Implementation of an Integer Linear Programming Model for the Timetabling Problem of the Louvain School of Management

Milko Diego Benitez Galle
Promoter: Professor Daniele Catanzaro

UCLouvain
Louvain School of Management
June 2020

Contents

Abstract

Constructing a course timetable is a process involving teams, material resources, and a large amount of time each year at the university. For this reason, this thesis tackled the timetabling problem relative to the Louvain School of Management. Firstly, we made an investigation about the needs and characteristics of this faculty. Secondly, we translated these needs and characteristics into an integer linear programming model to have the optimal solution for the course schedule. Thirdly, we compared the optimal solution with the current one to prove the strengths of this model. The model runs on a software called Fico Xpress Workbench and considers all the constraints needed for constructing the best timetable according to the parameters that the faculty has.

Key words: Timetabling, Integer programming, Optimization, University

---

1 Introduction

The planning of a course timetable in an university consists of choosing the adequate classroom and the correct starting and finishing time for each lesson [3]. This allocation of lessons in periods and in rooms needs to respect some constraints as the capacity constraint, the material constraint of a room, the availability of teachers, etc. [19].

Every year, the administration of the faculty spends a lot of time and resources to solve this issue by making the scheduling manually using the trial and error method. Even with all the resources used, the timetable is not optimal, some lessons are allocated to an inadequate room and some students are confronted to conflicts between two lessons that are given at the same time. The large amount of data concerning the lessons, students, teachers, and rooms makes the problem too difficult for the human brain that cannot see all the conditions, implications and possibilities interconnected between the data [6].

The utilization of operational research techniques and algorithms are fundamental to take into account the large number of variables and constraints related to this complex problem. For this reason, the problem of building timetables for universities, transport company [20], chemical processing systems [10] and other applications has been analysed in the operational research literature for long time[3]. Actually, the first timetabling approach was defined by Gotlib in 1963[13].

The main approaches found in the literature to solve this issue are the meta-heuristic and LP formulation approach. The meta-heuristic algorithms are the most efficient procedures that have appeared in recent years[3]. Specially, when the problems are too complex with a huge number of variables [11]. The meta-heuristic approach finds good feasible solution derived from prescriptive analysis that is not guaranteed to yield on exact optimum, furthermore the meta-heuristic approach does not inform about how close the feasible solution is from the global optimal [16]. For this reason, linear programming can be a good alternative to take when the global optimal solution is targeted.

Some authors already tackled the academic timetabling problem using linear programming as Dimopolu (2001) with a integer programming and a heuristic procedure [12], Daskalaki(2004) using a binary integer programming taking into account the rules present in most institutions [10] or Alvarez Valdes(2002) suggesting an integer programming formulation and a heuristic algorithm using Tabu search [3] . Nevertheless, all these models are not directly applicable since each institution has their own specific needs [1]. To answer to the specific needs of the LSM, this thesis will mainly be inspired by the integer programming model from the Alvarez Valdes article.

Furthermore, the scope will be on a faculty of the University Catholic of Louvain called the Louvain School of Management. The scope of the problem is limited and should be realizable through integer programming since the size of the faculty has a great impact on solving the problem by exact methods [5]. The model will consider the campus of Louvain-La-Neuve and the campus of Mons with all the courses given during the day and during the night. The campus of Charleroi was not take into consideration due to the lack of information about the rooms in this campus. Also, the practical lessons concerning some theoretical courses were not taken into account. The scope of the model is important to determine the strengths and the weaknesses in section 4.

Two ways of making a timetable are distinguished by Carter and Laporte. The master timetabling or demand driven system. In master timetabling, the allocation of lessons to time slot is done first, then the students choose courses and section from the timetable. In demand driven system, the students choose first courses and then the timetable is made according to the number of students in each course [7]. This thesis applies the demand driven system by assigning lessons to time slots and rooms based on data collected from the Louvain School of management. However, the information about the number of students per course was not available due to confidential issue. Therefore, the data about the number of students are based on an approximation.

In section 2, an explanation of the scheduling problem is provided, by explaining the data, the constraints, and the variable that we found thanks to the interviews with the administration. Furthermore, we explained which criteria a course timetable needs to have to be considered as a good timetable. In section 3, we describe the integer linear model by explaining the objective function, the constraints, and the variables. In section 4, a description of the application of the model to the LSM case will be described. Moreover, an explanation of the software used for this problem is shortly explained and the analysis of the solution and the comparison with the current timetable are highlighted. Finally, in section 5, weaknesses, strengths and possible improvements of this model are described to allow future investigations to improve these weaknesses.

