AUTOMATED DISTRIBUTION OF TEACHING TASKS WITH MAXIMUM CONSTRAINT SATISFACTION: MATHEMATICAL MODELING OF A REAL CASE STUDY AT UNIVERSITY

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***ABSTRACT**: University timetable generation is a complex NP-hard problem requiring robust decision-support tools for effective planning and management. While significant research exists in this domain, most efforts focus on automating time and space allocation, often overlooking the critical aspect of teaching task assignment. This study aims to bridge that gap by proposing a new mathematical model for the automatic distribution of teaching tasks, prioritizing the satisfaction of faculty preferences and the equitable balancing of workloads. Applied to a real case study in a university department, the results demonstrate that the automated system significantly outperforms manual methods. It provides a practical and scalable solution to enhance operational efficiency while saving substantial time and effort. By addressing a vital yet underexplored aspect of academic planning, this work contributes to the optimization of university management systems and highlights the benefits of integrating advanced methodologies in institutional processes.*

***KEYWORDS**: University Course Timetabling Problem UCTTP; Faculty Assignment Problem; Automated Tasks Distribution; Constraint Satisfaction; Mathematical Modelling.*

1 INTRODUCTION

Several contributions related to the problem of planning teaching tasks have appeared since the end of the fifties. This type of problem is very complex due to the huge number of constraints that must be met (Ceschia et al., 2023).

The objective of the schedule planning task is to organize human activities over time and optimize the use of resources to cover a need expressed by a workload planned under various constraints. If done manually, this kind of planning may be a tedious task that involves several people over several days. Furthermore, the slightest change in terms of data or constraints of the problem will cause a reset of the optimal plan search. Therefore, the use of IT tools and optimization algorithms will seem necessary in order to automate the generation of timetables. Automatic generation of a timetable is the activity of creating, managing and maintaining a timetable with minimal human intervention while maximizing the satisfaction of constraints (teachers' preferences, rooms' availability, etc.). Therefore, the developed system should be able to manage temporal and material resources as well as imposed constraints (Aziz & Aizam, 2018).

The scheduling problem comes in many different forms, each specific to the environment or institution (Tan et al., 2021). In our case, the studied timetable problem is that of the university. Each year, our pedagogical managers need to establish a new plan for the different training courses by trying as well as possible to satisfy teachers and students' constraints, pedagogical constraints as well as material resources' constraints.

Teaching nature has changed considerably over the years, so that planning requirements have become much more complicated than before. Therefore, the need for automated schedule generation systems is increasing.

Regarding university timetables problem, it can be divided into two sub-problems. First, teachers should be assigned to teaching tasks. This case is generally referred to as "Teaching Tasks' Distribution". Second, to each teacher/teaching task pair, timeslots, rooms and groups of students should be affected. This mission is well known as ‘Timetable Programming”. In the literature, some works have treated each case separately (Betaouaf et al., 2021) while others have chosen to make it a single problem (Algethami & Laesanklang, 2021). In addition, the constraints used in the academic scheduling problem can be divided into hard or mandatory constraints and soft or preferential constraints. Hard constraints are mandatory rules that must be respected at all costs, while soft constraints represent desirable preferences, and the aim is to minimize their violation as much as possible (Babaei et al., 2015).

In our study, we chose to deal with teaching tasks’ distribution separately to the timetable programming by taking into account the studied system constraints (teacher preferences, etc.).

The distribution of teaching tasks, or the assignment of teachers to teaching tasks (teacher A teaches practical laboratory work for subject B), is one of the parts of university timetable generation that requires an automatic system to manage it because of the complexity involved in assigning human resources to teaching tasks while respecting pedagogical constraints and satisfying teachers' preferences and requirements.

In this paper, a support decision system for the teaching tasks’ distribution is proposed. To this end, the new developed mathematical model attempts to satisfy the maximum of teachers' preferences and balances the assigned loads between teachers within a reasonable time.

This article is structured as follows: the first section introduces our problem context. A detailed problem description is provided in the second one, while the third presents a literature review. Proposed solution through mathematical modelling can be found in the fourth section. Implementation of our case study as a fifth one. Finally, results are discussed in section six before concluding our paper.

2 PROBLEM DESCRIPTION

At each university, officials distribute teaching according to the qualifications of each teacher during the two semesters of the academic year. In addition, they can respect task parameters such as each teacher’s preferences or educational background that reflects his or her expertise in certain areas compared to others. We can also use teacher rating to give teaching preferences. Each department decides the nature and number of criteria to be observed in order to achieve maximum satisfaction of teachers, students and the department in terms of administration.

To optimize the objective function desired in this study, we need to satisfy the necessary number of units of each teaching for the two semesters in order to respect constraints such as: hourly volume of each teacher, satisfy the preferences of each teacher and respecting the qualifications of their specialty.

Each teacher belongs to a specific specialty according to their academic status while each teaching belongs to a specific specialty. Therefore, our first criterion of assignment is each teacher qualification for a specific specialty. In addition, to better manage our system, we considered the maximum satisfaction of teachers’ preferences.

In our study, each teacher has the possibility to choose some preferences for the first semester and others preferences for the second one, but this is not mandatory. In addition, each teacher has an annual hourly volume that must be respected in the final allocation of the system, additionally to a maximum threshold not to be exceeded in each semester.

Each teaching is defined by a code, a type with its own weighting coefficient, an option, a specialty, a semester and a number of required units. All this information is used in our study to assign all our teachers to the teachings we have in this department in order to respect the specialties of both, the teaching demand, the annual hourly volume and the teacher's maximum threshold in the two semesters, and even to respect the teacher assignment priorities with the aim of satisfying its preferences and even balancing loads between teachers.

