A Mathematical Model for Rationality in Timetable Planning

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Abstract **– The preparation of a study timetable (or schedule) depends on the school or university for which it is made and on the specific work practices applied in this educational institution. The preparation of a school timetable in a school or university aims to plan for the conduct of classes in certain academic disciplines for a certain period of time, while optimally engaging the classrooms and professors available for the relevant period.**

The aim of this paper is to provide a mathematical model for rationality in planning a study timetable. This mean to make forecast on whether the accepted number of students, organised in groups, could be instructed during defined period of time in the available classrooms in the educational institution. The developed model aims to make better use of available classrooms and places for students in them. Calculating a rationality ratio will give the educational institution an idea of the:

- **Need for more classrooms;**
- **Need to extend the study period (number of days for the planned semester)**
- **Need for more optimal planning of the study timetable and better use to the rooms.**

The prepared model also includes a coefficient of specific rationality, in case the educational institution has classrooms of different capacities - for lectures and practical exercises.

The developed mathematical model can be useful to higher education institutions for the purpose of planning their educational activity and it can be applied before the actual process of planning a study schedule.

The data used and calculations results serve as the basis for an in-depth analysis related to the requirements for the educational process and the opportunities provided by the educational institution.

Keywords **– rationality ratio, study timetable, mathematical model, school, university.**

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1. Introduction

The task of preparing a study timetable does not have a universal solution.

The preparation for a study timetable depends on the educational institution for which it is made and on specific work process applied there. Therefore, any mathematical model is good for some educational institutions and inapplicable for others.

In general, the preparation on a study timetable is the process drawing up a schedule with fixed hours, and it aims to optimize the use of an organization's resources and to improve its productivity.

Usually, the timetable is prepared for a specific fixed period of time, as it is influenced by a number of factors such as the availability of a certain resource, fixed period of time (academic/school year, summer/winter season, etc.). After that, the preparation of a new timetable for the following period is initiated.

Each university admits a certain number of students for each course it offers - full-time, part-time or distance learning. The preparation of the study timetable for each academic year should be done in a way that allows for the proper organization of the learning process - availability of a classroom, a professor and the necessary technical equipment depending on the course.

The purpose of this article is to prepare a mathematical model for rationality in planning a school timetable. It calculates whether the accepted number of students, formed in groups, could be trained in the set period of time in the available training rooms of the educational institution.

Can the accepted number of students, formed in groups, could be trained in the set period of time in the available training rooms of the educational institution?

2. Timetable Preparation - Background and Specifics

The timetable is prepared for a specific fixed period of time, as it is influenced by a number of factors such as the availability of a certain resource, fixed period of time.

The study timetable is prepared for a specific fixed period of time, in which lectures and exercises are distributed according to academic disciplines from a given semester of an academic year.

A. Organization of the Learning Process

There are over 50 universities in Bulgaria, including state and private ones. Each university instructs specialists in a certain scientific field in a certain course. A syllabus is prepared for each course. The syllabus contains all academic disciplines that student's study throughout their study period, as well as the number of study hours (lectures and seminars) for each discipline. These academic disciplines are divided into semesters.

The organization of the learning process during each academic year is divided into winter and summer semesters, both for bachelor's and master's degree courses. With certain deviations, the winter semester lasts for 6 months, and covers the period from September to January. The summer semester also lasts for 6 months, and covers the period from February to June.

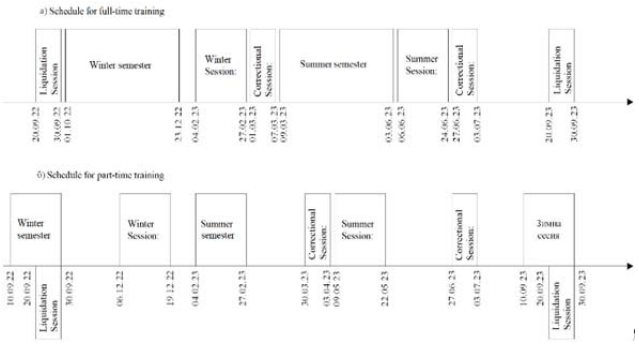

Figure 1. Long-term planning of the study timetable for the academic year 2022/2023 in ULSIT [1]

In the beginning of each academic year, the university announces:

- The duration of each semester for bachelor's and master's degree courses,
- The duration of the exam sessions (regular, remedial and liquidation).

