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Modelling and construction of curriculum optimization algorithms in order to improve the effectiveness of management of the educational process

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Modelling and construction of curriculum optimization algorithms in order to improve the effectiveness of management of the educational process

A K Guts[1], A A Senkovskaya[2] and I I Furayeva[2]

[1]Department of Computer Science, Dostoevsky Omsk State University, 55a Mira avenue Omsk, Russia
[2]Department of Information technologies, L.N. Gumilyov Eurasian National University, 2 Satbayev st. Nur-Sultan, The Republic of Kazakhstan

Abstract. This article discusses the principles of influence on improving the management of the educational process of a university from the perspective of analysis and optimization of work plans. Mathematical models are presented for optimizing working curricula separately for the first and senior courses, taking into account such factors as the contingent of students, the classroom fund of the university. Different approaches to the analysis of curricula for the first and senior courses are demonstrated. The basic functions of an automated system that implements the formulated models for the analysis of curricula are described.

1. Introduction

One of the important stages of planning the educational process of the university, especially the formation of the teaching load for the next academic year, is primarily carried out on the basis of the work curricula of the university specialties. Also, a factor that has an important influence on the organization of the educational process for any university is the existing classroom fund, both specialized audiences and general-purpose audiences.

Optimally compiled curricula will allow for the most effective implementation of such stages of the educational process as the formation of the pedagogical load from a position of uniformity and the preparation of the curriculum.

In order to increase the effectiveness of the educational process at the initial stage of the formation of the teaching load of the university, a preliminary analysis of the working curricula should be carried out. It should be noted that in the problem of analysis and optimization of curricula it is rational to use mathematical methods. Moreover, mathematical modelling in this case is applicable both for evaluating the curriculum for the given optimality parameters, and for optimizing the initial data block. All components, such as working curricula, the formation of the teaching load of departments, a specialized classroom fund, to one degree or another, influence the effective organization of the educational process. For example, if the teaching load of the department is distributed evenly throughout the semesters, the search for a solution in the task of compiling an optimal curriculum is greatly facilitated. It should be noted that this is especially important when the department carries out service disciplines in special-purpose audiences. The task of uniform use of classrooms by semesters can be solved by controlling the process of forming a working curriculum for the specialties of each faculty [1].

Therefore, the analysis and optimization of working curricula is carried out in order to evenly distribute the teaching load for a given contingent of students.

It should be noted, as a rule, the main contingent of any university consists of students in the undergraduate program. Therefore, despite the fact that training at a university is carried out at all levels of education (bachelor's, master's, postgraduate studies), it is the optimization of the work curriculum of the bachelor's program that depends on the workload of the existing classroom fund, especially a specialized one.

2. Modelling the optimization process of curricula

Analysing the working curricula, we can conclude that in the 1st year of specialties there is a maximum number of general disciplines, some of which are included in the mandatory component of a certain specialty, some are optional components (which are usually conducted by the graduating department and are associated with prerequisites with subsequent profile disciplines). In senior courses, the main disciplines are conducted, and, therefore, are not transferred to other departments and comprise the bulk of the academic load of the graduating department.

Therefore, the analysis and subsequent optimization of working curricula can be divided into two main tasks:

- analysis and optimization of curricula for first-year students;
- analysis and optimization of working curricula for senior students (2 and 3 courses).

The working curricula for the final course of study are not analysed, since theoretical training at the final course is planned only for the first semester, in the second semester graduates are scheduled to practice and write a thesis, and therefore, from the point of view of the uniformity of load distribution, there is nothing to optimize in these curricula. Therefore, analysis and optimization at this stage involves working with the curricula of the second and third courses.

The first-year working curricula of any specialty contain the maximum number of general disciplines, as a rule, read by service departments and combined into flows in the areas of study. Moreover, some of these disciplines require specialized classrooms for conducting classes (for example, “Information and Communication Technologies”, “Physics” and others).

In this case, when forming proposals for optimizing educational flows, uniformity should be taken into account from the standpoint of disciplines conducted by service departments. From the perspective of graduate departments, the uniformity of load distribution is not so relevant, since in the formation of modular educational programs, and therefore working curricula, the uniformity of the classroom load is one of the requirements and amounts to 18-20 credits per semester.

Moreover, this task is relevant for a university of any scale. Even if the discipline is conducted only by the service department, there can still be such a number of flows that it will not fit into the schedule in one semester (both in terms of length and distribution of specialized classrooms).