3 LITERATURE REVIEW

In recent decades, automatic timetable generation has attracted enormous attention from the scientific community. This resulted in several approaches and research works that have been proposed to solve the problem of the preparation of timetables in academic institutions.

Generating a valid timetable that, at the same time, meets hard constraints related to teachers and student groups and maximizes the satisfaction of soft constraints (Alghamdi et al., 2020; Song et al., 2021), is the main objective of the proposed methods.

As already mentioned, studies have considered the problem of teacher assignment separately from the scheduling part of the timetable. In 1976, these studies began to be published following the results obtained by Breslaw (1976), and in parallel with the appearance of the notion of “Faculty Assignment Problem”. This research has continued to the present day. Moreira & Costa collected and analyzed research carried out from 1976 to 2022. This study, published in 2023, presented 37 publications including 27 scientific journal articles and 11 conference communications.

In order to identify our research field and position ourselves within similar studies, here are some approaches used in the studies carried out to resolve the teacher -course assignment problem:

The Hungarian method has been frequently used to solve the scheduling problem of teachers in order to automatically generate timetables. For instance, the Hungarian algorithm was exploited in Mampong-Akuapem Presby Senior High School to solve their assignment problem (Simon, 2012). Thus, a case study conducted in 2017 at Dutse Model International School demonstrated the effectiveness of the Hungarian allocation algorithm and LINGO software in optimizing course planning. The results obtained by these two methods were identical, maximizing the overall efficiency of the educational process (Kabiru et al., 2017). Furthermore, in 2021, Wattanasiripong and Sangwaranatee developed a program using this Hungarian method to assign teachers to each subject, reducing preparation time based on teachers' specific skills at a university in Thailand (Wattanasiripong & Sangwaranatee, 2021). In addition, Mallick et al. (2021) and Solaja et al. (2020) presented the same method for solving a concrete problem. In 2024, Ibrahim et al. used a modified Hungarian method to solve an unbalanced allocation problem, i.e., when the number of courses exceeds the number of teachers. The main objective of this study was therefore to allocate a teacher to a course corresponding to his /her area of expertise, level of preference and teaching competence. This model has been proposed to improve teacher satisfaction as well as teaching quality (Ibrahim et al., 2024). In another study by Mallick et al. (2024), a course allocation method has been designed to minimize the total number of teaching hours based on the Hungarian method. Subsequently, a simulation using MATLAB showed that the suggested method had a shorter computation time than the Hungarian method.

In addition to the Hungarian method, a general linear programming modelling is used to solve this kind of problem. In this context, Ongy (2017) developed a model to assign teachers to courses based on their skills (domain expertise) and their personal teaching-time preferences in terms of hours and days. Their proposed tool showed that overload and underload problems within a department can be solved. The corresponding mathematical model of the allocation process has been formulated using the mixed-integer linear programming and analyzed under MS Excel. In the same context, Szwarc et al. (2020) published a study aimed at assigning teachers to courses according to their skills fixed by the program, as well as the number and type of disruptions in the implementation of these courses, i.e., the needs of students and the skills of teachers faced with disruptions caused by teacher absenteeism and program changes. The principal contribution of this research therefore lies in its ability to absorb disruptions and produce robust teacher assignment schedules. The effectiveness of the developed method was verified using real data from Koszalin University of Technology for the 2019–2020 academic year. Thus, ILOG CPLEX Optimization Studio version 12.8 was used to implement an integer programming model in 2021 to allocate courses to teachers according to their specialty and to assign them a time slot at an institution in Mexico (Arratia-Martinez et al., 2021). In addition, the study of NA & HUSSIN (2021) is prepared to identify the most efficient method that can be used by the administrators of the Mathematics Department of the Faculty of Ocean Engineering Technology and Informatics in the University of Malaysia Terengganu. They suggest to automatically assign courses to teachers based on their years of experience in teaching the courses. Additionally, the system's constraints include the minimum and maximum number of courses to be assigned, as well as the number of teachers assigned to each course. A random assignment was carried out using Microsoft Excel, and the objective function of the obtained solution is compared with the objective functions of the exact solutions obtained using Open Solver and Python. Kusuma & Adiputra (2022) also proposed a model for assigning courses to teachers by taking into account the teachers' preferences in courses and time slots in order to adapt to Indonesia's national joint courses program. This study has three objectives. The first objective is to allocate courses to the most competent teachers in order to maximize the quality of teaching. The second objective is to assign a course to a preferred time slot to maximize teachers' satisfaction. The third objective is to minimize the number of unserved classes. This model was developed using integer linear programming and optimized using cloud theory-based simulated annealing. The proposed model is then compared with four models for assigning teachers to classes. Furthermore, to formalize and optimize the problem of teacher assignment to courses, an integer linear programming model was developed in 2023 taking into account the workload constraints of a university department offering engineering courses. Their proposed model was implemented and validate using the Delphi software (Seboni et al., 2023).

Our work is carried out after an extensive study of the various published research and different case studies. So, our proposition is applied and tested with a real case data, and its results are compared with those obtained manually. In this study, we make an analogy between the described system and the real system using a new MILP mathematical modelling. This model is solved with a solver, and the obtained results are evaluated with a bi-objective function. The first objective is to minimize assignment costs, and the other is to balance the loads assigned to each teacher to avoid overloading one over the other. In order to respect the constraints imposed by the system described and also to satisfy the maximum number of teachers' preferences without neglecting the teaching pedagogical satisfaction.

