Developing Classroom Optimization Model with Integer Programming

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DECLARATION

This is to certify that project work entitled “Developing classroom optimization model with Integer programming has been carried out by Ahnaf Tahmid and Mohammad Farhan Akif in the department of Industrial Engineering and Management, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above project work or any part of this work has not been submitted anywhere for the award of any degree.

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ABSTRACT

Scheduling is a very important part of modern industrialization and civilization. This is creating a time-oriented pre-plan that helps any person to plan their working time efficiently. In education sector like schools, colleges and universities do also use scheduling to make their class routines. In this research, the optimization of classroom is done without proposing new length of classes but only packing the classrooms with course classes throughout their available periods. After doing that, the schedule is being optimized again to be more efficient. This time the factor considered is the distance of the classrooms from the office of the faculties. Here, three classrooms are considered and optimization suggests only one having shortest path. This paper states the steps of creating the constraints of the mathematical model in brief.

Key Words: Optimization, Integer Linear Programming, Increasing Utilization, Cutting plane, Weighted bipartite matching.

CONTENTS

CHAPTER I

1.0 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 utilization of the resources. The university timetabling problem is defined as the process of assigning courses to specific time periods throughout the five working days of the week and to specify classrooms suitability for a class and the requirements of each course. The construction of a timetable of a university that satisfies all the needs, at the same time fulfill many requirements of the faculty members and the students which are very important as well as extremely difficult task. The timetables are prepared manually which is a high time-consuming process since a scheduler has to concern limitations.

The most effective formulation of the classroom assignment problem tries to find an optimum assignment for a set of classes (or *events*) to a set of rooms. A simple measure of quality may also be used, where a cost is assigned for all possible event to-room assignments. This system allows each time period to be modeled as a unique and independent assignment problem, which can be solved in polynomial time [1]. This is equivalent to finding a maximum weighted bipartite matching between the set of events and the set of rooms [2].

The timetabling problem, like many others in the area of combinatorial optimization, has been approached by several well-known techniques of the operational research and the computer science fields. Several surveys on course timetabling [3] and automated timetabling [4], as well as others on more focused aspects of the problem, have managed to record this work in a systematic way, categorizing thus the different variations of the problem and solution approaches.

In our models, all the classrooms are under the register's office of the university and considers many requirements. A set of courses, a set of teachers. A set of courses, a set of rooms, a set of classes (i.e. group of students attending the same course), a set of teachers, a set of time periods, Educational timetabling problems aim at finding a feasible assignment of courses to rooms and to time periods, satisfying additional constraints related to the classroom optimization (e.g. PASQUALE AVELLA and IGOR VASIL'EV, 2005).

In model – 1, we proposed a model that can optimize the undesirability of the time slot for the teacher and the class and also increase the utilization of the classroom. We consider some requirements and formulate them 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.

In model – 2, we proposed a model to minimize the total distance traveled by the faculty members from their office to classrooms. This model takes a pre-designed class schedule and provides the best classroom option to the faculty.

1.1 OBJECTIVES

The objectives of this project are:

a) To develop a model for optimizing the use of classrooms
b) To maximize the rate of infrastructure usage.
c) To ensure proper distribution of classroom according to the class schedule.
d) To minimize the inefficiency of the classroom in a short time.

CHAPTER II

2.0 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 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 scheduling of the sections into time slots and classrooms are investigated and congregated in scheduling and decision support system by Z. Houhamdi Et Al (2019) [5]. An interface will be built where courses, day, timeslot and classroom can be given as input.

The university timetabling problem is defined as the process of assigning university courses to specific time periods throughout the five working days of the week and to specify classrooms suitability for the number of registered students and the requirements of each course. In practice, here are three main steps. First, each department processes the lecturers and course assignment depending on their skills and experience. In this step, the balancing load is considered based on the department policy. The second step is that the department will specify the day and study period in that day based on the lecturer and students' availability. Finally, in the third step, all the information of each department will come together to the scheduler for assigning all courses to suitable classrooms. [6]

For a comprehensive survey of formulations and of state-of-the-art approaches, we refer the reader to the surveys by Bardadym (1996)[7], Burke, de Werra, and Kingston (2003)[8], Carter (1986, 2001)[9], Petrovic and Burke (2004)[10] and Burke and Trick (2004)[11].

