Proceedings of the Federated Conference on Computer Science and Information Systems pp. 441–444
DOI: 10.15439/2018F143
ISSN 2300-5963 ACSIS, Vol. 15

Lecturers' competences configuration model for the timetabling problem

Jarosław Wikarek
Kielce University of Technology
Al. 1000-lecia PP 7, 25-314 Kielce, Poland,
Institute of Management and Control Systems
e-mail:j.wikarek@tu.kielce.pl

Abstract—**The article presents the problem of academic teachers' competences configuration in the context of the university course timetabling problem (UCTP). Usually when solving UCTP, the set of available academic teachers and the competences they have is defined. The sets of lecture rooms, subjects (courses), student groups, time-slots, etc. are also known. Problems can emerge when it is not possible to find a satisfactory UTCP solution due to the missing sufficient number of specific academic teachers' (lecturers') competences, which is reflected in the possibility to teach specific classes (courses). In order to detect early such a situation and effectively manage the available and required lecturers' competences, a mathematical model of lecturers' competences configuration has been formulated in the form of a MILP (Mixed Integer Linear Programming) problem. Its solution has a direct impact on UTCP. The article also presents the implementation of the model in the LINGO solver environment and computational experiments.**

I. Introduction

University course timetabling problem (UCTP) is a problem in operation research, which raises interest in the communities both in the area of operational research (OR) and artificial intelligence (AI). In the most general manner, UCTP can be defined as the allocation of students and academic teachers (lecturers) to classes (courses) with consideration given to the available resources such as: lecture halls, laboratories and research workrooms. Additionally, the allocation must take place in appropriate periods (time-slots) that most often include a semester of teaching classes divided into single units (these are most often weeks). It is assumed that before starting work on an UCTP solution the number of all the resources and their availability are known; also, the characteristic features of the resources are known, such as: number of seats in the halls, number of students in particular student groups, the set of competences held by particular lecturers, whether a given room has a multimedia overhead projector, etc. With regard to the lecturers, each of them may have a certain set of competences, which is usually directly reflected in the list of courses which he or she may offer. Apart from the sets of resources with specific properties and time-slots, there are also numerous constraints for UCTP. The most important of them include the allocation of the lecturers and student groups to the halls, limited teaching load (teaching hours) per lecturer in a given semester, limited capacity of the lecture halls, laboratories and research workrooms, etc. Very often, there are also additional time restrictions related to preferences and availability of the lecturers as well as requirements for different courses. At the beginning of every semester, the dean, or the head of the department, faces the problem of an optimal solution to the UCTP problem.

Let's ask the question, what is going to happen, if it turns out, when solving UTCP, that it is impossible to find any acceptable solution due to a certain resource? The answer seems to be evident: the accessibility and/or the number of the given resource should be increased. Unfortunately, it is not always easy. It is particularly difficult with regard to the resource of lecturers' competences which are available when solving UCTP, as this requires them to complete additional training, studies, internships, and/or employment of new lecturers. The article proposes a model for the problem of managing and configuration such competences. On its basis an answer can be given to two key questions:

a. Do we have the appropriate resource of lecturers' competences, which will allow an UCTP solution to be found according to the rules (not exceeding the teaching load excessively)?
b. What and how many competences are missing to find an UCTP solution? What is the minimum number of the missing competences that guarantees an UCTP solution?

Fig. 1 presents the location of the problem of competences configuration in the context of UCTP. The main contribution of the presented research is a unique model for the problem of lecturers' competences configuration in the form of a MILP (Mixed Integer Linear Programming) problem [1]. The examined problem can be classified as a problem of resource distribution (teaching loads) with constraints, among others concerning the teaching load. Additionally, the implementation of the model in the MP solver environment and numerous computational experiments have been presented.