The idea of a mathematical model for the analysis and optimization of curricula for first-year students is to arrange service disciplines in such a way as to optimize the uniform distribution of the load of service departments over semesters, taking into account the classroom, especially specialized [1]. The objective function of the first-year curriculum optimization model is formulated as follows (1):

$$\sum_{j=1}^{N}\left(V_j * \sum_{t=1}^{M}\left|RP_{tj}^1 - RP_{tj}^2\right|\right) \rightarrow min, \quad (1)$$

where V_j is the weight of the *j*-th department, presented as the initial load of the department before all movements begin, and the more service disciplines the department teaches, the more the uniformity of the load distribution of the department throughout the semesters matters;

RP_{tj}^1, RP_{tj}^2 – load of the *j*-th department in service disciplines at the *t*-th faculty, respectively, for the first and second semester, after some optimization transformations of the curriculum.

As constraints, the mathematical model includes (2)-(3):

$$\left|\sum_{k=1}^{K_i^1}\delta_{ijk}^1 * Kr\left(D_{ijk}^1\right) + \sum_{k=1}^{K_i^2}\delta_{ijk}^2 * Kr\left(D_{ijk}^2\right)\right| \leq 1 \quad (2)$$

$$S_1 \leq S\Delta_1, S_2 \leq S\Delta_2 \quad (3)$$

where $Kr(D_{ijk})$ – the number of credits of discipline in the working curriculum;

$\delta_{ijk}^{1}, \delta_{ijk}^{2}$ take values (0, 1), and the value 1 – when the discipline D_{ijk} moves to another semester, and 0 – when it does not move;

$S\Delta_1, S\Delta_2$ – existing specialized classroom fund of the university.

Moreover, the number of constraints (2) is proportional to the number of curricula analyzed. Constraint (3) determines the need for specialized classrooms for conducting first-year disciplines, and separately for each semester.

The idea of a mathematical model for optimizing first-year curriculas is to eliminate the imbalance in the distribution of the teaching load of departments over semesters, taking into account the student contingent. As a result, options for placing disciplines in the first-year curricula are formed in accordance with the goal of management, namely, the uniform distribution of the teaching load of service departments.

It should also be noted that if you analyze the curricula of all specialties in all areas (faculties) at once, the block of input data will be redundant with a large number of repeating variables. However, since classes in service disciplines are carried out in the stream at each of the faculties, and not in separate groups of the specialty, it makes sense to define one main curriculum for each of the areas, the data from which are analyzed, and the rest of the curriculum refer to the main.

As a result of several iterations to optimize the first-year curricula, it turned out that all optimal solutions are achieved if the constraint (2) is converted into equality (4):

$$\sum_{k=1}^{K_i^1} \delta_{ijk}^{1} * Kr\left(D_{ijk}^{1}\right) + \sum_{k=1}^{K_i^2} \delta_{ijk}^{2} * Kr\left(D_{ijk}^{2}\right) = 0 \qquad (4)$$

Converting one of the constraints allows us to use a different approach to finding the optimal solution, discarding the obviously trivial solutions.

Moreover, in the course of experimental calculations, the optimization problem was considered both taking into account constraint (3) on the classroom fund, and without it. As expected, the inclusion of constraint (3) in the formulation of the problem for optimizing the curricula of the first course of study leads to an increase in the value of the objective function (1).

Thus, the final version of the algorithm was formed to find the optimal solution to the problem of optimizing the first-year curriculum, which includes the following steps:

A. Implement a semester distribution of the study of disciplines taught for all 1st year specialties, for which a condition is set to limit the specialized classroom fund (3). In our case, such a discipline was “Information and communication technology”.

B. Then consider the consolidated curricula in each direction (faculty) for the remaining disciplines and search for suitable transfers of disciplines in semesters that satisfy the restriction (4).

C. Form a set of suitable options for each direction (faculty).

D. Determine the optimal solution by combining the options obtained in the previous step.

The first stage of the algorithm actually reduces to the problem of dividing a one-dimensional array into two equal parts (by the sum of the elements). It should be noted that after the first stage is completed, the system is greatly unbalanced, since now one discipline is precisely distributed over semesters for each of the areas (faculties). Moreover, such a distribution significantly reduces the number of possible options already at the second stage of the proposed algorithm.

After the analysis of the curricula for the first year has been carried out, the analysis of the flow rate of service disciplines in order to optimize the teaching load has been carried out, we can proceed to the optimization of the curricula of senior courses.

Next, we consider the task of analyzing curricula for 3 courses. According to the rules of the organization of the educational process in the third year, students are only taught in majors, which is carried out by the graduating department. Therefore, in this case, the task of optimizing the pedagogical load from the position of the department is not worth it, since the movement of disciplines is performed for one department taking into account the same number of credits and does not affect the total amount of hours [2]. In this case, the load optimization is aimed at combining flows for the same disciplines in the specialties within the department in order to minimize the understaffing of educational flows.