The solution of the classroom/time scheduling problem requires man-machine interaction as seen on Mulvey [12]. While this is an important area of concern, it has received little formal attention in the management science/operations research literature. According to him, there may be many different criteria by which the solution to an ill-defined problem may be evaluated, many of which are not quantifiable.

The work of Mulvey was the expansion of the solution strategy of the faculty/course scheduling problem as described in Dyer and Mulvey [13] to include the classroom/time assignment model. In that work of Dyer and Mulvey, they did the formulation, implementation and actual use of an integrated information system to aid in the task of allocating and assigning faculty resources in an academic department.

Their work, according to them is a natural extension of previous work of Geoffrion, Dyer and Feinberg [14], 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. When there are only two criteria, a commonly accepted approach is to compute numerically the relevant portion of the tradeoff curve in criterion space and let the decision-maker select the point which he most prefers [14]. Multiple criteria in mathematical programming were also stated by Johnsen [15] and Roy [16].

Along with the mathematical formulation, several authors separate requirements into two main groups; the hard ones, which are included in the constraints and they define the search space, and the soft ones, which are included in some way in the objective function [17].

A similar strategy for a timetabling problem for universities is solved in [18] by clustering sub-problems. A solution approach for the same problem, however with schedules of different length is provided in [19]; in this formulation approach classes may last one, two or three periods.

On our point of view to address the underutilization problem of classrooms, the multi-criteria approach is not necessary to maximize the utilization instead a proper scheduling of classes can improve it. So further studying found out the presence of a computer software that can allocate the student and faculties to a vacant classroom according to their need. We will be proposing a new mathematical model that can integrate the scheduling of class to different classroom facilities and improvise the underutilization of classrooms.

2.1 MAIN PRINCIPLE IN OUR APPROACH

In recent years, there have been huge advancements in computer software and hardware. And thus, integer programming and MIP formulations have started being again an acceptable approach for many combinatorial problems [20]. The new inventions in information systems, the increased tranquility of reliable software and the ability to solve relatively large problems in a remarkable short time are the main reasons for making this traditional modeling approach attractive for the solution of realistic problems. Two decades back the problems that were solvable by classical IP techniques, mainly branch-and-bound, carried tens of integer variables. Now a problem with many thousands and on special occasions millions of binary variables is not necessarily a problem. In regards with the timetabling problems, IP models have been presented in [21] for the university timetabling problem and in [22,23] for the school timetabling problem; the solutions produced with commercial software presented no real problem in terms of computation times.

In the sections that follow, a university timetabling problem is modeled as an optimization problem using 0–1 binary variables. The model that we have developed first provides constraints for a large number of different rules and regulations that are found in academic environments. More specifically, the model succeeds in creating timetables that do not create collisions between courses, teachers and classrooms and they are complete from all aspects; moreover, it supports the scheduling of courses that require consecutive time periods, as well as courses that require sessions that are repeated several times to accommodate different groups of students.

In these models, we used basic integer programming formulation techniques so that we can use various solving software for further future uses. In these models at first, we considered the basic constraints that a classroom scheduling process can face by analyzing different classroom schedules. Thus, we used those observations to fabricate the constraint sets. The two developed models contain different point of views.

In the first model, we considered several constraints of classroom scheduling, considering the selection of senior teachers, In the second model we optimized the total distance traveled by a faculty to reach the assigned classroom from his/her office.

2.2 CHARACTERISTICS OF UNIVERSITY COURSE TIMETABLING

The university course timetabling problem has different special features that highly depend on the characteristics that the courses taught in a university have. Even the timetabling of different universities contains different given requirements.

2.2.1 Fundamental structure of university courses

A course offered by any department in the university may comprise of just lectures or work in a lab. The lectures are delivered by professors, lecturers or other teaching staff and they choose to carry out the weekly requirement in single or multi-period sessions. The number of periods for lectures is determined by the credit hours of a course. Occasionally two or more faculties may be assigned the lectures for a given course, in which case they have to decide the type of sharing for the teaching load.

Lab work is usually part of a given course or sometimes a course by itself and the group of students is split into several sub-groups for attending the labs. Lab work takes place in specially equipped classrooms and is assigned to the professor that teaches the lectures or to lab assistants. In our case we consider the labs to be of constant value that will not be a part of our integer programming model. While optimizing the distance, the lab rooms are also not considered as they do not have alternatives to choose between. So, the lab rooms are completely not considered.