B. Syllabus

The syllabus contains all academic disciplines, distributed by semester, that the students enrolled in a specific course will study during a given period of time (bachelor's and master's degree courses). There are three types of disciplines for each semester - compulsory, optional and facultative. The compulsory disciplines and only the selected optional and/or facultative disciplines are planned in the study timetable.

C. Study Timetable

Usually, the study timetable is prepared for a specific fixed period of time. It can be prepared manually or automatically. [2],[3],[4] The preparation process itself is influenced by a number of factors such as the availability of a certain resource, a fixed period of time (academic year, summer/winter season, etc.) as well as a number of initial parameters (number of students, number of classrooms available, etc.). [5],[6],[7] In any case, there is a need for a mechanism to check beforehand whether proceeding with the preparation of the semester timetable is done in a reasonable or rational manner. Otherwise, the study timetable planning process may be faced with a challenge that will lead to the difficult implementation of the syllabus requirements.

Generally, the reasonableness or rationality in the process of planning a study timetable can be seen as a prediction of whether the number of students enrolled, organized in groups, could be instructed during the defined period of time in the classrooms available in the educational institution.

This type of forecasting could give the institution insight into the:

- Need for additional classrooms.
- Need to change the organization of the study groups.
- Need to extend the academic period (number of days for the planned semester).
- Need for more optimal planning of the study timetable and better use of the classrooms.

For this purpose, it is necessary to analyse the factors that are important in the process of preparing a study timetable, and to prepare a mathematical model for rationality, which calculates whether all resources needed to plan a timetable for the given study period are available.

The developed mathematical model can be applied before starting the actual process of planning a study timetable, which will give a preliminary idea of whether the requirements as to the syllabus can be effectively implemented with the available capacity of the educational institution.

3. Rationality in the Process of Planning a Study Timetable

Rationality in the process of planning the academic study timetable has significance about the optimal use of the classrooms in a school or university. The rationality of a one classroom means that the classroom is used for training during most of the working hours. The rationality of all university classrooms means that the classrooms are used for training during most of the working hours.

A. Definition of Rationality

Rational means reasonable, meaningful, expedient; pertaining to or ensuing from reason [8],[9],[10].

It is used as a concept for a wide range of actions, phenomena and different types of systems, etc. Bearing in mind the definition of rationality in [11],[12] and focusing only on the preparatory work for drawing up a study timetable for conducting the learning process in a school or university, the following definition of rationality can be given:

The rationality of the preparation of the semester study timetable shall be understood as the distribution of the training potential[1] of the educational institution in space and time, for the full realization of the requirements of the syllabuses in the interest of students.

This definition, although general, can be beneficial for constructing a mathematical model, which is to be used for verification by the planning personnel so that it can be determined to what extent the defined planning parameters are appropriate for proceeding with the development of the study timetable.

B. Main Parameters Relevant In The Planning Process

According to the definition of rationality, the parameters, assumptions and limitations guiding the work of the planning group can be classified as spatial and temporal.

Spatial parameters

- N_{rooms} - number of classrooms. This is the sum of classrooms with certain seating capacity (attendance). Depending on the educational institution, there may be: lecture halls; seminar halls; specialized halls (offices/laboratories) and others.
- N_{groups} - number of learning groups (classes). This is the sum of learning groups, and each learning group represents a group of students learning a single academic discipline. The number of students in a group is determined based on the number of seats in the classrooms, according to the specialization.
- $N_{cources}$ - number of academic disciplines (subjects). This is the sum of academic disciplines defined in the syllabuses for the semester by course (for university only).