Suppose that in the conditions of a certain university there are two specialties assigned to each graduating department, therefore, no more than 4 curricula are analyzed for each department – for two undergraduate specialties with a study period of 3 and 4 years. In addition, the number of credits for theoretical training in the curriculum is strictly defined, i.e. the amount of credits allocated per semester is known in advance.

The analysis process is carried out as follows, and sequentially for each department of the university and aims to minimize the number of educational flows in the same disciplines of the department, which ultimately will optimize the teaching load.

First, all disciplines are selected, regardless of the semester of study, from the curricula of the *k*-th department. After that counted how many times such disciplines occur in the curricula of one year of admission. Based on this, a table with repeating disciplines is formed, which subsequently is desirable to sort by the number of repetitions of the discipline in the curriculum (Figure 1).

Discipline	1-st semester				2-nd semester				SKr1	SKr2	Move Mark
	R1	R2	R3	R4	R1	R2	R3	R4			
D1	2		2	2		3			6	3	-1
D2					3	3	3		0	9	2
D3	3	3					3	3	6	6	-1
D4	2		2			2		2	4	4	-1
D5	2	2	2						6	0	1
...									0	0	
Dn	2						2		2	2	-1

Figure 1. Table of repeating disciplines in the curriculum of the *k*-th department.

In addition, in this table, disciplines are labeled:

- -1 – disciplines repeated in different semesters, therefore, requiring movement in some of the curricula;
- >1 – unique numbers for disciplines repeating in one semester, therefore, undesirable for moving.

After a similar table is formed, we proceed to a direct analysis and search for alternatives for combining flows for conducting repeated disciplines [3].

The task of analyzing and optimizing curricula for the 3rd year is formulated as follows: it is necessary to simulate the curricula of the specialties of each department in such a way as to reduce the number of ungraded groups, and therefore the pedagogical load of the current department to a minimum. Moreover, it should be noted that the curricula for each department are considered separately, that is, the optimization task is decomposed according to the parameter of the leading department.

The mathematical model for the formation of working syllabi for the 3rd year, excluding the presence of low-grade groups, is formalized as follows: it is necessary to distribute the disciplines D_i according to the semesters Sd_i of each curriculum ($j = \overrightarrow{1,4}$) for a particular department in such a way as to minimize the number of low-grade groups in the specialties of the department.

At the initial stage, the total number of KQ_j credits for each of the four working curricula of the department allocated to theoretical training is known, therefore, half of the total volume of credits is planned for each semester.

Then for each curriculum, after some movement of disciplines, the following identities should be fulfilled for both semesters (5):

$$\left|\sum_{i=1}^{n} SKr_i^1 - \frac{KQ_j}{2}\right| \le 1, \quad \left|\sum_{i=1}^{n} SKr_i^2 - \frac{KQ_j}{2}\right| \le 1 \qquad (5)$$

As mentioned earlier, the goal of optimizing the curriculum of the 3rd year of study is to minimize the number of macro-complete flows in the same disciplines, and the number of movements of the disciplines should also be the smallest.

The evolutionary optimization approach is chosen as a solution method [4].

Based on the source table shown in figure 1, a work table of disciplines is formed (Figure 2), which contains options for the “ideal” distribution of each discipline by semester for all curricula (that is, it is assumed that the discipline is in all curricula or in the first, either in the second semester).

Discipline	Genes	1-st semester				SKr1+SKr2	MKr
		R1	R2	R3	R4		
D1	0	2	3	2	2	9	3
	1	0	0	0	0	9	6
D2	0	0	0	0	0	9	9
	1	3	3	3	0	9	0
D3	0	3	3	3	3	12	6
	1	0	0	0	0	12	6
D4	0	2	2	2	2	8	4
	1	0	0	0	0	8	4
D5	0	2	2	2	0	6	0
	1	0	0	0	0	6	6
...	0						
	1						
Dn	0	2	0	2	0	4	2
	1	0	0	0	0	4	2

Figure 2. The initial table for the formation of the initial population.

In the table of “ideal” options, two additional parameters are introduced:

- the parameter $\Delta SKr_i = SKr_i^1 + SKr_i^2$, which characterizes the amount of credits for this discipline in all curricula;
- MKr_i parameter determines the number of discipline credits transferred to another semester to form an “ideal” option.

Moreover, when constructing the table, it is enough to take into account only the first semester, since for discipline D_i, combination with gene 0 corresponds to the consolidation of the discipline in the first semester, with gene 1 in the opposite second semester. This table is the initial table for the formation of the initial chromosome population [5]. Chromosomes are formed by randomly choosing the i-th gene of one of the combinations of the D_i discipline.

