sum_{c\in C_s}\sum_{r\in R} (x_{ct_1r} - x_{ct_2r} + x_{ct_3r}) \le 1, \quad s \in S, d \in D \quad \ldots \quad (9)$$

$$\sum_{r\in R}\sum_{t_m\le t<t_{m+1}} x_{ctr} \ge n_{c_{min}}\, y_{cd}, c \in C, d \in D, t_m \le t_1 < t_2 < t_3 < t_{m+1} \quad \ldots \quad (10)$$

$$\sum_{r\in R}\sum_{t_m\le t<t_{m+1}} x_{ctr} \ge n_{c_{max}}\, y_{cd}, \quad c \in C, d \in D, t_m \le t_1 < t_2 < t_{m+1} \quad \ldots \quad (11)$$

$$x_{ct_1r_1} - x_{ct_2r_2} \le 1, \qquad c \in C,\ 1 \le r_1 < r_2 \le r,\ d \in D \quad \ldots \quad (12)$$

$$\sum_{r\in R} x_{c_1t_1r} + \sum_{r\in R} x_{c_2t_2r} \le 1, s \in S, c_1, c_2 \in C_s, c_1 \ne c2, d \in D, t_m \le t_1 < t_{af} \le t_2 < t_{m+1} \quad \ldots \quad (13)$$

$$\sum_{c\in C}\sum_{r\in R} k_p = 1 \quad \ldots \quad (14)$$

Objective function (1), the sum of penalties means all the undesirability is minimized and the utilization of the classroom is increased (requirement i). Constraints (2), n_c is the amount of weekly hours for each course c (requirement ii). Constraints (3), a room at time t cannot host more than one course *c* (requirement iii). Constraints (4), only one course is allowed to teach by a teacher at time period *t* (requirement iv). Constraints (5), only one course is allowed to attend by a class *s* course at time period *t* (requirement v). Constraints (6) and (7), a teacher's limitation of working days in a week (requirement vi). Constraints (8), maximum k_s number of daily teaching hours should be attended by a class *s* (requirement vii). Constraints (9), empty period between two courses for any class *s* are not allowed (requirement viii). Constraints (10) and (11), if a course *c* is allocated in day *d*, it must be arranged between $n_{c_{max}}$and $n_{c_{min}}$ hours (requirement ix). Constraints (12), all hours of a course *c* arranged in a day should be allocated in the room *r* (requirement x). Constraints (13), a class *s* should attend courses either in the morning session or in the afternoon session (requirement xi). Constraint (14), the amount of teaching hours of a course a class can take in each day. For better understanding, assuming dummy values of 2 classrooms for 2 classes who will take 2 courses each. The courses are of 3 credit hours weekly in a week of 5 working days. Every class will attend 2 courses daily at max. A classroom is available for 3 credit hours daily. Teachers are assumed to be uniquely assigned to courses. By considering these values, a cluster of the table is made in the appendix thus a routine is formed.

5. Result & Discussion

On the Software, classroom utilization is optimized at a large scale. For assumed values, the results are as follows. Here, 4 classes having 5 courses each is considered. Each course is of 3 credit hours per week holding 5 working days. A current scenario of 4 classrooms having 9 credit hours to be occupied each day that results into a total of 180 teaching hours per week. So, the optimization model results into a 50% increment of classroom utilization.

Table 1. Present & Current Scenario of Classroom utilization

Criteria	Previous Scenario	Current Scenario
Number of classrooms needed	4	2
Total teaching hours per weak	180	90
Occupied teaching hours per weak	60	60
Unoccupied teaching hours per weak	120	30
Percentage utilization	33.33%	66.66%

