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AUTOMATED SCHEDULE SYSTEM FOR UNIVERSITIES UNDER THE BOLOGNA EDUCATION PROCESS

The paper examines the problems of scheduling classes in higher educational institutions in the conditions of the Bologna education system. An analysis of the specific problems of scheduling classes and their comparison with the classical form of education was carried out. The methodology takes into account the specifics of the Bologna system, which provides the possibility of individual selection of disciplines for the semester, drawing up a personal schedule of classes and choosing teachers. To implement this methodology, a three-stage approach to planning class schedules in the credit education system, a model of "hard" and "soft" restrictions, as well as an algorithm for generating a schedule in interactive mode are proposed. The developed system ensures the construction of an acceptable schedule and, to the greatest possible extent, its efficiency. The result of the program is two schedules: individual schedules of teachers and all subgroups, including students enrolled in them.

Keywords: *Bologna process of education, credit system, asynchronous learning system, class schedule, scheduling requirements, computer system.*

Introduction. The Bologna Process is an intergovernmental initiative aimed at creating a European Common Educational Space. The process started in June 1999 in Bologna (Italy), when representatives of 29 countries signed the Bologna Declaration. To date, 48 have already become participants in the Bologna process. The Bologna education system is aimed at bringing higher education to unified standards and creating a unified educational space [1–4].

One of the important areas of the Bologna Process is the European Credit Transfer System (ECTS), which aims to increase the comparability of national education systems. The main feature of the credit system in education is its ability to quantify the volume and level of knowledge of students during their studies in bachelor's, master's or doctoral programs. ECTS ensures the availability of higher education under a unified system, the mobility of students and teachers, the recognition of their academic qualifications and periods of study abroad, and allows credits received at one higher education institution to be counted towards obtaining qualifications at another university and even in another country [5–12].

An important component of any form of training is the availability of a high-quality class schedule. With the beginning of each semester, educational institutions are faced with the problem of scheduling classes and assigning classrooms for them [13–15].

When creating a class schedule, there are many requirements and constraints that must be taken into account in terms of time, space and types of resources such as number of teachers, students, classrooms, classroom capacity, laboratory equipment in the classroom, variety of subjects studied, wishes of teachers and students, and many other factors [16–17].

Scheduling classes for both the classical form of education and the Bologna process of education is a complex planning problem in which the schedule must be organized in available time slots along with limited resources (teaching staff, classrooms, laboratory facilities, etc.) and a variety of requirements (medical, organizational, pedagogical), wishes of teachers and students. Finding such a solution is quite difficult, because an attempt to take into account absolutely everything usually leads to conflict situations. But the extent to which the compiled schedule satisfies the restrictions and requirements, and also takes into account the wishes of teachers and students, i.e. the quality of the schedule depends on the quality of the educational process as a whole. Many universities have their own specific requirements, taking into account the capabilities of the teaching staff and classroom facilities [18–19].

An important difference between scheduling for the Bologna learning process and the classical one is as follows. The scheduling of the Bologna form of training is carried out iteratively. Each iteration consists of three stages. At the first stage, a draft class schedule for teachers is formed, at the second stage, students draw up their classes taking into account the teachers' schedule. The third stage consists of a joint assessment of the received schedules of teachers and students. If a large number of students could not be included in the teachers' schedule or the teachers did not have groups, then a return to the first stage occurs – the teachers' schedule is adjusted.

Note that even for the classical form of training there is not yet an algorithm for optimizing schedules taking into account absolutely all requirements criteria for real cases. This work sets the task of drawing up such a schedule, taking into account the requirements of the Bologna training system, which will avoid conflicts and will take into account more significant restrictions and the most important preferences.

Taking into account a significant amount of input information and a large number of constraints and requirements, the task of scheduling training sessions is a complex combinatorial multi-criteria problem. As is known, this problem, like many other problems of planning and distributing work, belongs to NP-complete problems of discrete mathematics.

As is known, both mathematical and heuristic methods are used to solve such scheduling problems. The paper proposes a heuristic algorithm based on the "traffic light" principle in an interactive mode of operation.

Due to the significant differences between the credit education system and the traditional one, there is a need to develop special algorithms and software designed specifically for use in educational institutions with a credit education system.

The main goal of this article is to develop a full cycle for creating class schedules, starting from enrolling students in the chosen discipline and ending with obtaining ready-made schedules taking into account the requirements of the Bologna training system. In chapters 1 and 2, the problem is stated, a description of the credit education system is given, its features are given, and the process and stages of creating schedules are proposed. Chapter 3 describes the requirements and restrictions for schedules, chapter 4 provides their mathematical model, chapter 5 describes how to create a schedule evaluation function, chapter 6 provides a description and protocol of the scheduling process.

1. Problem statement

When creating a class schedule "manually", it is necessary, first of all, to have qualified specialists who have experience in creating a schedule in a given educational institution, a lot of time spent on preparing a large amount of input information, and monitoring (checking) the finished schedule. At the same time, as a rule, there is no guarantee that the result will be at least an acceptable solution, not to mention its optimality to some extent.

The solution to this problem is to automate this process. Many packages have been developed for scheduling classes in educational institutions. We won't go into detail about them, but the problem is that they are all designed to create a class schedule for the traditional education system. Just as the credit education system itself differs greatly from the traditional one, the organization of the educational process and, accordingly, the principle of scheduling classes and the restrictions imposed on it change significantly.

