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ON THE FORMATION OF THE CLASS SCHEDULE AT UNIVERSITIES WITH THE BOLOGNA CREDIT-MODULAR SYSTEM OF EDUCATION

The study is devoted to the methodology for assessing the quality of class schedules in universities where the educational process is based on the Bologna credit-modular system. This paper examines factors that influence the quality of a university's class schedule: balanced faculty workload, even distribution of subjects throughout the week, consideration of faculty and student preferences, avoidance of conflicts, and compliance with institutional organizational and methodological standards. Special attention is paid to issues related to the specific nature of the academic process under a credit-modular system of education, such as the formation of temporary study groups and student registration for selected subjects. The task of schedule development is a discrete multi-criteria optimization problem. To solve it, we propose using the method of linear convolution of criteria. This means that the generalized criterion is a weighted sum of partial indicators. This approach allows for assessing the quality of the schedule not only as a whole but also by individual criteria.

Keywords: class schedule, credit-modular system, schedule assessment, hard requirements, soft requirements, additional factor, genetic algorithm.

Introduction. The work is devoted to the problem of timetable scheduling in universities that use the credit-modular education system, which is a key component of the Bologna Process. Learning within the credit-modular system differs significantly from the classical education system [1–4]. Its essence lies in the fact that the Bologna system transfers the initiative and responsibility for learning to the student, whereby:

- a unified grading scale is used – the credit, i.e., a unit that depends on the number of academic hours required to master a specific part of a subject or an educational module;
- student mobility is increased – the compatibility of curricula allows students to transfer to another university within the list of Bologna Process participants;
- no loss of accumulated credits occurs when students transfer between universities.

To obtain the required number of credits, each student independently compiles an individual study plan in accordance with their own interests, abilities, and preferences. As a result, there are no fixed academic groups, and each student creates their own class schedule. Students build their schedules based on the timetable of teachers, which is provided by the university (or faculty) administration. During the designated registration period, students must enroll in their chosen subjects. If they successfully meet the selection criteria and fall within the numerical limit set for the subject, they are included in a temporary study group for that subject.

The resulting student schedules are individualized, and each student is personally responsible for their quality. In this work, the focus is on the teachers' timetable, which is offered to students for the academic semester.

An important element in the effectiveness of the educational process is the class schedule. Creating a schedule means, based on the study plan, assigning teachers, distributing subjects, and allocating these subjects within the constraints of limited spatial and temporal resources. A finalized schedule must be free of conflicts (overlaps) involving teachers, time slots, and classrooms. Moreover, the quality of the schedule depends on the extent to which it satisfies the requests and preferences of all stakeholders: the university (or faculty) administration, the teaching staff, and the students. However, their preferences do not always coincide and often contradict each other, which creates additional complications [5–7].

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In scheduling problems, two types of requirements are considered: hard requirements, which are mandatory and determine the feasibility of a schedule, and soft requirements, which define the optimality, i.e., the quality of the schedule. Hard requirements, with few exceptions, are similar across most universities. Soft requirements include teachers' and students' preferences regarding schedule planning, individual teachers' requests for specific times and locations of classes, and methodological and organizational requirements. The composition and priority of soft requirements depend on the specific educational institution [8–10].

As is well known, from a mathematical point of view, the problem of creating a university class schedule is an NP-complete combinatorial optimization problem. Its goal is to develop a schedule that satisfies all hard constraints while considering soft requirements to the greatest possible extent [11, 12]. Consequently, only feasible schedules are subject to quality evaluation, and therefore, only soft requirements are considered in this assessment.

In this work, a scalar function will be used to evaluate the schedule, based on a weighted sum of functions determined by the degree to which the requirements are met, specifically their full or partial violation. The weight coefficients assigned to individual requirements are set by a group of experts in such a way that higher-priority requirements correspond to larger weight values. Consequently, the violation of a higher-priority requirement has a more significant impact on the schedule's evaluation compared to requirements of lower priority.

Problem Statement for Timetable Scheduling in the Credit-Modular Education System. To evaluate a schedule, the following mathematical multi-criteria decision-making methods are often used, especially when it is necessary to consider multiple criteria and constraints [13, 14]:

1) the main criterion method, in which all criteria are arranged in descending order of importance. The first criterion is designated as the objective function, while the others act as constraints, thereby reducing a multi-criteria problem to a single-criterion one;

2) the weighted coefficients method (linear combination of weights), in which each criterion is assigned a specific weight reflecting its importance, and the resulting function values are summed. This approach also reduces the problem to a single-criterion formulation;

3) the method of successive concessions (priority or preference method), in which all criteria are ordered by decreasing importance, and for each, an allowable concession is defined. That is, criteria that cannot be simultaneously satisfied are gradually weakened.