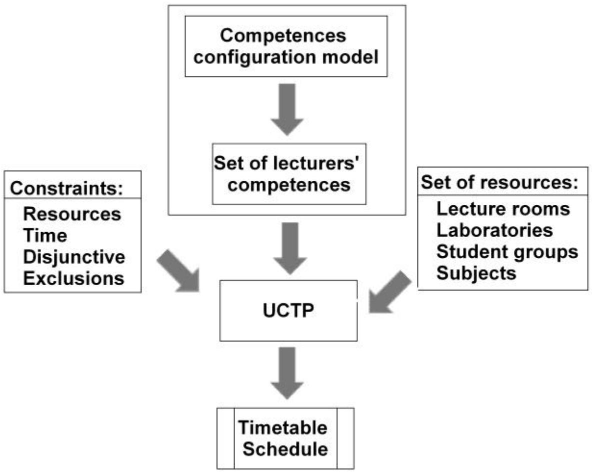

Fig. 1 Place of the competences configuration problem in the context of UCTP

II. LITERATURE REVIEW

For the first time the timetabling problem appears in [2] as a problem consisting of three sets of (i) teachers, (ii) classes and (iii) timeslots. Since then, the timetabling problem has been the subject of interest of many scientists and practitioners [3-6]. Over the years, many approaches have been developed to modeling and solving the principal variety of the problem, the so-called UCTP. The most important of them include: (a) operational research (OR) methods based on Integer/Linear programming (IP/ILP), Graph Coloring (GC), (b) methods and techniques of constraint programming (CP) and constraint logic programming (CLP), (c) metaheuristic methods, such as Case Base Reasoning method (CBR), Genetic Algorithms (GAs), Ant Colony Optimization (ACO), Partial Swarm Optimization (PSO), Variable Neighborhood Search (VNS), Tabu Search Algorithm (TS), etc., (d) hybrid methods and (e) multi-agent methods [7-10]. Practically, the competences configuration problem has not been considered in any of the presented approaches; it has been assumed that the set of lecturers with specific competences is given prior to finding an UCTP solution.

III. PROBLEM DECRIPTION

The competences configuration problem is discussed for the selected organizational unit of the university, which can be: chair, department or faculty. In the given organizational unit, lecturers are employed $E=\{e_1, \ldots, e_k, \ldots, e_{ZE}\}$ where ZE – number of lecturers employed in the unit. Each of the lecturers k has a certain teaching load allocated s_k i.e. the minimum number of hours to be realized in the given period (semester, academic year etc.). For instance, according to the valid law at Polish universities the teaching load is most often: 150, 210, 240, or 360 hours per academic year. In practice many lecturers teach courses in the number of hours exceeding their teaching load. For this reason, z_k coefficient has been introduced. If $z_k=1$, this means that lecturer k agrees to teach courses in the number of hours exceeding the teaching load (otherwise $zk=0$). *Wsp* coefficient has also been introduced, which determines by which percent a lecturer's teaching load can be exceeded without the need to obtain his or her consent (currently it is 15%). Certain types of courses are allocated to the given organizational unit (different forms for the given subject: lectures, projects, laboratory classes etc.) $P=\{p_1, \ldots, p^i, \ldots, p_{ZP}\}$ where ZP – number of types of courses in particular subjects assigned to the organizational unit. Each type of courses i has a specified number of hours l_i in which it is realized. In addition, for all classes the number of student groups h_i is defined. Lecturers of a given unit have certain qualifications (competences) to teach certain types of courses (coefficient $g_{i,k}=1$ means that lecturer k, without any further training, courses or postgraduate studies, etc. may offer subject i, otherwise $g_{i,k}=0$).

A. Illustrative example

In the example chair at a technical university, 18 different teaching courses are provided $P=\{p_1, \ldots, p_i, \ldots, p_{18}\}$. Each course has two characteristic parameters i.e.: the number of teaching hours in a semester and the number of student groups for which it is provided. The respective numerical data are presented in Table 1.

TABLE I.
DATA DESCRIBING THE SUBJECTS FOR THE ILLUSTRATIVE EXAMPLE.

courses	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9
Number of hours taught under the course	15	15	30	15	30	15	30	15	15
Number of student groups assigned to the course	1	2	1	2	1	2	1	2	1
courses	P_{10}	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}	P_{16}	P_{17}	P_{18}
Number of hours taught under the subject	15	30	15	30	15	30	30	30	15
Number of student groups assigned to the course	2	1	3	1	3	1	3	1	3

In the considered organizational unit, four lecturers are employed. Each of the lecturers has competences authorizing him or her to teach specific groups of courses, which have been specified in Table 2 (where "1" means having qualifications certifying the given competence, and "0" means that it is missing). The respective numerical data are presented in Table II.

