PROJECT 2 – 2024-2025

University Course Timetabling Problem (UCTP)

DEM-ISEP University Course Timetabling

1. Introduction

Modernizing and optimizing the timetabling process at ISEP, particularly in the Mechanical Engineering Department (DEM), is essential for improving operational efficiency and responsiveness to both faculty and student needs. To date, university timetables at DEM-ISEP have been created manually. This process requires a significant investment of resources, both in terms of the faculty responsible for the task and the time spent ensuring the schedules are error-free.

The current manual method of creating schedules is labour-intensive, often requiring faculty to rely on past timetables and adjust. As the complexity of academic scheduling increases, with the need to balance various types of classes—such as theoretical, practical-laboratory, and seminars—against the availability of resources like classrooms and faculty, the limitations of this manual approach become increasingly apparent.

As universities face increasing demands for flexibility and efficiency in managing their operations, the ability to adopt and integrate new technological solutions will be key to maintaining competitive and effective educational environments.

This project addresses these needs directly, positioning ISEP to better meet the challenges of contemporary academic scheduling.

1.1 Objectives

This project aims to study the current process, develop, and implement an algorithm to address the University Course Timetabling Problem (UCTP) at the Mechanical Engineering Department.

2. University Course Timetabling Problem (UCTP)

According to (Babaei et al., 2015), the goal of the university course timetabling problem (UCTP) is to allocate events, which include students, professors, and courses, to predefined timeslots and rooms while satisfying all constraints. These constraints encompass the availability and capacities of resources such as classrooms and their equipment. Timeslots consist of daily and weekly components, varying by institution. The challenge lies in creating a conflict-free schedule that efficiently meets the requirements of all involved parties and optimizes the use of resources.

In contrast to high schools, universities often have larger and more diverse student populations, resulting in greater complexity in timetabling. Universities may need to accommodate various degree programs, each with its own set of required courses and scheduling preferences.

Two main approaches to university course timetabling are Curriculum-based and Enrolment-based. In Curriculum-based Timetabling, courses are scheduled according to the university's curriculum, ensuring that required courses are offered at appropriate times to meet degree requirements. Enrolment-based Timetabling, on the other hand, considers individual student enrolment data to accommodate students' preferences and ensure that they can attend all required courses without scheduling conflicts.

The university timetabling problem is complex and challenging, particularly when approached using integer programming (IP) models. The model proposed by Daskalaki et al. (2004) was selected as the basis for adapting the scheduling system at DEM-ISEP. This choice was driven by several factors. First, the Daskalaki model utilizes a 0-1 integer programming formulation that aligns well with the complexities and characteristics of DEM-ISEP scheduling needs. The use of binary variables simplifies the modelling of multiple classes, professors, rooms, and course units, making it suitable for DEM-ISEP requirements. Second, the model's structure reduces complexity by using auxiliary variables to manage consecutive periods and repeated sessions, which are essential for effective timetable creation at DEM-ISEP. This approach helps keep the problem computationally tractable, avoiding excessive complexity despite the numerous elements involved. Third, the effectiveness of the Daskalaki model is supported by its proven results. The model has demonstrated success in solving problems of various sizes, with optimization times ranging from minutes to slightly over an hour, depending on the problem scale. This performance indicates that the model can be adapted to DEM-ISEP with reasonable expectations of achieving viable solutions within a suitable timeframe.

3. Description of the DEM Timetabling Process

Course-based timetables are created twice a year, before the beginning of each semester. Several problems can arise when creating timetables manually:

- Creating timetables manually can be a time-consuming process, often taking several days to complete by a faculty team.
- The quality of the timetables may be affected by tight deadlines and the varying experience of those involved in timetable creation.
- The outcome is significantly influenced by the initial method used for creating the timetables.
- Each department has different constraints, making it difficult to apply a general algorithm.
- Inefficient allocation of rooms and resources can lead to underused spaces and scheduling conflicts.
- There is an increased risk of mistakes, such as overlapping classes or incorrect course assignments.
- Adjusting schedules to accommodate unexpected changes or faculty availability can be challenging.
- It can be difficult to accommodate professors' preferred teaching times.
- Poor communication between departments can result in conflicting or poorly distributed schedules.
- As the university grows, manual processes become increasingly unsustainable.