Time parameters

- t_{slot} - duration of a study time slot (in number of study hours). A study time slot is a time interval (a block of a fixed number of study hours) that divides each school day into study periods of equal duration with the same start and end time. The time slot is determined by the educational institution and can consist of 1, 2, 3, 4, 5 study hours. It is important to point out that lectures or seminars for only one discipline are held in a study time slot. It is also necessary to clarify that the use of slots is a convenient way of working in the planning process and facilitates the arrangement of the study timetable.
- t_{day} - duration of a study day (in number of study hours). It is determined as a constant for the semester. For the purposes of this paper we assume that the length of the study day is 10 study hours at most.
- $t_{daySlots}$ - duration of a study day (in slots). It can be defined as the ratio of t_{day} и t_{slot} by the following formula: $t_{daySlots} = \frac{t_{day}}{t_{slot}}$. For example, if we assume that the duration of the study day is 10 study hours, and that the duration of the study time slot is 2 study hours, then the duration of the study day (in slots) is 5 slots.
- T_{sem} - duration of a semester (in days). It is determined as a constant by order of the Rector of the educational institution. It represents the number of working days in the semester.
- T_{lec} - duration of lecture hours (in study hours). It represents the number of lecture hours included in the syllabus for a given academic discipline.
- T_{labs} - duration of practical work/seminar hours (it is a Practice in study hours). It represents the number of hours for seminars (practice) included in the syllabus for a given academic discipline.

[1] potential of the educational institution - teachers, suitable UMB - halls with different volume of places for attendance, technical equipment, study plans, students.

Limitations and Assumptions

The following limitations and assumptions are made for the development of the mathematical model:

- The learning process is considered to be 100% provided by professors, according to Opening a new speciality in a university – an operational estimate [13].
- The study hours per study day cannot exceed 10. (t_{day}).
- Claims regarding time and other claims of professors are not taken into account; they are considered invalid/groundless.

4. Rationality Coefficient

Let us assume, according to the definition of rationality, that if the potential of the educational institution distributed over time corresponds to/satisfies the requirements of the syllabuses, then the planning of the study timetable for the semester can be approached with a certain rationality, and this can be expressed, in general, with the equality (the balance in a certain interval) of two functions (with input arguments), expressing mathematically the binding of the spatial and temporal parameters discussed above in the following way:

$$S1\left(N_{\boldsymbol{rooms}}, T_{sem}, t_{day}, t_{slot}\right) = S2(N_{\boldsymbol{groops}}, N_{\boldsymbol{courses}}, \mathrm{T}_{lec}, \mathrm{T}_{labs}, t_{slot}) \quad (1)$$

The first function (S1) reflects the actual (available) potential/resources of the educational institution, distributed within the limits determined by the duration of the semester, and the second function (S2) reflects the required potential/resources, according to the requirements of the syllabuses in the interest of students.

The comment made suggests that the formula be improved as follows:

$$S_{avaible}\left(N_{\boldsymbol{rooms}}, T_{sem}, t_{day}, t_{slot}\right) = S_{req}(N_{\boldsymbol{groops}}, N_{\boldsymbol{courses}}, \mathrm{T}_{lec}, \mathrm{T}_{labs}, t_{slot}) \quad (2)$$

The balance, in the case of their equality, reflects the rationality of proceeding with the development of the study timetables by the planning group. The violation of this balance is a matter of analysis, which should show a shortage or an excess of potential of the educational institution for a particular semester. From a practical point of view, it is suitable for the metric of the result of these two functions to be in time slots.

For the convenience of calculating rationality, the authors of the paper consider it appropriate to introduce a rationality coefficient that reflects the ratio of the two functions. It will quantitatively provide information on how suitable the set planning parameters are for proceeding with the development of the study timetable:

$$k_r = \frac{S_{req}(N_{\boldsymbol{groops}}, N_{\boldsymbol{courses}}, \mathrm{T}_{lec}, \mathrm{T}_{labs}, t_{slot})}{S_{avaible}(N_{\boldsymbol{rooms}}, T_{sem}, t_{day}, t_{slot})} \quad (3)$$

The S_{rec} function binds its input parameters to the following mathematical expression:

$$S_{req} = N_{\boldsymbol{groops}} \times \left(\sum_{i=1}^{N_{\boldsymbol{courses}}}(T_{lec}/t_{slot}) + \sum_{i=1}^{N_{\boldsymbol{courses}}}(T_{labs}/\,t_{slot})\right) \quad (4)$$

It is the result of the multiplication between the determined number of study groups and the sum of the lecture and seminar hours for the disciplines in the syllabuses. According to the formula, it is obvious that the result is expressed in slots.

