

COURSE TIMETABLING AT A TUNISIAN UNIVERSITY: A CASE STUDY

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Abstract

This paper deals with the Course Timetabling Problem at an institution in a Tunisian University. We introduce a heuristic procedure to construct a feasible timetable for all lectures and tutorials taken by different groups of each sub-section of any section. We describe the timetabling problem using a list of all specific hard and soft constraints. We formulate the problem as a set of linear constraints using two sets of binary variables corresponding to lectures and tutorials, respectively. This heuristic is illustrated with real data for a sub-section of the Faculty of Economics and Management Sciences of Sfax in Tunisia, and the resulting timetables are compared with those generated manually. The results of another full section have confirmed the good quality of the proposed heuristic when compared with the hand made solution.

Keywords: Educational timetabling, integer programming, implementations, heuristic search

1. Introduction

The course timetabling problem has been extensively studied and solved with several approaches. This problem is to assign a timeslot to each activity (lecture, tutorial and practical work) of each course in an educational institution. Several different formulations of the problem exist since some specific constraints may differ from one institution to another. In this paper, we

give the formulation for the timetabling problem as specified for the Faculty of Economics and Management Sciences of Sfax in Tunisia. The course timetabling problem is a scheduling problem including both hard and soft constraints. The hard constraints have to be satisfied in order to have a feasible solution; however, the soft constraints are used to improve the quality of the feasible solution.

Different techniques are proposed to study this difficult problem. Graph colouring is one of the earliest procedures used to find a feasible solution for this type of problems. The vertices of the graph represent events and when there is a conflict between two events (common resource) the vertices are connected. De Werra is a pioneer in this field and has several papers dealing with timetabling solved via graph colouring. In his thesis (1969), De Werra used this approach to find a solution for the course timetabling problem. De Werra (1995) provided formulations with graph colouring for a set of class-teacher timetabling problems and discussed the complexity of this formulation. Recently, Timothy (2004) has used graph colouring to solve both course and exam timetabling problems.

Integer programming has been frequently used to formulate this problem, and good solutions have been generated in spite of the scale of this type of problems: Tripathy (1984) formulated the timetabling problem as large integer linear programming problem with zero-one variables. In order to reduce the scale of the problem, he used a grouping operation for a new definition of the variables. A Lagrangian relaxation technique combined with a branch and bound method is used to solve the original problem.

Daskalaki et al. (2004) propose a zero-one integer program formulation, similar to our real case. They include, in this formulation, constraints concerning a large number of various rules and regulations that are commonly encountered in academic institutions. The problem is solved using the CPLEX package, since the instances considered include only from

7 543 to 17 159 constraints and between 4 100 and 19 295 binary variables. Our real case is much bigger than their instance.

Ferland and Roy (1985) formulated the timetabling problem as assignment of activities to resources using a mathematical programming procedure. They decompose it into two sub-problems solved sequentially: the first concerns the scheduling of classes to periods and the second concerns the assignment of classes to classrooms. Aubin and Ferland (1989) developed a more general procedure dealing with large scale timetabling problems. They also decompose the problem into two sub-problems: the timetabling sub-problem and the grouping sub-problem. A heuristic approach was proposed to solve this problem by working simultaneously on the timetabling and the grouping sub-problems until a final solution is found and no improvement is possible. Al-Yakoob and Sherali (2006) consider the faculty-class assignment problem. Their goal was to minimize dissatisfaction among faculty members. They develop two mixed integer programs to assign faculty members to given classes and time slots. A specialized linear programming based heuristic is used when the commercial software package fails to solve the problem.

Some decision support systems have been developed for this problem, and they led to real world implementations in some institutions: Galssey and Mizrach (1986) formulated the problem of assigning classes to rooms as a large 0-1 integer program, and they used a fast heuristic which is embedded into a decision support system. This system was developed for the problem at the University of California at Berkley. Dinkel et al. (1989) solved the problem

of scheduling teacher to courses, to classrooms and to time slots using a network based decision support system approach. They tested their system at the college of business administration at Texas A & M University. Ferland and Fleurent (1994) developed a decision support system for course timetabling called SAPHIR. This system is flexible since the user can modify some parameters such as data on courses, instructors, rooms and students. This automatic system embeds the heuristic algorithm approaches developed in Aubin and Ferland (1989).

Burke et al. are the first authors to adapt the case-based reasoning to university timetabling problems. Burke et al. (2000) used case-based-reasoning (CBR) with attribute graphs to solve the course timetabling problems structurally. The main idea of this procedure is to exploit previous solutions of the same problem to find good quality solutions to the new problem. Burke et al. (2001) improved the structured case-based-reasoning approach for course timetabling problems developed in the previous paper to tackle an extended set of problems. Burke et al. (2002) developed a first version of a hyper-heuristic method using CBR to select the heuristic to use for solving course timetabling problems. They used knowledge discovery techniques to predict the best heuristic for the new problem on the basis of the previous knowledge. Burke et al. (2006a) investigated a case-based heuristic selection approach for the automation of both course and exam timetabling. They used knowledge discovery techniques to get the knowledge of problems modelling and compare cases to select heuristics and refine the case base. Burke et al. (2006b) tried to find a procedure to deal with large and complex

timetabling problems. They used multiple-retrieval approach to decompose the original problem into a set of sub-problems with sufficiently small size to be solved with simple procedures. Burke et al. (2007) investigated a hyper-heuristic framework in which both Tabu search and graph heuristic are used as general methods for solving a large spectrum of university timetabling problems.

The main objective of this paper is to construct a suitable heuristic that can find a feasible solution to the course timetabling problem for the entire faculty taking into account all hard and some soft constraints.

The paper is organized as follow. The problem for the Faculty of Economics and Management Sciences of Sfax in Tunisia is first described and then formulated in Sections 2 and 3, respectively. Then we introduce the Timetabling Heuristic Approach (THA) in Section 4. In Section 5, we introduce and analyze some numerical results obtained with the procedure. We also analyze the performance and the efficiency of the procedure by comparing the results with those obtained manually by the administrative personnel. Finally, concluding remarks and perspectives for future research are given in the conclusion.