Since the “ideal” combination of discipline distribution by semester is selected as the genes during the formation of the initial population, the minimization of small-sized groups is decided at the initial stage. However, the choice of "ideal" combinations is not yet the optimal solution from the point of view of uniform distribution of loans over the semesters of the curriculum. Therefore, minimization by the number of credits transferred in the curriculum can be used as the objective function in the conditions of the evolutionary optimization approach.

Then the model for optimizing the curriculum of the 3rd year of study is formulated as follows: to optimize the study flows of the 3rd year of study, it is necessary to minimize the number of credits transferred in the curriculum according to the objective function (6):

$$\sum_{j=1}^{n} MKr_i \rightarrow min, \qquad (6)$$

provided that the constraints (5) are met for each of the 3rd year curricula for each of the considered Departments.

Moreover, it should be noted that the optimal value of constraints (5) for each of the curricula in the context of the problem under consideration is zero (that is, after moving the disciplines, the curriculum of the department fully corresponds to the required number of credits KQj).

A flow chart of an algorithm that implements the optimization of 3-year curricula is presented in figure 3.

The analysis of the curricula of the 2nd year of study is a certain symbiosis of the algorithms for the analysis of the curriculum for the first and third year. Since the second year provides for the study of general educational disciplines (assigned to service departments) and specialized disciplines (conducted by graduate departments), the analysis of the second year curriculum contains two subtasks - identifying service disciplines and combining flows faculty and identifying core disciplines assigned to graduating departments, therefore minimization of educational flows in each specialty.

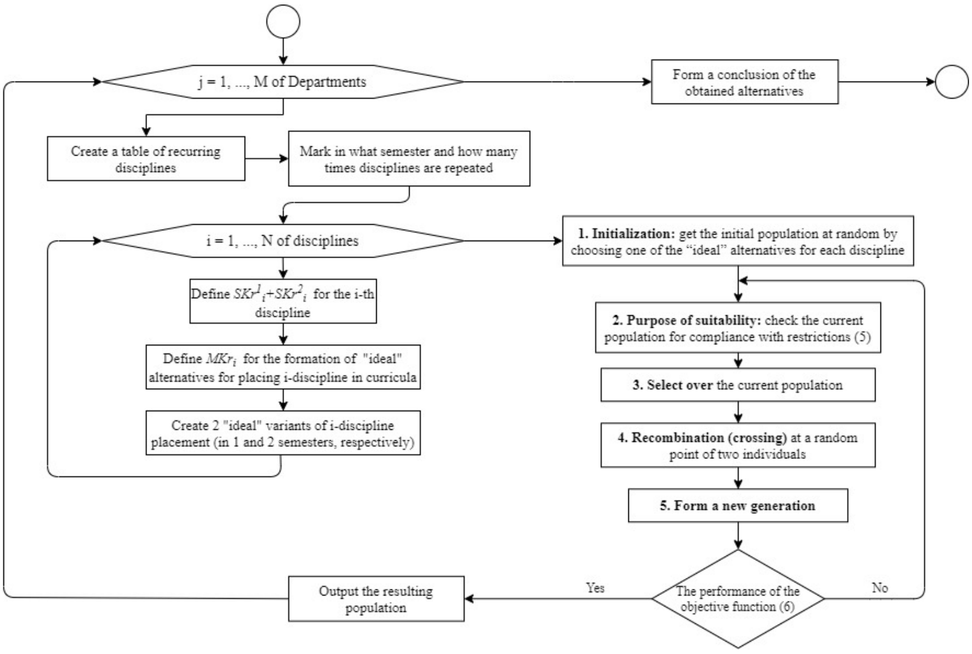

Figure 3. Algorithm for the formation of alternatives for 3-year curricula.

Since with an increase in the number of specialties, the volume of initial data for the formation of the pedagogical load of the university increases, the analysis of curricula with the aim of optimizing them is a rather long and laborious process. Therefore, there is a need to develop an automated system to perform a preliminary analysis of curricula with the subsequent selection of optimal alternatives formed by the system (Figure 4).

The automated system for the analysis of curricula in addition to the main task of optimizing the curriculum of specialties implements the functions of preliminary analysis of the source data to identify all kinds of technical errors that affect the correctness of work in the future. These errors include: duplication of curricula (several files were found for the flow of the same specialty); working curricula with uncertain parameters, such as specialty, course, learning path, and others; unidentified specialties and trajectories of specialties (errors in ciphers and spelling); files with working curricula containing several sheets, including hidden ones.