2 Problem description

Data and parameters

A course timetabling problem in the Louvain School of Management has the following elements:

- A set of courses $C = \{c_1, .., c_m\}$
- Each course c_j is divided in section according to the number of students and other factors as the number of teachers and rooms available $S_j = \{s_{j,1}, .., s_{j,q}\}$. Each section needs to have a certain amount of hour per quarter.
- As said before, each section of a course $s_{j,q}$ needs to respect a certain amount of hour per quarter. These sections will be divided in number of lessons to be given every week. Set of lessons $L_(j,k) = \{l_{jk1}, .., l_{jkn}\}$ where $j = 1, .., m$ (course index) and $k = 1, .., q$ (section index)

- A set of classes $\mathfrak{C} = \{\mathfrak{c}_1, .., \mathfrak{c}_\mathfrak{c}\}$. A class defines a group of students taking the same set of courses. The classes are important to determine which lessons cannot be given simultaneously.
- A set of teachers $T = \{t_1, .., t_u\}$. Each teacher teaches a set of course and these courses cannot be given simultaneously too.
- A set of rooms $R = \{r_1, .., r_o\}$. There are different kind of rooms that have different materials, some have computers, others have laboratories and some provide access to disabled person. Also, the capacity space is not the same for every room. These criteria need to be considered to allocate the right room to the right lessons.
- A set of periods $P = \{p_1, .., p_s\}$. The set of periods corresponds to a week, each day has the same number of period and the same length per period (=1hour). The total number of periods is $55 = 11\ (number\ of\ period\ per\ day) * 5\ (number\ of\ days\ in\ a\ week)$ [3][4][14]

Objectives and constraints

The course planning of the Louvain School of management needs to respect some constrains to be considered as a good timetabling. We will distinct two kinds of constraints, hard constraints, and soft constraints [3]. Hard constraints are constraint that the model must respect to have a feasible solution and a correct timetable. Soft constraint specifies requirements that are desirable to achieve but which can be violated in feasible solution [16].

Below, we discuss about the hard constraints identified in the interview with the administration and in the literature.

1. Every lesson must be assigned to period according to the hours needed.
2. Every lesson needs to be assigned to the correct period. For example, some lessons need to be given at night for the class belonging to the option Master staggered hour [120/60 credits] .
3. A room cannot have two lessons at the same time.
4. The lessons need to be allocated to the right room. For instance, a lesson belonging to the Louvain-La-Neuve campus must have a room in Louvain-la-Neuve and not in Mons and vice versa.
5. Two lessons belonging to a class cannot be given at the same time.
6. Two lessons of the same course cannot be given in the same day.
7. A teacher cannot teach two lessons at the same time.
[3][2]

As said before, these hard constraints are fundamental to provide an adequate timetable. About, the soft constraints, those are conditions that can improve the quality of a timetable but there are non essential [4][14][17]. In this model these soft constraints are considered by making preferences [1], the value of the preferences concerning time slot or room will influence the priority in the objective function. Below, the soft constraints are mentioned.

I Having a schedule that is convenient for the student. For example, the model will avoid fixing a lesson on Friday at 4:15 pm.

II Selecting as a priority the rooms that have the best materials (screen, microphone, projector, etc) and access for disabled people.

III Giving preferences to rooms that are near to the city centre.

IV Increasing the utilisation rate of the capacity room by allocating the lessons that have a certain number of students with the rooms that fit the best in term of capacity.

3 Integer linear model

Basic explanation

The model can be formulated as follows:

$$\begin{aligned} &max \quad f(x) \\ &s.t x \in S_x \end{aligned}$$

To remember, the problem of assigning students to sections is not considered in this model, this point is already tackled by making an approximation of the number of students per course and section. This model is only focused on the allocation of lessons. The variable x represents an array of 3 dimensions that allocates lesson (i) to a starting period (p) and a room (r). The function $f(x)$ is the value of the timetable according to x and the set S_x are the feasible sets that respect the seven hard constraints described above [3]. This model maximises the function $f(x)$ that is based on preferences [1].

Mathematical model

- **Set**
  - Set of lessons $L = 1, .., l, .., n$
  - Set of teachers $T = 1, .., t, .., u$
  - Set of rooms $R = 1, .., r, .., o$
  - Set of kind of rooms $K = 1, 2$
  - Set of periods $P = 1, .., p, .., 55$
  - Set of days $D = 1, .., d, ..5$
  - Set of course $C = 1, .., c, .., z$

- **Subset**
  - Set of lessons of the teacher(t):$LT(t) \in L$
  - Set of lessons that need room of type 1 or 2: $LK(1), LK(2) \in L$
  - Set of lesson belonging to course(c):$LC(c) \in L$
  - Set lessons given during the day: $L\mathfrak{D} \in L$
  - Set of lessons given during the night: $L\mathfrak{N} \in L$
  - Set of forbidden periods for night lessons:$PF\mathfrak{N} \in P$
  - Set of forbidden periods for day lessons: $PF\mathfrak{D} \in P$
  - Set of periods in day (d): $PD(d) \in P$
  - Set of rooms of type 1 or 2: $RK(1), RK(2) \in R$

- **Parameters**
  - Duration of lesson (l) :$\mathbb{d}_{\mathbb{l}}$
  - Number of students in lesson (l) :$\mathbb{N}_{\mathbb{l}}$
  - Capacity of the room (r) :$\mathbb{C}_{\mathbb{r}}$
  - Preference of room (l) :}$\mathbb{P}_{\mathbb{r}}$
  - Preference of slot (s) :$\mathbb{P}_{\mathbb{s}}$
  - Conflict between lesson (l) and (k):

$$CM_{l,k} = \begin{cases} 1, & \text{if lesson(l) and (k) can be given simultaneously} \\ 0, & \text{otherwise} \end{cases}$$

- **Variable**

$$x^r_{l,p} = \begin{cases} 1, & \text{if lesson(l) starts at period(p) in room(r)} \\ 0, & \text{otherwise} \end{cases}$$