In the same way, we can express mathematically the other function:

$$S_{avaible} = N_{\boldsymbol{rooms}} \times \mathrm{T}_{sem} \times \frac{t_{day}}{t_{slot}} \quad (5)$$

In the case of this expression, it is also obvious, according to the formula, that the result is expressed in slots, and as a result of the functions developed in this way, the rationality coefficient will take the following form:

$$k_r = \frac{N_{\boldsymbol{groops}} \times (\sum_{i=1}^{N_{\boldsymbol{courses}}}(T_{lec}/t_{slot}) + \sum_{i=1}^{N_{\boldsymbol{courses}}}(T_{labs}/t_{slot}))}{N_{\boldsymbol{rooms}} \times \mathrm{T}_{sem} \times \frac{t_{day}}{t_{slot}}} \quad (6)$$

In other words, the rationality coefficient represents the ratio of the slots for planning the necessary study hours for lectures and seminars to the slots that the available classrooms in the educational institution provide.

The formula gives a good idea about the extent and the manner in which the parameters affect the result. In case of problematic values of the calculated coefficient and following analysis, an answer can be sought as to whether it is necessary to change the value of a parameter and of which parameter.

The formula is open to changes, according to the characteristics of the educational institution and the requirements laid down in the syllabuses.

5. Mathematical Model Use Cases

The mathematical model could be used in two cases:

- in a school or university with the same type of classrooms
- in a school or university with different types of classrooms

A. *Calculation of Rationality Coefficient for a School or University with the Same Type of Classrooms*

The first case, in which the developed mathematical model can be used, is that of a school or university, which has a fixed number of seats in the classrooms. In this case, the educational institution has classrooms with approximately the same seating capacity. The number of students in each group is organized in advance, with the number of students being smaller than the capacity of the classroom (number of seats), for example, a primary school. In this way, the number of students in lecture groups equals the number of students in exercise groups.

In this case, the formula of the mathematical model would be as follows, like 6:

$$k_r = \frac{N_{\boldsymbol{groops}} \times \left(\sum_{i=1}^{N_{courses}} (T_{lec}/t_{slot}) + \sum_{i=1}^{N_{courses}} (T_{labs}/t_{slot}) \right)}{N_{\boldsymbol{rooms}} \times \mathrm{T}_{sem} \times \frac{t_{day}}{t_{slot}}}$$

B. *Calculation of Rationality Coefficient for a School or University with Different Types of Classrooms*

The second case, in which the developed mathematical model can be used, is when the school or university has both large and small classrooms.

The small classrooms are used for holding seminars, while the large classrooms are used for holding lectures. Lecture groups are predetermined and combine more than one seminar group.

In this case, it is necessary to use a specific rationality coefficient that takes into account the planning rationality of both the lecture classrooms $k_{r_{specLec}}$ and the seminar classrooms $k_{r_{specLabs}}$.

In this case, it is also necessary to make the following distinction:

- for the number of classrooms where - $N_{\boldsymbol{rooms}}$are:
  - lecture classrooms N_{Lrooms},
  - seminar classrooms N_{Urooms}
- for the number of learning groups, where - N_{groups} are:
  - lecture groups $N_{Lgroups}$ -
  - seminar groups $N_{Ugroups}$

Thus, the total rationality coefficient is the sum of the specific rationality for lecture classrooms and the specific rationality for seminar classrooms, or:

$$k_r = k_{r_{specLec}} + k_{r_{specLabs}} \quad (7)$$

where:

$$k_{r_{specLec}} = \frac{N_{\boldsymbol{Lgroops}} \times \sum_{i=1}^{N_{\boldsymbol{courses}}} (T_{lec}/t_{slot})}{N_{\boldsymbol{Lrooms}} \times \mathrm{T}_{sem} \times \frac{t_{day}}{t_{slot}}} \quad (8)$$