In addition, the system allows you to identify flows that are left without curricula for the current academic year.

A preliminary analysis of the curriculum for these parameters is necessary, since such errors occur with sufficient regularity, and computer analysis allows them to be identified and eliminated with minimal time spent.

After correcting errors identified during the preliminary analysis, the curriculum is entered into the system. Saving the block of source data in the system is a prerequisite in order to save time and simplify the data processing algorithm, since multiple access to external files, as well as searching for the required information in them, significantly complicates the process of data processing and analysis.

After the identified errors are eliminated, the curriculum is checked again, after which the preliminary pedagogical load calculated according to the curriculum is entered into the system. At the same time, a check is made for the correct distribution of hours in accordance with the allocated number of credits for the study of discipline.

The next stage is an analysis of already amended curricula in order to optimize the volume of hours.

As a result of the algorithm, curriculum optimization options are presented for convenience in the MS Excel template.

After a decision has been made to optimize the curriculum based on the analysis and the corresponding changes have been made, updated data are entered into the system for subsequent work on the formation and distribution of the pedagogical load.

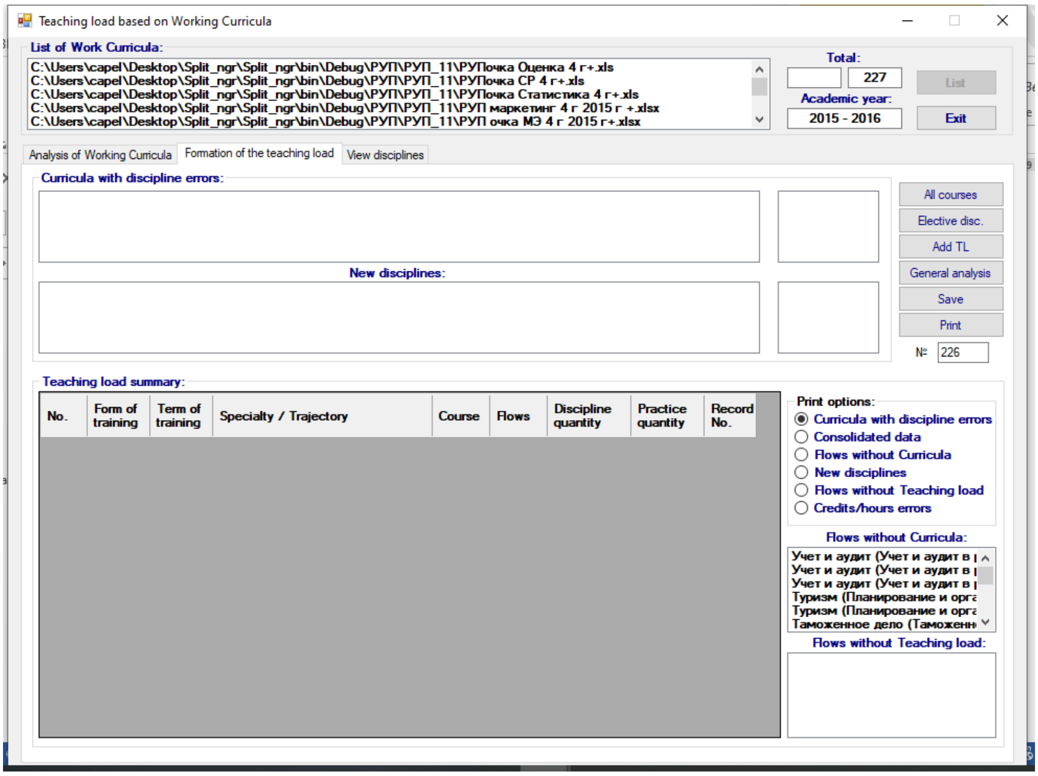

Figure 4. Curriculum Analysis System Window.

After a decision has been made to optimize the curriculum based on the analysis and the corresponding changes have been made, updated data are entered into the system for subsequent work on the formation and distribution of the pedagogical load.

3. Conclusion

The analysis of working curricula with their subsequent optimization is one of the most important tasks of the organizational process of the university as a whole, since the curriculum is a block of initial data for the formation of the pedagogical load, and ultimately affects the process of scheduling training sessions.

During the simulation of the curriculum optimization process, the curriculum analysis algorithms were formulated for both the first and senior courses, as well as the basic discipline search algorithms were proposed for the formation of curriculum optimization options, the main purpose of which is to minimize learning flows by subject and pedagogical load in whole.

Ultimately, the decision to transfer disciplines in accordance with the formed options for optimizing curricula is made by the staff of the educational unit after agreement with the relevant departments.

4. References

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