An Optimization Model for University Course Timetabling. A Colombian Case Study

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Abstract. Course Timetabling at universities can be defined as the scheduling of different courses in specific time slots. To carry out this process it is necessary to take into account key factors such as: available courses, the distribution of time slots and lecturers' availability. In addition, there are resources that are essential for the model performance. For instance, the available classrooms and their capacity to completely satisfy the specific demand of students. In this study, a mixed integer linear programming model is presented to find the optimal schedule of the courses. Results show that the proposed model provides feasible solutions where all the proposed factors are considered.

Keywords: University Course Timetabling, Scheduling, Mixed Integer Linear Programming, Classroom Programming

1 Introduction

Scheduling has been widely used in educational institutions due to its importance for optimizing physical and human resources [1]. Institutions such as universities, which have a high demand for subjects and students, must organize each of these resources in the best way to comply with all the quality conditions they have offer and are accountable for. Not having a systematic methodology to generate feasible schedules efficiently may result in the use of human resources to carry out the task manually. This situation worsens when considering all the different conditions given to determine the viability of schedules to be used.

For educational institutions, organizing academic schedules is not an easy task. Moreover, it is not unusual that budget for these processes is scarse, meaning that an efficient planning schedule must be carried out by qualified staff and with minimum cost. Lawrie [2] and Tripathy [3] took that into consideration and defined the number of hours per week that were necessary for a course to prevent courses from overlapping, as main requirements. These generates the fulfillment of the estimated hours and the assignment of teachers without conflict. During the following years, different authors adapted these first models, adding specific conditions for their institutions or some other general ones that could be applied to other studies. An example of this is the study by Schimmelpfeng [4], where the application of a Mixed Integer Programming (MIP) model was carried out at the German School of Economics and Administration, adding elements such as the capacity of the available rooms and establishing as a objective function the minimization of violation of planning constraints.

The aim of this paper is to propose a MIP model for the course timetabling in a Colombian University. In this case study, an academic program and its core courses are considered. The academic program consists in 10-semesters, 17 core subjects, each with a certain number of subgroups determined by the expected demand of students. The model focuses mainly on avoiding the overlapping of subjects from the same semester, guaranteeing that students can enroll the courses of the semester they are. The proposed MIP model also considers the classroom capacity, the assignment of professors to courses according to a subject ability and the type of contract to determine the maximum number of hours each professor can teach per week.

The rest of this paper is organized as follows. Section 2 presents a bibliometric analysis of related studies. Section 3 shows the MIP model formulation. Section 4 presents the computational results. Lastly, Section 5 drawns some conclusions of the study and provides some interesting avenues for future research.

2 Bibliometric Analysis

In order to delve deeper into schedule and timetabling problems, a bibliometric analysis was carried out. Bibliometric analysis helps one to understand who are the authors more interested on a specific topic, as well as which are the journals, countries and institutions that have worked more on it. (Sierra-Henao et al., 2019) [5]. In addition, citation and co- citation analysis help identify the most cited authors, articles and prevailing topics. According to Noyons et al. (1999) [6], bibliometrics combine two main procedures: scientific mapping and performance analysis. The importance of this type of analysis is to estimate how well the reviewed topics have been studied and draw conclusions from there, as mentioned by Solano, Castellanos, Rodríguez and Hernández [7].

Table 1 shows a summary of the methodology followed for the analysis. The bibliometric analysis was based on the literature collected from Scopus database (www.scopus.com) as it is defined as "the largest abstract and citation database, with over 1.4 billion cited references indexed from high-quality of peer-reviewed literature as scientific journals, books and conference proceedings" (Elsevier, 2020) [8].

Unit of analysis	Published
Period of analysis	2010 to 2020
Search engine	Scopus
Query string	TITLE-ABS-KEY((course OR class*) AND timetable AND schedul* AND optim*) AND (LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2012) OR LIMIT-TO (PUBYEAR , 2011) OR LIMIT-TO (PUBYEAR , 2010)) AND (LIMIT-TO (DOCTYPE , ”ar”) OR LIMIT-TO (DOCTYPE , ”cp”) OR LIMIT-TO (DOCTYPE , ”re”)) AND (LIMIT-TO (LANGUAGE , ”English”)) AND (LIMIT-TO (SUBJAREA , ”COMP”) OR LIMIT-TO (SUBJAREA , ”ENGI”) OR LIMIT-TO (SUBJAREA , ”MATH”) OR LIMIT-TO (SUBJAREA , ”DECI”))
Number of evaluated articles	1,059

Table 1. Research method.