2. Problem Description

In all institutions the Timetabling Problem has to be solved at least once each academic year. The administrative personnel spend much time and effort solving this problem. The Faculty of Economics and Management Sciences of Sfax includes several administrative entities called sections related to different disciplines. Currently, the administrative personnel have to prepare all

timetables of all the faculty sections. Our formulation considers all the sections simultaneously.

The students of each section are partitioned into sub-sets of student's called sub-sections. A sub-section of students is considered as an entity where all students follow the same curriculum. Now, the curriculum of each sub-section includes several courses where each course may include two types of activities: lectures and tutorials. Each lecture of a course is taught to the whole set of students belonging to the same sub-section. The set of students of each sub-section is partitioned into smaller groups of students that take tutorials together.

Dammak et al. (to appear in 2009) have developed a heuristic procedure called Lecture Timetabling Heuristic (LTH) to find a feasible solution for the sub-problem including only the lectures. It has been implemented and tested on real data of the Faculty of Economics and Management Sciences of Sfax. In this paper we extend the formulation to include both the lectures and the tutorials. This generalization induces an increased number of hard and soft constraints.

In our formulation, the week is partitioned into 30 time slots of 90 minutes (Table 1).

Monday, Tuesday, Thursday, and Friday includes 3 time slots in the morning and 3 in the afternoon, and Wednesday and Saturday includes only 3 time slots in the morning.

The following hard constraints are considered in our model:

1. All course activities (lectures and tutorials) included in the curriculum of each section must be taught.
2. No professor can teach more than one activity in any time slot.
3. No classroom can be used for more than one activity in any time slot.
4. No group can be taught more than one activity in any time slot.
5. No sub-section can take two lectures in two consecutive time slots.
6. Two lectures or two tutorials of the same course cannot be taught to the same sub-section during the same day.
7. No professor can teach three activities in three consecutive time slots.
8. No group can have successive activities in the third and fourth periods of Monday, Tuesday, Thursday or Friday.
9. No professor can teach successive activities in the third and fourth periods of Monday, Tuesday, Thursday, or Friday.

Table 1 30 timeslots of teaching in the faculty

Day / Hour	08:00-9:30	09:45-11:15	11:30-13:00	13:30-15:00	15:15-16:45	17:00-18:30
Monday						
Tuesday						
Wednesday						
Thursday						
Friday						
Saturday						

10. Each professor has a limited number of time slots in which activities (lecture or tutorial) has to be taught. Each professor has a limited duty according to his academic grade.

Note that these hard constraints include those (1 to 4) that are present in any feasible timetable and others (5 to 10) that help to obtain good quality timetables. The FEMSS timetabling problem has similar features to other institutions. Indeed, in the University of Sfax, there are at least four institutions which have a timetabling problem with similar features (i.e. same event duration and having some similar hard and soft constraints). Since the hard constraints numbered 5 to 10 are aimed at improving the quality of the timetabling problem, we expect that these institutions would appreciate the existence of these constraints in their timetabling problem.

The soft constraints which will be listed below are not included in the formulation of the problem in this paper.

11. The time preferences of professors should be satisfied as much as possible.
12. Try to maximize the seat occupation rate of the classrooms.
13. Minimize the number of free time slots (hole) between two consecutive activities for any group.
14. Try to maximize the number of free half day for all groups.
15. Try to minimize the number of half days having only one activity

3. Problem Formulation

In this section we formulate the course timetabling problem described in Section 2 as a set of linear constraints containing two sets of

binary variables associated with the lectures and the tutorials, respectively.

Notation

In order to complete the model formulation we require the following notation.

I : the number of sections in the faculty ($1 \leq i \leq I$)

J_i : the number of subsections of section i ($1 \leq j \leq J_i$)

G_{ij} : the number of groups in sub-section j ($1 \leq g \leq G_{ij}$)

K_i : the set of activities of the section i

T_i : The set of tutorials of section i .

$K_{i\ell}$: the sub-set of lectures of section i having ℓ sessions per week; $\ell = 1, 2$.

K_{it} : the sub-set of tutorials having t sessions per week; $t = 1, 2$

K_{i01} : the sub-set of tutorials without lecture and only one session per week.

K_{i02} : the sub-set of tutorials without lecture having double sessions per week.

$T_{i1} = K_{i01} \cup K_{i11} \cup K_{i21}$: the sub-set of tutorials of section i having one session per week

$T_{i2} = K_{i02} \cup K_{i12} \cup K_{i22}$: the sub-set of tutorials of section i having two sessions per week

H : the set of professors in the faculty.

H_i : the sub-set of professors teaching section i

H_{ik} : the sub-set of professors teaching lecture $k \in K_i$ for the section i

HT_{ik} : the sub-set of professors teaching tutorial $k \in T_i$ for the section i

KH_{ih} : the sub-set of lectures taught by professor h to section i

TH_{ih} : the sub-set of tutorials taught by professor h to section i

S : the number of classrooms available in the faculty ($1 \leq s \leq S$)

M : the number of time slots available in the week ($1 \leq m \leq M$)

n_{ikh} : the number of periods during the week that professor h has to teach the lecture $k \in K_{ih}$ for the section i .

r_{ikh} : the number of periods during the week that professor h has to teach the tutorial $k \in T_{ih}$ the section i .

In the Faculty of Economics and Management Sciences of Sfax, there are 30 time slots as illustrated in Table 1 that are coded in increasing order starting with the first period of Monday.

