Tabu Search Techniques for Polish Higher Education Timetabling Problems

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ABSTRACT

This article discusses the problem of creating university class timetables. When formulating the mathematical model, the author took into account the organisational conditions in Poland. He applied heuristic methods when searching for solutions. The model was defined as an ordered string of variables representing: the subject, the lecturer, the student group, the time slot (teaching block) and place of study. The author proposed a three-stage scheme of looking for solutions. Model construction was based on the preferences of lecturers who conduct classes in obligatory and facultative subjects for the student groups organised, and the preferences of students with permission for an individualised course of study.

INTRODUCTION

Scheduling classes at Polish universities is becoming an increasingly difficult logistic challenge, not only due to the large number of students and lecturers as well as the wide range of courses and subjects to choose from, but primarily because of the growing number of students who participate in classes as part of their individualised course of study. In the vast majority of cases, the timetables are created with the perspective of utilising the lecturer’s time, classroom capacity and the organisation of study hours of the student groups. Solutions taking into account the preferences of an individual student are not commonly used. Approving an individualised course of study without verifying that classes from separate courses the student is taking up will not collide with each other results in the necessity to partially or completely exempt the student from having to participate in organised group classes. This situation certainly results in additional encumbrances for the lecturer in the form of tutorship hours for the students with individualised study courses. It is important to note that at Polish universities constructing a class schedule is a cyclical task, repeated every semester. Due to the labour intensity of the process, developing an IT tool which would automatize its creation is desirable [26]. The study presented in this paper investigates solving the higher school problem for Polish higher education institutions. An informed tabu search heuristics is applied to the problem. The main contribution of the study is the evaluation of an informed tabu search heuristics in solving the Polish higher school problem.
LITERATURE OVERVIEW

The bigger the institution, the more complex a task scheduling classes becomes. In the subject literature, a lot of attention is given to both discussing the general issues connected with creating class timetables [20, 25, 38], and presenting the limitations present only in higher schools [11-12, 14-16, 19, 23, 24, 29].

The process of constructing a class schedule involves using, among others: simulated annealing [1, 35, 39], evolutionary algorithms [9], neural network algorithms [13], tabu search heuristics [2, 4, 5, 8, 11, 12, 14, 20, 30], genetic algorithms [10, 18, 36], integer programming [6, 11, 15, 16, 27, 31, 33] and constraint programming [19, 23, 25, 37].

It is obvious that the type of modelled restrictions is determined not only by the level of an individual school in the structure of the education system [29], but also the entire country in which said education takes place. In the literature, the way organisational and legal conditions are reflected was described with reference to schools in the Netherlands [17, 20, 39], Finland [25], Denmark [34], Germany [22], Greece [9-11, 15, 16, 27, 34], Italy [4, 7] and Spain [3, 5]. Their comparison has been presented in positions [28].

PROBLEM ASSUMPTIONS

Presented below are the basic problem assumptions for model construction present in Polish higher schools.

1. Class timetables encompass: classes and individual tutorship.
2. Classes are organised for groups of students and encompass mandatory and optional subjects.
3. Students are partitioned into groups called class-sections. A group follows the teaching programme in a subject-based system. Exceptions from this are students with permission for an individualised course of study. They can follow each subject with a different group. If, however, the time of the classes taken by such a student collide with each other, it is possible to choose the subject which will be taken in form of individual tutorship with the lecturer.
4. The workload of a lecturer per semester is defined by the management of the university. The number of class hours which should be given to a given subject in the semester is known. There are seven time-slots per school day, each lasting for ninety minutes. There is no possibility of dividing them (full appropriation).
5. A school week in Poland for lecturers starts on Monday and ends on Sunday. The lecturer’s availability may be restricted.
6. The final solution is personalised class schedules created for both the lecturer and the student.

PRELIMINARY NOTATION MODELS

The issue of scheduling refers to both the concept of resources and tasks. Table 1 presents a set of variables used for building the model of the class schedule. Additional restrictions were listed by the author in form of correlations and presented in Table 2.
Table 1. General sets and indices.

<table>
<thead>
<tr>
<th>Set or Index</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p \in P )</td>
<td>List of subjects with an assigned form (lecture, seminar, laboratory and classes) and number of hours</td>
</tr>
<tr>
<td>( w \in W )</td>
<td>Set of available lecturers (teachers)</td>
</tr>
<tr>
<td>( s \in S )</td>
<td>Set of available students</td>
</tr>
<tr>
<td>( g \in G )</td>
<td>Set of all the class-sections (groups of students)</td>
</tr>
<tr>
<td>( \Delta = [g] )</td>
<td>Maximum number of students in a class-section</td>
</tr>
<tr>
<td>( d_t \in [1, \ldots, 7] )</td>
<td>Indices of time-slots conducted in a given day ( t )</td>
</tr>
<tr>
<td>( m \in M )</td>
<td>Set of available classrooms</td>
</tr>
<tr>
<td>( K = [k_m] )</td>
<td>Number of stations/seats in the classroom/lecture hall</td>
</tr>
</tbody>
</table>

Table 2. General parameters and decision variables.