- **Objective function**

max

$$\sum_{l \in L} \sum_{p \in P} \sum_{r \in R} x^r_{l,p} * \mathbb{P}_{\mathbb{s}} + \qquad (I)$$

$$\sum_{l \in L} \sum_{p \in P} \sum_{r \in R} x^r_{l,p} * \mathbb{P}_{\mathbb{r}} - \qquad (II/III)$$

$$\sum_{l \in L} \sum_{p \in P} \sum_{r \in R} x^r_{l,p} |\mathbb{C}_{\mathbb{r}} - \mathbb{N}_{\mathbb{l}}| \qquad (IV)$$

- **Constraints**

$\forall l \in L$

$$\sum_{p \in P} \sum_{r \in R} x^r_{L,p} = 1 \qquad (1)$$

$\forall l \in L\mathfrak{N}$

$$\sum_{p \in PF\mathfrak{N}} \sum_{s=p-d_l+1}^{p} \sum_{r \in R} x^r_{l,s} = 0 \qquad (2)$$

$\forall l \in L\mathfrak{D}$

$$\sum_{p \in PF\mathfrak{D}} \sum_{s=p-d_l+1}^{p} \sum_{r \in R} x^r_{l,s} = 0 \qquad (3)$$

$\forall p \in P \ \ \forall r \in R$

$$\sum_{l \in L} \sum_{s=p-d_l+1}^{p} x^r_{l,s} \leq 1 \qquad (4)$$

$\forall l \in LK(2)$

$$\sum_{p \in P} \sum_{r \in RK(1)} x^r_{l,p} = 0 \qquad (5)$$

$\forall l \in LK(1)$

$$\sum_{p \in P} \sum_{r \in RK(2)} x^r_{l,p} = 0 \qquad (6)$$

$\forall k, l \in L, \ if \ k < l \ \ \forall p \in P,$

$$\sum_{r \in R} \sum_{s=p-d_k+1}^{p+d_l-1} x^r_{k,s} + \sum_{r \in R} x^r_{l,p} \leq (1 + CM_{l,k}) \qquad (7)$$

$\forall c \in C, \ \ \forall d \in D$

$$\sum_{l \in LC(c)} \sum_{p \in PD(d)} x^r_{l,p} \leq 1 \qquad (8)$$

$\forall p \in P, \ \ \forall t \in T,$

$$\sum_{l \in LT(t)} \sum_{s=p-d_l+1}^{p} \sum_{r \in R} x^r_{l,s} \leq 1 \qquad (9)$$

$\forall l \in L, \ \ \forall p \in P, \ \ \forall r \in R$

$$x^r_{l,p} = \{0; 1\} \qquad (10)$$

Detailed explanation

The objective function will maximize the preferences of the slots and rooms keeping a high utilization rate of the capacity room. An explanation of the formula is given below.

I This formula concernes the preferences of the slots which are determined to avoid lessons at inconvenient hours. Also, the scores of the preferences are designed to have a condensed timetable between 9:30 am and 5:15 p.m. In this model, the preferences of slots are assumed to be the same for each lesson or teacher. Table 1 shows the preferences of one day of the week.

II This formula considers the preferences of the room for the location and the material. If the room has a lot of materials or has access for disabled person this room will have more points than the others and will be preferred by the model , below you can see an example with the room Montesquieu 11:

$$\begin{aligned} P_{Montesquieu11} &= 100 * 1(projector) \\ &+ 5 * 1(microphone) \\ &+ 5 * 1(microgroove) \\ &+ 5 * 1(portable\ microphone) \\ &+ 30 * 1(chalkboard) \\ &+ 10 * 0(whiteboard) \\ &+ 40 * 1(disabledpersonaccess) \end{aligned}$$

1 means that the material is available , 0 means that the material is not available in the room. As you can see the model put a higher importance on three factors, projector availability, chalkboard availability and the access for the disabled person.

III As said before, this formula takes into account the location of the room. The place of the room has a weight of 100. If the room is near to the centre of the city the score will be near to 1 and if the room is far, the score will be closed to zero. A detail explanation is provided in the figure 1. For the campus of Mons all the location weights are fixed to 1 since all the rooms are in the same building called Building D.(UClouvain,2020)

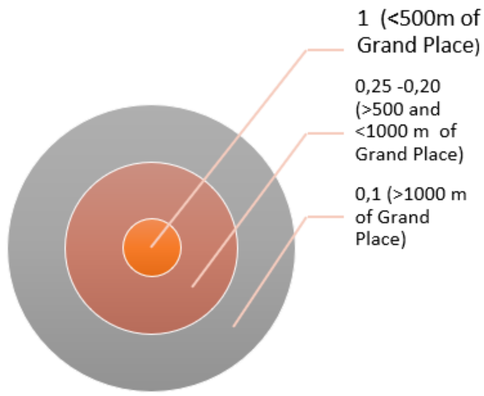

Fig. 1: room location weight

For Montesquieu 11 , this room will have a score of 100 (= 100∗1) for the location since this room is close to the center of the city. The total weight of this room is 185. The preferences of the rooms vary from 20 for the worst rooms to 300 for the best rooms. Furthermore, I assumed that every course has the same preferences for the rooms.

IV This formula is about the capacity of rooms, the model will penalize the difference between the capacity of the room and the number of students for the lesson giving in this room.

The constraints in the model will be there to respect the seven hard constraints described in section 2, detail explanations are given below:

1) The first constraint said that every lesson needs to start only once. Therefore, every lesson is allocated to only one starting time.