2.2.2 Types of university courses

In universities, courses are characterized as either mandatory or optional. Mandatory courses are those that a given department considers as basic for the students. During lower-grade years, most courses are mandatory and the students do not get the chance to choose in between those. Therefore, they are designed for all students of the same year. On the contrary, optional courses are less in number, however, in the timetable, they should never overlap with any mandatory or other optional course.

Again, different courses are of different credit hours. For this, the courses need separate attention. The course credit hours determine the weekly number of periods needed for that course.

2.2.3. Resources availability

For the university timetabling problem resources refer to student, teachers and classrooms. Availability of human resources for teaching is defined by the people themselves. Duties of administrative nature consume a number of periods during the week from each individual in the faculties.

Availability of classrooms is defined by the system followed by the university. Some classrooms may be considered as available during all periods, some others might have limited availability. These factors are needed to be considered in scheduling classroom.

CHAPTER III

3.0 MODELING THE UNIVERSITY TIMETABLING OPTIMIZATION PROBLEM

We developed two models. First one constructs a timetable in the optimize way and increases the utilization of classrooms and the second one minimizes the total distance traveled by the faculty member from their office. The models are as follows:

3.0.1 Model – 1: Optimizing classrooms considering various constraints

1. In this section, we introduce some notations which are used in our model:

Let,

R = A set of rooms {1, …, r}.

C = A set of courses {1, …, c}. n_c = Number of teaching hours scheduled per week. n^c_{max} and

n^c_{min} respectfully, the maximum and minimum daily number of teaching hours.

T = A set of time periods {1, …, t}. (50 minutes, all are the same length)

D = The teaching days of the week {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 taught by teacher

a. k_a = Maximum weekly number of teaching days allowed for the teacher a.

S = A set of classes (group of students attending the same course) {1, …, s}. $C_s \subset C$ is the courses that the class s should attend.

k_s = Maximum daily number of teaching hours allowed for any class s.

P_{ct} = A penalty occurring if the course c is scheduled at the time t. Usually P_{ct} measures the "undesirability" of time slot t for teacher a and class s.

2. Here, we discuss the problem requirements in detail:

i. The sum of the penalties should be minimized, i.e., we aim to maximize the satisfaction degree of the
teachers and also increase the utilization of classroom.

ii. Each course $c \in C$: n_c hours a week must be scheduled.

iii. Each room $r \in R$: room r cannot host more than one course at time $t \in T$.

iv. Each teacher $a \in A$: teacher a cannot teach more than one course at time $t \in T$.

v. Each class $s \in S$: class s cannot attend more than one course at time $t \in T$.

vi. A teacher $a \in A$ cannot work more than k_a days a week.

vii. No class can attend more than k_s teaching hours a day.

viii. The timetable should be "consecutive" for each class, empty periods between any two courses are not allowed.

ix. If a course $c \in C$ is scheduled in day $d \in D$, it should take between $n^c{}_{min}$ and $n^c{}_{max}$ hours.

x. All the hours of a course $c \in C$ scheduled in a day $d \in D$ should be located in the same room $r \in R$.

xi. We divided a day d between two sessions (morning and afternoon sessions). All the courses of a class s in the day d must be scheduled either in the morning or in the afternoon session.

3. Now we define a integer programming formulation for classroom optimization problem. We introduce
three binary variables:

x_{ctr} = 1, if course $c \in C$ at time $t \in T$ is scheduled in room $r \in R$, x_{crt} = 0 otherwise;

y_{cd} = 1, if course $c \in C$ is assigned to the day $d \in D$, 0 otherwise;

z_{ds} = 1, if $d \in D$ is a teaching day for teacher $s \in S$, 0 otherwise.

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

Objective function,

$$Minimization, \sum_{c \in C} \sum_{t \in T} Pct \sum_{r \in R} x\,ctr \qquad (1)$$