The binary variables are specified as follows:

$$X_{ijkhsm} = \begin{cases} 1 & \text{If the lecture } k \text{ is taught by} \\ & \text{professor } h \text{ in the classroom } s \\ & \text{during the time slot } m \text{ to} \\ & \text{the subsection } j \text{ of section } i \\ 0 & \text{Otherwise} \end{cases}$$

$$Y_{ijgkghsm} = \begin{cases} 1 & \text{If the tutorial } k \text{ is taught by} \\ & \text{professor } h \text{ in the classroom } s \\ & \text{during the timeslot } m \text{ to the group} \\ & \text{g of the subsection } j \text{ of section } i \\ 0 & \text{Otherwise} \end{cases}$$

Hard Constraints:

Using this notation, the hard constraints can be formulated as follows:

$$\sum_{s=1}^S \sum_{m=1}^M X_{ijkhsm} = Z_{ijkh}$$

$$\forall 1 \leq i \leq I, \forall 1 \leq j \leq J_i, \forall k \in K_{i1}, \forall h \in H_{ik} \quad (1)$$

$$\sum_{s=1}^S \sum_{m=1}^M X_{ijkhsm} = 2Z_{ijkh}$$

$$\forall 1 \leq i \leq I, \forall 1 \leq j \leq J_i, \forall k \in K_{i2}, \forall h \in H_{ik}$$

where

$$Z_{ijkh} = 0 \text{ or } 1$$

$$\forall 1 \leq i \leq I, \forall 1 \leq j \leq J_i, \forall k \in K_{i1} \cup K_{i2}, \forall h \in H_{ik},$$

and

$$\sum_{h \in H_{ik}} Z_{ijkh} = 1$$

$$\forall 1 \leq i \leq I, \forall 1 \leq j \leq J_i, \forall k \in K_{i1} \cup K_{i2},$$

$$Z_{ijkh} = \begin{cases} 1 & \text{If the professor } h \text{ has} \\ & \text{taught the lecture } k \text{ to} \\ & \text{sub-section } j \text{ of section } i \\ 0 & \text{Otherwise} \end{cases}$$

$$\sum_{s=1}^S \sum_{m=1}^M Y_{ijgkghsm} = Z_{ijgkh}$$

$$\forall 1 \leq i \leq I, \forall 1 \leq j \leq J_i, \forall 1 \leq g \leq G_j,$$

$$\forall k \in T_{i1}, \forall h \in HT_{ik}$$

$$\sum_{s=1}^S \sum_{m=1}^M Y_{ijgkghsm} = 2Z_{ijgkh}$$

$$\forall 1 \leq i \leq I, \forall 1 \leq j \leq J_i, \forall 1 \leq g \leq G_j$$

$$\forall k \in T_{i2}, \forall h \in HT_{ik}$$

where

$$Z_{ijgkh} = 0 \text{ or } 1 \quad \forall 1 \leq i \leq I, \forall 1 \leq j \leq J_i,$$

$$\forall 1 \leq g \leq G_j, \forall k \in T_{i1} \cup T_{i2}, \forall h \in HT_{ik}, \text{ and}$$

$$\sum_{h \in HT_{ik}} Z_{ijgkh} = 1 \quad \forall 1 \leq i \leq I, \forall 1 \leq j \leq J_i,$$

$$\forall 1 \leq g \leq G_j, \forall k \in T_{i1} \cup T_{i2}$$

$$Z_{ijgkh} = \begin{cases} 1 & \text{If the professor } h \text{ has taught} \\ & \text{the tutorial } k \text{ to the group } g \\ & \text{of sub-section } j \text{ of section } i \\ 0 & \text{Otherwise} \end{cases}$$

Constraints (1) ensure that all lectures and tutorials listed in the curriculum of each section are taught. Moreover, they also insure that the two lectures (the two tutorials) of a course for a sub-section (for a group) are taught by the same professor.

$$\sum_{i=1}^I \sum_{j=1}^{J_i} \sum_{k \in K_i} \sum_{s=1}^S X_{ijkhsm} + \sum_{i=1}^I \sum_{j=1}^{J_i} \sum_{g=1}^{G_j} \sum_{k \in T_i} \sum_{s=1}^S Y_{ijgkghsm} \leq 1$$

$$\forall h \in H, \forall 1 \leq m \leq M \quad (2)$$

Constraints (2) ensure that no professor is teaching more than one activity (lecture or tutorial) in any time slot.

$$\sum_{i=1}^I \sum_{j=1}^{J_i} \sum_{k \in K_i} \sum_{h \in H_{ik}} X_{ijkhsm} + \sum_{i=1}^I \sum_{j=1}^{J_i} \sum_{g=1}^{G_{ij}} \sum_{k \in T_i} \sum_{h \in HT_{ik}} Y_{ijgkhs} \leq 1$$

$$\forall 1 \leq s \leq S, \forall 1 \leq m \leq M \quad (3)$$

Constraints (3) ensure that no classroom is used for more than one activity in any time slot.

$$\sum_{k \in K_i} \sum_{h \in H_i} \sum_{s=1}^S X_{ijkhsm} + \sum_{k \in T_i} \sum_{h \in H_i} \sum_{s=1}^S Y_{ijgkhs} \leq 1$$

$$\forall 1 \leq i \leq I, \forall 1 \leq j \leq J_i, \forall 1 \leq g \leq G_{ij}, \forall 1 \leq m \leq M \quad (4)$$

Constraints (4) ensure that no group can be taught more than one activity in any time slot.

$$\sum_{k \in K_i} \sum_{h \in H_{ik}} \sum_{s=1}^S [X_{ijkhsm} + X_{ijkhs(m+1)}] \leq 1$$

$$\forall 1 \leq i \leq I, \forall 1 \leq j \leq J_i, \forall 1 \leq m \leq M - 1 \quad (5)$$

Constraints (5) ensure that no sub-section is taking two lectures in two consecutive timeslots.

$$\sum_{s=1}^S \sum_{m=p}^{p+5} X_{ijkhsm} \leq 1$$

$$\forall 1 \leq i \leq I, \forall 1 \leq j \leq J_i, \forall k \in K_{i2}, \forall h \in H_{ik}, \quad (6)$$

$p=1, 7, 16, 22$ for Monday, Tuesday, Thursday and Friday.

$$\sum_{s=1}^S \sum_{m=p}^{p+2} X_{ijkhsm} \leq 1$$

$$\forall 1 \leq i \leq I, \forall 1 \leq j \leq J_i, \forall k \in K_{i2}, \forall h \in H_{ik},$$

$p=13, 28$ for Wednesday and Saturday.

$$\sum_{s=1}^S \sum_{m=p}^{p+5} Y_{ijgkhs} \leq 1$$

$$\forall 1 \leq i \leq I, \forall 1 \leq j \leq J_i, \forall 1 \leq g \leq G_{ij}, \forall k \in T_{i2}, \forall h \in HT_{ik}$$

$p=1, 7, 16, 22$ for Monday, Tuesday, Thursday and Friday.

$$\sum_{s=1}^S \sum_{m=p}^{p+2} Y_{ijgkhs} \leq 1$$

$$\forall 1 \leq i \leq I, \forall 1 \leq j \leq J_i, \forall 1 \leq g \leq G_{ij}, \forall k \in T_{i2}, \forall h \in HT_{ik}$$

$p=13, 28$ for Wednesday and Saturday.