2) The second constraint will force the model to put the night lessons for the night periods.

3) This constraint is the same than constraint two but for the day lessons. Day lessons cannot be given at night period, so the model will force these lessons to be given at day periods.

MONDAY							
8:30-9:30	**9:30-10:30**	**10:45-11:45**	**11:45-12:45**	**14:00-15:00**	**15:00-16:00**	**16:15-17:15**	**17:15-18:15**
40	200	200	200	200	40	20	0

Tab. 1: Preferences of times slot

4) Fourth constraint said that every rooms can only attend one lesson per period. The $s = p - d_l + 1$ in the sum is there to consider the time when the room is occupied during the duration of the lesson and not only the starting point.

5) This constraint will force the model to allocate a lesson in Louvain-La-Neuve to a room in Louvain-La-Neuve and not in Mons.

6) This constraint has the same meaning as constraint (5) but applies for the lessons from the campus of Mons.

7) This constraint is there to avoid conflict between lessons followed by the same class. Simultaneity is defined when a lesson is given at the same time than another one. This involves that lesson (k) cannot begin before lesson (l) if the duration will lead to a conflict (figure 2). And lesson (k) cannot begin before the end of the lesson (l) (figure 3).

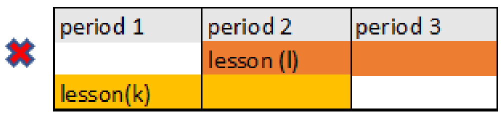

Fig. 2: lesson k finishes after the beginning of lesson l

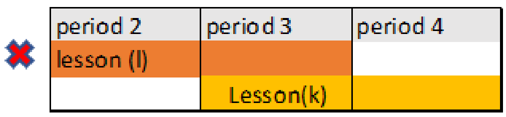

Fig. 3: lesson k starts before the end of lesson l

As the conflict matrix of lessons CM is a triangular matrix of 0 and 1 (figure 4). We compared the lesson l and k only if $k < l$ to not make the same calculation twice.

lesson	1	k	n
1	0	1	0
l	1	0	1
n	0	1	0

Fig. 4: triangular matrix

8) This constraint does not allow to give lessons belonging to the same course two times in a same day. For instance, the lessons for the course *Tools for supply chain* cannot be given in the same day.

9) The last constraint does not allow teachers to give two lessons simultaneously. For example: *Tools for supply chain* in L-L-N cannot be given at the same time than *Optimization* in Mons because these lessons are given by the same professor. As said before, the $s = p - s = p - d_l + 1$ in the sum is there to consider the duration of the lesson and not only the starting point.

4 Model application and analysis

Application to the LSM case

The LSM faculty has some particularities that need to be taken into account when we apply this model.

The Mons campus offers courses for different master's degrees as master's degree for business engineering and management science (120 credit), master's degree for management science (60 credit) and master's degree with staggered schedule (120 and 60 credit). Also, they offer courses for the bachelor's degree. In total, the campus of Mons offers more than 152 courses with 28 available rooms [21] [22].

The Louvain-La-Neuve campus only offers master's degree courses for business engineering and management science . In total, the campus of Louvain-La-Neuve offers more than 159 courses with 165 available rooms. In the whole faculty more than 182 teachers are present [21] [22].

The particularity is the fact that the courses from the master's degree (120 credit) for business engineering and management science are split in courses of 6 weeks, the rest are split in courses of one quarter (=12 weeks). This constraint forces the model to be divided in 4 because making only one model by quarter will skew the model due to the constraints which will consider all the lessons at the same time.

For example, in constraint (4) a room can be allocated to only one lesson during all the lesson duration. For instance, in period (2) the room (Socrate10) will be allocated for the lesson (project management). But in reality, the room (Socrate 10) can be allocated for the lesson (supply chain management) in period (2) too because these two lessons are not given in the same period of the year but the model don't make the distinction because the period ($p \in P$) has a scope of one week.

$\forall p \in P \;\; \forall r \in R$

$$\sum_{l \in L} \sum_{s=p-d_l+1}^{p} x^r_{l,s} \leq 1 \qquad (4)$$

Splitting the model in four means that we have to process some data to have the same units, for example:

$$Bachelor\ courses = 12\ weeks$$

$$Master\ courses = 6\ weeks$$

$$Number\ of\ hour\ needed\ per\ course : 36\ hours$$

$$Hours\ needed\ for\ bachelor\ courses = \frac{36}{12} h/week$$

$$Hours\ needed\ for\ masters\ courses = \frac{36}{6} h/week$$

The number of hours per week that a course or a section of a course needs is important to determine the number of lessons needed by week and the duration of these lessons.

Softwares

The software used for solving this issue is Fico Xpress Workbench. This software is an environment for modelling and solving problems using a programming and a modelling language [9].

The software used to input, transform, and analyse the data is Excel. Actually, Fico Xpress is able to import/export information from/to Excel [9].

The steps to solve the problem are the following. First, collect and transform the data to be able to use these data in the model. Import the data from Excel to Fico Xpress. Run the model in the software. Analyse the numerical results and export the solution from Fico to Excel in a table to be able to analyse if all the constraints are met. See in annex(7) to have an example about the output on Excel.