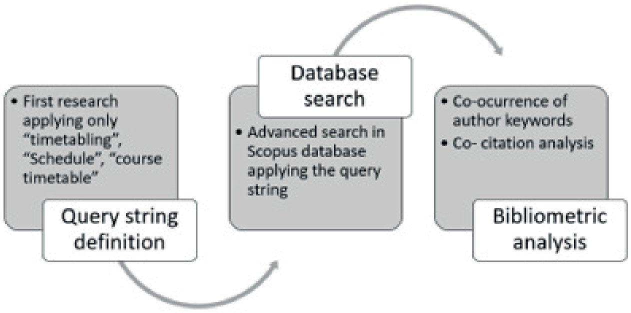

Figure 2. Summary of methodology used.

After having collected the search results from the query string, a software called VOSviewer was used. This software is a tool for building and visualizing bibliometric networks for better understanding and detect non relevant repeating terms to excluded them from the list. VOSviewer was developed by Van Eck and Waltman [9] where the software has the capacity to distinguish two types of bibliographic maps, one of them related between the investigated elements and the other facilitates the identification of groups of related elements.

First of all, an analysis of author keywords was performed. Figure 2 shows the 85 most frequent keywords with at least three occurrences for easier reading. Keywords are represented with circles, where the largest circles represent the keywords that have been used the most. As shown in figure 2, eight different clusters are separated by distinct colors. The green cluster identified as “timetabling”, represents the prescriptive approaches for solving this type of problems.

Keywords related with “scheduling problem”, such as “combinatorial optimization” and ”course timetabling problem” appear in the yellow cluster. Other words such as “timetabling problem”, “genetic algorithm”, “high school timetabling problem”, “exam timetabling” and “particle swarm optimization” appear in the purple, blue, orange, red and light blue clusters, respectively. In addition, the brown subgroup are linked with “robustness” and “course timetabling” topics.

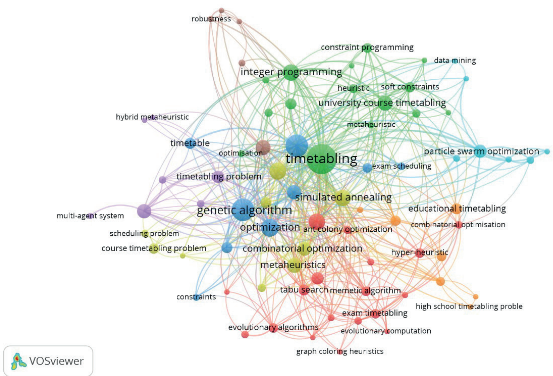

Figure 2. Co-occurrence of author keywords.

Additionally, in order to obtain a deeper insight into the gained results, figure 3 shows the timeline visualization overlay of the co-occurrence of author keywords on the evaluated contributors. In other words, it exhibits the evolution of the different keywords through the years. Considering what was mentioned above, new or trending concepts can be highlighted: university course timetabling, educational timetabling, bi-criteria optimization, , and integer linear programming. The latter has the highest average publication year among 85 keywords between 2018. At the other end of the spectrum, keywords as "course timetabling problem" and "school timetabling problem" have been less popular recently with an average publication year between 2012.

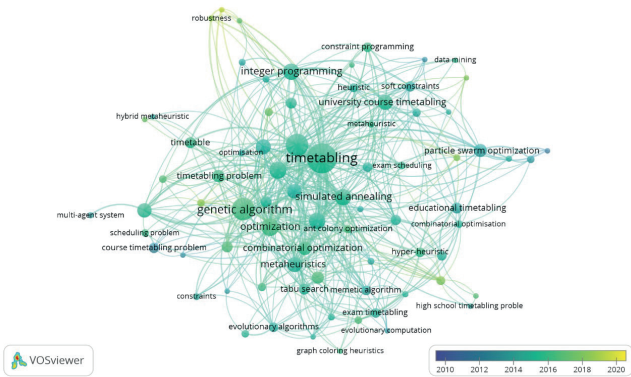

Figure 3. Evolution of co-occurrence of author keywords from 2010 to 2020.

