Optimal School Scheduling Problem

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The main problem investigated in the paper is optimization of the profiled school schedule. This kind of task does not have any algorithms of polynomial complexity therefore the principal attention is paid to heuristic methods. The paper reports on the results of experimentation with the local search techniques – such as Local, Local Random, Simulated Annealing and Bayes – for optimization of the profiled school schedule. A new element of this work is optimization of Simulated Annealing (SA) parameters using special Bayes (BA) methods. Another new element is application of vectorial optimization theory by fixing Pareto optimal schedules such that would satisfy the subjective criteria of a concrete school. The created "Optima" program has four optimization algorithms for making the best school schedule. The results of application of each technique are analyzed.

Introduction: the Profiled School Scheduling Problem

A school timetabling specifies which teachers will meet the pupils, at which classroom and at what lesson (Abramson, 1996; Cooper, 1993). The timing of lessons must be such that nobody would have more than one lesson at the same time. Here the last grades of a secondary school or gymnasium (i.e., a profiled school) are referred. Pupils of these grades, in comparison with the pupils of the lower grades, can mostly choose the preferred learning profile subjects and learning hours of the subject. This makes the optimal scheduling task more complex in comparison with a lower grade secondary school scheduling.

All pupils have the official group names in the profiled schools. These names are used in the school documents. Therefore these pupils can choose available subjects in conformity with their own wishes. They are grouped into different new groups by a particular subject and subject learning hours. These new groups of pupils, that are specific to the subject and learning hours, are called subject-groups. A simple task for the profiled school scheduling is to put the subject lessons, taught by a teacher into a subject-group in a single classroom.

Some combinations of placements are leading to acceptable timetables. It is true, while the constraints follow the conditions imposed by the rooms, pupils, or teachers. A profiled school distinguishes two types of constraints (conditions): hard constraints (that must be met) and soft constraints (that should be fulfilled desirably, if possible). An example of a hard constraint is: a teacher or a pupil cannot attend more than one lesson simultaneously. The examples of the soft constrains are the compactness of teachers and pupils schedules or free days for teachers, etc. We increase the compactness by eliminating free gaps between lessons. The goal of making a profiled school schedule is to compose a timetable that satisfies all the hard constraints and minimizes the violation of the soft constraints.

Heuristics for the Efficient Decision

Every school in Lithuania has its own rules how to achieve the best schedule. It is true, while there is a different importance of the soft constraints depending on the certain school preferences. The soft constraints are regarded here as heuristic parameters.

They are most flexible at schools and are rated using penalty points. The penalties depend on the expert evaluation.

The main soft constraints are shown in Fig 1.

The penalty points for hard constraints are calculated too. The main hard constraints are shown in Fig 2.

The quality of the profiled school schedule is described by the total sum of all penalty points for all constraints, both hard and soft. The best schedule is a schedule that has the lowest sum of the penalty points. Therefore the main problem of the school schedule optimization can be described as follows:

$$\min_{\tau \in \Theta} F(\tau) \tag{1}$$

where

F(τ) is the total sum of all penalty points of some schedule τ;

A is the set of schedules satisfying the physical constraints.

The total sum of all penalty points is calculated as follows:

$$F = F_f + F_n \tag{2}$$

where

F_f is the sum of penalties for breaking the hard constraints;

F_n is the sum of penalties for breaking the soft constraints.

All the data used to create the profiled school schedule are described in the initial data file. A mathematical description of the schedule τ is as follows:

$$\tau = schedule[D[M]][V][G[S]][K] \tag{3}$$

where

M is the total number of all teachers;

D[M] is the matrix of all subjects;

V denotes the total number of weekly working hours;

S is the total number of all pupils per group;

G[S] is the matrix of all school groups;

K is the total number of classrooms.

The program "Optima" was created by the researchers at the Institute of Mathematics and Informatics for a fast making of the optimal school schedule. Several optimization methods are needed to make the optimal profiled school schedule. The analysis of these methods was made by the authors in order to evaluate the efficiency of each method. The real school timetabling problems are too difficult for the exact methods. Therefore heuristic approaches are widely used in all optimization methods.