Adjustment of the model

During the launching of this model, the memory of the computer was not large enough to be able to solve the problem due to the constraint(7):

$\forall k, l \in L,\ if\ k < l \;\; \forall p \in P,$

$$\sum_{r \in R} \sum_{s=p-d_k+1}^{p+d_l-1} x^r_{k,s} + \sum_{r \in R} x^r_{l,p} \leq (1 + CM_{l,k}) \; (7)$$

The matrix CM was the source of the issue because the model considered the constraint for all the possibilities amongst all the lessons. The number of constraints were too large, and the problem became too complex to be solved by exact method [19] . A solution was to change this constraint by using the same form as the teacher constraint (9).

$\forall p \in P, \;\; \forall t \in T,$

$$\sum_{l \in LT(t)} \sum_{s=p-d_l+1}^{p} \sum_{r \in R} x^r_{l,s} \leq 1 \qquad (9)$$

$\forall\ \mathfrak{c} \in\ \mathfrak{C},\ \forall p \in P,$

$$\sum_{l \in L\mathfrak{C}(\mathfrak{c})} \sum_{s=p-d_k+1}^{p} \sum_{r \in R} x^r_{l,s} \leq 1 \qquad (7')$$

where $\mathfrak{C} = 1, .., \mathfrak{c}, \ldots, y$ is the set of classes and $L\mathfrak{C}(\mathfrak{c})$ the set of lessons belonging to the same class.

This constraint allowed to decrease the number of constraints and allowed to decrease the complexity of the problem. However, this constraint needs to be encoded too many times when a lesson is followed by more than 10 different classes. For these exceptions, the simultaneity constraint with the conflict matrix was used to keep a condensate code and to avoid to make errors. For example, the course current managerial issue is followed by all the options from Business Engineering and Management Science, the simultaneity constraint for this example was written as follow:

$for\ k = current\ man.issue,$

$\forall l \in L\mathfrak{C}(Bus.eng.) \cup L\mathfrak{C}(Man.sci.),$

$\forall p \in P,$

$$\sum_{r \in R} \sum_{s=p-d_k+1}^{p+d_l-1} x^r_{k,s} + \sum_{r \in R} x^r_{l,p} \leq (1 + CM_{l,k}) \; (7'')$$

Using the two changes explained above, the mathematical model became less complex and the number of constraints decreased. Finally, the software was able to run successfully and to find optimal solutions described in the following subsection.

Numerical results

In the table 2 you can see the result for the 2 quarters. Q1 represents the first 6 weeks of the quarter one and Q1* represents the last 6 weeks of the quarter one, the same methodology is used for quarter 2. The utilization mean is the mean of the utilization of all the rooms when an allocation of a lesson is done, the formula used for the utilization mean is:

$$U(Q_x) = \frac{\sum_{l\in L}\sum_{p\in P}\sum_{r\in R} x^r_{l,p} \frac{\mathbb{N}_l}{\mathbb{C}_r}}{n(= number\ of\ lessons)}$$

The objective values are different between quarters. In quarter 1* and quarter 2* there are more lessons offers because the specializations of the different classes are given in this period. This explains the bigger value for Q1* and Q2*.

Quarter	Objective value	Utilization rate
Q1	84037	95%
Q1*	96132	99%
Q2	60361[1]	95%
Q2*	86649	96%

Tab. 2: Solutions of the model

The utilization means of the rooms are high for all the quarters. However, by analysing each room utilization individually we can notice that some rooms have an utilization rate higher than 100%. These results are normal since the soft constraint allowed this choice. An utilization room of 110% can be considered as acceptable if we assume that at least 10% of students registered will not go to the lesson.

Finally, like in the Abel model based on preferences, this model can have distinct feasible solutions with the same value [6]. If the administration of the Louvain School of Management wants to keep some form of control and influence over the timetabling, the administration could choose one of these several feasible solution based on their experiences and knowledge.

Comparison with the current timetable

To see the improvements or weaknesses of this model, we encoded the current timetable on Ficoxpress Workbench to be able to compare the results at table 3 of the first 6 weeks of the quarter 2 between the current and the optimal schedule.

	Obj. value	Utiliz. rate
Q2(opt.)	60361	95%
Q2(current)	39580	75%

Tab. 3: Comparison table

We can easily see the difference of 20781 between the optimal and the current solution. Also, the utilization rate decreased of 20 %. In some cases, the room utilization rate of the current solution can reach 166% due to my wrong approximation of the number of students per course. A higher collaboration between stakeholders is necessary to have accurate data and realistic solution.

To be able to understand the difference of 20781 in the objective function between the optimal and the current solution, we will make an analysis about the most important factors that the model considers. Figure 5 shows the summary of the different weights that each preference has in the objective function.

room	
room location	100
projector availability	100
other materials	55
acces for disabled person	40
utilization room	1
total weight for room	196
slot time	
08:30	40
9:30-14:00	200
15:00-16:15	40
16:15	20

Fig. 5: the weights of the attributes

About the rooms, the weights concerning the locations, the projectors and the access for disabled person are the 3 dominants factors. The rooms location avoid making long travels for students between each lesson and the projector availability is an important criterion asked by the teachers.

Regarding the time slots, the schedule will prefer to begin a class from 9:30 until 2:00 p.m to avoid to finish the lessons after 5:15 p.m, the other period are considered as inconvenient. Concerning the preferences for the staggered schedule, it is not necessary to give a weight since all the lessons must begin at 6:15 pm.