<table>
<thead>
<tr>
<th>Set or Index</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \forall [\varphi_{w_t,e}] &gt; 0 )</td>
<td>Lecturer’s time availability</td>
</tr>
<tr>
<td>( \Gamma = [\varphi_{w,t}] : \varphi_{w,t} \in {0,1,2} )</td>
<td>Lecturer’s priority time slots</td>
</tr>
<tr>
<td>( \Psi = [\psi_{s,t}] : \psi_{s,t} \in {0,1} )</td>
<td>Student’s individual preferences</td>
</tr>
<tr>
<td>( B = [\beta_{s,g}] : \beta_{s,g} \in {0,1} \text{ and } \sum_{g=1}^{G} \beta_{s,g} \geq 1 )</td>
<td>Assigning a student to a class-section</td>
</tr>
<tr>
<td>( Y = [\nu_{g,t}] : \nu_{g,t} = \sum_{s=1}^{S} (\beta_{s,g} \cdot \psi_{s,t}) )</td>
<td>Time preferences of the class-section</td>
</tr>
</tbody>
</table>

The solution finding scheme proposed by the author is characterised by a step-based approach. Stage 1 involves creating a model class timetable of obligatory and optional subjects for the class-sections. As part of Stage 2, the previously created schedules are complemented with tasks carried out by those students with permission for an individualised course of study, while during stage 3 a timetable is chosen from among the possible solutions which is then executed.

**Class Timetable Model**

The timetable model was formulated in the following form:

\[
X_e = \left\{ p_e, w_e, s_e, d_{e,t}, m_e \right\} 
\]

(1)

Assigning a subject to a student group and lecturer was defined as a correlation:

\[
\Omega = \left| \omega_{p,g} \right|
\]

(2)

where: \( \omega_{p,g} = \left\{ \begin{array}{l} 0; \text{ when there is no order for execution} \\
\omega; \text{ when the contractor is the lecturer} \end{array} \right. \)

Verification of the number of classes organised for student groups in obligatory subjects taking place in the given planning period was based on the following correlation:

\[
E = \sum_{g=1}^{G} \sum_{p=1}^{P} h_{p,g} = \left\{ \begin{array}{l} 1; \text{ when } \omega_{p,g} > 0 \\
0; \text{ when } \omega_{p,g} = 0 \end{array} \right. 
\]

(3)
Scheduling of classes in facultative subjects is preceded by a declaration of choice submitted by the student group. The choice is made from a presented list of optional subjects taught by specified lecturers. The decision is noted in the following form:

\[ H = \left\lfloor \gamma_{p,g} \right\rfloor \]  

(4)

where: \( \gamma_{p,g} = \begin{cases} 0; & \text{when there is no order for execution} \\ w; & \text{when the contractor is the lecturer} \end{cases} \)

The primary criterion for the choice of subject is the number of credits given to the student after completing the class, defined based on the assessed difficulty of the material taught in the class. Each subject has a dedicated number of points of:

\[ \lambda = [\lambda_p], \text{ where: } \lambda_p \in [1, \ldots, k] \]  

(5)

The requirement for approving a student group’s declaration is obtaining a number of credits from the \((n_{min}, n_{max})\) range in the planning period. Therefore, the correlation which determines the optionality of taking a class is noted as:

\[ \forall g \sum_{p=1}^{P} n_p = \begin{cases} \lambda_p; & \text{when } \gamma_{p,g} = 0 \lor \omega_{p,g} = 0 \\ 0; & \text{when } \gamma_{p,g} = 0 \land \omega_{p,g} = 0 \end{cases} \in [n_{min}, n_{max}] \]  

(6)

Verification of the number of classes in facultative subjects organised for student groups taking place in the given planning period was based on the following correlation:

\[ E = \sum_{g=1}^{G} \sum_{p=1}^{P} h_{p,g} = 1; \text{ when } \gamma_{p,g} = 0 \]  

\[ 0; \text{ when } \gamma_{p,g} = 0 \]  

(7)

Moreover, the mathematical model of the problem for both obligatory and facultative subjects should meet the restrictions contained in Table 3. The goal function took the following form:

\[ F_1 = \sum_{e=1}^{E} (\phi_{l_e,t_e} \cdot \Omega_{l_e,t_e}) \rightarrow \max \]  

(8)