The DEM comprises more than 2000 students, offering 3 bachelor's degrees, 5 master's degrees, and 18 postgraduate degrees. Over 100 faculty members are involved in teaching these programs. It is noteworthy that each program follows a semester-based curriculum structure, with student cohorts organized by course and faculty allocation.

Each semester, the created timetables must provide specific and indispensable information, including:

- Course name
- Subject

- Name of the professor
- Class type
- Classroom
- Day of the week
- Period of the day

The creation of timetables at ISEP is a manual process, based on some rules/definitions and the schedules of previous years, such as:

- Each degree consists of multiple courses, which are taught based on predefined number of hours and class types outlined in the course syllabus.
- Each course is designated as either semester-long or year-long and is assigned to a specific year within the degree program.
- All students within a particular group attend the same degree program, courses, and classes, scheduled at designated time slots.
- The allocation of student groups and faculty members to courses is predetermined (e.g., group 1NA of LEM attends ALGAN taught by MGM).
- A weekly plan is established for each course, specifying the types of classes (e.g., ALGAN comprises 2 hours of theoretical class and 2 hours of theoretical-practical class).
- Theoretical (T) classes may be taught by more than one faculty member.
- The classes for 1st and 3rd-year undergraduate courses are held during the morning periods, while the classes for 2nd-year courses are scheduled in the afternoons.
- Availability of department classrooms is generally not restricted.

Also, there are some pre-assignments defined, such as the number of students enrolled in each course are considered to divide them into several timetables (Table 1).

Table 1 - Distribution of students into several timetables for each course

Degree	Course	Type	Hours	Prof	A	B	C	D	E
LEM	ALGAN	T	2	ATM	1	1	1	1	1
LEM	ALGAN	TP	2	ATM	1	1			
LEM	ALGAN	TP	2	ATM			1	1	1
LEM	APROG	T	1	ARF	1	1	1	1	1
LEM	APROG	PL	2	ARF	1				
LEM	APROG	PL	2	ARF		1			
LEM	APROG	PL	2	ARF			1		
LEM	APROG	PL	2	ARF				1	1
LEM	CMATE	T	1	RBC	1	1	1	1	1

Each type of class has a maximum allowed number of students. For example, in theoretical classes, a maximum of 100 students is permitted, meaning that a course with more than 100 students will need to be divided into 2 timetables.

Subsequently, each faculty member is assigned to their respective courses, detailing the number of each type of class each professor will teach. The following table illustrates how the professors' assignments were made. For example, as we can see on Table 2, Professor MGM teaches one TP class and one T class for the course ALGAN in the evening. Meanwhile, Professor DPP teaches two PL classes for the course APROG, also in the evening.

Table 2 - Distribution of classes for each course according to each professor.

Course	Professor	Program	Num T	Num TP	Num PL	Num OT
ALGAN	MGM	Evening	1	1		
ALGAN	GCV	Evening		1		
APROG	JSM	Evening	1			
APROG	DPP	Evening			2	

Additionally, considering the characteristics of each room and the specific requirements of each class, each classroom is assigned a type based on type of class. Also, in the case of Laboratories it is assigned a knowledge area according to the equipment present in the room.

Therefore, considering the characteristics of each room and the specific needs of each class, each classroom is attributed a type, according to its features and function (Table 3).

Table 3 - Designation of each classroom defining the type and knowledge area (example).