In total, 47 lessons were given at inconvenient hours in the current solution against 9 in the optimal. 19 lessons were allocated to rooms without projector against 0 in the optimal solution. 6 lessons were allocated to rooms considered as bad location against 0 in the optimal. Finally, 3 lessons were allocated to rooms without access for disabled students against 0 for the optimal solution. The table 4 in the next page shows the detailed analysis between the optimal and the current solution according to the most important factors described above.

The better allocation of lessons to rooms concerning the utilization rate, the location and the access for disabled person. And the better allocation of lessons to the time slots explain the better solution obtained via the integer linear programming than the current solution.

# of lessons assigned to		Current solution				Optimal solution			
		Bad period	No projector	Bad location	No access for disabled person	Bad period	No projector	Bad location	No access for disabled person
MONS	Mast. staggered sche.	0	**2**	0	0	0	**0**	0	0
	Bac.1	**1**	**9**	0	0	**1**	**0**	0	0
	Bac.2	**16**	**5**	0	0	**4**	**0**	0	0
	Bac.3	**12**	0	0	0	**4**	0	0	0
	Mast.120	**11**	**2**	0	0	**0**	**0**	0	0
	Mast.60	0	0	0	0	0	0	0	0
L-L-N	Mast. staggered she.	0	**1**	0	**1**	0	**0**	0	**0**
	Mast.120	**3**	0	**4**	**2**	**0**	0	**0**	**0**
	Mast.60	**1**	0	**2**	0	**0**	0	**0**	0
	Mast. doct.	**2**	0	0	0	**0**	0	0	0
	Entreprenarial min.	**1**	0	0	0	**0**	0	0	0

Tab. 4: Comparison analysis

5 Strengths and weaknesses of the model

Strengths

The main strengths of using a linear programming for a timetable are the savings in terms of time and resources for the administration of the Louvain School of management [19]. The time would be of one hour instead of weeks for making the timetable for the academic year. Furthermore, the hard constraints allow to have a timetable that respects all the fundamental needs that an acceptable course schedule should have.

Also, the integer programming always gives the global optimal solution of a problem. So, the output of the model is the best solution according to the data inserted.

Furthermore, the current schedule allows giving lessons of the same course in the same day, this characteristic is inconvenient for students who have difficulties to stay focus during a lot of time for a same course. The model tackled this point thanks to the constraint (8):

$\forall c \in C, \quad \forall d \in D$

$$\sum_{l \in LC(c)} \sum_{p \in PD(d)} x^r_{l,p} \leq 1 \qquad (8)$$

Also, the model chooses the most convenient hours to allocate the lessons, avoiding the inconvenient hours when it is possible thanks to the preferences. In the current schedule some lessons are given on Saturday, this model does not allow this possibility by assigning all the lessons from Monday to Friday to let a free week-end for the students. This point improves the quality of the timetable for the students.

Finally, the better utilization of the room that allowed this model is not negligible comparing to the current result.

Weaknesses

One of the weaknesses of this model is the scope. The model does not take into account the other faculties of the UCLouvain. The rooms used for this model can also be used by the others faculties. Implementing all the lessons of the other faculties could become the problem too complex to be solved by integer programming, a metaheuristic approach could be more adequate [2].

Another weakness found in this model is in the constraint (9). The set of lessons belonging to the teacher (t) cannot be given simultaneously.

$\forall p \in P, \quad \forall t \in T,$

$$\sum_{l \in LT(t)} \sum_{s=p-d_l+1}^{p} \sum_{r \in R} x^r_{l,s} \leq 1 \qquad (9)$$

This constraint is correct when all the courses are given by one teacher. In the LSM a lot of courses are given by several teachers. For instance, *Corporate social responsibility(A-E)* and *Corporate Social Responsibility(F-Z)* are given by the same 2 teachers, called teacher 1 and teacher 2. In this model these 2 lessons cannot be given at the same time because they belong to the set of lessons of teacher (1) and (2). The model has a limitation because it cannot determine which teacher will give the lesson.But in practice, these two lessons can be given at the same time if the configuration of figure 6 is respected:

period 1	period 2	period 3
CSR(A-E)-teacher 1	CSR(A-E)-teacher 1	CSR(A-E)-teacher 1
CSR(F-Z)-teacher 2	CSR(F-Z)-teacher 2	CSR(F-Z)-teacher 2

Fig. 6: possible configuration

Possible improvements

The first improvement that can be made is to have a higher collaboration with the stakeholders during the process to have correct and more accurate data to be able to add more elements as the practical lessons of theoretical courses for the bachelor's degree. Also, by having this collaboration with the stakeholders, we can add to the model the preferences of the teachers for the rooms and the slots.

During the interview, the administration said that they try to let one day free for the students in master during the week. This point is not tackled in this thesis. But it is a point that could be integrated to improve the quality of the timetable.

Also, as the quarters are split in two, the courses of the bachelor's degree in Mons have two schedules, one schedule for the 6 first weeks and another one for the 6 last weeks. If this characteristic is not convenient for the administration, a solution could be to take the solution of the first model (Q1) concerning the bachelor's courses. And to fix this schedule in the second model (Q1*), so the second model will only be focus on master's courses. However, making this process could decrease the optimal solution for the second model [16].