The evaluation methods described in this work are used for both the classical and the credit-modular education systems. However, there are significant differences between them, including in the process of schedule formation and in the assessment of its quality [2, 3, 15]. Subjects consist of module blocks that students can arrange in different sequences, thereby creating their own individual learning paths (class schedules). The teachers' timetable is provided by the faculty administration.

The subjects under study are divided into the following groups:

- compulsory (core) subjects – mandatory subjects stipulated by the program for the chosen specialty;
- restricted elective subjects – subjects chosen from a set list for the chosen specialty;
- free elective subjects – subjects of free choice (without restrictions, at the student's discretion).

A number of works and publications on the preparation of class schedules are focused specifically on universities with a credit-modular education system, taking into account the specifics of this process. The criteria (objective functions) that can be adopted include, in particular, minimizing the number of time conflicts (time overlaps) between compulsory subjects [16], optimization according to one of the selected criteria (number of classrooms, minimizing the number of slots) [17, 18], minimizing the number of unassigned subjects, reloading existing teachers and the number of new staff required, reassigning classrooms and time slots [19, 20], teachers' wishes taking into account the priority of the subject [21, 22], and maximizing the number of cases when students register for the subjects they desire [23].

To evaluate the schedule, we'll use a linear weighted combination of criteria. We'll consider all soft requirements, as well as factors related to the specifics of the credit-modular system. The schedule evaluation function is a linear aggregation of all partial weighted criteria:

$$S(P) = \sum_{i=1}^{n} \omega_i S_i(P) + \sum_{j=1}^{m} w_j V_j(P),$$

where P is a feasible schedule or part of it, $S_i(P)$ is the value of the individual criterion corresponding to the *i*–th soft requirement, ω_i is its weight, *n* is the number of soft criteria, $V_j(P)$ is the value of the individual criterion corresponding to the *j*–th factor, w_j is its weight, and *m* is the number of factors [3, 15].

To solve the timetable scheduling problem, a two-stage approach was used, involving the formation of an initial schedule followed by its optimization using a genetic algorithm. In the first stage, the initial population is generated in a mixed manner: part of the individuals are created using various greedy algorithm variants, another part through a slight modification of the greedy algorithm (a greedy algorithm with mutation), and the remaining part of the population is generated stochastically.

In the second stage, the DEAP framework (Distributed Evolutionary Algorithms in Python) [24, 25] is used to perform the genetic algorithm operations (selection, crossover, mutation). The genetic algorithm consists of three steps:

- selection – tournament selection (selTournament) with elitism, i.e., a specified percentage of the fittest individuals (best solutions) are carried over to the next population without undergoing selection;
- crossover – two-point crossover (cxTwoPoint);
- mutation – mutShuffleIndexes, a mutation operator for permutation-based chromosomes that randomly changes the order of elements while preserving chromosome length.

The algorithm terminates upon reaching the predetermined number of generations.

Requirements for Class Schedules Determining Their Evaluation and Optimality

Soft requirements for university class schedules include:

Organizational and methodological requirements from the administration:

- compliance of the schedule with the university's working hours;
- adherence to the norms for teachers' daily and weekly workloads;
- consideration of the requirement to minimize transitions between buildings;
- efficient use of classroom resources, taking into account capacity and the availability of necessary equipment.

Teachers' preferences:
- consideration of individual requests regarding the time and location of classes;
- minimization of the number of "gaps" in their schedules.

Students' wishes:
- compulsory subjects within the same program are scheduled in different time slots;
- not scheduling classes for the same subject in consecutive time slots.

Factors Related to the Features of the Credit-Modular System:

The most significant factor affecting evaluation is that a planned group may not be formed. The reasons for this may include:
- insufficient number of students – the number of students enrolled in the subject is below the minimum required to form a group;
- low interest in the subject, which applies to elective and free-choice subjects;
- poorly constructed schedule, where several subjects, primarily compulsory ones, are assigned to overlapping time slots;
- students' personal preferences regarding the choice of instructor.

Another important factor of schedule quality is when the number of students wishing to enroll in an interest subject exceeds the established maximum. The reasons for this may include:
- high interest in the subject due to its relevance and demand;
- a strong academic and pedagogical reputation of the teacher teaching the subject;
- an insufficient number of teachers for the subject;
- the desire of students in their final years to enroll in missing subjects;
- insufficient number of available seats, limited by the physical capacity of the classroom.

These two factors indicate that an objective assessment of the quality of the class schedule at universities with a credit-modular system of education can only be made after students have completed registering for courses.

Mathematical model for the formation of schedule evaluation criteria

The mathematical formulation and the process of constructing the soft requirements formulas are described in detail in [3, 15]; therefore, we will focus here on the formulas that describe the features of the credit-modular education system, which influence the quality of the class schedule.