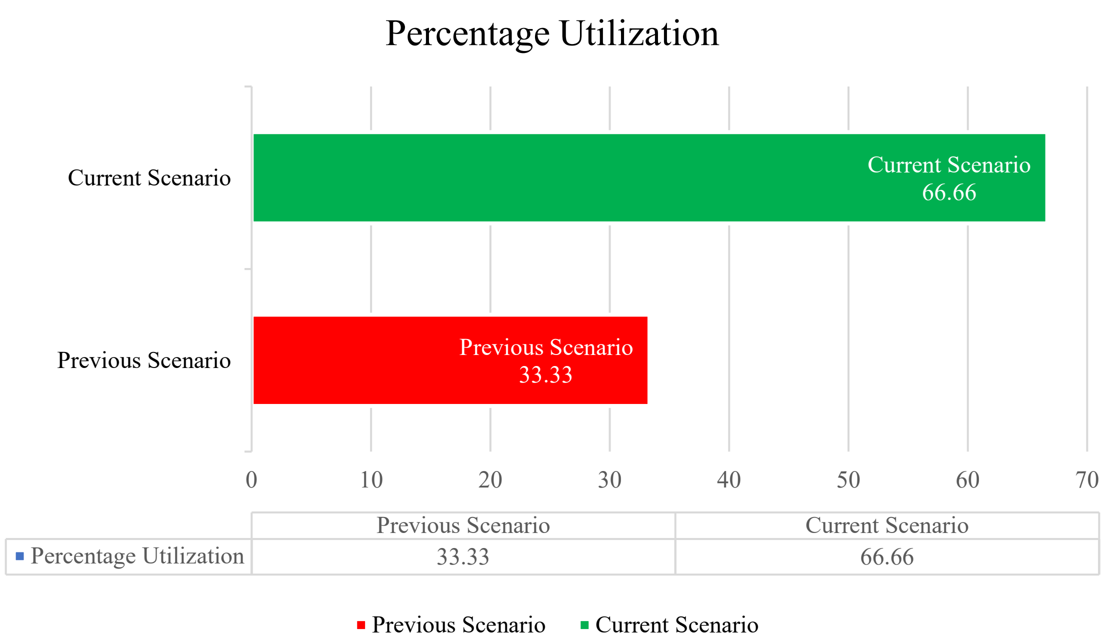

Figure 1. Graphical Representation of increased Classroom Utilization

Classroom assignment and the optimization problem is a difficult one and complex. To the best of our knowing, this is the first time that an optimized timetable will develop by the model and the model is solved manually and through a software where all the constraints are considered as conditions. Due to complexity few considerations had to be sacrificed which are as follow:

- Those who are lower-grade students require large classrooms as they are large in quantities, on the other hand those who are higher-level students require small classrooms as they are small in quantities.
- All the attributes of the classroom such as natural air passing system, types of light, number of fans, etc.
- Cost optimization of the university.
- And mainly distance. (When the classrooms are far away from one another, the faculty members may have to travel a long distance which is not minimized here.)

By this model, an optimized timetable will be developed in which there is no undesirability of time periods for the teachers and students. Solving this model using software makes it more effective and less time-consuming.

7. Conclusion

There are also some requirements which aren't considered due to shortage of time and a higher degree of complexity as classroom assignment and optimization problem is considered as hard one. More complex multi-target optimization approaches will be developed in the future that enables us to explore the interdependencies between targets in greater detail. Advanced integer programming techniques will be developed to use the framework of the most complex problems. The room attribute (e.g. room is either air-conditioned or not, projector facility is available or not) and also the room capacity will also be considered in the future. The developed software will be improved more sophisticatedly using the model which can easily construct a time schedule for a university course in an optimized way. A model that will minimize the distance travel by the faculty members (e.g. when classrooms are far away from one another) will be developed.

Authors Credit Statement

Dr. Azizur Rahman: Supervision, Validation; **Ahnaf Tahmid:** Conceptualization, Formal analysis, Investigation, Methodology, Visualization, Roles/Writing – Original draft, Writing – review & editing; **Mohammad Farhan Akif:** Conceptualization, Project administration, Software, Roles/Writing – Original draft.

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