Moreover, some professors teach in the campus of Louvain-La-Neuve and in the campus of Mons. A constraint can be added to avoid a teacher to make travels between the 2 campus in a same day.

$$\forall l \in LTM(t),\ \forall k \in LTL(t)\ \forall t \in T,\ \forall d \in D$$
$$\sum_{p \in PD(d)} \sum_{r \in R} x^r_{k,s} + x^r_{l,s} \leq 1$$

[2]

$LTM(t)$:Set of lesson of teacher (t) in Mons
$LTL(t)$:Set of lesson of teacher (t) in LLN

Possible Soft constraint to add

To improve the quality of this model, a soft constraint can be added to have a condensed schedule for each class, as described below:

$$max\ f(x) - \sum_{s \in P} \sum_{p \in P} \sum_{l \in L\mathfrak{C}(\mathfrak{c})} \sum_{k \in L\mathfrak{C}(\mathfrak{c})\ and\ k \# l} \sum_{\mathfrak{c} \in \mathfrak{C}} \sum_{r \in R} x^r_{l,p} * x^r_{k,s} * |p - s|$$

This soft constraint will penalize the value of the objective function if the periods of two lessons belonging to the same class are far from each other. However, this constraint is nonlinear due to the multiplication of the 2 variables [16].

A possible solution is to add an artificial variable for this soft constraint that will imitate the result of the multiplication of the 2 variables, see table 5 and constraint(11) [15].

$$max\ f(x) - \sum_{s \in P} \sum_{p \in P} \sum_{l \in L\mathfrak{C}(\mathfrak{c})} \sum_{k \in L\mathfrak{C}(\mathfrak{c})\ and\ k \# l} \sum_{\mathfrak{c} \in \mathfrak{C}} z^{k,s}_{l,p} * |p - s|$$

$S.t$

$$z^{l,p}_{k,s} = \begin{cases} 1, & \text{if lesson(l) starts at period(p) and} \\ & \text{lesson (k) starts at period (s)} \\ 0, & \text{otherwise} \end{cases}$$

$$\forall k \# l \in L, \forall\ s\ and\ p \in P$$
$$z^{k,s}_{l,p} = \sum_{r \in R} x^r_{l,p} - (1 - \sum_{r \in R} x^r_{k,s}) \quad (11)$$

$\sum_{r \in R} x^r_{l,p}$	*	$\sum_{r \in R} x^r_{k,s}$	=	$z^{k,s}_{l,p}$
0	*	1	=	0
1	*	0	=	0
0	*	0	=	0
1	*	1	=	1

Tab. 5: multiplication result

Adding this soft constraint increased the complexity of the model due to the large number of variables that the model needs to take into account. For this reason, this soft constraint was not added to the model to avoid complexity and a high computational time[18].

6 Conclusion

The timetabling problem, is a problem taking time and resources to the Louvain School of Management. This thesis tackled this issue using an integer linear programming model applicable to the specification of the faculty. We proved the better performances of this model by comparing the optimal solution with the current solution, and we highlighted some weaknesses and strengths. At this moment, this thesis does not pretend to solve all the problems of the LSM concerning the scheduling. However, this model can be useful for the faculty to assign lessons to time slot avoiding unnecessary conflict of teacher and students. But not for the allocation of rooms since the scope of this thesis does not consider the other faculties. Nevertheless, in the future, this model could be implemented to the LSM case if a higher collaboration with the stakeholders, an

[2] This constraint was successfully implemented and encoded on the trymodel

expansion of the scope with the other faculties and the use of a powerful computer with enough memory space is provided to be able to run the successfully.

Note

To have access to the data used, the designed codes, the excel sheets, the results and the trymodel file please go to the Webpage.

Aknowledgement

I am grateful to the administration of the Louvain School of management for the useful information and time shared with me in order to understand the timetabling issue. Furthermore, I am grateful to the professor Daniele Catanzaro for his support during this master thesis.

References

[1] Acosta-Amado, R.J. (2013) *An Integer Programming Model for The Academic Timetabling Problem*, Proceedings of the 2013 Industrial and Systems Engineering Research Conference.doi:10.13140/2.1.3910.9122

[2] Akif Bakır,M., & Aksop.C (2008) *A 0-1 integer programming approach to a university timetabling problem*,Hacettepe Journal of Mathematics and Statistics, 37(1), 41-55.

[3] Alvarez-Valdes,R. Crespo,E. & Tamarita,J. (2002). *Design and implementation of a course scheduling system using Tabu Search*, European Journal of Operational Research, 137, 512-523

[4] Asmuni, H. (2008). *Fuzzy methodologies for automated university timetabling solution construction and evaluation*, Ph.D. Thesis, School of Computer Science University of Nottingham.

[5] Babaei,H., Karimpour,J., & Hadidi,A. (2015).*A survey of approaches for university course timetabling problem*, Computers Industrial Engineering, 86, 43–59

[6] Borges, A., Leite,A., Ospina,R. Silva.G. (2015).*Integer Programming model for university courses timetablinh:A case study*, Retrieved from Google Scholar: http://www.din.uem.br/sbpo/sbpo2015/pdf/142935.pdf.

[7] Carter, M. & Laporte, G. (1997). *Recent developements in practical course timetabling. Practice and Theory of Automated Timetabling*, Lecture Notes in Computer Science, 1408, 3-19.