With the Bologna form of education, two schedules must be created: a teacher schedule and a schedule for temporarily formed groups of students on a subject basis. The input information for students' schedules are their chosen disciplines included in their academic course and the teachers' schedules for their chosen subjects.

The disciplines studied have different credit prices and are divided into compulsory, optional disciplines from a list specified for a given specialty, and free choice outside this list. Moreover, if at the beginning of training, compulsory subjects predominate in the list of selected subjects for students, then later the ratio changes, disciplines can be chosen from other specialties or even faculties, and the spread in the choice of subjects becomes very large. An important feature of the credit education system is that each student has a personal schedule of classes, which allows students to effectively manage time. By clearly defining the workload of each course, students can plan their schedule and allocate time accordingly. The composition of students in the formed groups is not stable and, as a rule, the composition of the groups changes every semester. This leads to the fact that it is difficult to find a good solution for the timetable and it is impossible to create an “almost” static timetable valid for each year, with minor changes, as is possible with the traditional education system.

From this it is clear that for creating a schedule of classes in universities under the conditions of a credit education system, software tools developed for similar tasks under the traditional education system are not suitable. For the credit education system, there are no timetable software systems that have proven themselves positively in various universities.

Taking into account the above, there is a need to develop methods, algorithms and a software application for creating a class schedule in universities with a credit education system, covering the entire process of creating a class schedule: from registering students in groups by subjects and teachers, creating a schedule of teachers according to their workload, registering students in groups by subjects and teachers, taking into account the necessary control over the possibility and admissibility of student wishes and until ready-made schedules are received.

2. Scheduling process

Features of the asynchronous learning system. Studying at a university under the traditional education system, which is also called synchronous, begins with the formation of study groups, the composition of which, with rare exceptions, may not change until graduation. Within one specialty, all students study according to a single curriculum, scheduled by year of study and each semester. The class schedule is strict and mandatory for the entire group.

The Bologna education system is based on asynchronous learning. “Asynchronous” means that objects or events do not occur simultaneously, i.e. that different students may participate in the same event, but at different times.

Asynchronous learning is a way of organizing the educational process in which students, within certain limits, have the opportunity to individually plan their studies according to their own schedule. This allows you to build training in a scheme convenient for each student at a pace that suits him, which he can change within the framework of the academic course and credit requirements. With asynchronous learning, the set of disciplines studied is determined not by the year of study, but by the choice of the student. Students who entered the same specialty or direction in the same year do not all study together and according to different individual plans, i.e. asynchronously [20–22].

Principles for designing an asynchronous schedule. In universities that operate a credit education system, both the principles and the process of creating a schedule differ from those in traditional educational institutions.

The university provides each student with a curriculum for the entire period of study, indicating the terms of study for each subject, i.e. the number of credit units that a student must spend to master this discipline.

One of the main stages of this is the enrolment of students in subject groups. Until then, students must enroll for the upcoming semester and submit an online application with a list of all the disciplines they want to study. The Dean’s Office verifies these applications for student eligibility for each subject, based on consistency requirements in the study of each subject, and receives a forecast of student demand for certain classes.

Then the dean's office begins to draw up a class schedule. This process is broken down into the following steps:

- analysis of the list of disciplines chosen by students for the current semester, in particular checking that a large number of applications have been received for the discipline than the university can provide with teachers and classrooms;
- appointment of teachers for planned disciplines;
- determination of the flow quantity, which is limited both from below and from above;
- distribution of classes in acceptable time intervals;
- assignment of classrooms for classes held in a traditional (of-line) format.

Note. Many universities use on-line teaching as a form of education in any subject. In this case, the only difference is that there is no need to assign an audience.

After this, students are given a period of time ("window") to register in order to select courses for the upcoming semester. Registration of students for each discipline and teacher chosen by them occurs strictly in the order of application. Student applications are processed for eligibility for this subject by coordinators and, if approved and if there is a place in the group of a particular teacher, the student is enrolled in the course. After this, the student can begin to draw up his personal schedule in accordance with his capabilities and needs. Thus, the teachers' schedule is the input to the students' schedule. When the upper permissible limit for the number of students in a group is reached, the registration process for the desired discipline stops. Classes in a discipline for which the number of registered students is less than the lower limit will be canceled and in the future this subject for this teacher will be excluded from the schedule. If the same course is taught by several teachers, then the student, if desired and if there are free places, can enroll in it. Otherwise, transfer the study of this discipline to the next semester (if it will be taught again in the current academic year), or to the next academic year.

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As you can see, the process of creating a class schedule consists of several stages and as a result, two types of schedules are created: first, the teachers' schedule must be created and the classrooms assigned for classes, and only after that the students are registered and each student creates his own schedule. Naturally, the classic composition of "hard" and "soft" restrictions imposed on the schedule will also change.

3. "Hard" and "soft" constraints on the class schedule

Depending on whether the restrictions are mandatory or desirable, they are classified as "hard" and "soft" respectively. "Soft" and "hard" restrictions are fundamental elements, the consideration of which is important both for creating a high-quality schedule and for the normal functioning of the educational process as a whole.

"Hard" restrictions are the main elements of the schedule and must be observed without fail. If any of the "hard" constraints cannot be successfully met, then the schedule is rejected.

A schedule that satisfies all the "hard" requirements is a valid schedule.

The degree of optimality of the compiled admissible schedule depends on the fulfillment of "soft" requirements in it, which can be violated, but must be fulfilled to the maximum extent possible to improve the quality of the schedule. The list of "soft" requirements in educational institutions may be different.