Room	Type	AREA
F102	L	FLUID
F103	L	META
F104	L	ROBOT
F114	L	AUTO
F209	TP	
F214	L	PC
F223	L	CM
F224	M	PC
F225	M	PC
F226	M	PC
F317	TP	
F322	M	PC
F341	T	
F342	T	

Room Type Symbol	
T	Theoretical
TP	Theoretical-practical
L	Laboratory
M	Mixed (TP or L)

Knowledge Area	
FLUID	Fluids
META	Metalography
ROBOT	Robotic and Automation
AUTO	Automobile
CM	Mechanical Construction

The Table 4 it is an extract of the room assignment table for every curricular unit based on the type of the class (T, TP and PL). In particular for the PL classes, each teaching session is assigned to a specific laboratory according to the type of laboratory required for the knowledge area.

Table 4 – Assignment of each classroom based on the type and the knowledge area for each course.

Course	T	TP	PL	Type Laboratory
ALGAN	T(1h+1h)	TP(2h)	-	
ANPRO	-	-	L(3h)	PC
APROG	T(1h+1h)	-	L(2h)	PC
AUTO1	T(1h+1h)	-	L(2h)	ROBOT
AUTO2	T(1h+1h)	-	L(2h)	ROBOT
CEFAC	-	-	L(3h)	PC
CMATE-M	T(1h+1h)	-	L(2h)	META
DEGER	-	TP(2h)	L(2h)	PC
DESET	-	TP(2h)	L(2h)	PC

Given the specific context of DEM-ISEP, it was necessary to adapt certain aspects of the Daskalaki model. To align the model with the department objectives, general parameters were added. As a result, parameters *I*, *J*, *K*, *L*, *M,* and *N* were kept, while parameter *T* was introduced considering the type of class:

I is the set of all days possible for scheduling (from Monday to Friday).
J is the set of all time periods in each day available for scheduling.
K is the set of all DEM degree/year/semester/regime that may be used for a given timetable.
L is the set of all the professors available to teach.
M is the set of courses.
N is the set of classrooms available.
T is the set of types of classes (T, TP, PL).
The parameter *T* was introduced to align with the department's need for the scheduling of classes based on their type. This enables lectures to be grouped specifically in the morning or afternoon and simplifies the assignment of classes to particular time slots depending on their nature. For instance, in certain cases, it may be preferable to schedule theoretical classes before theoretical-practical and laboratory-practical sessions.

The model was adapted also by incorporating new parameters based on the main ones, considering the available data to test the model and to simplify the process of fitting the constraints. Various combinations of these parameters were tested to adjust the model effectively.

In this approach, each professor is assigned specifically to their course and to the appropriate classrooms designated for that type of class. For instance, if Professor MGM is scheduled to teach the course ALGAN, he cannot be assigned to teach any other course in the same period time.

To organize this, "blocks" were established for student groups. Each block includes only one professor and one course. Each block represents a time period in the timetable. During each time period, parameters are set based on possible combinations of assignments.

The variables that can be adjusted are the day, the time of day, and the available classrooms for the class. Classrooms are pre-selected based on the type of class for that block, whether it is T, TP, or PL, as mentioned earlier.

Considering that the information is aggregated by k, the parameters were defined according to this logic. This means that for any given value of the other parameters (such as classrooms, professors, course, type of class), the value of k is unique for each combination. Consequently, the following parameters are defined:

I_k – day *i* available for degree/year/semester/regime *k*.

J_k – time period *j* available for degree/year/semester/regime *k*.

J_{ki} – time period *j* of the day *i* available for degree/year/semester/regime *k*.

L_k – faculty member of degree/year/semester/regime k.

L_{km} – faculty member of degree/year/semester/regime k, teaching course m.

L_{kmt} – faculty member of degree/year/semester/regime *k*, teaching a class of type *t* for course *m.*

K_l – set of degree/year/semester/regime for which professor *l* offers some course (for example, professor 'ABC' can teach more than one degree).

M_k – courses of degree/year/semester/regime *k*.

M_{kl} – courses of degree/year/semester/regime *k*, taught by professor *l*

M_{kn} – courses of degree/year/semester/regime *k*, taught in classroom *n*.