For the co-citation of authors analysis, a minimum of 20 citations per author was considered. Out of the 8,702 authors within the analysis, 218 of them met the threshold. As shown in figure 4, authors were classified in 5 different clusters evaluating the strength of correlations between co-citations. Authors Burke, E.K, Mccollum, B. and Qu, R, are the most relevant and most cited for timetabling and scheduling related topics. Table 2 shows a summary on the top 10 most cited authors, their total citations and the references to which citations are associated.

Rank	Authors	Year	Title	TC
1	Burke and Bykov[10]	2016	An adaptive flex-deluge approach to university exam timetabling	1,204
2	Abdul Rahman et al.[11]	2014	Adaptive linear combination of heuristic ordering in constructing examination timetables	735
3	Qu et al.[12]	2015	Hybridising heuristics within an estimation distribution algorithm for examination timetabling	491
4	Abdullah and Turabieh[13]	2012	On the use of multi neighbourhood structures within a Tabubased memetic approach to university timetabling problems	433
5	Burke et al. [14]	2010	Hybrid variable neighbourhood approaches to university exam timetabling	391
6	McCollum et al.[15]	2010	Setting the research agenda in automated timetabling: The second international timetabling competition	373
7	Abuhamdah et al. [16]	2014	Population based Local Search for university course timetabling problems	315
8	Lewis and Thompson [17]	2015	Analysing the effects of solution space connectivity with an effective metaheuristic for the course timetabling problem	218
9	Muklason et al.[18]	2017	Fairness in examination timetabling: Student preferences and extended formulations	217
10	Oner et al.[19]	2011	Optimization of university course scheduling problem with a hybrid artificial bee colony algorithm	192

Table 2. Top 10 most cited Authors

3 Problem Formulation

This section presents a MIP model to schedule a specific number of subjects, considering institutional policies and physical resources characteristics. The objective function and operational constraints aim to minimize the number of missed hours to fulfill professors workload while assuring that all classes are programmed and avoiding the overlapping of subjects from the same semester.

Therefore, the model considers students demand, professor availability, classrooms capacity, days and hours where classes could be programmed, and type of contract (full or part time) of the professors, seeking to generate optimal schedules for both students and professors. The following sections present the sets, parameters, decision variables, objective function and operational constraints of the model.

3.1 Indices

The following indices were defined for the proper development of the model:

i = timeslots (T1: 7-9, T2: 9-11, T3: 11-13, T4: 13-15, T5: 15-17, T6: 17-19, T7: 8-10, T8: 10-12, T9: 12-14, T10: 14-16, T11: 16-18, T12: 7-10, T13: 10-13, T14: 13-16, T15: 16-19, T16: 8-11, T17: 11-14, T18: 14-17, T19: 9-12, T20: 12-15, T21: 15-18). These are defined considering that courses may be offered in two- and three-hours spaces only.
j = days (Monday,..., Friday).
k = courses (C1,..., C59).
p = professors (1,...,25).
t = contract type (full time, part time).
s = semester (1,..., 10).
a = available classrooms (S1,..., S10).
m = number of days in which the class is taught. That is, a class needs either one day a week or two.

3.2 Parameters

The following parameters were defined for the development of the model:

$Hours_k$= Week hours for course k.
$Maxdays_m$= Days m per week required for course. Either one or two.
$Numberhours_i$= Hours for timeslot i.
$Capacity_a$= Student capacity of classroom a.
$Students_k$ = Expected demand of students for course k.
$Contract_{p,t}$= 0-1 Matrix indicating if professor p has contract type t.
$Semester_{k,s}$= 0-1 Matrix indicating if course k is offered in semester s.
$Timeslots_{i,i'}$= 0-1 Matrix indicating if timeslot i does not overlap with timeslot i'.
$Courseprof_{k,p}$= 0-1 Matrix indicating if course k can be taught by professor p.
$Courseday_{k,m}$= 0-1 Matrix indicating if course p requires m days per week.
$Disp_{p,k,i,j}$= 0-1 Matrix indicating if professor p is available for teaching course k during timeslot i on day j.
$Minhoursparttime$= Maximum number of teaching hours per week for part-time lecturers.
$Maxhoursfulltime$= Minimum number of teaching hours per week for full-time professors.
$Maxhoursfulltime$= Maximum number of teaching hours that can be allocated per day for each semester.
$BigM$= Very large integer value.