Restrictions on teachers' schedules. "Hard" restrictions are the need to meet the following requirements:

- implementation of the entire planned curriculum by teachers;

- the total number of classes assigned in each time period should not exceed the permissible classroom fund of the university;
- absence of problems for teachers in terms of time and space, namely:
  - each teacher may teach in only one classroom during each time period;
  - each classroom in each time period can be assigned only for one lesson.

"Soft" restrictions consist of taking into account the following requirements:
- the assignment of classes must correspond to the work schedule of the educational institution;
- provision of classrooms with special equipment;
- location of classrooms and their capacity;
- taking into account the wishes of teachers.

There are also wishes from students regarding the teachers' schedule:
- equal allocation of hours for each subject during the school week;
- lack of overlap by time periods of compulsory subjects, which limits students' choice.

Restrictions on students' schedules. Due to the fact that each student forms his own schedule based on his wishes, needs and opportunities, using the already prepared timetable of teachers, there are no restrictions to their already formed individual schedules, control is carried out at the stage of their registration for courses.

Requirements at the stage of student registration. The following requirements must be met for the successful registration of students for the selected disciplines:
- each student at each time period can be in only one class;
- the number of students in the formed groups of students must correspond to the established number;
- maintaining the sequence of studying disciplines when creating individual educational programs for students;
- the number of disciplines during the school day should not exceed the restrictions and medical standards available in the educational institution;
- compliance of the number of declared courses with the established norm;
- compliance of the declared subjects with the program of the chosen specialty.

Note. The last two requirements can only be slightly violated with the permission of the faculty leadership.

Due to the fact that each student creates his own schedule, based on his wishes, needs and capabilities, using the teachers' ready-made schedule, there are no "soft" restrictions on their individual schedules.

4. Statement of the task of scheduling classes at the university

Basic notation used in the task. To describe the restrictions in the formulation of the problem of scheduling classes at a university, we introduce the following notation:

J – many classes: (lectures, seminars, laboratory classes) in all subjects;

R_1, R_2, R_3 – set of resources: respectively, teachers, students, classroom fund, $R = R_1 \cup R_2 \cup R_3$;

$T = \bigcup_{i=1}^{D} T_i$ – set of time periods per week in which classes can be held, D – number of school days during the week;

C – is a set of restrictions, consisting of two subsets, $C = C_1 \cup C_2$, where C_1 is a set of "hard" restrictions, C_2 is a set of "soft" restrictions.

Let us note that all educational institutions, as a rule, consist of faculties, which are their composite and fairly independent constituent units. Educational processes in faculties are organized almost independently of each other, not counting a small number of common classrooms and common departments conducting classes in different faculties.

The task of scheduling classes is to assign for each of the classes from the set J the available time intervals from the set T and the available resources R so as to fully satisfy the "hard" constraints C_1 and, to the maximum possible extent, the "soft" requirements C_2.

To specify the formulation of the problem, we introduce the following notation.

F is the set of the codes of the faculties of the educational institution, $f \in F$ is code of the faculty.

C – set of department codes of an educational institution, $c \in C$ is code of the department.

P is set of teacher codes of the educational institution,, $p \in P$ is teacher code.

S is the set of codes of students studying at the educational institution, $s \in S$ is the student code.

J – set of codes of disciplines studied in an educational institution, $j \in J$ – discipline code; some disciplines must be studied in a certain order – each element $j \in J$ corresponds to the set B^j – the set of discipline codes immediately preceding the study of the discipline with code *j*. The sign of successful passing of exams in disciplines from the set B^j by a student with code s is reflected in the set L^{js}. If discipline with code j does not depend on others, then $B^j = \emptyset$. Classes are held in classrooms with the following characteristics:

K – number of educational buildings, $k \in K$– code of educational building;

$A = \bigcup A_k$ – set of classroom codes in the educational building with code k, $a_{kq} \in A_k$ – code of the *q*-th audience in the educational building A_k;

V^{kq} is the capacity of the classroom with code a_{kq} in the academic building with code *k*;

c^{qk} is the code of the department that owns the classroom with code a_{kq} in the academic building with code *k*.

Considering that when conducting classes in some disciplines, special equipment is required, we introduce the following notation:

Z – many codes of types of specialization of audiences, $z \in Z$ – code of type of specialization of audience; z^{qk} – code of type of specialization of audience a_{kq}in educational building with code *k*.

To describe the educational process at the university we use the following notations:

D – set of school days during the week, $d \in D$ – number of the day of the week.

T – set of possible time periods during the school week, $t \in T_d$ – time intervals in day *d*,

$$T_d = \{d * (m - (m-1)), d * (m - (m-2)), \dots, d * m\}, \tag{1}$$

where m is the maximum permissible number of time slots per school day.

On each day *d*, the first lesson is determined by the formula:

$$t_{d,1} = d * (m - (m-1)), \tag{2}$$

the last is by the formula:

$$t_{d,m} = d * m. \tag{3}$$

The mathematical model of restrictions and requirements for class schedule is formulated in terms of integer linear programming.

Restrictions on teachers' schedules. The following "hard" restrictions on the teachers' schedule in the mathematical formulation of the schedule optimization problem stipulate the following constraints of the type of equalities and inequalities.

Each *p*-th teacher in each time period *t*, regardless of the audience and subject, can conduct no more than one lesson:

$$F_1(x) = \sum_{j \in J} \sum_{a} x_{ta}^{pj} \le 1, \qquad \forall p \in P, \forall t \in T, \tag{4}$$

the binary variable x_{ta}^{pj} is equal to 1 if the *p*-th teacher conducts a lesson in *j* – that discipline in time period *t* in *a*-th audience, and 0 – otherwise.