TABLE II.
DATA DESCRIBING THE LECTURERS FOR THE ILLUSTRATIVE EXAMPLE.

courses / lecturers	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}	P_{16}	P_{17}	P_{18}
E_1	1	1	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0
E_2	0	1	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0
E_3	0	0	0	0	1	1	1	1	0	0	0	0	0	0	1	1	0	1
E_4	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	1	1	1

Each of the lecturers has an allocated teaching load in the number of 150 hours in a given semester and each of them expresses his or her consent to teach excess hours (exceeding the teaching load).

For the so described problem, two primary questions come up:

Q1. Is there any allocation of the courses that will guarantee that all the lecturers realize the teaching load without the need to change competences?

Q2. If it is not possible to allocate the courses without changing the competences, how to minimize the number of new/changed competences (additionally, it can be required that change of the competences of any of the lecturers should not be greater than *B* times)?

For the so allocation problem, a mathematical model has been formulated (Chapter B), its implementation has been made in the LINGO solver language (Appendix A) and computational experiments have been conducted (Chapter C).

B. Competences management problem model

The mathematical model has been formulated in the form of a MILP problem. Table 3 presents the description of parameters, indexes and decision variables of the model. Table 4 presents the description of constraints. The function minimizing the number of changes in the competences of the lecturers has been adopted as the objective function (1). The above model allows you to find the answer to question Q2. In order to answer the Q1 question instead of (1) we introduce an additional restriction (10).

Table III.
DESCRIPTION OF PARAMETERS, INDEXES AND DECISION VARIABLES OF THE MODEL.

Symbol	Description
Sets	
P	Set of lecturers
E	Set of courses
Indexes	
k	Index $k \in P$
i	Index $i \in E$
Parameters	
l_i	Number of hours taught under the course i, $i \in E$
h_i	Number of student groups assigned to the course i, $i \in E$
s_k	Number of hours of the teaching load of lecturer $k \in P$
z_k	If the lecturer k has given their consent to overtime hours $z_k=1$, otherwise $z_k=0$
$g_{i,k}$	If lecturer k, without any further training, may teach courses i $g_{i,k}=1$, otherwise $g_{i,k}=0$, $i \in E$, $k \in P$
wsp	Percent exceeded teaching load without lecturer's necessary consent
A	Arbitrarily high constant
B	Maximum number of changes in competences for lecturer k
Decision variables	
$X_{i,k}$	Number of student groups for course i which will be taught by lecturer k $i \in E$, $k \in P$
$Y_{i,k}$	If the competences of lecturer k to teach course i have been changed $Y_{i,k}=1$ otherwise $Y_{i,k}=0$, $i \in E$, $k \in P$

$$\min \sum_{i \in E} \sum_{k \in P} Y_{i,k} \quad (1)$$

$$X_{i,k} \le (G_{i,k} + Y_{i,k}) \cdot A \; \forall i \in E, k \in P \quad (2)$$

$$\sum_{k \in P} X_{i,k} = h_i \; \forall i \in E \quad (3)$$

$$\sum_{i \in E} l_i \cdot X_{i,k} \ge s_k \; \forall k \in P \quad (4)$$

$$\sum_{i \in E} l_i \cdot X_{i,k} \le wsp \cdot s_k \; \forall k \in P : z_k = 0 \quad (5)$$

$$\sum_{i \in E} \sum_{k \in P} Y_{i,k} \le B \quad (6)$$

$$Y_{i,k} = 0 \; \forall i \in E, k \in P : g_{i,k} = 0 \quad (7)$$

$$X_{i,k} \in C^{+} \; \forall i \in E, k \in P \quad (8)$$

$$Y_{i,k} \in \{0,1\} \; \forall i \in E, k \in P \quad (9)$$

$$Y_{i,k} = 0 \; \forall i \in E, k \in P \quad (10)$$

Table IV.
DESCRIPTION OF CONSTRAINTS AND OBJECTIVE FUNCTION

Constraints	Description
1	Minimum number of changed competences (Q2)
2	Only the employees having appropriate competences can teach the course which requires them
3	Each course is provided for the designated number of student groups.
4	The constraint ensures that the teaching load is realized
5	The constraint does not allow the teaching load to be exceeded by more than *wsp*, if there is no lecturer's consent
6	Change/extension of the competences may happen only a specified number of times;
7,8,9	Binarity and discreteness
10	No possibility to change competences (Q1).