Constraints (6) ensure that two lectures or two tutorials of the same course are not taught to the same sub-section during the same day.

$$\sum_{i=1}^I \sum_{j=1}^{J_i} \sum_{k \in K_{ih}} \sum_{s=1}^S [X_{ijkhsm} + X_{ijkhs(m+1)} + X_{ijkhs(m+2)}]$$

$$+ \sum_{i=1}^I \sum_{j=1}^{J_i} \sum_{g=1}^{G_{ij}} \sum_{k \in T_{ih}} \sum_{s=1}^S [Y_{ijgkhs} + Y_{ijgkhs(m+1)} + Y_{ijgkhs(m+2)}] \leq 2$$

$$\forall h \in H, \forall 1 \leq m \leq 13 \quad (7)$$

$$\sum_{i=1}^I \sum_{j=1}^{J_i} \sum_{k \in K_{ih}} \sum_{s=1}^S [X_{ijkhsm} + X_{ijkhs(m+1)} + X_{ijkhs(m+2)}]$$

$$+ \sum_{i=1}^I \sum_{j=1}^{J_i} \sum_{g=1}^{G_{ij}} \sum_{k \in T_{ih}} \sum_{s=1}^S [Y_{ijgkhs} + Y_{ijgkhs(m+1)} + Y_{ijgkhs(m+2)}] \leq 2$$

$$\forall h \in H, \forall 16 \leq m \leq 28$$

Constraints (7) ensure that no professor is teaching three activities in three consecutive time slots.

$$\sum_{(k,k') \in K_i \times T_i} \sum_{s,s'=1}^S \sum_{(h,h') \in H_{ik} \times HT_{ik'}} [X_{ijkhsm} + Y_{ijgk'h's'(m+1)}] \leq 1$$

$$\forall 1 \leq i \leq I, \forall 1 \leq j \leq J_i,$$

$$\forall 1 \leq g \leq G_{ij}, \forall m \in \{3, 9, 18, 24\} \quad (8)$$

$$\sum_{(k,k') \in T_i \times K_i} \sum_{s,s'=1}^S \sum_{(h,h') \in HT_{ik} \times H_{ik'}} [Y_{ijgkhs} + X_{ijk'h's'(m+1)}] \leq 1$$

$$\forall 1 \leq i \leq I, \forall 1 \leq j \leq J_i,$$

$$\forall 1 \leq g \leq G_{ij}, \forall m \in \{3, 9, 18, 24\}$$

$$\sum_{(k,k') \in T_i^2} \sum_{s,s'=1}^S \sum_{(h,h') \in HT_{ik} \times HT_{ik'}} [Y_{ijgkhs'm} + Y_{ijgk'h's'(m+1)}] \leq 1$$

$$\forall 1 \leq i \leq I, \forall 1 \leq j \leq J_i,$$

$$\forall 1 \leq g \leq G_{ij}, \forall m \in \{3, 9, 18, 24\}$$

Constraints (8) prevent any group from having successive activities in the third and fourth periods of Monday, Tuesday, Thursday, or Friday.

$$\sum_{i,i'=1}^I \sum_{j=1}^{J_i} \sum_{j'=1}^{J_{i'}} \sum_{g=1}^{G_{ij}} \sum_{(k,k') \in T_i \times T_{i'}} \sum_{s,s'=1}^S [X_{ijgkhs'm} + Y_{i'j'gk'hs'(m+1)}] \leq 1$$

$$\forall h \in H, \forall m \in \{3, 9, 18, 24\} \quad (9)$$

$$\sum_{i,i'=1}^I \sum_{j=1}^{J_i} \sum_{j'=1}^{J_{i'}} \sum_{g=1}^{G_{ij}} \sum_{(k,k') \in T_i \times T_{i'}} \sum_{s,s'=1}^S [Y_{ijgkhs'm} + X_{i'j'gk'hs'(m+1)}] \leq 1$$

$$\forall h \in H, \forall m \in \{3, 9, 18, 24\}$$

$$\sum_{i,i'=1}^I \sum_{j=1}^{J_i} \sum_{j'=1}^{J_{i'}} \sum_{g=1}^{G_{ij}} \sum_{g'=1}^{G_{i'j'}} \sum_{(k,k') \in T_i \times T_{i'}} \sum_{s,s'=1}^S [Y_{ijgkhs'm} + Y_{i'j'g'k'hs'(m+1)}] \leq 1$$

$$\forall h \in H, \forall m \in \{3, 9, 18, 24\}$$

Constraints (9) prevent that any professor teaches successive activities in the third and fourth periods of Monday, Tuesday, Thursday, or Friday

$$\sum_{i=1}^I \sum_{j=1}^{J_i} \sum_{k \in K_{ih}} \sum_{s=1}^S \sum_{m=1}^M X_{ijgkhs'm} = \sum_{i=1}^I \sum_{k \in K_{ih}} n_{ikh} \quad (10)$$

$$\forall h \in H$$

$$\sum_{i=1}^I \sum_{j=1}^{J_i} \sum_{g=1}^{G_{ij}} \sum_{k \in T_{ih}} \sum_{s=1}^S \sum_{m=1}^M Y_{ijgkhs'm} = \sum_{i=1}^I \sum_{k \in T_{ih}} r_{ikh}$$

$$\forall h \in H$$

Constraints (10) ensure that any professor has a limited number of time slots in which activities

(lecture or tutorial) has to be taught.