No more than one lesson may be held in each a-th audience in each time period t:

$$F_2(x) = \sum_{j \in J} \sum_{p} x_{ta}^{pj} \leq 1 , \qquad \forall a \in A, \forall t \in T. \tag{5}$$

The total number of classes assigned during the time period t cannot exceed the university's classroom fund:

$$F_3(x) = |A| - \sum_{p} \sum_{j} x_{ta}^{pj} \geq 0, \qquad \forall\, t \in T. \tag{6}$$

During the study week, each teacher is required to complete all the classes planned for him:

$$F_4(x) = \sum_{j \in J} \sum_{a \in A} \sum_{t \in T} x_{ta}^{pj} - \left|\overline{PJ_J}\right| = 0, \tag{7}$$

$\overline{PJ} = \left\{\overline{PJ}_{p,j} : p \in P, j \in J\right\}$ – given matrix of planned classes of the p-th teacher, $p \in P$.

The following "soft" requirements imposed by teachers and students, and some conditions desirable for the successful conduct of classes in a single-criteria or multi-criteria schedule optimization problem, stipulate the possible criteria for assessing the quality of the class schedule given below.

Minimizable function that numerically evaluates the failure to fulfill the wishes of teachers who indicated school days and time periods undesirable for assigning classes:

$$G_1(x) = \sum_{p \in P} \sum_{t \in T} w^p * {O_1}_t^p, \tag{8}$$

w^p is the amount of the fine depending on the status of the teacher with code p, the binary variable ${O_1}_t^p$ is equal to 1 if the teacher with code p does not want to conduct a lesson in time period t, and 0 otherwise.

Minimizable function, numerically estimating the number of «windows» for all teachers:

$$G_2(x) = \sum_{p \in P} \sum_{j \in J} \sum_{t = t_{d,1}+1}^{t_{d,m}} \left| x_{ta}^{pj} - x_{(t-1)b}^{pj} \right|, \quad \forall a, b \in A. \tag{9}$$

Minimizable function, numerically estimating the number of transitions of teachers between academic buildings:

$$G_3(x) = \sum_{p \in P} w^p \sum_{t = t_{d,1+1}+1}^{t_{d,m}} \left| {\varphi_3}_t^p - {\varphi_3}_{(t-1)}^p \right|, \tag{10}$$

where ${\varphi_3}_t^p$ is the code of the educational building in which the teacher with code p conducts a lesson in the time period t, w^p is a value depending on the status of the teacher.

Function caused by the uneven distribution of disciplines studied during the school week:

$$G_4(x) = \left({O_2}_t^{pj} + {O_2}_{t+m}^{pj}\right) - 1 \leq 0 , \qquad j \in J, p \in P, t \in T, \tag{11}$$

the binary variable ${O_2}_t^{pj}$ is equal to 1 if a teacher with code p is assigned a lesson in a discipline with code j in time period t, and 0 otherwise.

A function stipulated by the degree of non-divorce (non-distribution) of compulsory subjects over different time periods:

if $O_3^{j_i}, O_3^{j_n}$ are compulsory subjects, then the following condition must be met:

$$G_5 = \sum_{j_i, j_n \in J} \sum_{t \in T} \left| {O_3}_t^{j_i} - {O_3}_t^{j_n} \right| = 0, \tag{12}$$

binary variables ${O_3}_t^{j_i}, {O_3}_t^{j_n}$ are equal to 1 if academic disciplines with codes j^i, j^n are included in the schedule in time period *t*, and 0 otherwise.

In each time period *t*, the number of students scheduled to study a specific discipline with a specific teacher should not exceed the capacity of the audience assigned for this lesson:

$$G_6(x) = \sum_{s \in S} y_{st}^{pj} - V^{kq} \leq \mathcal{E} * V^{kq}, \tag{13}$$

where $p \in P$, $j \in J$, the binary variable y_{st}^{pj} is equal to 1 if a student with code *s* must be present at the lesson in the time period *t*, 0 – otherwise, $\mathcal{E}$ is the permissible value of the number of students exceeding the number of seats in the classroom ($\mathcal{E} \in [0{,}0{,}1]$).

If the audience with code a is assigned to the department, then for ($c^{qk} \neq 0$) the following condition must be met:

$$G_7(x) = c^{qk} - {\varphi_1}_t^{pj} = 0, \tag{14}$$

where ${\varphi_1}_t^{pj}$ is the code of the department whose teacher with code *p* conducts a lesson with code *j* in time period *t*.

If a specialized audience is required to conduct a lesson in a discipline with code *j*, then the following condition must be met:

$$G_8(x) = {\varphi_2}_t^{j} - z^{qk} = 0, \tag{15}$$

where ${\varphi_2}_t^{j}$ is the code of the type of audience that is required to conduct a lesson in discipline with code *j* in time period *t*.

Control over student registration. Teachers' schedules that have been generated and verified, indicating the academic discipline being taught, the time of classes and, possibly, the assigned audience, appear on the website of the educational institution. After this, a “window” opens for students to register for their chosen courses. The disciplines chosen by the student during the registration process are monitored for belonging to the chosen specialty, the number of credits established by the regulations, and the admissibility of the number of formed groups. Mathematical description of these requirements.