C. Computational experiments

For the proposed model (Chapter 3.B) using the LINGO environment [11] and the implementation model (Appendix A), computational experiments have been conducted. The experiments have been concerned with the illustrative example (P1) and other organizational units such as: chair, department and faculty (P2..P6). The obtained results are presented in Table V and Table VI.

Table V.
RESULTS OF CALCULATIONS

Nr	Unit	ZP	ZE	V	C	T	Q1	Q2
P1	Chair 1	18	4	132	121	1	YES	0
P2	Chair 2	16	6	177	145	1	NO	1
P3	Depart. 1	40	15	1159	717	2	NO	3
P4	Depart. 2	60	20	2287	1267	3	NO	1
P5	Faculty 1	120	50	6170	6352	10	NO	4
P6	Faculty 2	160	80	13040	13290	25	NO	6

ZP Number of curses; ZE Number of lecturers; V Number of decision variables; C Number of constraints; T Calculation time

Detailed results for the illustrative example (P1) are presented in Table VI.

Table VI
DETAILED RESULTS OF CALCULATIONS FOR P1

k	i	$X_{i,k}$	$Y_{i,k}$	k	i	$X_{i,k}$	$Y_{i,k}$
1	1	1	0	3	5	1	0
1	4	1	0	3	6	2	0
1	11	1	0	3	7	1	0
1	12	3	0	3	15	1	0
1	16	2	1	3	16	1	0
2	2	2	0	4	8	2	0
2	3	1	0	4	9	1	0
2	4	1	0	4	10	2	0
2	13	1	0	4	17	1	0
2	14	3	0	4	18	3	0

IV. CONCLUSION

The work presents the problem concerning lecturers' competences configuration. A MILP model has been proposed for this problem, which has been implemented in the LINGO package environment. Before starting work on an UCTP solution, it is necessary to designate the set of the missing competences and supplement them. As a result of solving the problem of lecturers' competences configuration (Table V), we obtain information how many and what competences are missing, which lecturers should supplement them, and we obtain the allocation of the lecturers to the classes and the student groups, namely we partly/initially solve UCTP. The received allocation meets the constraints related to the teaching load for different lecturers. As part of further works, research is planned on modeling and solving UCTP integrated with the configuration model (Chapter B) and additional logic constraints are to be introduced [12,13] related to lecturers' preferences as to the times and forms of the curses, halls etc. It is also planned to apply the method of hybrid modeling and solving to the above-mentioned problem [14-16].

APPENDIX A

```
Model:
Sets:
 lecturers   /1..4/:s,z;
 subjects   /1..18/:l,h;
 pom_1 (subjects,lecturers):g,X,Y;
EndSets
Data:
 s= 150 150 150 150; z= 1 1 1 1;
 l= 15 15 30 15 30 15 30 15 15 15 30 15 30 15 30
 30 30 15;
 h= 1 2 1 2 1 2 1 2 1 2 1 3 1 3 1 3 1 3;
 g= 1 0 0 0 1 1 0 0 0 1 0 0 1 1 0 0 0 0 1 0 0 0 1
 0 0 0 1 0 0 0 1 1 0 0 0 1 0 0 0 1 1 0 0 0 1 0 0 0
 0 1 0 0 0 1 0 0 0 0 1 0 0 0 1 1 0 0 0 1 0 0 1 1;
 wsp=1.25;  A=100; B=3;
EndData
Min=@sum(pom_1(i,k):Y(i,k));
 @for(pom_1(i,k): X(i,k)<=(G(i,k)+Y(i,k))*A);
 @for(subjects(i):
  @sum(lecturers(k):X(i,k))=h(i));
 @for(lecturers(k):
  @sum(subjects(i):l(i)*X(i,k))>=s(k));
 @for(lecturers(k)|z(k)#EQ#0:
   @sum(subjects(i):l(i)*X(i,k))<=s(k)*wsp);
 @sum(pom_1(i,k):Y(i,k))<=B;
 @for(pom_1(i,k):@GIN(X(i,k)));
 @for(pom_1(i,k):@BIN(Y(i,k)));
 @for(pom_1(i,k)|G(i,k)#EQ#1:Y(i,k)=0);
end
```