The number of the above constraints denoted NC is determined as follow:

$$NC = NC_1 + NC_2 + NC_3 + NC_4,$$

where

$$NC_1 = \sum_{i=1}^I J_i (|K_{i1}| \sum_{k \in K_{i1}} |H_{ik}| + |K_{i2}| \sum_{k \in K_{i2}} |H_{ik}| + |K_{i1} \cup K_{i2}| (1 + \sum_{k \in K_{i1} \cup K_{i2}} |H_{ik}|)) + \sum_{i=1}^I \sum_{j=1}^{J_i} G_{ij} (|T_{i1}| \sum_{k \in T_{i1}} |HT_{ik}| + |T_{i2}| \sum_{k \in T_{i2}} |HT_{ik}| + |T_{i1} \cup T_{i2}| (1 + \sum_{k \in T_{i1} \cup T_{i2}} |HT_{ik}|))$$

{constraints (1)}

$$NC_2 = MS + |H|(40 + M)$$

{constraints (2) + (3) + (7) + (9) + (10)}

$$NC_3 = 6 \sum_{i=1}^I J_i (|K_{i2}| \sum_{k \in K_{i2}} |H_{ik}| + 6 \sum_{i=1}^I \sum_{j=1}^{J_i} G_{ij} |T_{i2}|)$$

{constraints (6)}

$$NC_4 = (12 + M) \sum_{i=1}^I \sum_{j=1}^{J_i} G_{ij} + (M - 1) \sum_{i=1}^I J_i$$

{constraints (4) + (5) + (8)}

This number is very large for the model associated with the Faculty of Economics and Management Sciences of Sfax. In addition the number of binary variables associated with only one section in the above formulation is given by the following expression:

- The Number of Variables for Lectures is: $NVL = S.M.J_1 \cdot |K_1| \cdot |H_1|$ which is approximately evaluated at 375 840 for one section of our real case in section 5. The total number of variables for all sections is roughly 11 275 200.
- The Number of Variables for Tutorials is:

$$NVT = S.M.J_1 \cdot |T_1| \cdot |H_1| \sum_{j=1}^{J_1} G_{1j}$$

which is approximately evaluated at 29 816 640 for one section of our real case in section 5. The total number for all sections is roughly 894 499 200.

- Therefore, the overall number of variables associated with both lectures and tutorials is approximately evaluated at: 905 774 400.

This number is very large which prevent the problem to be solved by a commercial software package such as CPLEX. For this reason, the problem is decomposed into lectures and tutorials sub-problems. For this, we introduce two heuristics embedded into one heuristic procedure in order to find a feasible solution for this large scale problem. We believe that succeeding to produce a feasible solution is an important task in solving such a problem.

4. The Timetabling Heuristic Approach (THA)

The Timetabling Heuristic Approach (THA) to generate a feasible solution includes two procedures: Lecture Timetabling heuristic (LTH) and Course Timetabling Heuristic (CTH). The procedure LTH developed by Dammak et al. (to appear in 2009) generates a feasible timetable for the lectures. The procedure CTH is applied afterward to generate a feasible timetable for the tutorials using the time slots and the classrooms left. It is interesting to note that the two procedures use a similar idea by assigning first classes with the biggest size to classrooms with capacity closest to the size of this class (sub-section or group). However, new hard constraints (such as 8 and 9) are taken into account in THA and it does not start from empty timetables and uses the solution of LTH as input. The advantage of THA is the fact that it provides

a feasible solution for a large scale problem.

To specify the CTH procedure, denote:

Set_{i1} : sub-set of the first tutorial periods of courses in T_{i2} , $1 \leq i \leq I$

Set_{i2} : sub-set of the tutorial periods of courses in T_{i1} , $1 \leq i \leq I$

Set_{i3} : sub-set of the second tutorial periods of courses in T_{i2} , $1 \leq i \leq I$.

The tutorial periods of section i in Set_{i1} are first scheduled sequentially, then those in Set_{i2} , and finally those in set Set_{i3} . The procedure to determine a feasible timetable for the tutorials periods of section i can be summarized as follows:

Step 1 Order the classrooms into a list in non increasing order of their size.

Order the sub-sections in non increasing order of their size.

Set $\rho = 0$.

Step 2 $\rho = \rho + 1$.

Scheduling sequentially the tutorials in $Set_{i\rho}$ for each group g of each sub-section in the order specified above.

Set $g = 1$.

Step 3 (Scheduling each tutorial in $Set_{i\rho}$ for group g)

3.1 For each tutorial of group g , determine a classroom, a time slot, and a professor (in that order).

Set ccr = the last classroom in the list that can hold the group g . Go to 3.3.

3.2 If ccr is not the first classroom in the list, then take ccr = the preceding classroom in the list, and go to 3.3. Otherwise go to 3.6.

3.3 Look for a current time slot cts such that:

- ccr is available
- group g is free

- if cts is the third (respectively the fourth) period of the day, then the group g must be free in the fourth (respectively the third) period of the same day.

If such a cts exists, go to 3.4. Otherwise, go to 3.2.

3.4 If $\rho = 1$ or 2, look for a current professor ch such that

- ch can teach the tutorial to the group g
- ch is available
- the number of tutorial periods already assigned to ch is less than or equal

$$\text{to } \begin{cases} r_{ikh} - 2 & \text{if } \rho = 1 \\ r_{ikh} - 1 & \text{if } \rho = 2 \end{cases}$$

- ch has not taught the two immediately preceding periods, or the two immediately following periods, or the period immediately before and the period immediately after
- the period cts fits the professor ch preferences.

If $\rho = 3$, then the current professor ch must be the one teaching the first tutorial period of the course and

- ch is available
- ch has not taught the two immediately preceding periods, or the two immediately following periods, or the period immediately before and the period immediately after
- the period cts fits the professor ch preferences.

If such a cp exists, go to 3.5. Otherwise repeat 3.3 to find another cts .

3.5 Assign professor ch to teach the tutorial to group g in time slot cts in the classroom ccr .

3.6 If some tutorials in set Set_{ip} for group g

cannot be scheduled, then repeat step 3 and relax constraints 11, i.e. some of professors time preferences are modified in order to find a feasible solution.

Step 4 If the tutorials in set Set_{ip} for the group g are scheduled, and there remains one or more groups not scheduled then ($g = g + 1$ and repeat step 3).