Each formed group of students in the same time period can only attend one lesson with one teacher:

$$S_1(y) = \sum_{t \in T} y_{st}^{pj} \leq 1, \qquad \forall s \in S, \forall p \in P, \ \forall j \in J. \tag{16}$$

At each lesson, the number of registered students should not exceed the number of students established for this lesson, Q_{max}^{pj} – the maximum number of students scheduled for a lesson on studying the subject with code *j*, conducted by the teacher with code *p*.

$$S_2(y) = \sum_{s \in S} (Q_{max}^{pj} - y_{st}^{pj}) \geq 0, \qquad \forall t \in T, \forall p \in P, \forall j \in J. \tag{17}$$

Control of order in the sequence of studying disciplines, namely, if $B^l \neq \varnothing$, then a student with code *s* can start studying a discipline with code *l*, which is an element of the set B^j with number $i > 1$:

$$S_3(y) = (r_{i-1}^{js} - 1) = 0, \quad r_{i-1}^{js} \in R^{js}. \tag{18}$$

The number of disciplines studied during each academic day *d* should not exceed the recommended medical or norm established in a given educational institution or faculty – θ:

$$S_4(y) = \sum_{t = t_{d,1}}^{t_{d,m}} y_{st}^{pj} \leq \theta, \quad \forall s \in S, \forall p \in P, \forall j \in J. \tag{19}$$

Control of the established norm of loans with of a student with a code s for the current semester:

$$S_5(y) = (Credit_{max}^s - Credit^s) \geq 0, \qquad \forall s \in S. \tag{20}$$

$Credit_{max}^s$ – the maximum number of credits for which a student with code s can register, $Credit^s$ – the number of credit units that a student with code s wishes to take.

5. Formation of the schedule evaluation function

To assess the quality of teachers' class schedules, an objective function is formed. To assess its value for a specific schedule in the conditions of the credit education system, there are specific features that are influenced by two factors: the number of teachers who did not form groups, but who were present in the schedule, and the number of students who were unable to enroll in the chosen discipline due to lack of free places or due to the fact that several compulsory subjects are scheduled for the same time period.

Let w_p be the value of the weighting coefficient that determines the influence of unformed groups and flows of the p-th teacher included in the schedule on the quality of the schedule, and K_p be the set of such teachers; w_s is the value of the weighting coefficient that determines the impact on the quality of the schedule of the s-th student who is not enrolled in the classes they have chosen, and K_s is the set of such students. The specified coefficients are assigned by experts.

The objective function for estimating the schedule relative to teachers has the form:

$$\mathrm{C}(x, y) = \sum_{p \in K_p} w_p + \sum_{s \in K_s} w_s. \tag{21}$$

The value of the objective function for the formed teacher schedule is important both for the next stage – the formation of the student schedule, and for the educational process as a whole. Both terms of the objective function (21) should be analyzed and compared with the results of previous semesters. Its meaning characterizes the workload of the educational process for both teachers and students. The second term of formula (21) indicates an insufficient number of teachers included in the process, or the poor quality of this schedule.

As mentioned above, the scheduling process is iterative. At the third stage of the next iteration of drawing up the class schedule as a whole, depending on the value of the quality criterion of the compiled schedule (20), it is possible to return to the stage of adjusting the class schedule for teachers. Therefore, in this case, it will be necessary to carry out the second stage of adjusting (inclusion) of students' classes in the teachers' schedule.

6. Interactive scheduling mode

From a mathematical point of view, the problem of constructing an optimal training schedule is quite complex, since it belongs to the class of so-called NP-hard multi-criteria optimization problems [23–25]. Many approaches to solving this problem have been proposed, both exact mathematical algorithms and heuristic methods.

Among the mathematical methods, the best known are the "simulated firing" method, "graph coloring", genetic algorithms, methods of linear integer programming, constraint logic programming, greedy algorithms, and the branch and bound method [26–28]. The direction associated with the search for effective heuristic methods for solving the problem of scheduling classes at a university has received widespread development.

Given the large amount of information and many requirements and constraints, no method can provide an accurate solution to such problems in polynomial time. In addition, it cannot be ruled out that it will not be possible to meet absolutely all "soft" requirements and restrictions. The generated schedule must satisfy most of the requirements, restrictions and wishes of everyone involved in the educational process.

We have presented a model for scheduling classes at a university in an interactive mode. The interactive scheduling mode combines automatic scheduling, i.e. the program takes on all control of requirements and restrictions, with the interaction of the system with the user-dispatcher responsible for scheduling. The user sees the entire scheduling process and has the opportunity to intervene in this process at certain stages. To do this, it is provided with a convenient interface [29–30]. This approach is more convenient than fully automated scheduling, which often has to be modified manually after the program is completed.

The developed system consists of three subsystems:

1. Drawing up a schedule of classes for teachers.
2. Registration of students for their chosen disciplines.
3. Assessing the quality of the schedule.

The input information for the teacher schedule consists of all the necessary background information and operational information, which is presented in two documents:

1) the teacher's workload for the upcoming semester, agreed with the dean's office (Fig. 1);

2) wishes of teachers, which indicate days and hours undesirable for conducting classes, with preference given to third-party teachers, i.e. invited from other faculties of this university or from other universities (Fig. 2).