**Table 3.** Model restrictions for the first stage.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \forall e_1 \in {e_2 \neq e_1} ) ( w_{e_1} = w_{e_2} ) ( \Rightarrow ) ( d_{t_{e_1}} \neq d_{t_{e_2}} )</td>
<td>Simultaneous conducting of two classes by one lecturer</td>
</tr>
<tr>
<td>( \forall e_1 \in {e_2 \neq e_1} ) ( g_{e_1} = g_{e_2} ) ( \Rightarrow ) ( d_{t_{e_1}} \neq d_{t_{e_2}} )</td>
<td>Simultaneously conducting two classes with one group</td>
</tr>
<tr>
<td>( \forall e_1 \in {e_2 \geq e_1} ) ( d_{t_{e_1}} = d_{t_{e_2}} ) ( \Rightarrow ) ( m_{e_1} \neq m_{e_2} )</td>
<td>Two classes conducted simultaneously in one classroom/lecture hall</td>
</tr>
<tr>
<td>( \forall e_1 \in {e_2 \geq e_1} ) ( \omega_{p,g_{e_1}} = \omega_{p,g_{e_2}} ) ( \Rightarrow ) ( t_{e_1} \neq t_{e_2} )</td>
<td>Having more than one class in a given subject in the same day</td>
</tr>
<tr>
<td>( \sum_{e=1}^{E} \beta_{g_{e_1}, c_{e}} \leq k_{m} )</td>
<td>Conducting a class when the limit of stations/seats in the room has been exceeded</td>
</tr>
<tr>
<td>( \forall \left( \varepsilon_{g_{p,m}} = 1 \right) )</td>
<td>Approval for the classes to be held in a given classroom/lecture hall</td>
</tr>
<tr>
<td>( \varepsilon_{p,m} \in {0,1} ) and ( \Xi = [\varepsilon_{p,m}] )</td>
<td></td>
</tr>
</tbody>
</table>

**Class Timetable Model of an Individual Student**

Currently, the main reason for creating a class schedule which takes into account the preferences of an individual student is not completing the classes by
individual students. Taking into account the limited availability of lecturers, it has been assumed that individualised organisation of a student’s education will be based on the timetables of already existing student groups. For that purpose groups whose numbers do not exceed the maximum permitted value set by the University President’s decree were used. A student’s timetable model was noted in the following form:

$$X_e = \{p_e, w_e, s_e, d_e, m_e\}$$ (9)

The change in the order of variables does not affect the solution of the problem.

### Table 4. Model restrictions for the second stage.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ \forall e_1, e_2, q_1, q_2 \exists s_{e_1} \Rightarrow d_{q_1} \neq d_{e_2} ]</td>
<td>Simultaneously taking part in two classes by one student</td>
</tr>
<tr>
<td>[ \forall g, \sum_{i=1}^{S} \beta_{h_i} \leq \delta_g ]</td>
<td>Exceeding the maximum group size (university decree)</td>
</tr>
<tr>
<td>[ \forall s, \sum_{p=1}^{P} n_p = \begin{cases} 2_p, \text{ gdy } \phi_{p,s} \neq 0 \ 0, \text{ gdy } \phi_{p,s} = 0 \end{cases} \in {n_{min}, n_{max}} ]</td>
<td>Acceptable number of credits obtained by the student after completing their classes (substantive difficulty scale)</td>
</tr>
</tbody>
</table>

The acceptance of a student’s declaration on the list of subjects taken by them constitutes a basis for admitting the student to partake in classes. Due to the need to confirm the feasibility of these decisions, the following correlation was created:

$$\Phi = \{\phi_{p,s}\}$$ (10)

where: $$\phi_{p,s} = \begin{cases} 0 & \text{when the student does not take the subject} \\ 1 & \text{when the student partakes in classes in the subject} \end{cases}$$

Verification of the number of classes organised for student groups which take place in the given time slot, which the student analyses takes part in as an additional participant, was based on the following correlation:

$$E = \sum_{s=1}^{S} \sum_{p=1}^{P} n_p = \begin{cases} 1 & \text{when } \phi_{p,s} = 1 \\ 0 & \text{when } \phi_{p,s} = 0 \end{cases}$$ (11)

Other restrictions which determine the method, in which the tasks are carried out, are contained in Table 4.

In this case the goal function takes the following form:

$$F_2 = \sum_{e \in E} (\phi_{w_e, d_e} \cdot \psi_{x_e, t_e}) \rightarrow \max$$ (12)

### CONCLUSION

Scheduling cyclical classes and semester graduation exams entails searching for solutions which take into account settling resource conflicts by looking for structures which, with the given rules, guarantee finding quantitative and qualitative parameters of the multi-criteria goal function. Limiting the number of solutions generated can be done through introducing additional restrictions for the model or by using heuristics of eliminating non-prospective states [21, 32]. Additional limitations to the model can be, among others: a daily compensation of a lecturer’s or student group’s classes, a defined order in which subjects are taught, etc.
The mathematical description of the issue modelled, encompassing scheduling classes organised for student groups in obligatory and facultative subjects as well as taking into account the preferences of individual students, served to create an implementation which automatizes the creation of the class timetable. Verifying the usefulness of the solution has shown a significant relief in terms of human engagement in the process of taking scheduling decisions. However, due to having a solution which does not fully describe the restrictions present in the process, the use of this IT tool has currently been directed toward actions which supplement human labour as opposed to replacing it.

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REFERENCES