We found that general linear modeling is better suited to our system than the Hungarian method. Since, our system has to be modeled as a matrix and choosing the Hungarian method will produce a large multi-cell matrix. To this fact, minimizing our matrix size was mandatory in order to reduce the studied problem complexity. On the other hand, the Hungarian method does not allow to take into account certain scenarios that are part of our case study. These include the possibility of assigning a teacher to several teachings and assigning several teachers to a same teaching. Teachers' qualifications for each teaching, the maximum satisfaction of teachers' preferences, the requirements imposed for each teaching, the maximum thresholds of each teacher for the two semesters, the availability of each teacher and the balancing of loads between teachers are all mandatory constraints to be respected when using this method. Additionally, it should be noted that our system has been programmed to specify the missing units in each specialty in order to meet all the demands provided by the managers for all the teachings during the two semesters.

4 MATHEMATICAL MODEL

Using a mixed integer linear programming approach, this study's indices, restrictions, and problem-related parameters are explained below.

4.1 Index

The indexes used in the resolution model are:

$\boldsymbol{i = 1 .. n}$

n: number of permanent teachers.

$\boldsymbol{j = 1 .. m}$

m: number of teachings in semester 1.

$\boldsymbol{k = 1 .. p}$

p: number of teachings in semester 2.

$\boldsymbol{l = 1 .. q}$

q: number of part time teachers.

4.2 Data

In our model, various information about teachers is needed, such as: code, specialty, annual hourly volume, maximum threshold of the two semesters and preferences of each teacher. Regarding teaching, we need information such as: code, specialty, type, semester, demand, level and number of groups of each teaching. In addition, the qualification degree of each specialty is needed.

The notations used to represent these data are as follows:

$\boldsymbol{Demand\_S1_j}$:

Number of units necessary for each teaching j for all groups in semester 1.

$\boldsymbol{Demand\_S2_k}$:

Number of units necessary for each teaching k for all groups in semester 2.

$\boldsymbol{Supply\_P_i}$:

Maximum annual number of units assigned to the permanent teacher i.

$\boldsymbol{Supply\_Pt_l}$:

Maximum annual number of units assigned to the part time teacher l.

$\boldsymbol{Weighting\_coefficient\_S1_j}$:

A factor that is applied to the demand for each type of teaching j to weight it in order to equilibrate the charges assigned to each teacher in semester 1.

$\boldsymbol{Weighting\_coefficient\_S2_k}$:

A factor that is applied to the demand for each type of teaching k to weight it. This helps to balance the loads assigned to each teacher in semester 2.

$\boldsymbol{Maximum\_threshold\_S1\_P_i}$:

Maximum number of units assigned to the permanent teacher i in semester 1.

$\boldsymbol{Maximum\_threshold\_S1\_Pt_l}$:

Maximum number of units assigned to the part time teacher l in semester 1.

$\boldsymbol{Maximum\_threshold\_S2\_P_i}$:

Maximum number of units assigned to the permanent teacher i in semester 2.

$\boldsymbol{Maximum\_threshold\_S2\_Pt_l}$:

Maximum number of units assigned to the part time teacher l in semester 2.

$\boldsymbol{Cost\_S1\_P_{ij}}$:

A charge or penalty associated with each allocation of permanent teacher i to teaching j in semester 1.

$\boldsymbol{Cost\_S1\_Pt_{lj}}$:

A charge or penalty associated with each allocation of part time teacher l to teaching j in semester 1.

$\boldsymbol{Cost\_S2\_P_{ik}}$:

A charge or penalty associated with each allocation of permanent teacher i to teaching k in semester 2.

$\boldsymbol{Cost\_S2\_Pt_{lk}}$:

A charge or penalty associated with each allocation of part time teacher l to teaching k in semester 2.

Our system operates with two types of teachers: the permanent and the part time teacher. This means assignment costs differ from one kind to another. Therefore, costs are calculated as follows:

4.2.1 Permanent teachers' costs

The penalty associated with the assignment of a teacher who prefers to provide a teaching in his or her qualification is calculated by multiplying the preference with the qualification in that teaching. However, our system has the possibility of assigning to a teacher a teaching which he has not chosen but for which he is qualified. The penalty in this case is logically greater than the penalty associated with a teaching preference. It is therefore calculated by multiplying the qualification by a weight of 10 ($\boldsymbol{Penalty\_Qualif\_Not\_Pref}$), which means that our system favors teacher's preferences in order to minimize the objective function.

Though, if the teacher's preference is not based on their qualifications, then our system prohibits the possibility of entrusting this teaching to this teacher. This can be done by applying a penalty greater than that associated with previous cases. In this case, this allocation cost is the result of multiplying the preference by a weight of 1000 ($\boldsymbol{Penalty\_Not\_Qualif}$ or $\boldsymbol{Big\_number}$), which means that our system prefers to assign to the teacher one of his preferences or one of the teachings that belongs to its qualification. This helps in minimizing our system's total cost. Concerning teachings that do not belong to the preferences or qualifications of the teacher, our system penalizes the assignment of this teacher to this teaching with the multiplication of 10 ($\boldsymbol{Penalty\_Qualif\_Not\_Pref}$), which means that this teaching does not belong to the preferences of the teacher, with 1000 ($\boldsymbol{Penalty\_Not\_Qualif}$ or $\boldsymbol{Big\_number}$), which means that this teacher is not qualified to teach this teaching.