Constraints,

$$\sum_{r \in R} \sum_{t \in T} x_{ctr} = nc, c \in C \qquad (2)$$

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

(4)
(5)

$$\sum_{c\in Ca}\sum_{r\in R} x_{ctr} \leq 1, a\in A, t\in T \qquad (6)$$

$$\sum_{c\in Cs}\sum_{r\in R} x_{ctr} \leq 1, s\in S, t\in T \qquad (7)$$

$$\sum_{r\in R} x_{ctr} \leq z\,ds, c\in Ca, s\in S, d\in D, tm \leq t < tm+1 \qquad (8)$$

$$\sum_{d\in D} z\,ds \leq k\,a, a\in A \qquad (9)$$

$$\sum_{c\in Cs}\sum_{r\in R}\sum_{t_m\leq t<t_{m+1}} x_{ctr} \leq k\,s, s\in S, d\in D$$

$$\sum_{c\in Cs}\sum_{r\in R}\left(x_{ct_1r} - x_{ct_2r} + x_{ct_3r}\right) \leq 1, s\in S, d\in D, \qquad (10)$$

$$\sum_{r\in R}\sum_{t_m\leq t<t_{m+1}} x_{ctr} \geq nc\,min\,y\,cd, c\in C, d\in D, t_m \leq t_1 < t_2 < t_3 < t_{m+1} \qquad (11)$$

$$\sum_{r\in R}\sum_{t_m\leq t<t_{m+1}} x_{ctr} \geq nc\,max\,y\,cd, c\in C, d\in D, t_m \leq t_1 < t_2 < t_{m+1} x_{ct_1r_1} - x_{ct_2r_2} \leq 1, \quad c\in C,\ 1\leq r_1 < r_2 \leq \qquad (12)$$

$$r, d\in D \qquad (13)$$

$$\sum_{r\in R} x_{c_1t_1r} + \sum_{r\in R} x_{c_2t_2r} \leq 1, s\in S, c_1, c_2 \in C_s, c_1 \neq c2, d\in D, t_m \leq t_1 < t_{af} \leq t_2 < t_{m+1}$$

Objective function (1), minimize the sum of penalties and increase the utilization of classroom (requirement i). Constraints (2), number of weekly hours for each course c is n_c (requirement ii). Constraints (3), a room at time t cannot host more than one course *c* (requirement iii). Constraints (4), a teacher cannot teach more than one course at time period *t* (requirement iv). Constraints (5), a class *s* cannot attend more than one course at time *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 a class *s* should attend (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 scheduled in day *d*, it should take between $n^c_{\ max}$ and $n^c_{\ min}$ hours (requirement ix). Constraints (12), all the hours of a course *c* scheduled in a day should be located in the room *r* (requirement x). Constraints (13), a class *s* should attend courses either in the morning or in the afternoon session (requirement xi).

3.0.2 Model – 2: A classroom assignment model that uses distance optimization

In this model, the university registrar's office commences the scheduling process by requesting course information from each department. Course information includes, among other details, the number of credits, the student capacity of the course, the faculty member's name, his/her preferred timeslot and three candidate classroom buildings with differing levels of priority. After receiving all the profiles, the registrar's office feeds the data into a software package, which then attempts to determine the best possible classroom for each course in one of its three preferred buildings and at its preferred timeslot while satisfying the following two hard constraints: (1) no classroom can hold more than one class at any time; and (2) no faculty member can teach more than one class at any time. Since the number of available classrooms is limited for each building and the software is not designed to manipulate the course characteristics, occasionally, the software may fail to generate a "feasible" room for some courses. When this happens, the staff at the registrar's office manually schedules these "infeasible" courses by requesting the department concerned to alter the course characteristics.

In this model, we recognize all the classes in two main categories, $\boldsymbol{a}$ and $\bar{\boldsymbol{a}}$. Those in set $\boldsymbol{a}$ are to be scheduled in general assignment rooms. A general assignment room is defined as a "university owned" room, which is open for use for everyone in the university. In addition to the university-owned rooms, there exist department owned rooms, such as laboratories, seminar rooms and design studios. Courses in set $\bar{\boldsymbol{a}}$ are those that must necessarily be scheduled in these department owned rooms, such as laboratories, seminar rooms and design studios. Since courses in set $\bar{\boldsymbol{a}}$ do not have alternative classrooms, the scheduling problem does not apply to them. Therefore, the main focus of our model is only to schedule the courses in set $\boldsymbol{a}$ to the general assignment rooms at the faculty members' preferred timeslots. It is thus considered that, assumed that the courses in set $\bar{\boldsymbol{a}}$ can be scheduled after a schedule for the courses in set $\boldsymbol{a}$ has been determined. Alternatively, hard constraints between the courses in sets $\boldsymbol{a}$ and $\bar{\boldsymbol{a}}$ can be included a priority, if needed.