References

[1] A. Schrijver, "Theory of Linear and Integer Programming". John Wiley & sons, ISBN:0- 471-98232-6, 1998.
[2] C.C. Gotlib, "The construction of class-teacher timetables", *Proceedings of IFIP Congress*, 62, 1963, 73–77.
[3] R.J. Willemen, "School timetable construction: algorithms and complexity" *Printed by Universiteitsdrukkerij Technische Universiteit Eindhoven*, 2002, doi:10.6100/IR553569.
[4] J.H. Kingston, "Timetable Construction: The Algorithms and Complexity Perspective", Ann Oper Res, 2014, 218-249, https://doi.org/10.1007/s10479-012-1160-z
[5] M. Ilic, P. Spalevic, S. Ilic, M. Veinovic, Z. Milivojevic, B. Prlincevic: "Data mining techniques for student timetable optimization", *INFOTEH-JAHORINA* Vol. 14, March 2015, 578-583.
[6] H. Babaei, J. Karimpour, A. Hadidi, "A survey of approaches for university course timetabling problem", *Computers & Industrial Engineering 86*, 2015, 43–59.
[7] T.A. Redl, "A study of university timetabling that blends graph coloring with the satisfaction of various essential and preferential conditions" Ph.D. Thesis, Rice University, Houston, 2004, Texas.
[8] H. Asmui, E.K. Burke, J.M Garibaldi, "Fuzzy multiple heuristic ordering for course timetabling", *The proceedings of the 5th United Kingdom workshop on computational intelligence (UKCI05)*, London, UK, 2005, 302–309.
[9] S. Abdullah, E.K. Burke, B. McColloum, "Using a randomised iterative improvement algorithm with composite neighborhood structures for university course timetabling. metaheuristic – Program in complex systems", *Optimization*, 2007, 153–172.
[10] M. Mühlenthaler, "Fairness in Academic Course Timetabling", *Lecture Notes in Economics and Mathematical Systems 678*, Springer International Publishing, Switzerland, 2015, doi:10.1007/978-3-319-12799-6_2.
[11] Lindo, http://www.lindo.com/, Accessed May 04 2018.
[12] P. Sitek, I.E Nielsen J. Wikarek, "A Hybrid Multi-agent Approach to the Solving Supply Chain Problems", Knowledge-Based and Intelligent Information & Engineering Systems 18th Annual Conference, KES-2014 Gdynia, Poland, Volume 35, 2014, 1557-1566,.doi:https://doi.org/10.1016/j.procs.2014.08.239
[13] P. Sitek, "A Hybrid Approach to the Two-Echelon Capacitated Vehicle Routing Problem (2E-CVRP)", *Automation, Robotics and Measuring Techniques. Advances in Intelligent Systems and Computing*, 267. Springer, Cham, 2014, 251-263, doi:https://doi.org/10.1007/978-3-319-05353-0_25.
[14] P. Sitek, J. Wikarek, "A multi-level approach to ubiquitous modeling and solving constraints in combinatorial optimization problems in production and distribution", *Applied Intelligence 48*, 2018, 1344–1367, doi:https://doi.org/10.1007/s10489-017-1107-9
[15] P. Sitek, J. Wikarek, P. Nielsen, "A constraint-driven approach to food supply chain management", *Industrial Management & Data Systems 117(9)*, 2017, 2115-2138, doi: 10.1108/IMDS-10-2016-0465/
[16] P. Sitek, "A hybrid multi-objective programming framework for modeling and optimization of supply chain problems", *2015 Federated Conference on Computer Science and Information Systems (FedCSIS),* 2015, 1631-1640, doi: https://doi.org/10.15439/2015F83