Here is a short algorithm which explains the above-described procedure:

If Preference not specified:

$$\boldsymbol{Preference_{i\,(j\,or\,k)} = Penalty\_Qualif\_Not\_Pref}$$

If Teacher not qualified:

$$\boldsymbol{Qualification_{i\,(j\,or\,k)} = Penalty\_Not\_Qualif}$$

$$\boldsymbol{Cost_{i\,(j\,or\,k)} = Preference_{i\,(j\,or\,k)} * Qualification_{i\,(j\,or\,k)}}.$$

4.2.2 Part time teachers' costs

If a temporary teacher is needed, a specialist teacher must be assigned to this teaching, so the cost associated with this assignment is equal to 100 ($\boldsymbol{Penalty\_Qualif}$) to promote the assignment of a permanent teacher to a temporary teacher and prohibit the assignment to another specialty with a penalty of 1000 ($\boldsymbol{Penalty\_Not\_Qualif}$ or $\boldsymbol{Big\_number}$).

Below is a short algorithm that explains this procedure:

If Teacher specialty is the same as teaching:

$$\boldsymbol{Cost_{l\,(j\,or\,k)} = Penalty\_Qualif}$$

Else:

$$\boldsymbol{Cost_{l\,(j\,or\,k)} = Penalty\_Not\_Qualif}$$

4.3 Decision variables

The decision variables used in this model are:

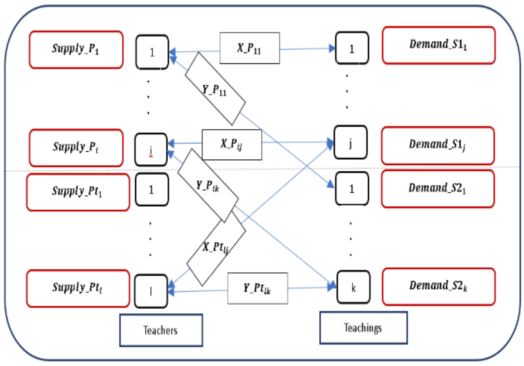

Fig. 1 Graph summarizes the system surveyed

$\boldsymbol{X\_P_{ij}}$:

Number of units assigned to each permanent teacher i by teaching j in semester 1.

$\boldsymbol{X\_Pt_{lj}}$:

Number of units assigned to each part time teacher l by teaching j in semester 1.

$\boldsymbol{Y\_P_{ik}}$:

Number of units assigned to each permanent teacher i by teaching k in semester 2.

$\boldsymbol{Y\_Pt_{lk}}$:

Number of units assigned to each part time teacher l by teaching k in semester 2.

$\boldsymbol{X\_P_{ij}}, \boldsymbol{X\_Pt_{lj}}, \boldsymbol{Y\_P_{ik}}, \boldsymbol{Y\_Pt_{lk}} \in \mathbb{N}$

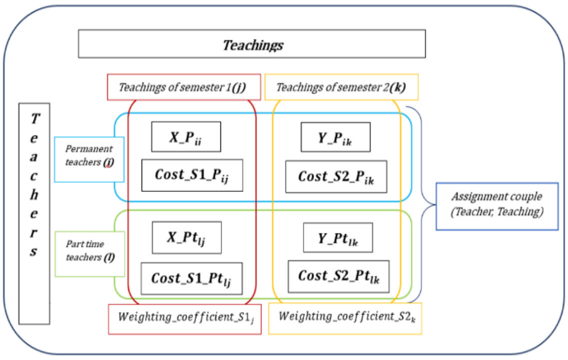

Fig. 2 Descriptive matrix of the used decision variables

4.4 Objective function

Assignments (teacher-teaching pairs) all have a defined cost. Therefore, minimizing these assignments' total cost is our first goal.

The first objective of our research is described in the mathematical equation Obj1, in the following form: the sum of the multiplication of the costs associated with each teaching assignment for all permanent and part-time teachers throughout the academic year, with the number of units assigned to the teacher-teaching pair. This means:

$$= \sum_{1}^{nbr\_teachers} \sum_{1}^{nbr\_teachings} (Assignments_{teacher\ teaching} * Cost_{teacher\ teaching})$$

$$Obj1 = \sum_{i=1}^{n} \sum_{j=1}^{m} X\_P_{ij} * Cost\_S1\_P_{ij} + \sum_{i=1}^{n} \sum_{k=1}^{p} Y\_P_{ik} * Cost\_S2\_P_{ik} + \sum_{l=1}^{q} \sum_{j=1}^{m} X\_Pt_{lj} * Cost\_S1\_Pt_{lj} + \sum_{l=1}^{q} \sum_{k=1}^{p} Y\_Pt_{lk} * Cost\_S2\_Pt_{lk} \quad (1)$$

In order to equilibrate the loads assigned to permanent teachers, we used the D_i function to calculate the difference between the annual supply and the weighted load assigned to each permanent teacher in the first and second semesters, so our second objective is to minimize the difference between the maximum of D_i (D_{max}) and the minimum of D_i (D_{min}) .

$$D_i = Supply\_P_i - S1\_P_i - S2\_P_i \quad (2)$$

$$Obj2 = D_{max} - D_{min} \quad (3)$$

Our main objective is to minimize the two objectives at the same time, so our model uses a bi-objective function defined as follows:

$$Obj = \alpha * Obj1 + \beta * Obj2 \quad (4)$$

$$minimize\ Obj; \quad (5)$$

α and β are the parameters used to prioritize one objective over another, as defined by the managers, and their sum is equal to 1. In our study, we defined $\alpha = 0.5$ and $\beta = 0.5$.