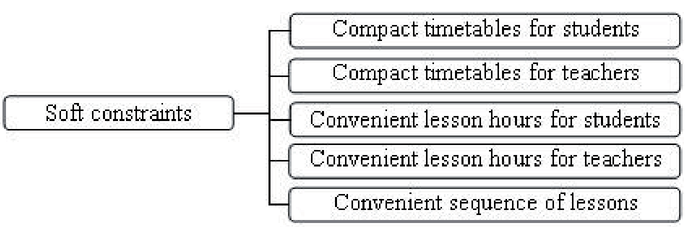


*Fig 1. **The main soft constraints on the profiled school schedule***

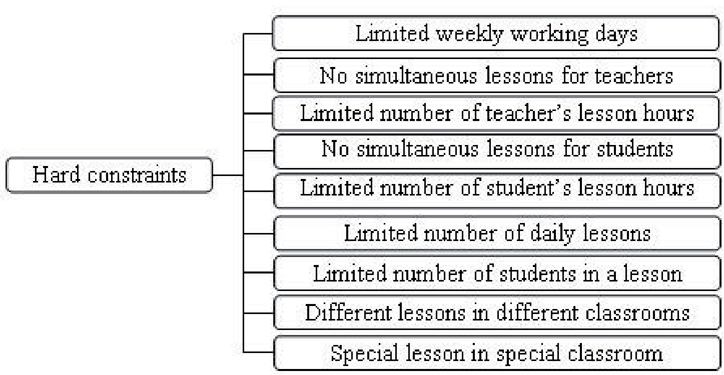


*Fig 2. **The main hard constraints on the profiled school schedule***

Comparison of the Applied Optimization Methods and the Results in the "Optima" Program

There are several optimization methods suitable for school scheduling realised in the "Optima" program: Local Deterministic (LD), Local Randomized (LR) (for local search techniques see, e.g., Schaerf A. and Schaerf, 2005; for Mathematical Programming see Žilinskas, 2005), Simulated Annealing (SA) (see, e.g., Abramson et. al., 1996; Yang, 2000; Mockus, 2002), and SA with the parameters optimized using the Bayesian approach (BA) (see, e.g., Mockus, 2002; Mockus, 2004; Mockus et. al., 2000). The efficiency of each method has been explored. The comparison of these methods is presented in Table 1.

The efficiency of the Bayes method is represented in Fig. 3 and Fig. 4.

Choosing and optimization of the heuristic parameters is very important in the profiled school. The best results will be obtained when the optimal parameters are chosen. The quality of the optimal schedule depends on the following parameters:

- Heuristics must be oriented to the fast and convenient search for an optimal schedule.
- Different internal rules must comply with heuristics.

Evaluation and formalization of the local conditions can be achieved using the scalarization method of vectorial optimization theory. This is convenient for practical applications and provides Pareto-optimal solutions. This approach was not used in the other publications on school scheduling.

Implementation of the Program

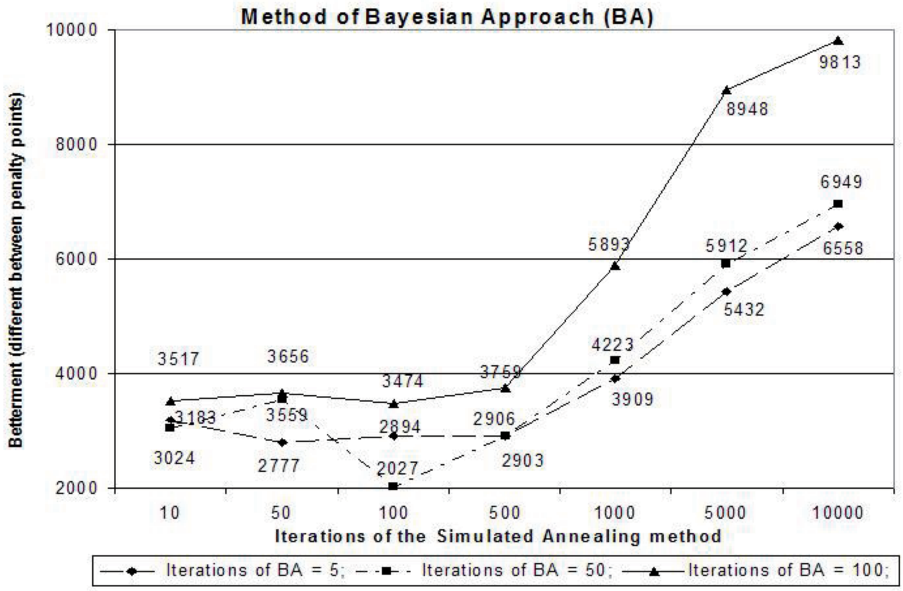
A platform independent architecture and the Java Servlet technology were chosen for creation of the "Optima" program. Java technologies (min v1.6.0_07-b06), XML technologies and the Apache web server were used to finalise the program.

This is the first case of Java Servlet technology usage in the school schedule optimization judging by the publications up to date. In this case, the school schedule optimization is performed very simply: only using a browser, without any additional tools. The "Optima" program is available for the user: http://soften.ktu.lt:8080/TvarkaNaujas.