And:

$$k_{r_{specLabs}} = \frac{N_{\boldsymbol{Ugroops}} \times \sum_{i=1}^{N_{\boldsymbol{courses}}} (T_{labs}/t_{slot})}{N_{\boldsymbol{Urooms}} \times \mathrm{T}_{sem} \times \frac{t_{day}}{t_{slot}}} \quad (9)$$

The specific coefficients allow for a disaggregated rationality analysis. Such an analysis of the data and the result of the calculation gives a clearer and distributed view of the problems in the process of drawing up the study timetable

6. Admissible Norms of the Rationality Coefficient

The calculation of the rationality coefficient gives the educational institution (a school or a university) an idea of whether the initial values of the parameters in p.5A and p. 5B allow for proceeding with the preparation of a study timetable.

The rationality coefficient should have a value between 0 and 1. If its value exceeds 1, then we speak of "the impossibility to prepare a study timetable" with these parameters and the need to increase the available resources. Table 1 sets out the acceptability scale of the rationality coefficient.

Table 1. Acceptability scale of rationality coefficient

Norms of the rationality coefficient	Explanation
$k_{r(t)} = 1$	Full occupancy of the classrooms with study hours. Practically difficult to reach. No reserve.
$0{,}8 \leq k_{r(t)} < 1$	Good. Realistically achievable. Allows for a 20% reserve.
$0.6 \leq k_{r(t)} < 0.8$	Admissible. Not good use of capacity. Excess reserve.
$k_{r(t)} < 0.6$	Excess reserve. Optimization of parameters is required.
$k_{r(t)} > 1$	It is not possible to do planning with the parameters set.

7. Technical Adjustment of the Model in a Real Situation

Let us look at the application of the model in a real-life situation. Table 2 gives an example of one semester of the syllabus.

Table 2. An example of a model semester of a syllabus with academic disciplines and scheduled lecture and seminars hours per discipline

Discipline		Work load	
		Lecture Hours	Seminar Hours (practice)
1.	D1	25	25
2.	D2	25	25
3.	D3	25	25
4.	D4	25	25
5.	D5	25	25
6.	D6	25	25
7.	D7	15	10

A. Option 1

Let us assume that according to the syllabus in Table 2, the number of students instructed is 98, and they are divided evenly into 4 study groups. The educational institution has 20 classrooms, which can accommodate the students according to their groups. The planned duration of the semester is 20 working days. It is decided that the study hours should be planned in slots of 5 study hours.

Then:

- **Application of the model for rationality in planning a study timetable in case 1 – an educational institution with the same type of classrooms**

Following the application of the mathematical expression in 6, we receive the following result:

$$k_r = \frac{4 \times (\quad 33+32 \quad)}{20 \times 20 \times \frac{10}{5}} == \frac{4 \times 65}{800} = \frac{260}{800} = 0.325$$

The final result for the rationality coefficient, obtained in case 1, is 0.325. According to the values set in Table 2, this means that the planning of the study timetable for 4 groups of students, for 7 academic disciplines with lectures and seminars, for a study period of 20 study days, in 20 classrooms leads to the presence of too many unused rooms. This can be improved either by increasing the number of students admitted or by organizing the instruction in a smaller number of study days.

- **Application of the model for rationality in planning a study timetable in case 2 - an educational institution with different types of classrooms**

The application of the rationality model in case 2 is possible only when the educational institution has 2 types of classrooms - lecture classrooms and seminar classrooms. Lecture classrooms have a larger number of seats for students. This means that during lectures, one or several groups of students can be brought together, depending on the capacity of the lecture classroom.

Let us assume that the school or university has the following classrooms with seats for students as follows:

Table 3. Example of a distribution of classrooms and number of seats for students

Classroom type	Pcs	Capacity
Lecture classroom 1	1	50 seats
Lecture classroom 2	2	60 seats
Lecture classroom 3	2	55 seats
Exercise classrooms	15	25 seats

Then:

Based on the data in table 3 and formulas 8 and 9 it follows that:

$$k_r = \frac{2 \times 33}{5 \times 20 \times \frac{10}{5}} + \frac{4 \times 32}{15 \times 20 \times \frac{10}{5}} = \frac{66}{200} + \frac{128}{600} = 0.33 + 0.213$$

The specific coefficient for lecture classrooms $k_{r_{specLec}} = 0.33$

The specific coefficient for seminar classrooms $k_{r_{specLabs}} = 0.213$

Given these values of the two specific rationality coefficients, it is clear that instruction under these parameters again leads to a large number of unused rooms, both lecture and seminar classrooms.