4.5 Constraint

In order to find results for our system, we have defined conditions for assigning a teacher to teaching as follows:

$S1\_P_i$:Weighted number of units for each permanent teacher i assigned to teaching j in semester 1.

$$\forall i \quad S1\_P_i = \sum_{j=1}^{m} X\_P_{ij} * Weighting\_coefficient\_S1_j \quad (6)$$

$S1\_Pt_l$:Weighted number of units for each part time teacher l assigned to teaching j in semester 1.

$$\forall l \quad S1\_Pt_l = \sum_{j=1}^{m} X\_Pt_{lj} * Weighting\_coefficient\_S1_j \quad (7)$$

$S2\_P_i$:Weighted number of units for each permanent teacher i assigned to teaching k in semester 2.

$$\forall i \quad S2\_P_i = \sum_{k=1}^{p} Y\_P_{ik} * Weighting\_coefficient\_S2_k \quad (8)$$

$S2\_Pt_l$:Weighted number of units for each part time teacher l assigned to teaching k in semester 2.

$$\forall l \quad S2\_Pt_l = \sum_{k=1}^{p} Y\_Pt_{lk} * Weighting\_coefficient\_S2_k \quad (9)$$

4.5.1 Supply constraint

The weighted number of units for each teacher in the two semesters must not exceed the teacher's annual load. This signifies that each teacher is assigned a load for the university year that is less than or equal to the annual load defined in the system.

$$\forall i \quad S1\_P_i , + S2\_P_i \leq Supply\_P_i \quad (10)$$

$$\forall l \quad S1\_Pt_l , + S2\_Pt_l \leq Supply\_Pt_l \quad (11)$$

4.5.2 Semester constraint

The weighted number of units for each teacher assigned to teaching j in the first semester must not exceed the teacher's semester load or the maximum number of units assigned to teacher in semester 1.

$$\forall i \quad S1\_P_i \leq Maximum\_threshold\_S1\_P_i \quad (12)$$

$$\forall l \quad S1\_Pt_l \leq Maximum\_threshold\_S1\_Pt_l \quad (13)$$

Also, in semester 2, the weighted number of units for each teacher assigned to teaching k in this semester must not exceed the teacher's semester load or the maximum number of units assigned to the teacher in this second semester.

$$\forall i \quad S2\_P_i \leq Maximum\_threshold\_S2\_P_i \quad (14)$$

$$\forall l \quad S2\_Pt_l \leq Maximum\_threshold\_S2\_Pt_l \quad (15)$$

The four last constraints means that the maximum load assigned to each teacher for the entire semester must be less than or equal to the maximum load defined by the managers.

4.5.3 Demand constraint

For each teaching j in semester 1, we need to allocate the total number of units required for it.

$$\forall j \quad \sum_{i=1}^{n} X\_P_{ij} + \sum_{l=1}^{q} X\_Pt_{lj} = Demand\_S1_j \quad (16)$$

Also, in semester 2, we must assign the required total number of units to each teaching k.

$$\forall k \quad \sum_{i=1}^{n} Y\_P_{ik} + \sum_{l=1}^{q} Y\_Pt_{lk} = Demand\_S2_k \quad (17)$$

All teaching throughout the university year has a demand that must be satisfied by assigning a certain number of qualified teachers to teach it, either permanent or part-time teachers if required. This constraint is defined by the two equations described above.

4.5.4 Constraint of non-qualification

Our system eliminates the possibility of assigning a teacher to a teaching that he or she is not qualified to teach it. The constraints below are defined to ensure that our system never assigns an unqualified teacher to teaching that does not belong to their qualifications.

$$\forall i,j \quad X\_P_{ij} * Cost\_S1\_P_{ij} < Big\_number \quad (18)$$

$$\forall l,j \quad X\_Pt_{lj} * Cost\_S1\_Pt_{lj} < Big\_number \quad (19)$$

$$\forall i,k \quad Y\_P_{ik} * Cost\_S2\_P_{ik} < Big\_number \quad (20)$$

$$\forall l,k \quad Y\_Pt_{lk} * Cost\_S2\_Pt_{lk} < Big\_number \quad (21)$$

5 IMPLEMENTATION

This work describes a decision support tool which has been tested on a real level within Abu Baker Belkaid University of Tlemcen, Algeria. More specifically, we offer a schedule planning tool to the heads of the departments in the Faculty of Technology in order to assist them in their administrative tasks and help them to apply the new 4.0 university strategy.

Our real case study includes 11 specialties, 33 permanent teachers and 185 teachings (103 teachings in the first semester and 82 teachings in the second one), for the national industrial engineering curriculum for all levels, from level 1 to level 5 for both semesters.

After processing the collected data: teaching demand, teacher supply, qualifications, maximum thresholds and preferences of each teacher for the two semesters, we implemented our new mathematical model using the IBM ILOG CPLEX Optimization Studio Version 12.8 solver. Using the Branch and Cut method, this solver provides an optimal solution in a reasonable execution time of 7 minutes and 50 seconds. Additionally, we used Microsoft Excel to import the necessary data and store the obtained results. We even used it to compare the obtained results from our model with the manual results. This result is significantly better than the manual one, which takes a period of a few days to weeks for multiple modifications.

6 RESULTS AND DISCUSSION

In order to evaluate the performance of our system, some qualitative values are calculated. These include the teacher satisfaction degree Ts (Eq. 25), the teaching pedagogical satisfaction Ps (Eq. 26, 27) as well as the number and workload of part-time teachers needed in our system to minimize resource allocation. These parameters are calculated from the preferences of teachers, the qualifications of teachers assigned to the teachings and the difference between the sum of teaching requests and the sum of offers from permanent teachers, in the same specialty, and who are qualified to teach these teachings.

In addition, in order to compare the manual task distribution to the proposed automatic one, we calculated the mean and standard deviation of the two parameters (Ts and Ps), as well as the number of part-time teachers. This comparison is summarized in Table 1.