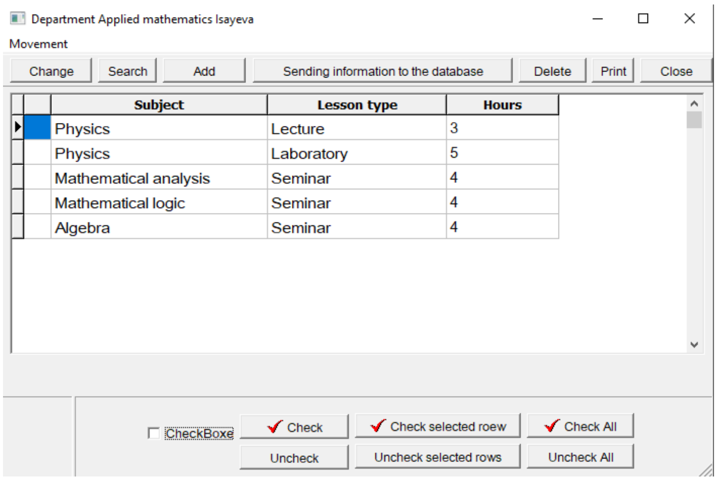

FIG. 1. Scheduled classes for the semester

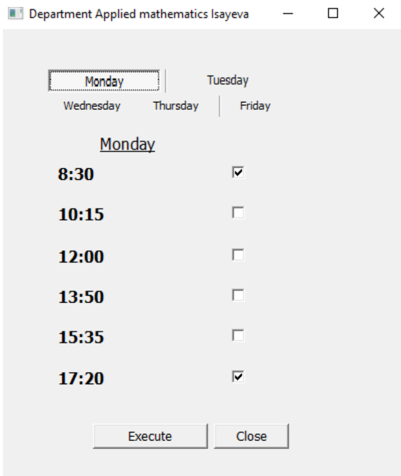

FIG. 2. Teachers' wishes regarding the timing of classes

The developed system is based on the so-called "traffic light" principle. After selecting a teacher, a document with his load for the academic period and a class schedule form for the selected teacher opens on the display screen (Fig. 3). The size of the schedule table (number of rows and columns) corresponds to the work schedule of the educational institution (number of days of the school week and the maximum number of time intervals).

Table cells have traffic light colors. Classes are assigned using the "drag and drop" method. Having selected the desired activity and grabbed it with the mouse, the employee responsible for scheduling places it in an accessible table cell. The availability of a cell is determined by its color. Green color is the best option for the chosen activity, because in this case, all types of restrictions are met – both "hard" and "soft". The yellow cell is also available for assigning an activity; the "hard" restrictions are fully satisfied, but some of the "soft" restrictions may be violated. The red cell is not available for the selected activity, because "hard" restrictions have been violated.

When you select a yellow cell, the system informs you about the "soft" requirements that have been violated and how much this affects the quality of the schedule. If the table has several cells colored yellow, you can select the one in which the assigned activity will least degrade the quality of the schedule.

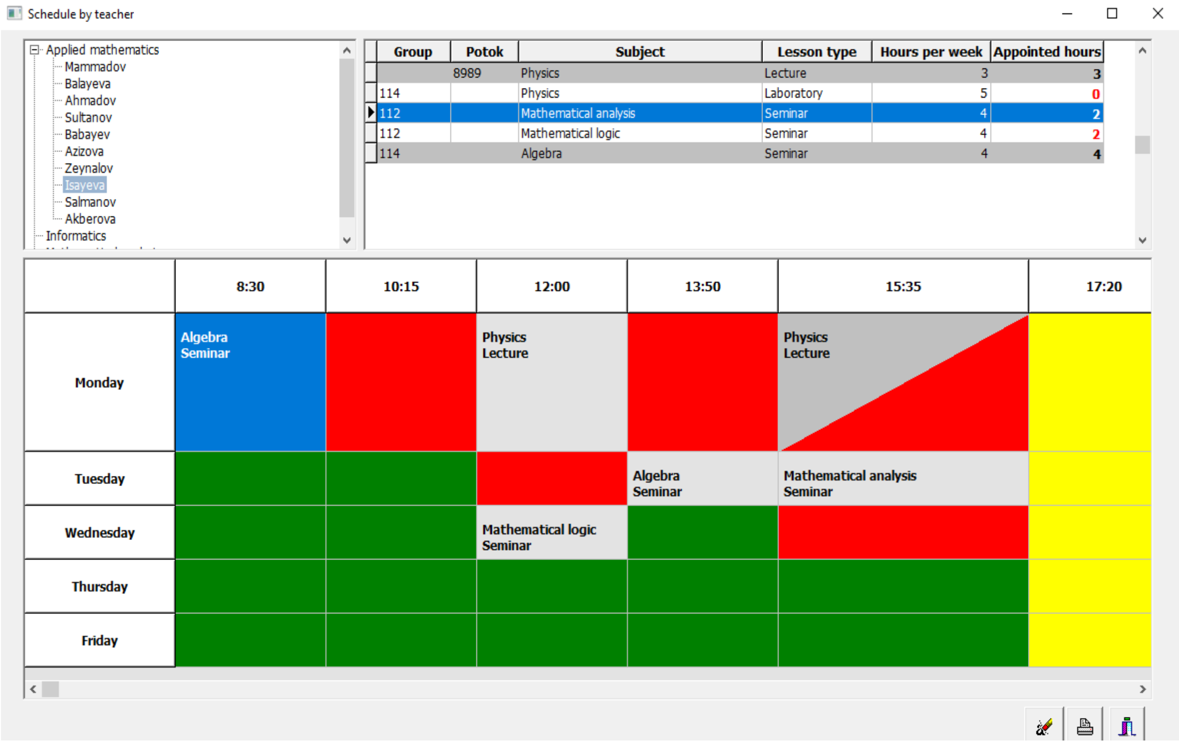

FIG. 3. Teacher's class schedule

To assign premises for classes, the system provides information about classrooms available for a given time period, indicating their capacity, affiliation and specialization (Fig. 4).