T_{km} – type of classes for course *m* of degree/year/semester/regime *k*

T_{kml} – type of classes for course *m* taught by professor *l* of degree/year/semester/regime *k*

T_{kmn} – type of classes for course *m* of degree/year/semester/regime *k*, taught in classroom *n*

N_k– classroom *n* that fits for degree/year/semester/regime *k*

N_{kt} – classroom *n* that fits for the type of class *t* of degree *k*/year/semester/regime

N_{kmt}– classroom *n* that fits for the type of class *t* for course *m* of degree/year/semester/regime *k*.

c_{kmlt} – number of classes (repetitions) of type *t* for course *m* of degree/year/semester/regime *k*, taught by professor *l*.

p_{ki} – periods available for degree/year/semester/regime *k* on day *i*.

h_{kmt} – duration (time periods) for the type of class *t* for course *m* of degree/year/semester/regime *k*.

A main set of binary variables is utilized, represented by $x_{i,j,k,l,m,t,n}$, *w*hich includes the newly added general parameter *t*. Additionally, an auxiliary binary variable with the same indices, $y_{i,j,k,m,l,t,n}$ is employed to enforce the completeness and consecutiveness constraints.

The variable $z_{i,l}$ is an additional binary variable introduced to monitor the number of days each professor *l* teaches.

To demonstrate how the adapted model functions, consider the following example. Suppose professor 'ABC' is assigned to teach two lab ('PL') sessions of the course 'VWXYZ'. If the variable *x*[*i*=0, *j*=0, *k*=11, *m*= 'VWXYZ', *l*='ABC', *t*='PL', *n*='F101'] is equal to 1, this indicates that on Monday (*i*=0) at 8 a.m. (*j*=0), professor 'ABC' is teaching a one-period block of the lab ('PL') sessions for the course 'VWXYZ' of degree/year/semester/regime 11,in room 'F101'. This variable corresponds to a specific one-period time slot.

The hard constraints for the adapted model include uniqueness constraints, ensuring the absence of conflicts; completeness constraints, ensuring the timetable is filled according to the required characteristics; and consecutiveness constraints, ensuring multiperiod classes are represented by consecutive blocks.

– Ensures that all classes of all courses in the curriculum should be in the timetable and in the right amount of teaching periods (c_{kmlt}):

$$\sum_{i \in I_k} \sum_{l \in L_{km}} \sum_{j \in J_{ki}} \sum_{n \in N_{kmt}} x_{i,j,k,l,m,t,n} = c_{kmlt}, \forall k \in K, \forall m \in M_k, \forall t \in T_{km} \tag{1}$$

– The equation (2) ensures that if a professor is scheduled to teach any class on a particular day, then the binary variable $z_{i,l}$ will be set to 1. Conversely, if the professor is not scheduled to teach on that day, $z_{i,l}$ will be 0.

$$\sum_{k \in K_l} \sum_{j \in J_k} \sum_{m \in M_{kl}} \sum_{t \in T_{kml}} \sum_{n \in N_{kmt}} x_{i,j,k,l,m,t,n} \leq |J| * z_{i,l}, \forall i \in I \ , \forall l \in L \tag{2}$$

– The equation (3) ensures the uniqueness for each professor, i.e., every professor is assigned at most one class and one classroom, on a given period of a given day:

$$\sum_{k \in K_l} \sum_{m \in M_{kl}} \sum_{t \in T_{km}} \sum_{n \in N_{kt}} x_{i,j,k,l,m,t,n} \leq 1 \ \forall i \in I \ , \forall j \in J \ , \forall l \in L \tag{3}$$

– This equation (4) guarantees that every classroom may be assigned at most one course, one professor on a given period of the day of a given day:

$$\sum_{k \in N_k} \sum_{l \in L_k} \sum_{m \in M_{kl}} \sum_{t \in T_{kml}} x_{i,j,k,l,m,t,n} \leq 1, \forall i \in I, \forall j \in J, \forall n \in N \tag{4}$$

– Considering the structure of the parameters created, the original set of completeness constraints was adapted, and the equations were merged due to the redundancy, obtaining equations (5) and (6), that ensure simultaneously the development of the timetables considering both the right amount of teaching periods for each group of students and the required teaching periods for each course. On equation (5), the auxiliary variable combined with the consecutiveness constraint – equation (6), ensures that each class that needs more than one teaching period, is present in the timetable in the right amount (h_{kmt}).