Table 1. Comparative table of the two systems

		Automatic method	**Manual method**
Execution time		7 min 50 sec.	A few days to weeks.
Teacher satisfaction degree	Average	82.96	78.23
	Standard deviation	16.45	21.52
Pedagogical satisfaction parameter	Average	79.07	77.08
	Standard deviation	39.64	39.78
Part-time teachers		20 units.	44 units.

To calculate each teacher's satisfaction degree Ts, we used the following procedure:

$\forall i$ $\text{MaxQ}_i =$ maximum qualification of each permanent teacher $\text{Qualification}_{i\,(j\text{ or }k)}$

when: $X\_P_{ij} \neq 0$ and $Y\_P_{ik} \neq 0$

$$\forall i \quad Best\_case_i = S1\_P_i + S2\_P_i \quad (22)$$

$\forall i$ $Worst\_case_i =$

$$10 * MaxQ_i * (S1\_P_i + S2\_P_i) \quad (23)$$

$$\forall i \quad Current\_case_i = \sum_{j=1}^{m} X\_P_{ij} * Cost\_S1\_P_{ij} + \sum_{k=1}^{p} Y\_P_{ik} * Cost\_S2\_P_{ik} \quad (24)$$

$$\forall i \quad Ts = \begin{cases} 100\ \%\text{if}: \boldsymbol{MaxQ_i} = \mathbf{1\ and\ preferences\ not\ specified} \\ 100 * \frac{Worst\_case_i - Current\_case_i}{Worst\_case_i - Best\_case_i} \quad \boldsymbol{Otherwise} \end{cases} \quad (25)$$

The following figures illustrate the obtained results in both systems. The graphs represent averages and standard deviations of satisfaction degrees for each specialty (Fig. 3, Fig. 4), as well as each teacher grade (Fig. 5, Fig. 6).

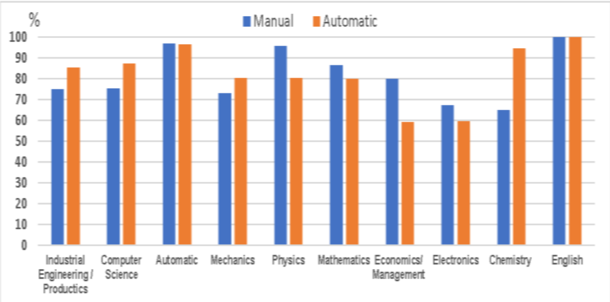

Fig. 3 Satisfaction degrees' averages of each teacher specialty

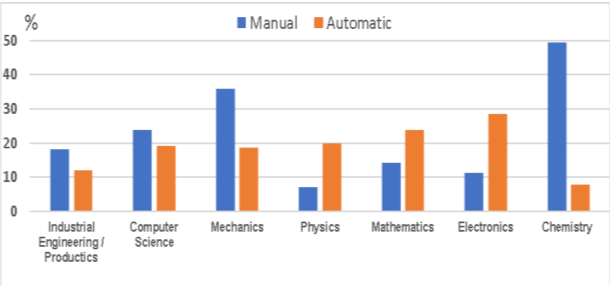

Fig. 4 The standard deviations of each teacher specialty satisfaction degrees

Figure 3 shows a comparison of the average teacher satisfaction degrees in our different specialties, depending on the used resolution method. Teacher satisfaction degrees vary considerably from one specialty to another. This graph shows that automatic distribution is satisfactory for the majority of specialties, with a low dispersion of data shown in Figure 4.

For specialties where manual distribution satisfies teachers better, the high standard deviations shown in Figure 4 indicate that these data are dispersed around their means. This means that there is a lot of variances in the data observed in the automatic system.

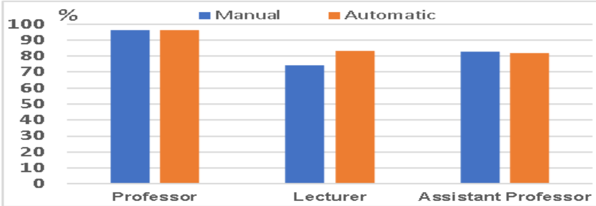

Fig. 5 The averages of each teacher grade satisfaction degrees

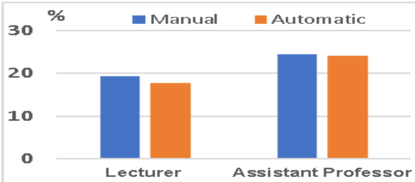

Fig. 6 The standard deviations of each teacher grade satisfaction degrees

Thus, the fifth graph compares the average teacher satisfaction degrees across grades, depending on the used resolution method. Teacher satisfaction degrees vary considerably from one grade to another. This graph shows that automatic allocation gives a good satisfaction for almost all grades and better satisfaction for the Lecturer grade than manual allocation, with a low data dispersion shown in Figure 6. This indicates a lot of variances in the manual allocation obtained data.

In general, the obtained results satisfy the maximum teachers' preferences better than the manual system. This can be concluded following the comparison (Table 1) between the average of each teacher satisfaction degrees in both systems; the automatic and the manual. The average of satisfaction degrees of the automatic system is 82.96, which is higher than the average of the manual results equal to 78.23. In addition, in relation to the standard deviation or dispersion between all satisfaction degrees, it is equal to 16.45 for the automatic system, inferior to the manual results equal to 21.52, which means that the automatic assignment satisfies teachers with closer satisfaction degrees than the manual system, which affects teachers with more disparity, resulting in a greater difference.

As our system aims to meet the exact demand for each teaching, we have calculated a pedagogical satisfaction parameter for each one. This parameter is calculated in relation to the qualification of the teachers assigned to this teaching, i.e., if we assign the most qualified teacher to this teaching, this parameter will increase; and vice versa.