If the selected audience does not satisfy some of the audience fund control criteria, then the final decision is left to the user, and he takes responsibility: take this audience or repeat the search to select another audience.

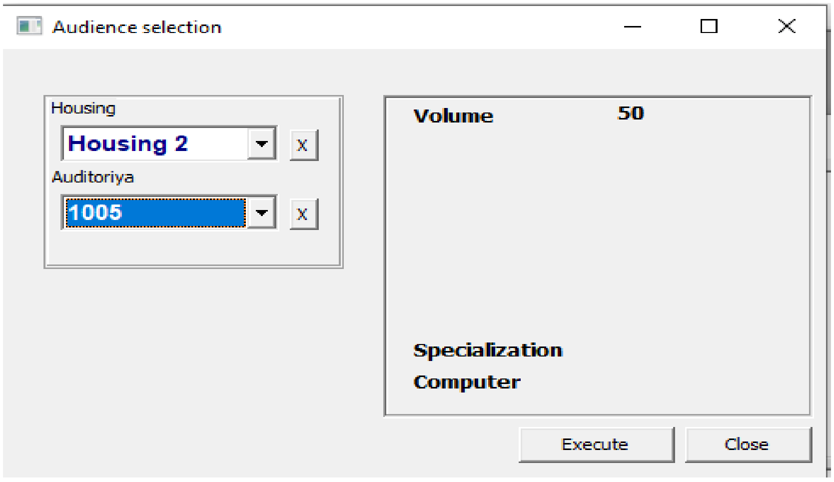

FIG. 4. Audience selection

After all classes have been assigned the teachers' schedule has already been formed. Then the second stage begins – students form their schedule. At the allotted time, they must register for the disciplines that interest them. The disciplines chosen by the student are tested for “admissibility,” i.e. whether he has the right to study this subject.

If the requirements are not met, the student is informed about this. The student's schedule, which satisfies all the “hard” restrictions, is displayed on the display screen (Fig. 5).

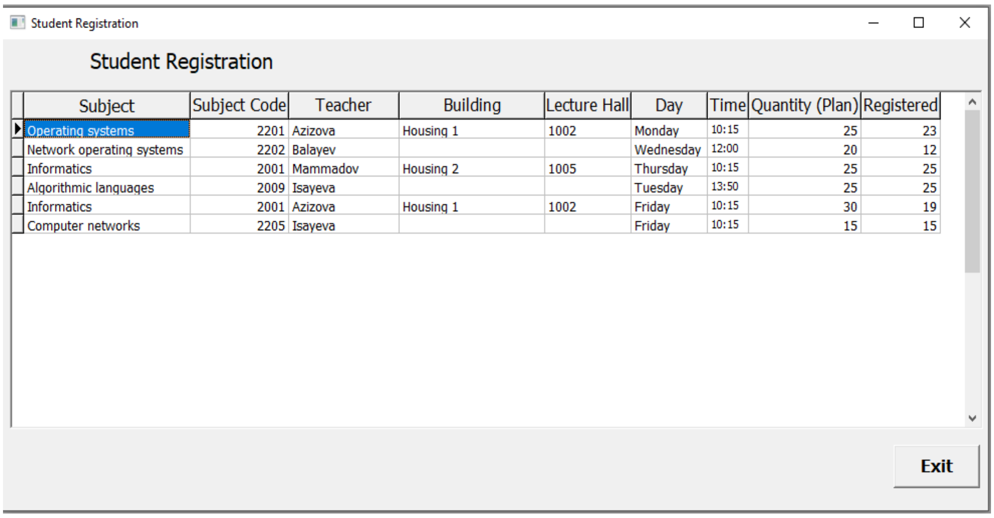

FIG. 5. Student schedule

In the event that there are no available places for the chosen discipline, students have the opportunity to register in the supplementary list and if for any reason there is a vacancy, the information is transferred to the main list in order of queue.

In general, the scheduling process is iterative, and at each iteration it is a two-stage process. As mentioned above, at the first stage, teachers themselves, or in agreement with them, set a schedule for the subjects they teach, indicating the time they will be taught; at the second stage, students draw up options for their schedules, on the basis of which they are included in groups to study selected subjects with specific teachers.

If, based on the results of the first iteration, a large number of teachers did not form groups (streams), i.e. the number of enrolled students is less than normal, then the reason may be either an inconvenient schedule or a lack of demand for this subject. In the first case, the dean’s office together with the teacher can change the time of the lesson to a more convenient one for students, taking into account the already formed class schedules of other teachers, and in the second, cancel the lesson and exclude it from the schedule.

If a large number of students were unable to enroll in the subjects they had chosen, either because the registration “window” was closed, or because the groups were overcrowded, then it is possible to assign an additional teacher in the relevant subject and include them in the schedule, again taking into account the already formed schedule. In addition, the location of the class may be changed if the number of students enrolled in the course exceeds the expected number and the allocated classroom cannot accommodate the number of students enrolled. This may mean that class days and times may also change. Accordingly, students also have the opportunity to adjust their schedules and join groups to study the subjects of their choice.

The work of the system is carried out during the semester, because students on individual results can apply to the dean’s office and change the selected subject. Deans' offices must carefully review their schedules every semester to ensure that students have access to the chosen subjects. This will also allow the most effective use of space in the days of the week and throughout the time.

The program results in two schedules: a teacher’s timetable and an individual student’s timetable.