3.3 Decision Variables

The following decision variables were defined for the model:

$X_{p,k,i,j}$= 1 if professor p teaches course k in timeslot i of day j, 0 otherwise.
$Y_{k,i,j}$= 1 if course k is taught in timeslot i of day j, 0 otherwise.
$N_{a,i,k,j}$= 1 if course k is taught in timeslot i of day j in classroom a, 0 otherwise.
$W_{p.k}$= If professor p teaches course k.
$G_{k,j}$= If course k is taught on day j.
$DELTA_p$= Hours professor p misses to fulfill his workload.
$DELTA2_{p,k,i,j}$= Hours missed to assign all courses.

3.4 Objective Function

The model is aimed at minimizing the hours professor p misses to fulfill his workload:

$$min\ Z = BigM \cdot \sum_p DELTA_p \tag{1}$$

3.5 Constraints

The following constraints were considered for the problem:

$$\sum_i \sum_j Y_{k,i,j} \cdot Numberhours_i = Hours_k, \ \forall k \tag{2}$$

$$\sum_i Y_{k,i,j} \leq 1, \ \forall k, j | Courseday_{k,m} = 2 \tag{3}$$

$$G_{k,j} + G_{k,j+1} \leq 1, \ \forall k, j | j \neq Friday \tag{4}$$

$$\sum_j G_{k,j} \cdot Courseday_{k,m} \leq Maxdays_m, \ \forall k, m \tag{5}$$

$$\sum_k Y_{k,i,j} \cdot Semester_{k,s} \leq 1, \ \forall i, j, s \tag{6}$$

$$Y_{k,i,j} = 0, \ \forall k, i = \{T4, T5, T6, T10, T11, T14, T15, T18, T20, T21\}, j = Friday \tag{7}$$

$$\sum_k \sum_i Y_{k,i,j} \cdot Semester_{k,s} \leq Maxhoursday, \ \forall k, s \tag{8}$$

$$\sum_p W_{p,k} \leq 1, \ \forall k \tag{9}$$

$$\sum_p X_{p,k,i,j} \leq 1, \ \forall k, i, j \tag{10}$$

$$\sum_k X_{p,k,i,j} + \sum_k \sum_{i' | i' \neq i \wedge Timeslots_{i,i'} = 0} X_{p,k,i',j} \leq 1, \ \forall p, i, j \tag{11}$$

$$X_{p,k,i,j} \leq Courseprof_{p,k}, \ \forall p, k, i, j \tag{12}$$

$$\sum_k \sum_i \sum_j X_{p,k,i,j} \cdot Contract_{p,t} \geq Minhoursfulltime - DELTA_p, \ \forall p, t = Fulltime \tag{13}$$

$$\sum_k \sum_i \sum_j X_{p,k,i,j} \cdot Contract_{p,t} \leq Maxhoursparttime, \ \forall p, t = PartTime \tag{14}$$

$$\sum_p X_{p,k,i,j} = Y_{k,i,j} \ \forall k, i, j \tag{15}$$

$$X_{p,k,i,j} \leq disp_{p,i,j} + DELTA2_{p,k,i,j},\ \forall p,k,i,j \tag{16}$$

$$\sum_{a} N_{a,i,k,j} \leq 1,\ \forall i,k,j \tag{17}$$

$$\sum_{k} N_{a,i,k,j} + \sum_{k} \sum_{i'|i' \neq i \wedge Timeslots_{i,i'}=0} N_{a,i',k,j} \leq 1,\ \forall i,j,a \tag{18}$$

$$\sum_{k} N_{a,i,k,j} \cdot Students_k \leq Capacity_a,\ \forall a,i,j \tag{19}$$