If $\rho < 3$, go to Step 2. Otherwise go to the next sub-section if it exists, else go to the next section if it exists, else Stop a feasible timetable is achieved.

It is interesting to note that the soft constraints 11 (trying to satisfy time preferences of the professors as much as possible) and 12 (trying to maximize the seat occupation rate of the classrooms) are implicitly accounted for in Step 3.4 and Step 1, respectively. If necessary, these soft constraints are relaxed in Step 3.6.

The ordering of the classrooms and sub-sections in step (1) takes:

$$O(S \log S + (\sum_{i=1}^I J_i) \log(\sum_{i=1}^I J_i)) \text{ operations.}$$

Constant operations are performed for each tutorial of group g , for each classroom, for each time slot and for each professor in steps (2), (3) and (4) which takes:

$$O((\sum_{i=1}^I |T_i|)(\sum_{i=1}^I \sum_{j=1}^{J_i} G_{ij}) SM |H|) \text{ operations.}$$

Therefore, the overall complexity of the heuristic CTH is:

$$O(S \log S + (\sum_{i=1}^I J_i) \log(\sum_{i=1}^I J_i) + (\sum_{i=1}^I |T_i|)(\sum_{i=1}^I \sum_{j=1}^{J_i} G_{ij}) SM |H|)$$

5. Numerical Examples Illustration

To illustrate the results obtained with our Timetabling Heuristic Approach (THA), we consider the problem associated with a particular section SE_1 at the FEMSS, for the first semester

of the academic year 2004-05. This section contains

$J_1 = 4$ sub-sections and the data are summarized in the Table 2.

Table 2 Sub-sections of section SE_1 arranged in non-increasing order of their size

Sub-sections	SE ₁₁			SE ₁₂			SE ₁₃			SE ₁₄								
Size	153			146			120			106								
No. of groups	5			5			4			4								
Group size	32	31	30	32	28	29	28	30	30	29	33	29	28	30	28	26	27	25

Table 3 Lectures of section SE_1 with their corresponding faculty staff

Lectures	multiplicity	Faculty Staff: h
C_{1j1} = Computer Systems	2	1
C_{1j2} = Mathematics	2	2, 3, 4
C_{1j3} = Introduction to Management	2	5
C_{1j4} = Algorithmic and Programming	1	6
C_{1j5} = Office software	1	7
C_{1j6} = Logic	1	8, 9

Table 4 Tutorials of section SE_1 with their corresponding faculty staff

Tutorials	multiplicity	Faculty Staff: h
D_{1j1} = Computer Systems	1	1, 10, 11, 12, 13, 14, 15
D_{1j2} = Mathematics	1	2, 3, 16, 17
D_{1j3} = Introduction to Management	1	18, 19, 20, 21
D_{1j4} = Algorithmic and Programming	2	6, 22, 23, 24, 25, 26, 27
D_{1j6} = Logic	1	9, 28, 29, 30
D_{1j7} = Expression Techniques	1	31, 32, 33, 34
D_{1j8} = English	1	35, 36, 37, 38

Table 5 Classrooms with their corresponding size

Classroom	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Size	400	200	180	180	150	100	100	100	100	100	100	100	100	80	80
Classroom	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Size	80	80	50	50	45	45	45	45	32	32	32	32	32	32	32
Classroom	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
Size	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32
Classroom	46	47	48	49	50	51	52	53	54	55	56	57	58		
Size	32	32	32	32	32	32	32	27	27	27	21	21	21		

For this section, there are $|K_{11}| + |K_{12}| = 3 + 3 = 6$ lectures and $|T_1| = |T_{11}| + |T_{12}| = 6 + 1 = 7$ tutorials taught by 38 instructors (4 teaching only lectures, 5 teaching both lectures and tutorials, and the remaining teaching only tutorials) as summarized in the Tables 3 and 4, respectively.

We arrange the classrooms of the faculty in non-increasing order of their size as illustrated in the Table 5.

Each faculty member specifies his time preferences by selecting a certain number of time slots among the thirty available timeslots. The number of time slots is determined by the faculty member and it depends on his teaching load and his grade. Furthermore each of them provides his teaching load specified in terms of the number of lecture periods n_{1kh} and of the tutorial periods r_{1kh} that he has to teach in section SE_1 .

To illustrate the results generated by applying the THA to the problem associated with section SE_1 , we provide the timetables corresponding to the 5 groups of sub-section SE_{11} in Table 6. Similar results are obtained for the other sub-sections, but we omit the corresponding timetables in order to reduce the length of the paper.

Analysis of the illustrative example

To analyze the performance and the efficiency of the Timetabling Heuristic Approach (THA), we provide in Table 7 the corresponding hand made timetables generated by the administrative personnel.

It is worth noting that the administrative personnel follow the same approach generating the lecture timetable first, and then the tutorial timetable. Hence, this allows a fair comparison

between the two approaches. The main features of this comparison are as follows.

1. In the timetables produced by THA no group has successive activities in the third and fourth period of Monday, Tuesday, Thursday or Friday (hard constraint 8). In the hand made solution this constraint is violated three times in the timetable of sub-section 1 (see Table 6 and 7).
2. The hard constraint 5 which impose that no subsection takes two lectures in two consecutive time slots is satisfied by THA, and it is violated three times in the hand made solution: Tuesday afternoon, Wednesday morning and Friday morning (see Table 6 and 7).
3. The timetables generated with the THA are compact in the sense that the number of free periods between two consecutive activities is reduced contrarily to the hand made timetables (2 holes in the hand made timetables and only one hole in the THA timetables see Tables 6 and 7). In addition, it is interesting to note that THA implicitly account for the soft constraints 15 (trying to minimize the number of half days having only one activity). In the hand made timetables this number is 15 and in the THA timetables it is only 9.
4. Considering, the first half of the week, we can see that 13 out of the 15 time slots of the first group SE_{111} are occupied in the THA timetable output. However, only 10 time slots are occupied in the hand made solution. This also illustrates the compactness of the timetables generated by THA. Furthermore, this compactness at the beginning of the week increases the chance

of having Saturday morning free of class. Hence, THA also implicitly account for the soft constraints 14 (trying to maximize the number of free half days for each group). In

the hand made timetables this number is 4 and in the THA timetables it is 10 (see Tables 6 and 7).