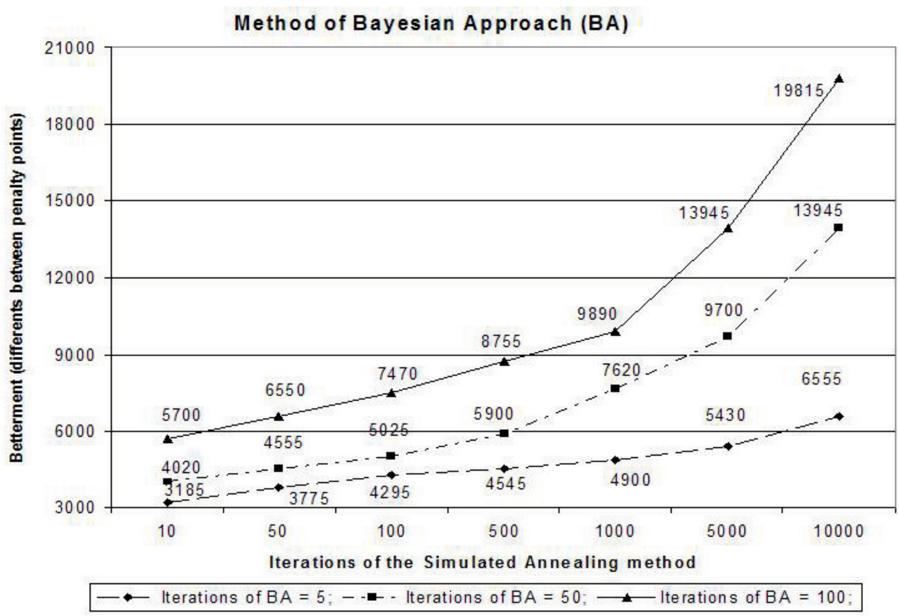
The results of the work could be used in Lithuanian high schools and gymnasia. The research of heuristic optimization methods, described in this work, has been performed at the Marijampolė Rygiškių Jono gymnasium and Trakų Vytauto Didžiojo gymnasium.

Table 1. ***Comparison of the optimisation methods***

	Efficiency of the results	Best results	Accuracy	CPU time
LD	Often "stuck" in local minimum.	Got when 1 000–10 000 iterations are set.	Not accurate. Elimination of free lessons sequence is fixed.	Working time 7–45 seconds.
LA	Results are more accurate than the results of LD.	Got when 1 000–10 000 iterations are set and LA parameter *K* = 5.	More accurate than LD. Difference between LD and LA: Elimination of free lessons sequence is randomized.	
AM	Results depend on the setting of SA parameters.	The parameters are different in different schools. The results are changing very fast using different constraints evaluation.	The probability of impairment is valued. Elimination of free lessons sequence is randomized.	Working time from 21 second until 10 hours.
BA	Results are very close to the real school schedule.	The best results are got when 500 iterations of BA and 10 000 iterations of AM methods were set.	BA is the automation of SA. It is a search for the best result generating and optimizing the parameters of SA.	



*F i g 3 . **Average improvements obtained while applying the Bayes method***



*F i g 4 . **Top improvements obtained while applying the Bayes method***

Conclusion

A new and efficient way of solving the profiled school scheduling problems by heuristic methods was achieved during the optimization of Simulated Annealing parameters using the Bayesian method. It has been estimated that the adapted optimization of Simulated Annealing parameters by the Bayesian methods is an efficient way of solving the profiled school scheduling problems. It can be recommended for the optimization of the profiled school schedules. The efficiency of optimization depends on the parameters of heuristics. Therefore the automated procedures should be applied to optimize these parameters. The best solution has been obtained while combining the Bayesian and Simulated Annealing methods.

Creation and usage of the effective school schedule optimization solutions should enhance the school management and effectiveness of the whole education system.

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OPTIMALAUS MOKYKLOS TVARKARAŠČIO SUDARYMO PROBLEMA

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S a n t r a u k a

Straipsnyje aprašomas profilinių klasių tvarkaraščio sudarymas. Šio tipo uždaviniams spręsti nėra sukurta polinominio sudėtingumo algoritmų, todėl naudojami euristiniai optimizavimo metodai. Šiame straipsnyje aprašomi rezultatai, gauti naudojant lokalios paieškos metodus – lokalų determinuotą, lokalų atsitiktinį, atkaitinimo modeliavimo ir Bayeso – siekiant palengvinti profilinių klasių uždavinio sprendimą. Straipsnyje aprašoma nauja metodika tokio tipo uždaviniams spręsti. Tai Atkaitinimo modeliavimo parametrų optimizavimas naudojant Bayeso metodus. Kitas naujumas, aprašomas šiame straipsnyje, yra vektorinis optimizavimas naudojant tokius Pareto optimalius tvarkaraščius, kurie tenkintų individualius euristinius mokyklos kriterijus. Sukurtoje programoje „Optima“ yra įdiegti keturi optimizavimo metodai. Analizuojami rezultatai gauti taikant šiuos metodus.