$$\sum_{k} N_{a,i,k,j} = Y_{k,i,j},\ \forall i,j,k \tag{20}$$

$$DELTA2_{p,k,i,j} \leq 1,\ \forall p,k,i,j \tag{21}$$

$$W_{p,k} \leq 1,\ \forall p,k \tag{22}$$

$$G_{k,i} \leq 1,\ \forall k,j \tag{23}$$

$$X_{p,k,i,j} \leq W_{p,k},\ \forall p,k,i,j \tag{24}$$

$$Y_{k,i,j} \leq G_{k,j}\ \forall k,i,j \tag{25}$$

$$X_{p,k,i,j}, Y_{k,i,j}, N_{a,i,k,j} \in (0,1), \forall i,j,k,p,a \tag{26}$$

$$W_{p,k}, G_{k,j}, DELTA_p, DELTA2_{p,k,i,j} \geq 0, \forall j,k,p \tag{27}$$

Constraints 2 guarantee that all the hours of each class are scheduled. Constraints 3 guarantee that, if a course has more than one session per week (i.e., requires two or more days of the week), the sessions of the class cannot be scheduled on the same day. Constraints 4 apply to those subjects that require days between their sections, in this case at least one day in between. Constraints 5 guarantee that a class cannot be programmed in more days than it is permitted to. In addition, it is necessary to ensure that classes that belong to the same semester do not overlap, this is done by constraints 6. Considering the university, Friday afternoons are reserved for postgraduate courses, meaning that constraints 7 guarantee that no undergraduate classes are assigned during said timeslots. Constraints 8 limit the maximum number of hours a day that can be taught to each semester.

It is also considered that each of the courses may be taught by a single professor, just as they may teach only one class at a time. This is ensured with constraints 9, 10 and 11. Constraints 12 establish that professors will only be able to teach courses that they are able to teach. Additionally, according to the contract type, full-time professors must teach a minimum 6 hours of class per week, while part-time professors may dictate maximum 21 hours. This is done in constraints 13 and 14 respectively. Constraints 15 establish that professors can only be assigned to courses-slots that have already been assigned. Part-time professors have a certain availability according to their needs. Constraints 16 contemplate the availability matrix of all professors, both full-time and part-time professor, in order to assign them to courses that are available in time slots to teach the class.

For the last resource (i.e., classrooms), constraints 17 ensure that each class may be assigned to only one timeslot on a single day. On the other hand, constraints 18 guarantee that classrooms may have only one course allocated on each timeslot. Constraints 19 establish that all courses will be assigned to classroom that can support the expected student demand. Lastly, the number of classrooms assigned must correspond to the number of courses in each of the time slots of each day. This is given by constraints 20. Constraints 21 to 25 establish relationship conditions between variables, and constraints 24 and 25 indicate the nature of the variables of the model.

4 Results

The proposed model was coded and solved using GAMS (General Algebraic Modeling System) version 28.2.0 and solved using CPLEX on a laptop computer equiped with an Intel Core i5 processor, 8GB RAM and a 64-bit Windows 10 operating system.

For this particular project, it is important to consider, within the result analysis, different scenarios that provide useful information for decision makers. Despite the foundations of the model being exclusively on course timetabling, it is ideal to develop ideas that revolve on the impact that the model may have on other areas, such as economics or the optimization of resource utilization.

The structure of the scenarios considered is based on two variables: teachers' availability and courses' demand. Based on information shared by the University, the code states an initial expected students demand for each course and a specific amount of groups for dividing students in order to meet classrooms maximum capacity and a homogeneous distribution. For the problem analyzed in this paper, only ten classrooms of the university were considered, seven of them can accommodate 40 people while the other three have a capacity for 30. The academic program has 20 teachers, 12 of them are part-time, while the rest are full-time teachers.

For evaluating different scenarios, eight indicators were selected, depending on classrooms, courses, teachers and time frames. The following indicators were defined: classroom usage hours per day (%HU), classroom average occupied capacity (%AVG CAP), scheduled and unscheduled courses (%CA and %UC, respectively), assigned full- and part-time professors, critical time slots, and number of classrooms used.

Three scenarios were examined. The first one with the normal expected student demand. The second one consideres a 10% demand increase. It is worth mentioning, that in this scenario classes still have a maximum number of 40 students, as this is the largest classroom capacity. The third one evaluates a 10% demand decrease. In addition, each scenario considers five possible professor availability (100%, 75%, 60%, 50% and 40%)

		100%	**75%**	**60%**	**50%**	**40%**
Classrooms	%HU	33.82%	33.82%	33.82%	33.27%	32.73%
	%AVG CAP	91.66%	90.06%	83.55%	88.98%	91.70%
Courses	%CA	100%	100%	100%	98%	97%
	%UC	0%	0%	0%	2%	3%
Professors Used	Full-Time	8	8	8	8	8
	Lecturers	10	12	11	12	12
Critical Hour		17-18	8-9	9-10	8-9	9-10
Classrooms Used		10	10	9	10	10
Used Resources Indicators		**100%**	**75%**	**60%**	**50%**	**40%**
Classrooms	%HU	33.82%	33.82%	37.58%	33.27%	32.73%
	%AVG CAP	91.66%	90.06%	92.84%	88.98%	91.70%

Table 3. Results with a students demand decrease of 10%.