Hereafter the formula we used to calculate this parameter of pedagogical satisfaction for each teaching in our system:

$$\forall j,k \quad MaxQ_{j\ or\ k} = \text{maximum qualification of each teaching } Qualification_{i\,(j\ or\ k)}$$

$$\text{when } X\_P_{ij} \neq 0 \text{ or } Y\_P_{ik} \neq 0$$

$$\forall j \;\; Ps = \begin{cases} 100\,\% & \text{if}: \boldsymbol{MaxQ_j = 1} \\ 100 * \dfrac{MaxQ_j * Demand\_S1_j - \sum_{i=1}^{n} X\_P_{ij} * Q_{ij}}{Demand\_S1_j * (MaxQ_j - 1)} & \boldsymbol{Otherwise} \end{cases} \quad (26)$$

$$\forall k \;\; Ps = \begin{cases} 100\,\% & \text{if}: \boldsymbol{MaxQ_k = 1} \\ 100 * \dfrac{MaxQ_k * Demand\_S2_k - \sum_{i=1}^{n} Y\_P_{ik} * Q_{ik}}{Demand\_S2_k * (MaxQ_k - 1)} & \boldsymbol{Otherwise} \end{cases} \quad (27)$$

For a better presentation of the obtained results in both systems, we have produced the following figures. These graphs represent the means and the standard deviations of the pedagogical satisfaction parameters for each type of teaching unit (Fig. 9, Fig. 10) in addition to the levels for each teaching (Fig. 7, Fig. 8) in both semesters.

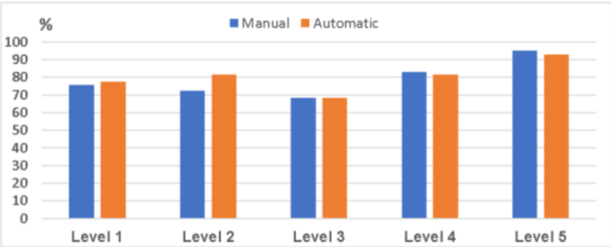

Fig. 7 The averages of the pedagogical satisfaction parameters for each teaching of each level

The graph in Figure 7 compares the average of the pedagogical satisfaction parameters for each teaching of each level, depending on the used resolution method. These parameters vary considerably from one level to another. This graph shows that automatic assignment gives very nearly equal satisfaction for almost all levels and a better satisfaction for the Level 2 than manual assignment, with almost equal data dispersion for both systems, as shown in Figure 8. This indicates almost equal variances in the obtained data.

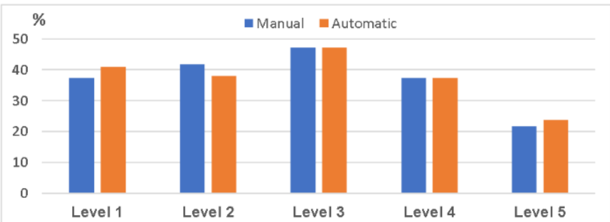

Fig. 8 The standard deviations of the pedagogical satisfaction parameters for each teaching of each level

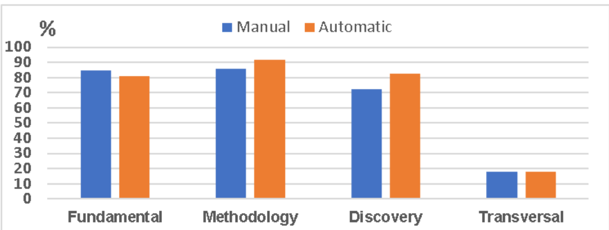

Fig. 9 The averages of the pedagogical satisfaction parameters for each teaching of each teaching unit type

Furthermore, the average of the pedagogical satisfaction parameters for each teaching of each teaching unit type is compared in graph 9, according to the used resolution method. This graph shows that automatic assignment gives almost equal satisfaction to manual assignment for both types of teaching units (fundamental and transversal) and better satisfaction for the other two (methodology and discovery), with low data dispersion for the last two, as shown in Figure 10. This indicates a high variability in the data obtained in the manual system, and low variability for the other two (fundamental and transversal).

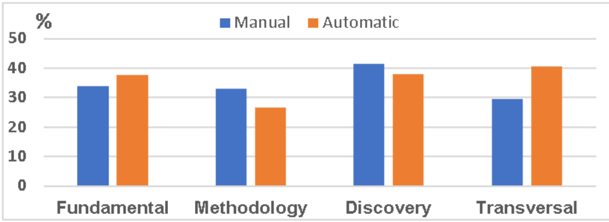

Fig. 10 The standard deviations of the pedagogical satisfaction parameters for each teaching of each teaching unit type

Then, we calculated the mean and the standard deviation of these values for both systems in order to know the dispersion of these values around the mean (Table 1). Also, we noticed that the manual system has more disparity compared to the proposed system, with a mean of 77.08 and a standard deviation of 39.78. Regarding the automatic system, we have a mean of 79.07 and a standard deviation of 39.64. This means that our proposed system has assigned the majority of the teaching to qualified teachers.

In addition, we notice that the demand sum for some teachings in the same specialty is greater than the permanent teachers' supply sum in this specialty and who are qualified to teach these teachings. This means that we need part-time teachers to satisfy all the demand for our teachings in this specialty, so we've programmed our system to inform us of the number of part-time teachers needed and also the workload assigned to them.

This makes another point we used to compare both systems (Table 1), i.e., the manual assignment assigned several teachings to part-time teachers compared with the automatic system, which requires considerably fewer part-time teachers in order to minimize resource allocation.