Unformed groups for teachers

The function assessing the impact of unformed groups on the quality of the class schedule is defined as follows:

$$\Phi_1(P) = \sum_{r\in R} s_r \sum_{q\in Q} w_q^1 k_q^1. \tag{1}$$

Here, R is the set of teachers, s_r is the rating of the teacher with code r, Q is the set of groups into which the studied courses are divided $(Q = \{1, 2, 3\})$, w_q^1 is the coefficient determining the penalty for each unformed student group for which a course belonging to the group with code q was scheduled, and k_q^1 is the number of unformed student groups in which a course belonging to the group with code q was scheduled.

Number of students unable to enroll in chosen courses

The function assessing the impact of students' inability to register for desired courses on timetable quality, broken down by senior and junior students and considering the course type, is defined as follows:

$$\Phi_2(P) = \sum_{s\in S_1} \sum_{q\in Q} \left(w_{s_1,q} \cdot k_{s_1,q}\right) + \sum_{s\in S_2} \sum_{q\in Q} \left(w_{s_2,q} \cdot k_{s_2,q}\right). \tag{2}$$

Here S_1, S_2 are the sets of students of the junior and senior years of study, respectively, defined by the following formulas:

$$S_1 = \left\{ s \in S | 0 \leq \frac{D_{current} - D_{start,s}}{365} < 2 \right\},$$

$$S_2 = \left\{ s \in S | \frac{D_{current} - D_{start,s}}{365} \geq 2 \right\},$$

where $D_{current}$ is the current date, $D_{start,s}$ is the start date of study for the student with code s, $w_{s_1,q}, w_{s_2,q}$ are the coefficients reflecting the grades for the unfulfilled desires of students who started (S_1) and are completing their studies (S_2) to enroll in a discipline with code q, $k_{s_1,q}, k_{s_2,q}$ is their number.

Unfulfilled soft requirements

For the general formula for assessing the quality of a schedule, in general form, the formula reflecting the assessment of unfulfilled soft requirements is added:

$$\Phi_3(P) = \sum_{i=1}^{N_1} (w_{3,1,i} \cdot k_{3,1,i}) + \sum_{r \in R} s_r \sum_{i=1}^{N_2} (w_{3,2,i} \cdot k_{3,2,i}) + \sum_{i=1}^{N_3} (w_{3,3,i} \cdot k_{3,3,i}). \quad (3)$$

Here, N_1, N_2, N_3 are the numbers of soft requirements from the administration, teachers, and students, respectively; $k_{3,1,i}, k_{3,2,i}, k_{3,3,i}$ are the corresponding numbers of violated soft requirements; and $w_{3,1,i}, w_{3,2,i}, w_{3,3,i}$ are their respective weighting coefficients. The assessment of teachers' soft requirements takes their status into account.

The general form of class schedule assessment at universities with a credit-modular education system is defined by the following formula:

$$\Phi(P) = \sum_{i=1}^{3} \lambda_i \Phi_i(P). \quad (4)$$

Here $\lambda_i \geq 0$ is a parameter that determines the degree of importance of soft requirements and additional factors influencing the quality of the schedule, $i = 1, 2, 3$.

The values of the coefficients included in formulas (1)– (4) are determined based on empirical data, expert evaluations, or a combination of these approaches.

Description of the process of scheduling classes in a credit-modular education system

An important feature of the class schedule in the credit-modular education system is that the process of its creation is iterative. The evaluation of the schedule is largely influenced by factors related to its specific characteristics. To eliminate such problems, the following approaches can be used:

- involvement of additional teachers;
- making changes to the schedule structure;
- redistribution of classes to classrooms with larger capacity.

In addition, students often make changes to their own registration for various reasons, which also requires adjustments to the schedule. In practice, a period of two weeks is usually allocated for this purpose.

To minimize the objective function $\Phi(P)$, various methods of finite-dimensional discrete (integer) optimization can be applied. For conducting computer experiments on the constructed test data, we used several variants of genetic algorithms available in the DEAP (Distributed Evolutionary Algorithms in Python) framework and the Python programming language.

The analysis of the results obtained showed that the problem formulation and the proposed numerical approach to timetable generation presented in this study can be applied to schedule planning under real-world conditions. It is clear that the main challenge in automating this process lies in the preparation of the initial (input) information, both reference data (university and faculty structure, teaching staff, list of courses and curricula, classroom resources) and operational data (requests submitted by departments, as well as individual teacher's requests indicating planned workload for the current semester and preferences regarding class times and locations). Frequently, faculties possess outdated information; there is no unified structure for the data, which is stored across different databases in inconsistent formats, or is available in various formats (PDF, Excel, Word), and in some cases, it is even maintained manually. This also applies to data from human resources, academic affairs, and administrative departments. The issues listed above create difficulties both in the implementation of the system and during its operation.