This first scenario, represented in Table 3, is based on the usual expected demand for each course. It is very important to highlight the fact that with the 40% and 50% professors' availability the total courses were not assigned. Despite the latter, the percentage of average capacity used for the 40% scenario, is the best within this frame, mainly because of the use of classrooms 7 and 10, whose capacities were entirely used by one course in a time frame, this is why these spaces have the lowest percentage of hours used. It is important to point out that the teacher 19 is the only entitled to teach for 6 groups due to its subject speciality; therefore when the availability is less than 60%, the professor is not able to teach all of them, in the 40% he matches 4 out of 6 and 5 out of 6 in the scenario with 50% of professor availability.

Once it is possible to teach all the courses due to professors' availability, an interesting phenomenon appears: the proposed schedule distributed the hours through the classrooms in a very similar way, resulting in an equal percentage of used hours. Nevertheless, it is interesting to see that the average capacity used increases as the availability does, stating the fact that when teachers have better availability, it is more likely to use resources better.

However, in the scenario with 60% of professor availability, there is a fact that needs to be taken into account: not all the classrooms are used, that is, there is at least one empty classroom which increases the usage percentage of the classrooms. That is the reason why the second part of Table 3 is important, because it takes into account only used resources. Therefore, analyzing the behavior of the results, the 60% scenario is the best possible, regarding average capacity used of the classrooms and the hours used. This is explained by the fact that, the model focuses mainly on avoiding the overlapping of subjects from the same semester and ensuring certain amount of hours for part-time professors.

Students demand increases 10%		**100%**	**75%**	**60%**	**50%**	**40%**
Classrooms	%HU	33.82%	33.27%	33.82%	33.09%	33.09%
	%AVG CAP	74.89%	82.40%	82.22%	80.46%	80.35%
Courses	%CA	100%	100%	100%	98%	97%
	%UC	0%	0%	0%	2%	3%
Professors Used	Full-Time	8	8	8	8	8
	Lecturers	9	10	10	11	11
Critical Hour		17 - 18	8 - 9	8 - 9	9 - 10	8 - 9
Classrooms Used		8	9	9	9	9
Used Resources Indicators		**100%**	**75%**	**60%**	**50%**	**40%**
Classrooms	%HU	42.27%	36.97%	37.58%	36.77%	36.77%
	%AVG CAP	93.61%	91.55%	91.35%	89.40%	89.27%

Table 4. Results with a students demand decrease of 10%.

The results for the second scenario are presented in Table 4. It can be observed that the best used hours percentage is achieved with a 100% professor availability. Basically, when demand increased there were only 2 courses that could be taught in less than 30 people capacity classrooms, each of them with 22 students demand. The model scheduled these two classes in one classroom, leaving low demands concentrated in one space and not distributed, saving the possibility of lowering the average of the rooms with a capacity of 40 people. This scenario is the best possible for all indicators: hours used, average classroom capacity, classrooms used and teachers scheduled. Nevertheless, all the instances (i.e., 75%, 60%, 50% and 40%) for this scenario have a good performance in terms of average capacity used.

Students demand decreases 10%		100%	75%	60%	50%	40%
Classrooms	%HU	33.82%	33.82%	34.18%	33.27%	32.73%
	%AVG CAP	84.04%	84.34%	81.99%	83.96%	81.89%
Courses	%CA	100%	100%	100%	98%	97%
	%UC	0%	0%	0%	2%	3%
Professors Used	Full-Time	8	8	8	8	8
	Lecturers	10	12	11	12	12
Critical Hour		9-10	12-13	17-18	11-12	12-13
Classrooms Used		10	10	10	10	10

Table 5. Results with a students demand decrease of 10%.

For the last scenario, when demand decreases, the model tends to distribute equally the classes within the classrooms as it can be concluded after analysing Table 5. For the different variants of teachers' availability, the 10 classrooms were used; all of them with less than 85% capacity used. This is due to the use of all classrooms where the low and high students courses are mixed and the fact the demand itself decreased. It is really interesting the fact that when demand is lower the model tends to distribute almost equally teachers and classrooms. This could be explained by considering that a demand decrease would generate smaller groups and, therefore, a better usage could be achieved for the classrooms with capacity for 30 students.