$$\sum_{i \in I_k} \sum_{n \in N_{kmt}} \sum_{j=1}^{j=p_{ki}-h_{kmt}+1} y_{i,j,k,l,m,t,n} = 1, \forall k \in K, \forall m \in M_k, \forall l \in L_{km}, \forall t \in T_{km} \tag{5}$$

– To ensure that multiperiod classes (classes with more than one time period) are consecutive, i.e., in periods of the day with no break between them, equation (6) was adapted:

$$\sum_{j_v=j}^{j+h_{kmt}} x_{i,j,k,l,m,t,n} \geq h_{kmt} * y_{i,j,k,l,m,t,n} \tag{6}$$

$\forall k \in K, \forall i \in I_k, \forall m \in M_k, \forall l \in L_{km}, \forall t \in T_{kml}, \forall n \in N_{kmt}, \forall j \in J_{ki} \;\wedge\; j \leq p_{ki} - h_{kmt}$

A constraint was also added to prevent the overlapping of classes, ensuring that the same class group does not take different classes simultaneously. For example, in the case of ALGAN, the service distribution indicates that there is one theoretical (T) class for two practical (TP) classes. None of these TP classes can be scheduled at the same time as the T class, as defined by Equation 7.

$$\sum_{n \in N_{kt}} \sum_{j=1}^{j=p_{ki}-h_{kmt}+1} y_{i,j,k,l,m,t,n} + \sum_{(kr,mr,lr,tr) \in S_{kmlt}} \sum_{n \in N_{krtr}} \sum_{j=1}^{j=p_{kri}-h_{kmt}+1} y_{i,j,kr,mr,lr,tr,n} \leq 1, \tag{7}$$

$$\forall (k,m,l,t) \in C_{kar},\ \forall i \in I_k,$$

The multiobjective function is the following:

$$Min \left\{ \sum_{k \in K} \sum_{l \in L_k} \sum_{m \in M_{kl}} \sum_{n \in N_{mk}} \sum_{i \in I_{ln}} \sum_{j \in J_{iln}} \left[(w_1 a_{i,j,k} + w_2 j + w_3 b_{i,j,l}) * x_{i,j,k,m,l,t,n} \right] + w_4 \sum_{l \in L_k} \sum_{i \in I_k} z_{i,l} \right\} \tag{8}$$

In the multiobjective function, the aim is to minimize a cost function composed of four components.

The first component relates to the cost of scheduling a specific class for a course at a given day time block. Given the high risk of schedule conflicts for students enrolled in course units from previous academic years, the Department has established that class schedules for consecutive years should not use the same daily blocks. Therefore, it has been decided that, whenever possible, daytime classes for first-year students should be scheduled in the morning period (8:00 AM – 1:00 PM). Second-year daytime classes should be scheduled in the afternoon period (1:00 PM – 6:00 PM), and third-year daytime classes should be scheduled in the morning period (8:00 AM – 1:00 PM). Similarly, since the Department offers programs in both daytime and evening formats, daytime classes must take place between 8:00 AM and 6:00 PM, while evening classes must be scheduled between 6:00 PM and 11:30 PM.

The second component accounts for the cost of scheduling classes with interruptions or holes in the daily blocks.

The third component reflects the professors' preferences for teaching during specific periods on specific days. The fourth minimizes the total number of days per week professors need to teach.

In this model, the cost coefficients are assigned to reflect preferences for specific time slots throughout the day and particular days of the week and are defined empirically. The weights (w_1, w_2, w_3, w_4) are used by the decision maker to tune the solutions to desired timetabling preferences.

– Assignment of values to $b_{i,j,l}$ coefficients according to professor *l*'s preferences for teaching during period *j* on day *i*.