Table 6 Output of the THA heuristic for the five groups of sub-section 1

Timetable for SE_{111}

Day / Hour	08:00-09:30	09:45-11:15	11:30-13:00	13:30-15:00	15:15-16:45	17:00-18:30
Monday	C_{111} , $s = 4, h=1$	D_{114} , $s = 52, h=23$		C_{113} , $s = 4, h=5$	D_{111} , $s = 50, h=1$	D_{113} , $s = 51, h=18$
Tuesday	C_{112} , $s = 4, h=2$	D_{112} , $s = 51, h=17$	C_{114} , $s = 4, h=6$		C_{115} , $s = 4, h=7$	D_{117} , $s = 49, h=31$
Wednesday	C_{111} , $s = 4, h=1$	D_{116} , $s = 51, h=30$	D_{118} , $s = 51, h=37$			
Thursday	C_{112} , $s = 4, h=2$	D_{114} , $s = 50, h=23$		C_{113} , $s = 4, h=5$		
Friday	C_{116} , $s = 4, h=9$					
Saturday						

Timetable for SE_{112}

Day / Hour	08:00-09:30	09:45-11:15	11:30-13:00	13:30-15:00	15:15-16:45	17:00-18:30
Monday	C_{111} , $s = 4, h=1$	D_{114} , $s = 51, h=24$		C_{113} , $s = 4, h=5$	D_{113} , $s = 49, h=18$	D_{116} , $s = 50, h=29$
Tuesday	C_{112} , $s = 4, h=2$	D_{111} , $s = 52, h=10$	C_{114} , $s = 4, h=6$		C_{115} , $s = 4, h=7$	D_{112} , $s = 50, h=3$
Wednesday	C_{111} , $s = 4, h=1$	D_{117} , $s = 50, h=32$	D_{114} , $s = 50, h=24$			
Thursday	C_{112} , $s = 4, h=2$	D_{118} , $s = 51, h=35$		C_{113} , $s = 4, h=5$		
Friday	C_{116} , $s = 4, h=9$					
Saturday						

Timetable for SE_{113}

Day / Hour	08:00-09:30	09:45-11:15	11:30-13:00	13:30-15:00	15:15-16:45	17:00-18:30
Monday	C_{111} , $s = 4, h=1$	D_{112} , $s = 50, h=2$		C_{113} , $s = 4, h=5$	D_{114} , $s = 52, h=6$	D_{117} , $s = 49, h=31$
Tuesday	C_{112} , $s = 4, h=2$	D_{116} , $s = 50, h=29$	C_{114} , $s = 4, h=6$		C_{115} , $s = 4, h=7$	D_{111} , $s = 52, h=10$
Wednesday	C_{111} , $s = 4, h=1$	D_{118} , $s = 49, h=37$	D_{114} , $s = 49, h=6$			
Thursday	C_{112} , $s = 4, h=2$	D_{113} , $s = 52, h=20$		C_{113} , $s = 4, h=5$		
Friday	C_{116} , $s = 4, h=9$					
Saturday						

Timetable for SE_{114}

Day / Hour	08:00-09:30	09:45-11:15	11:30-13:00	13:30-15:00	15:15-16:45	17:00-18:30
Monday	C_{111} , $s = 4, h=1$	D_{112} , $s = 49, h=3$		C_{113} , $s = 4, h=5$	D_{114} , $s = 51, h=22$	D_{117} , $s = 48, h=34$
Tuesday	C_{112} , $s = 4, h=2$	D_{118} , $s = 49, h=35$	C_{114} , $s = 4, h=6$		C_{115} , $s = 4, h=7$	D_{111} , $s = 51, h=13$
Wednesday	C_{111} , $s = 4, h=1$	D_{114} , $s = 48, h=22$	D_{116} , $s = 52, h=30$			
Thursday	C_{112} , $s = 4, h=2$			C_{113} , $s = 4, h=5$	D_{113} , $s = 52, h=20$	
Friday	C_{116} , $s = 4, h=9$					
Saturday						

Timetable for SE_{115}

Day / Hour	08:00-09:30	09:45-11:15	11:30-13:00	13:30-15:00	15:15-16:45	17:00-18:30
Monday	C_{111} , $s = 4, h=1$	D_{112} , $s = 48, h=17$		C_{113} , $s = 4, h=5$	D_{116} , $s = 48, h=29$	D_{114} , $s = 52, h=6$
Tuesday	C_{112} , $s = 4, h=2$	D_{118} , $s = 48, h=36$	C_{114} , $s = 4, h=6$		C_{115} , $s = 4, h=7$	D_{117} , $s = 48, h=34$
Wednesday	C_{111} , $s = 4, h=1$	D_{111} , $s = 52, h=14$				
Thursday	C_{112} , $s = 4, h=2$	D_{114} , $s = 49, h=6$		C_{113} , $s = 4, h=5$		D_{113} , $s = 52, h=20$
Friday	C_{116} , $s = 4, h=9$					
Saturday						

Table 7 Output of the manual solution for the five groups of sub-section 1

Hand made timetable for SE_{111}

	08:00-09:30	09:45-11:15	11:30-13:00	13:30-15:00	15:15-16:45	17:00-18:30
Monday	D_{112} , $s = 52, h=3$	D_{118} , $s = 51, h=38$		C_{115} , $s = 2, h=7$	D_{113} , $s = 49, h=18$	
Tuesday		D_{114} , $s = 49, h=6$		C_{116} , $s = 3, h=8$	C_{113} , $s = 2, h=5$	D_{116} , $s = 51, h=9$
Wednesday	C_{114} , $s = 2, h=6$	C_{111} , $s = 1, h=1$				
Thursday	C_{112} , $s = 4, h=2$	D_{111} , $s = 51, h=1$	D_{117} , $s = 49, h=31$		D_{114} , $s = 51, h=6$	
Friday	C_{112} , $s = 3, h=2$	C_{111} , $s = 49, h=1$			C_{113} , $s = 3, h=5$	
Saturday						