Conclusion. The formation of a model for class schedules at a university under the conditions of a credit education system is described. An approach is proposed that covers the entire process, including enrollment and registration of students in the disciplines they are interested in, and the development of class schedules for both teachers and students. The proposed technology allows you to avoid conflict situations, i.e. guarantees that all "hard" constraints are met and an acceptable schedule is obtained, and most of the "soft" constraints are taken into account. An interactive algorithm has been developed to solve these problems.

The algorithm can be easily extended by adding additional procedures that describe other soft constraints.

The above specific features of scheduling in the conditions of the Bologna education system are implemented within the framework of the previously developed system "Automated dialog system for compilation of schedule lessons in high school" for the classical education system. Work in this direction will continue.

Authorship contribution statement.

Aida-zade K.R. – scientific guidance, mathematical formulation of the problem, discussion of the concept and methodology for solving the problem.

Ismibayli R.E. – discussion of the concept and methodology for solving the problem, analysis of the results obtained, selection and analysis of literary sources.

Rzayeva S.H. – development of a mathematical formulation of the problem, creation and design of algorithms, software, analysis of the results of computer experiments.

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Automated Schedule System for Universities under the Bologna Education Process

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Introduction. Countries that have joined the Bologna Process in higher education assume certain obligations. One of them is the transition to a credit education system, which is based on the personal participation of each student in the formation of their curriculum. Each student has the opportunity to structure the learning process, choose subjects and the sequence of their study within the framework of the curriculum for the chosen specialty, create their own individual schedule in accordance with their interests, capabilities and needs. The credit training system is asynchronous. Naturally, software applications for scheduling classes, developed for the classical education system, do not work in this case.

Purpose. Development of an algorithm and software for a class scheduling system designed for the credit education system and taking into account its features, and also meets all the “hard” restrictions and most of the “soft” requirements for the class schedule.

Results. The algorithm and software of the interactive system of scheduling classes for universities that have joined the Bologna process, which takes into account the features of credit-modular system of training, have been developed.

Conclusions.

The developed system covers the full cycle of including students in groups to study selected subjects and teachers, starting from scheduling teachers, registering students and ending with the formation of individual schedules for each student;

The proposed iterative process of scheduling makes it possible to make changes to the schedule of teachers and re-register students in the case of teachers who have not formed groups, or a significant number of students who were unable to enroll in subjects of interest to them;

The interactive mode of operation with the system combines an automated process of scheduling with active participation of the user responsible for scheduling;

The system guarantees the preparation of permissible timetables for teachers and students, taking into account the implementation of all "hard" restrictions, and significantly reduces the time required for scheduling;

The system ensures to the maximum extent the quality of teachers’ schedules, namely, taking into account “soft” requirements with the active participation of the user, who has the opportunity to choose an option that reduces the value of the function proposed in the article that evaluates the quality of the schedule;

The developed system ensures the effective use of the classroom fund in accordance with its capacity, specialization and affiliation.

Keywords: Bologna process of education, credit system, asynchronous learning system, class schedule, scheduling requirements, computer system.

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Автоматизована система складання розкладу для ВНЗ при болонському процесі освіти

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Вступ. Країни, які приєдналися до Болонського процесу освіти у вищих навчальних закладах, беруть на себе певні зобов'язання. Одним із них є перехід до кредитної системи навчання, в основі якої лежить особиста участь кожного студента у формуванні свого навчального плану. Кожен студент має можливість будувати процес навчання, вибирати предмети та послідовність їх вивчення у рамках навчального плану з обраної спеціальності, складати свій індивідуальний розклад відповідно до своїх інтересів, можливостей та потреб. Кредитна система навчання є асинхронною. Природно, що програмні докладання складання розкладу занять, розроблені для класичної системи навчання, у разі не працюють.

Ціль. Розробка алгоритму та програмного забезпечення системи складання розкладу занять, призначеної для кредитної системи навчання та враховує її особливості, а також відповідає всім "жорстким" обмеженням та більшості "м'яких" вимог, що висуваються до розкладу занять.

Результати. Розроблено алгоритм та програмне забезпечення інтерактивної системи складання розкладу занять для вузів, що приєдналися до Болонського процесу, в якій враховано особливості кредитно-модульної системи навчання.

Висновки. Розроблена система охоплює повний цикл включення студентів до груп з вивчення обраних предметів та викладачів, починаючи від складання розкладу викладачів, реєстрації студентів та закінчуючи формуванням індивідуальних розкладів кожного студента.

Запропонований ітераційний процес складання розкладів дає можливість внесення змін до розкладу викладачів та повторної реєстрації студентів у разі наявності викладачів, у яких не сформувалися групи, або значної кількості студентів, які не змогли записатися на предмети, що їх цікавлять.

Інтерактивний режим роботи з системою поєднує автоматизований процес складання розкладу з активною участю в ньому користувача-відповідального за складання розкладу.

Система гарантує складання допустимих розкладів викладачів та студентів з урахуванням виконання всіх “жорстких” обмежень, що істотно скорочує час складання розкладу.

Система забезпечує максимально якість розкладів викладачів, а саме, облік “м'яких” вимог за активної участі користувача, який має можливість вибрати варіант, що зменшує значення запропонованої у статті функції, що оцінює якість розкладу.

Розроблена система забезпечує ефективне використання аудиторного фонду відповідно до його місткості, спеціалізації та належності.

Ключові слова: Болонський процес навчання, кредитна система, асинхронна система навчання, розклад занять, вимоги до розкладу, комп’ютерна система.