Parameters:

Let,

I The set of all the courses in section $\boldsymbol{a}$

T The set of all timeslots for the courses in the set

I

Q The set of all classrooms

G The set of all faculty members

G_i The set of all faculty members who can teach course i

C_g The set of courses in I that can be taught by faculty member g

R_i The set of all candidate classrooms which can accommodate course i

P_j The set of all courses in set I which can be accommodated by classroom j

$d_{m,n}$ The distance between buildings m and n

BC_i The building code of the department, which offers course i

BR_j The building code of classroom j

$F_{x,1}$ The x^{th} set of courses, which can- not be scheduled simultaneously due to faculty member conflict or administrative requirements, $x \in \pi$, where π is the union of all these course sets (in I) that conflict with each other

Binary decision variables

$$y_{igkt} = \begin{cases} 1, \textit{if a course } i \textit{ is taught by faculty } g \textit{ is assigned room } k \in \textit{timeslot } t \text{ ¿ } 0, \textit{otherwise} \, (i,t) \in (I,T) \text{ ¿} \end{cases}$$

The mathematical programming formulation for problem P is as follows:

$$Minimize\, \theta = \sum_{i \in I} \sum_{g \in G} \sum_{k \in R} \sum_{t \in T} d_{BC_i, BR_k} \cdot y_{igkt}$$

Subject to,

$$\sum_{i \in P_k} \sum_{g \in G_i} y_{igkt} \leq 1, \forall k \in Q \wedge t \in T \qquad (1)$$

$$\sum_{g \in G} \sum_{k \in R} \sum_{t \in T} y_{igkt} = 1 \forall i \in I \qquad (2)$$

$$\sum_{i \in C_g} \sum_{k \in R_i} y_{igkt} \leq 1, \forall g \in G \wedge t \in T \qquad (3)$$

$$\sum_{k \in R_i} \sum_{t \in T} y_{igkt} = 1, \forall i \in C_g \wedge g \in G \qquad (4)$$

$$y_{igkt} = 0{,}1 \, \forall i \in I, g \in G_i, k \in R_i \wedge t \in T \qquad (5)$$

The objective θ, was chosen to minimize the total distance that faculty members have to travel from their offices to the classrooms, where the courses are scheduled. A timeslot in T is designated. Thus, a course in I ought to occupy only one timeslot. The constraint set (1) ensures that a classroom in a given timeslot can hold at most one class with at most one faculty member teaching it. Constraint set (2) indicates that every course in I must be assigned to only one combination of the faculty member required to teach it, a classroom capable of holding it and one timeslot in T. Constraint set (3) models the requirement that a faculty member in a given timeslot can teach at most one course in one of the classrooms capable of holding that course. Finally, constraint (4) guarantees that every pair of a faculty member and a course that the faculty member is required to teach is assigned only one combination of a classroom capable of holding the course and a timeslot. The binary nature of the $\boldsymbol{y}$ variables is captured by the constraint set (5).

CHAPTER IV

4.0 DISCUSSION

Here we presented an Integer linear programming formulation which developed our mathematical model. Classroom assignment and optimization problem is a hard one and complex. To the best of our knowledge, it is the first time that an optimized timetable will develop by model – 1 and the prepared timetable will use in the model – 2 for optimize the distance of faculty member’s office from the classrooms. Due to complexity few considerations had to be sacrificed which are as follow:

a) Lower-grade students are large audiences and requires auditoriums and higher-grade students are usually small audiences and require small classrooms.
b) All the attribute of the classroom such as natural air passing system, types of light, number of fans etc.
c) Distance of student hostels from the classrooms.
d) Cost optimization of university.

By this model, we can develop an optimized timetable in which there is no undesirability of time periods for the teachers and students. It also increases the utilization of classrooms and minimize the total distance travel by the faculty member from their office to classrooms.

CHAPTER V

5.0 CONCLUSION AND FUTURE DIRECTION

There are also some requirements which aren’t considered due to shortage of time. We are interested in implementing more sophisticated multi objective optimization methods, which will allow us to explore the trade-offs between objectives more fully. We are also trying to explore more advanced integer programming techniques to exploit the structure of the most difficult problems. We will consider the room attribute (e.g. room is either air conditioned or not, projector facility is available or not) and also the room capacity. We will develop an automated software using these models which can easily construct time schedule for university course in the optimized way.

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