The values assigned to the $b_{i,j,l}$ coefficients are based on the preferences of professors for teaching during specific periods on specific days. Table 4 shows an extract from the professor's preferences matrix. The values 1 and -1 represent the 'prefer' and 'not available' statuses, respectively, while 0 represents 'neutral'.

These coefficients are crucial because they reflect the individual preferences of professors, which are essential for creating a timetable that aligns with both personal and institutional needs. The higher a professor's preference for a particular time slot, the lower the penalty value assigned.

Table 4 - Preferences of professors

Professor	Mon_1	Mon_2	Mon_3	Mon_4	Mon_5	Mon_6	Mon_7	Mon_8
ABG	1	0	0	1	1	1	1	0
ACT	1	0	1	1	1	0	0	0
ADP	1	0	1	1	1	1	1	1
ADS	0	0	1	0	1	1	1	0
AFO	0	0	0	0	1	0	1	1
AFS	1	1	1	1	1	0	1	0
AGM	1	-1	0	1	1	0	1	1
AGP	0	1	1	-1	1	0	0	0
AGR	1	0	0	1	1	1	-1	1
AGS	1	-1	0	1	1	1	0	-1

4. Projects

The following projects are available for teams of a maximum of two students:

1. Using SQLite database engine (SQLite Home Page), create a database to support the problem dataset.
2. Using *Python* programming language:
    a. Create a constructive heuristic to solve the problem for the given test instance.
    b. Select and implement a metaheuristic to improve the solution obtained in a).

5. Project Dataset

In the PRJT2 Support Data excel file it is provided the dataset relative to the 1st semester 2020-2021.

The PRJT2 Support Data excel file has the following sheets:

- Course Plan – list of curricular units of the LEM course
- Rooms – list of department rooms with the description of the room type and knowledge area
- UC_Room – classroom assignment matrix correlating for every curricular unit class type the respective duration quantity and in case of laboratory sessions the respective laboratory.
- Service – the teaching duty for every teacher defining the number of classes per curricular unit session type.
- Week_Frame – to ensure clarity and consistency in scheduling, the weekly timetable is divided into three distinct time blocks
- L-1D_20_21: this sheet presents the assignment to every curricular unit the set of blocks of classes detailing the respective teacher.
- Output_Example – presents an example of the filled output template
- Output Template – presents the excel sheet which must be filled with every class schedule solution.

6. Rules and Deliverables

The assignment is compulsory and must be solved and reported by a team of no more than 2 students.

The proposed solution should be coded using *Python* as programming language.

The deliverables of the project are:

- The report of the solution proposal, that should include:
    - the description and explanation of the proposed solution

        - a performance analysis of the proposed solution
    - The solution implementation (including the pseudocode of the algorithms)
    - The presentation

The work developed will be presented and discussed after its conclusion. A template for the report of the solution proposal is available in UC page in Moodle.

The grade given to each student has two main components: the first results from work submitted by the group and the second from the presentation and discussion of the work. The result of the second component is individual. The submission dates of the deliverables and the weight in the evaluation of the first component of the work are indicated in Table 5.

Table 5 - Submission dates and grade weights of the first component

Deliverable	Due Date	Weight (%)
Solution and Report	July 22, 2025	50
Presentation and Discussion	July 23-25, 2025	50

No submissions are accepted beyond the dates indicated in the table. The presentation and discussion of the work are scheduled for the period of 23-25, July, at a time to be agreed with each group. The presentation has a maximum duration of 10 minutes and has as main objective the demonstration of the functionalities of the developed solution. The presentation is followed by an up to 20 min discussion. The Report of the solution proposal and the project Solution and Presentation files must be submitted by one of the members of the group via Moodle, on the UC page. If more than one file is to be submitted in each deliverable, a single zip-file containing all files must be created for submission. The name of the submitted files must follow the format indicated in Table 6.

Table 6 - File name format

Deliverable	File Format
Report	Group xx - Report
Solution	Group xx - Solution

References

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

Daskalaki, S., Birbas, T., & Housos, E. (2004). An integer programming formulation for a case study in university timetabling. European Journal of Operational Research, 153(1), 117–135.