Hand made timetable for SE_{112}

	08:00-09:30	09:45-11:15	11:30-13:00	13:30-15:00	15:15-16:45	17:00-18:30
Monday				C_{115} , $s = 2, h=7$	D_{117} , $s = 58, h=31$	D_{114} , $s = 43, h=22$
Tuesday			D_{114} , $s = 44, h=22$	C_{116} , $s = 3, h=8$	C_{113} , $s = 2, h=5$	
Wednesday	C_{114} , $s = 2, h=6$	C_{111} , $s = 1, h=1$	D_{118} , $s = 27, h=37$			
Thursday	C_{112} , $s = 4, h=2$				D_{112} , $s = 37, h=16$	
Friday	C_{112} , $s = 3, h=2$	C_{111} , $s = 1, h=1$		D_{113} , $s=39,h=19$	C_{113} , $s = 3, h=5$	
Saturday		D_{116} , $s=58, h=28$	D_{111} , $s = 22, h=10$			

Hand made timetable for SE_{113}

	08:00-09:30	09:45-11:15	11:30-13:00	13:30-15:00	15:15-16:45	17:00-18:30
Monday				C_{115} , $s = 2, h=7$	D_{114} , $s = 43, h=22$	D_{116} , $s = 41, h=29$
Tuesday	D_{118} , $s = 27, h=37$			C_{116} , $s = 3, h=8$	C_{113} , $s = 2, h=5$	D_{114} , $s = 43, h=22$
Wednesday	C_{114} , $s = 2, h=6$	C_{111} , $s = 1, h=1$				
Thursday	C_{112} , $s = 4, h=2$			D_{112} , $s=25,h=16$		
Friday	C_{112} , $s = 3, h=2$	C_{111} , $s = 1, h=1$		D_{117} , $s=57,h=34$	C_{113} , $s = 3, h=5$	
Saturday	D_{113} , $s = 25, h=19$		D_{111} , $s = 56, h=11$			

Hand made timetable for SE_{114}

	08:00-09:30	09:45-11:15	11:30-13:00	13:30-15:00	15:15-16:45	17:00-18:30
Monday	D_{112} , $s = 49, h=2$	D_{114} , $s = 38, h=23$		C_{115} , $s = 2, h=7$	D_{118} , $s = 34, h=37$	
Tuesday	D_{114} , $s = 38, h=23$	D_{111} , $s = 21, h=10$		C_{116} , $s = 3, h=8$	C_{113} , $s = 2, h=5$	
Wednesday	C_{114} , $s = 2, h=6$	C_{111} , $s = 1, h=1$	D_{117} , $s = 52, h=32$			
Thursday	C_{112} , $s = 4, h=2$		D_{116} , $s = 56, h=28$	D_{113} , $s=44,h=20$		
Friday	C_{112} , $s = 3, h=2$	C_{111} , $s = 1, h=1$			C_{113} , $s = 3, h=5$	
Saturday						

Hand made timetable for SE_{115}

	08:00-09:30	09:45-11:15	11:30-13:00	13:30-15:00	15:15-16:45	17:00-18:30
Monday			D ₁₁₂ , s = 31, h=2	C ₁₁₅ , s = 2, h=7	D ₁₁₄ , s = 46, h=6	
Tuesday	D ₁₁₈ , s = 35, h=36			C ₁₁₆ , s = 3, h=8	C ₁₁₃ , s = 2, h=5	
Wednesday	C ₁₁₄ , s = 2, h=6	C ₁₁₁ , s = 1, h=1				
Thursday	C ₁₁₂ , s = 4, h=2	D ₁₁₄ , s = 44, h=6		D ₁₁₇ , s=36,h=33		
Friday	C ₁₁₂ , s = 3, h=2	C ₁₁₁ , s = 1, h=1	D ₁₁₆ , s = 58, h=28		C ₁₁₃ , s = 3, h=5	D ₁₁₃ , s = 43, h=19
Saturday	D ₁₁₁ , s = 52, h=12					

Table 8 Comparison between THA and HM solution

Criteria \ Sub-section	NC8V		NSL		NH		NHDSA		NOS	
	HM	THA	HM	THA	HM	THA	HM	THA	HM	THA
Sub-section 1	9	0	5	0	9	0	12	11	2	0
Sub-section 2	1	0	5	0	6	6	15	11	4	1
Sub-section 3	2	0	0	0	5	2	10	14	2	3
Section 2 (total)	12	0	10	0	20	8	37	36	8	4

Experimental results

In order to confirm the results of the illustrative example using the real data of SE_1 , we consider now another section SE_2 that contains three subsections SE_{21} , SE_{22} and SE_{23} including respectively 5, 5 and 4 groups. The criteria considered in comparing THA with hand made solution are as follow:

- NC8V: number of constraint 8 violations
- NSL: number of successive lectures
- NH: number of holes (idle time slots)
- NHDSA: number of half days with single activity
- NOS: number of occupied Saturdays

According to the table (8), we can see that the THA outperforms the hand made (HM) solution

in all the four criteria considered for both sub-sections 1 and 2. However, results of sub-section 3 show good performance of THA for the first three criteria but not for the two last criteria. This result is expected since our procedure is heuristic and it has room for further improvements. The overall results for all sub-sections validate the good quality of THA when compared with HM solution.

6. Conclusion

In this paper, we introduce a formulation of the timetabling problem at the Faculty of Management of Sfax as a set of linear constraints. The Timetabling Heuristic Approach (THA) proposed to deal with this problem includes two

procedures, LTH and CTH for the lectures and the tutorials, respectively. The LTH procedure was introduced first by the authors to generate a timetable for the lectures. The CTH procedure fully described in Section 4 is an extension of the LTH procedure generating a timetable for the tutorials once the timetable for the lectures is completed. When comparing the timetables generated using THA with those obtained manually, we note the compactness of the former with respect to the later. In particular, the number of holes, the number of half days with single activity and the number of occupied Saturdays in THA are smaller than those in the HM solution (see Table 8).

The ongoing research on this topic includes the development of metaheuristic methods such as Tabu search to minimize the number of soft constraints violations such as reduce the number of holes and isolated activities. At this stage we can perform tests over several academic years to get even more conclusive results on the quality of the timetables generated.

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