B. Option 2

Let us assume that according to the syllabus in Table 2, the number of students instructed is 98, and they are divided evenly into 4 study groups. This time the educational institution has 10 classrooms, which can accommodate the students according to their groups. The planned duration of the semester is 10 working days. It is decided that the study hours should be planned in slots of 5 study hours.

Then:

- **Application of the model for rationality in planning a study timetable in case 1 – an educational institution with the same type of classrooms**

Following the application of the mathematical expression in 6, we receive the following result:

$$k_r = \frac{4 \times (\quad 33+32 \quad)}{10 \times 10 \times \frac{10}{5}} = \frac{4 \times 65}{200} = \frac{260}{200} = 1.3$$

The application of the rationality coefficient model in case 2: 4 groups of students, 7 academic disciplines with lectures and seminars, organized in fewer classrooms and for a shorter academic period, could not be implemented.

The educational institution does not have enough classrooms for this academic period so that it could organize the study timetable. A solution could be to extend the study period or the length of the study day or to use holidays, etc

- **Application of the model for rationality in planning a study timetable in case 2**

The application of the rationality model in case 2 is possible only when the educational institution has 2 types of classrooms - lecture classrooms and seminar classrooms. Lecture classrooms have a larger number of seats for students. This means that during lectures, one or several groups of students can be brought together, depending on the capacity of the lecture classroom.

Let us assume that the school or university has the following classrooms with seats for students as follows:

Table 4. Example of a distribution of classrooms and number of seats for students

Classroom type	Pcs	Capacity
Lecture classroom 1	1	50 seats
Lecture classroom 2	2	60 seats
Lecture classroom 3	2	55 seats
Exercise classrooms	5	25 seats

Then:

Based on the data in table 4 and formulas 8 and 9, it follows that:

$$k_r = \frac{2 \times 33}{5 \times 10 \times \frac{10}{5}} + \frac{4 \times 32}{5 \times 10 \times \frac{10}{5}} = \frac{66}{100} + \frac{128}{100} = 0.66 + 1.28$$

The specific coefficient for lecture classrooms $k_{r_{specLec}} = 0.66$

The specific coefficient for seminar classrooms $k_{r_{specLabs}} = 1.28$

This means that the study timetable for 4 lecture streams of students and 4 seminar groups could not be prepared. The specific rationality coefficient for lecture classrooms $k_{r_{specLec}} = 0.66$ indicates that the educational institution has enough lecture classrooms available, while the specific rationality coefficient for seminar classrooms $k_{r_{specLabs}} = 1.28$ indicates that there are not enough seminar classrooms, where instruction could be organized.

8. Conclusion

The study timetable planning process should be approached carefully in order to make optimal use of the resources available to the educational institution. The planning process of a study timetable (or schedule) depends on the school or university for which it is made and on the specific work practices applied in the educational institution (school or university).

The developed mathematical model calculates a rationality ratio - better use of available classrooms and places for students in them for or a set period of time (academic year, semester).

Calculating a rationality ratio gives the educational institution an idea of the:

- Need for more classrooms;
- Need to extend the study period (number of days for the planned semester)

The prepared mathematical model could also be used be used as a serve as the basis for an in-depth analysis related to the requirements for the educational process and the opportunities provided by the educational institution. This mathematical model also includes a coefficient of specific rationality, in case the educational institution has classrooms of different capacities - for lectures and practical exercises.

It can be useful to higher education institutions for the purpose of planning their educational activity and it can be applied before the actual process of planning a study schedule.

The data used and calculations results could also in “special” cases, for example, the transition to remote or semi-remote learning caused by the global COVID pandemic.

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