5 Conclusions and Future Research

This paper studied a university course timetabling problem. The objective was to schedule the set of courses of an academic program while professors and classrooms were assigned. A set of data from a Colombian University was taken as a sample to carry out a mathematical model that meets the conditions of schedules, crossings of subjects from the same semester, the maximum number of hours that a professor can dictate and keeping in mind the demand of students for each of the courses to allocate classrooms.

The problem is solved and provides to the researchers a tool to assess and evaluate different scenarios. The computational results show that it is possible adapt the model to different educational scenarios that require the optimal use of resources. The initial conditions are very favourable for the University as classrooms and teachers are enough. Nevertheless, numbers may highlight the underuse of available classrooms and the possibility of leaving these spaces for another purpose; for all scenarios at least 57% hours are free in the classrooms, meaning that other programs could take advantage of this spaces.

The results also show that the model can comply with the guidelines established by the board of directors and the quality standards necessary in the academic offer. This is clear as the scheduling conditions can be modified to meet specific requirements and make the assignment process more complete, while maintaining high levels of service for both students and teachers and for the institution.

As future research, the model can be considered to be applied with all academic programs of the university to coordinate efficiently the manage of resources and to deliver one system that take control of them. Also, the inclusion of distances between classrooms can be contemplated as part of a new optimization criterion. The route that students and teachers must take could be an objective to take into account when there are two or more consecutive classes, so the less distance they travel the more time they will have to arrive. Also, integrating other scenarios with alternate students demand. In addition, as in the result analysis, assigning an opening cost for each classroom and each time frame, could transform the programming into an optimization tool as well.

It is also possible to add preference conditions at specific times, determined by the institutions to give priority to other academic activities. This should contain a matrix with weights for each of the time slots where it will be possible to indicate which of them are more pertinent to specific interests. Finally, new ways of addressing the problem can be designed, such as heuristic methods, that allow finding feasible solutions comparable with the results obtained in this research and obtaining conclusions about the performance of the models and the management of resources for their optimization.

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Identificação de fatores para avaliação da qualidade de energia elétrica: os impactos na geração, distribuição e setores de consumo

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Resumo. A qualidade da energia elétrica é importante para todos os setores da cadeia de fornecimento, desde a geração até a transmissão e distribuição da eletricidade. O aumento do número de empresas resulta em um acréscimo de cargas na rede, tornando necessário um monitoramento adequado da qualidade de energia, tanto pelas distribuidoras quanto pelos consumidores. A baixa qualidade de energia elétrica independente da sua causa, pode gerar perdas significativas aos consumidores, sendo as indústrias as mais afetadas em razão do seu alto consumo para produção de bens. Os distúrbios e as perdas de energia podem ocasionar a queima ou mau funcionamento de equipamentos, afetando diretamente o processo produtivo. É necessário identificar através do monitoramento, medição e análise, as situações que afetam a qualidade da energia em todos os segmentos. Nessa perspectiva, o presente estudo tem como objetivo realizar uma revisão sistemática de literatura para identificar os fatores que mais influenciam na qualidade do fornecimento da energia elétrica. O conhecimento dos fatores torna possível às organizações traçar um plano de gerenciamento da qualidade, podendo gerar um maior investimento em tecnologias para melhoria da produção e diminuição de gastos advindos desse consumo.

Palavras-chave: Qualidade da Energia Elétrica, Revisão Sistemática, Fatores, Fornecimento de Energia, Setor Elétrico Brasileiro.

1 Introdução

Nos setores industriais, a energia elétrica é considerada um dos produtos mais caros necessários à produção de bens [1], sendo gastos aproximadamente um terço da energia disponível [2], o que leva as empresas a equacionarem seus gastos advindos desse consumo [3]. A Energy Information Administration (EIA) estima que até 2050 a nível mundial, haja um aumento de aproximadamente 50% no uso da energia [4], sendo a China responsável por um quarto do consumo mundial de eletricidade [5]. No Brasil, embora o setor residencial seja responsável por 86,1% das unidades consumidoras de energia elétrica, em relação ao consumo, fica atrás do setor industrial, sendo