Generally, balancing loads among teachers is a difficult task among manual assignments. This is rather one of the important points for teachers since it avoids overloading certain teachers and allocating less workload to others. To this end, balancing criterion is one of the main goals of our system and that we have successfully achieved.

Table 2. A comparative chart between the two separate objectives and our studied bi-objective for all our specialties

	Obj 1	Obj 2	Bi-Obj
Industrial Engineering / Productics	4.5	0	1.5
Computer Science	3	0	1.5
Automatic	0	0	0
Mechanics	1.75	0	1.5
Physics	2.5	0	1.5
Mathematics	1	0	1
Economics/ Management	0	0	0
Electronics	0.75	0	0.75
Chemistry	0	0	0.5
French	0	0	0
English	0	0	0
Total part-time teachers	20	65	20

This comparative table (Table 2) shows that when we optimize our solution with only the first objective, we expect the optimal solution and assign the maximum number of teachers to their preferences with a minimum number of part-time teachers. However, we can see that the loads are balanced, with a maximum difference of 4.5 weighted units. Unlike the second study, optimizing our system with only the second objective produces an optimal solution with full load balancing and a difference of 0 weighted units, but with 65 part-time teachers. However, considering both objectives simultaneously, i.e., minimizing the number of part-time teachers and balancing the workload of permanent teachers with maximum preference satisfaction, we achieved the optimal solution with 20 teachers part-time, a balanced workload with a difference of 1.5 weighted units, maximum satisfaction of preferences and a mission respecting qualifications according to specialties.

It is clearly visible that our system results are better than manual assignments within our department. In fact, this result can be generalized to all universities with a similar teaching system (weekly program, semester subjects, two types of teaching staff: full-time and part-time), according to the information collected previously (Houar et al., 2022). For this reason, we proposed a standard system that meets the educational constraints of the department, takes into consideration the preferences and qualifications of teachers, maximizes the satisfaction degree of teachers and guarantees the full satisfaction of educational demands. Our system even guarantees a balanced distribution of the workload between teachers.

The result obtained in this first part has been imported into a timetable generation algorithm that uses a set of activities (teacher-teaching-student group) and constraints (hard and soft) as inputs for their resolution heuristics. The time slots and rooms for each activity are the outputs of this automatic generation.

This algorithm must place each activity in a time slot and a room, respecting its constraints. It first considers time constraints, then immediately considers space constraints. Recursive swapping is the name of this algorithm, which simulates the operation of a human time manager. Placing activities in turn, starting with the most difficult; if it doesn't find a solution, it indicates potentially impossible activities. The algorithm swaps activities recursively, if possible, to make space for a new activity, or in extreme cases, backtracks and changes the order of evaluation. When the heuristic places an activity, it chooses the place with the lowest number of conflicting activities and recursively places them. This heuristic uses a tabu list to avoid cycles.

When we implemented this, we achieve a satisfactory solution for all the constraints imposed by our system in a reasonable time. All hard constraints and the majority of soft constraints for all student groups, rooms, time slots and teachers were satisfied. Thus, our proposed study showed that this hybridization gives better results in a reasonable time.

7 CONCLUSION

The academic tasks distribution is one of the main missions of university managers in each year, each semester, or each term. This distribution must respect a certain number of hard and soft constraints in order to assign qualified teachers to teaching, respect the hourly volume and preferences of teachers, satisfy the demand for teaching, consider the number of available teachers (permanent and temporary teachers), balancing the workload assigned to teachers and many other constraints are specified by departmental educational managers. Each year, the number of student groups changes according to the number of enrolled students in each department. To this fact, the teaching requirements change and so does the distribution. The distribution therefore changes each time the students number changes, and this change is also based on the change in teachers and their annual hourly volume, or even the change in the maximum thresholds of the two semesters.

Furthermore, each teacher prefers to teach according to their own choices, skills, qualifications and areas of research or other preference criteria. These preferences are taken into account by managers when allocating tasks to satisfy the teachers' preferences.

In addition to satisfying teachers' preferences, managers try to balance the loads distributed among teachers in order to avoid overloading some teachers and underloading others.

In this study, we chose to create a decision support system for educational managers, and to approve our proposal, we used real data on the distribution of tasks at the national recruitment Industrial Engineering field level. Our study has a double objective. The first is to minimize the assigning teachers cost, which means the assignment of teachers who are qualified to their preferences in order to respect the demand for teaching, with no exceeding of the annual hourly volume and the maximum thresholds for the two semesters of each teacher, or to assign teachers according to their qualifications and even satisfy the maximum preferences of teachers and forbid to assign to a teaching unqualified teacher. The second objective is to balance the loads assigned among teachers and minimize the difference in load remaining with each teacher. This system also specifies the missing load in each specialty so that we know how many part-time teachers we need in our allocation.

After developing the new mathematical model representing our objectives and constraints, we run it through the solver and compared the two allocations; the automatic one (our system result) and the manual allocation produced by the department managers. The goal behind the comparison is to validate our model and identify the strengths and weaknesses of our proposal.

This proposal respected all the constraints imposed by the system and gave us an optimal distribution with maximum satisfaction of the teachers' preferences. It assigned qualified teachers to the teachings and avoided assigning unqualified teachers. It also balanced the loads between all the teachers and even specified the missing load in each specialty in a very short execution time compared to the manual distribution time.

Other objectives and constraints can be added to achieve a decision support system that perfectly fulfills the task distribution mission. For example, we can optimize the number of different subjects assigned to each teacher, the distribution of tasks of all teachers and teachings throughout the faculty, and include the assignment of two different teachers to the same teaching. We can even add other constraints imposed by teachers, students or department heads.

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