Conclusion. In this work, several important factors are emphasized that determine the quality of class scheduling in universities operating under the Bologna credit-modular education system. These include compliance with organizational standards, consideration of teachers' preferences regarding class times and days, even distribution of courses, balance between the workload of teachers and students, and the necessary flexibility that students require in their academic timetables. Particular attention is given to two key aspects that often arise in the planning of the educational process within credit-modular universities: the formation of study groups and the availability of courses. Unformed study groups can disrupt the learning process and lead to inefficient allocation of resources, such as teaching staff and classrooms, while students often find themselves unable to enroll in the desired courses. This situation also results in empty time slots that could otherwise be used for more in-demand subjects. Such problems may increase the workload of teachers, administrative staff, and students, creating unnecessary scheduling conflicts and reducing the overall efficiency of the educational process.

The proposed multi-criteria schedule evaluation model provides a clearer understanding of where the most significant issues occur within the analyzed timetable. This approach enables universities to appropriately adjust their planning processes and resource allocation. In turn, it contributes to more efficient utilization of educational resources, greater satisfaction among all stakeholders, and an overall improvement in academic performance.

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Щодо формування розкладу занять в університетах з Болонською кредитно-модульною системою навчання

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Вступ. Невід'ємною складовою Болонського процесу є кредитно-модульна система навчання (ECTS – Європейська система трансферу і накопичення кредитів). У межах цієї системи формується два типи розкладів: розклад викладача та розклад студента. Кожен студент має можливість формувати індивідуальний персональний розклад відповідно до власних можливостей, уподобань і побажань з урахуванням часу проведення занять.

Розклад викладачів у кредитно-модульній системі навчання має низку особливостей порівняно з традиційною організацією освітнього процесу. Це зумовлено принципом модульності, а також поділом дисциплін на блоки (обов'язкові дисципліни; дисципліни за вибором у межах спеціальності; дисципліни вільного вибору студентів, вивчення яких не є обов'язковим для конкретної освітньої програми). Однак найважливішими показниками якості розкладу в умовах кредитно-модульної системи навчання є ефективність формування тимчасових навчальних груп і можливості студентів записатися на обрані курси.

Мета. Розробити та описати процес оцінювання якості розкладу занять з урахуванням усіх "м'яких" вимог і додаткових факторів, а також запропонувати відповідну математичну модель.

Результати. Запропоновані методологія, математична модель та алгоритм оцінювання якості розкладу враховують "м'які" вимоги, зокрема, уподобання викладачів, рівномірність навчального навантаження, мінімізацію прогалин у розкладі та додаткові фактори. Це дозволяє кількісно визначити ступінь оптимальності розкладу в університетах, що функціонують за кредитно-модульною системою навчання.

Висновки. Запропонований підхід до оцінювання якості розкладів занять в університетах, що працюють у межах Болонського (кредитно-модульного) процесу, дає змогу виявити ключові чинники, які впливають на ефективність освітнього процесу, а також окреслити напрямки його вдосконалення. Визначено та проаналізовано характеристики розкладів, що безпосередньо впливають на якість організації навчання.

Особливу увагу приділено двом важливим аспектам, які часто виникають під час планування освітнього процесу в умовах кредитно-модульної системи: формуванню навчальних груп і доступності навчальних курсів. Неповні навчальні групи можуть порушувати перебіг освітнього процесу та призводити до неефективного використання ресурсів, таких як викладацького складу та аудиторного фонду, тоді як студенти нерідко не мають змоги записатися на бажані курси, що спричиняє появу не використаних часових проміжків, які могли б бути задіяні для більш затребуваних дисциплін. Такі проблеми підвищують навантаження на викладачів, адміністративний персонал і студентів, створюють конфлікти в розкладі та знижують загальну ефективність освітнього процесу.

У дослідженні запропоновано багатокритеріальний підхід до оцінювання якості розкладу з використанням системи штрафних коефіцієнтів. Цей підхід забезпечує кількісну оцінку різних видів порушень, зокрема, перевантаження і недовантаження викладачів, невдоволеності студентів та проблеми із доступністю навчальних курсів. Розглядаючи ці фактори цілісно, запропонована система оцінювання забезпечує більш цілісний підхід до оцінки аналізованого розкладу. Цей підхід дозволяє визначити складові розкладу, які не оптимальні, та надає практичні рекомендації щодо покращення процесу планування.

Ключові слова: розклад занять, кредитно-модульна система, оцінювання якості розкладу, жорсткі вимоги, м’які вимоги, додаткові фактор, генетичний алгоритм.