[8] Christodoulos A., Floudas & Xiaoxia.L. (2005).*Mixed Integer Linear Programming in Process Scheduling: Modeling, Algorithms, and Applications*,Annals of Operations Research volume,139,131-162

[9] Dash Optimization. (2007). *Xpress-Mosel Reference manual*,UK.

[10] Daskalaki, S. , Birbas, T. & Housos, E. (2004).*An integer programming formulation for a case study in university timetabling*,European Journal of Operations Research,153, 217-235

[11] De Werra, D. & Hertz.(1989)*A. Tabu search techniques: a tutorial and an application to neural networks*,OR Spectrum,11,131-141

[12] Dimopoulou, M., & Miliotis, P. (2001).*Implementation of a university course and examination timetabling system*,European Journal of Operations Research,130, 202-213.

[13] Gotlib,C. (1963).*The construction of class-teacher timetables*,International Federation for Information Processing,73-77.

[14] Obit, J. H., Landa-Silva, D., Ouelhadj, D., Khan Vun, T., Alfred, R. (2011). *Designing a multi-agent approach system for distributed course timetabling.* IEEE

[15] Rafeek, F. & Siswanto, N. (2016). *Solving Course Timetable Problem by using Integer Linear Programming (Case Study IE Department of ITS)*, Surabaya, Indonesia

[16] Rardin, R. L. (2014). *Optimization in Operations Research,* Edinburgh:Pearson New International Edition.

[17] Redl, T. A. (2004). *A study of university timetabling that blends graph coloring with the satisfaction of various essential and preferential conditions.* Ph.D. Thesis, Rice University, Houston, Texas.

[18] Saldaña Crovo, A., San Martín, C. & Pradenas Rojas,L. (2007) *Model of integer programming for an university timetabling problem*, Revista chilena de ingeniería,15(3), 245-259

[19] Sánchez-Partida,D. , Martínez-Flores,J.F & Olivares Benítez,E.(2014).*An integer linear programming model for a university*

timetabling problem considering time windows and consecutive periods,Journal of Applied Operational Research,6(3),158-173.

[20] Tomi Aij,O., Pekka,J., Askel,A., ,Tapio.E., Heikki,K. & Jarmotakala. (2015).*Integer Linear Programming-Based Scheduling for Transport Triggered Architectures*,ACM Transactions on Architecture and Code Optimization,12(4),1-22

[21] UCLouvain. (2020). *Caractéristiques et équipements des auditoires,* Retrieved from UCLouvain: https://intranet.uclouvain.be/fr/myucl/administrations/adpi/equipements-auditoires-lln.html.

[22] UCLouvain. (2020). *Formations de la Louvain School of Management (LSM),* Retrieved from UCLouvain: https://uclouvain.be/fr/catalogue-formations/faculte-2019-lsm.html

7 Annex

	LUNDI											MARDI							
	8:30 - 9:30	9:30 - 10:30	10:45 - 11:45	11:45 - 12:45	14:00 - 15:00	15:00 - 16:00	16:15 - 17:15	17:15 - 18:15	18:15-19:15	19:15-20:15	20:15-21:1	8:30 - 9:30	9:30 - 10:30	10:45 - 11:45	11:45 - 12:45	14:00 - 15:00	15:00 - 16:00	16:15 - 17:15	17:15 - 18:15
LLSMS2032* Advanced Operations Management : Models and Appl																			
LLSMS2033 International Supply Chain Management																			
LLSMS2033* International Supply Chain Management *													Socrate23	Socrate23	Socrate23				
LLSMS2034 Supply Chain Planning					Socrate25	Socrate25													
LLSMS2034* Supply Chain Planning *																			
LLSMF2043 Innovation Policy and Ecosystems				Lecl73	Lecl73														
LLSMF2043* Innovation Policy and Ecosystems*																			
LLSMS2374 Economics of the Internet																			
LLSMS2374* Economics of the Internet*																			
LLSMS2080 International Entrepreneurship		Lecl73	Lecl73																
LLSMS2080* International Entrepreneurship*																Lecl73	Lecl73	Lecl73	
LLSMS2028 Central banking, financial regulation, supervision					Erasm58	Erasm58													
LLSMS2028* Central banking, financial regulation, supervision*																			
LLSMS2140 International corporate finance																			
LLSMS2140* International corporate finance*													Erasm58	Erasm58	Erasm58				
LLSMS2129 International financial management																			
LLSMS2129* International financial management*																			
LLSMS2012 Macro Finance																			
LLSMS2012* Macro Finance*													Lecl73	Lecl73	Lecl73				
LLSMS2226 Credit and interest rate risk																			
LLSMS2226* Credit and interest rate risk *																			
LLSMS2138 Big data in finance																			
LLSMS2138* Big data in finance *																			
LLSMS2003 Brand Management				More54	More54														
LLSMS2003* Brand Management*																			
LLSMS2004 Big Data/Data Mining Applied to Marketing																			
LLSMS2004* Big Data/Data Mining Applied to Marketing*																			
LLSMS2006 On-line and Off-line Communication Strategies		More54	More54																
LLSMS2006* On-line and Off-line Communication Strategies*																More57	More57	More57	
LLSMS2065 Cross Cultural Competences and Management																			
LLSMS2065* Cross Cultural Competences and Management*																			
LLSMS2114 Entrepreneurship																			
LLSMS2114* Entrepreneurship*													Lecl82	Lecl82	Lecl82				

Fig. 7: possible configuration