Training complex for developing and evaluating skills for solving optimization and control problems in food production facilities

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Abstract. The paper is devoted to the development of theory and practice of creating computer simulators for professional training of personnel in the food industry. The prototype of the Intellectual Training Complex (ITC) is developed for training engineering specialists in knowledge and skills in solving problems of optimization and control of production processes. The functioning of the ITC software is based on algorithms that allow modeling typical optimization and control problems in exercises, in particular, the processes of formation and evaluation of individual exercise variants are determined by the properties and structure of this type of problems. Implementation of the ITC prototype in the educational process of technological universities to train engineering specialists in the skills of solving optimization and control problems in the practical aspect allows simplifying the creation and evaluation of exercise courses, contributes to better formation of knowledge and skills of a specialist taking into account the specifics of the chosen training direction (in particular, as applied to the professional training of food production technologists, specialists in the automation of technological processes at food enterprises).

1 Introduction

Optimization and control problems are the basis for mathematical support of automated information systems (AIS) of modern enterprises (in particular, food industry).

In the process of training of engineering specialists (technologists, automation and informatization specialists) for production processes an important task is the formation of knowledge and skills of solving optimization and control problems at the required level.

Modern e-learning tools and distance education technologies insufficiently provide control and formation of skills for solving such problems [1]. Control activities are reduced either to knowledge testing (which does not allow to check the skills of solving practical problems), or to time-consuming checking the solution of practical problems directly by the instructor taking into account his subjective opinion (which preliminarily includes also

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time-consuming compilation of the required number of exercise variants by the instructor depending on the number of students).

In the process of professional training in many industries, computer simulators are used, allowing to overcome the above-mentioned drawbacks to a large extent [2-4]. Exercises on simulators include modeling of real production tasks (in particular, when training specialists in various hazardous spheres of activity), automatic evaluation of the results of the performance of these tasks by trainees [5-7].

The present study, the results of which are presented below, is aimed at developing the theory and practice of developing intelligent training complexes (ITC) for training engineering specialists, in which the formation and control of skills by means of exercises are based on the simulation of the studied tasks (in particular, optimization and production process control tasks). The use of these ITCs in the process of professional training will reduce the share of routine operations in the development of training courses and assessment of students' training results in the course of skills control.

2 Adjustment and execution of exercises on mathematical programming problems in the training complex

Based on the analysis of the theory and practice of computer simulators creation, shortcomings of existing methods and means of training specialists of engineering profile, a visual model in the form of Use Case UML diagram (Fig. 1) describing the functional requirements to ITC for the formation of skills for solving optimization and production process control problems has been developed.

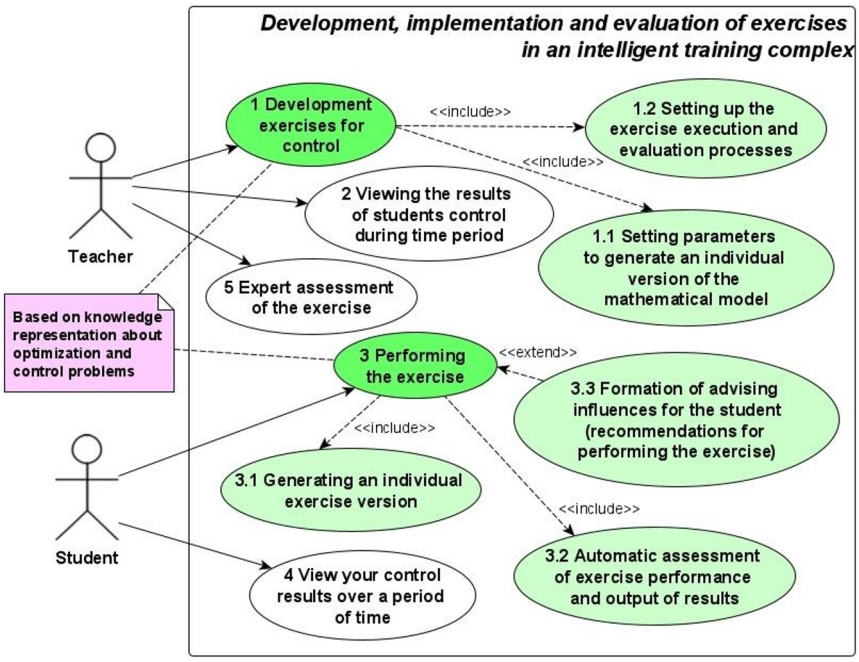

Fig. 1. Visual model (Use Case UML diagram) of functional requirements to ITC

Exercises on ITC mainly consist in building mathematical models of optimization and control problems or individual components of these models.

The ITC software in Fig. 1 is implemented using mathematical models and algorithms whose parameters define the properties, structure and specifics of typical optimization and control problems. Based on a set of parameters, the instructor sets up exercises for optimization and control problems, automatically generates individual variants of exercises for each student, students perform exercises in the ITC virtual learning environment, and automatically evaluates the results of exercises.

Let's consider the functionality of the ITC prototype developed in the form of a web-application on the example of system generation and execution of individual exercise variants on mathematical programming problems by a student.

Example No.1. Exercise on development of a mathematical model of a dual linear programming (LP) problem based on the model of the initial LP problem.

Setting up by the teacher in ITC of exercises on development and analysis of models of mathematical programming problems includes setting the following parameters:

1) Parameters defining the structure and properties of the mathematical model of the problem. As shown in Fig. 2(1), for the example under consideration, the teacher sets the number of variables and constraints of the model, minimization or maximization of the target function (TF) of the original problem, and permissible signs of the constraints using the web interface.

2) Parameters defining a set of actions of the student to define the components of the mathematical model when performing the exercise. In the example in Fig. 2(1), the instructor configures which components of the mathematical model (components of the TF and constraints, types of variables) are set by the student (by entering them in the text fields or selecting them from the list of possible variants), and which are defined by the system automatically and specified as known in the individual version of the exercise. Together, the degree of difficulty of the exercise for the student depends on the setting of these parameters.

3) Parameters that determine the process of evaluating the results of developing a mathematical model of the problem. They can be explicitly set by the instructor as an addition to the interface in Fig. 2(1). Automatic determination depending on the properties of the mathematical model and possible actions of the student, i.e., the parameters described in 1) and 2) above, is also acceptable. Examples of parameters of the evaluation process are the weights that determine the difficulty of setting by the student of each element of the mathematical model of the task (can be set explicitly by the instructor or calculated on the basis of processing the collected data on the learning outcomes of some number of students).

An individual variant of an exercise for a student is formed according to the values of the set of parameters mentioned above.

There are possible variations of exercises on developing mathematical models of LP tasks. For example, building a model of the production planning problem on the basis of the initial description of the problem statement (in textual and/or tabular form). It is required to create a model of the LP problem to determine what quantity of each type of product should be produced in order to maximize profit for the enterprise. In order to generate individual variants of such problems, the teacher should set the permissible values of the number of types of raw materials, the number of types of products produced and other parameters of the production process.

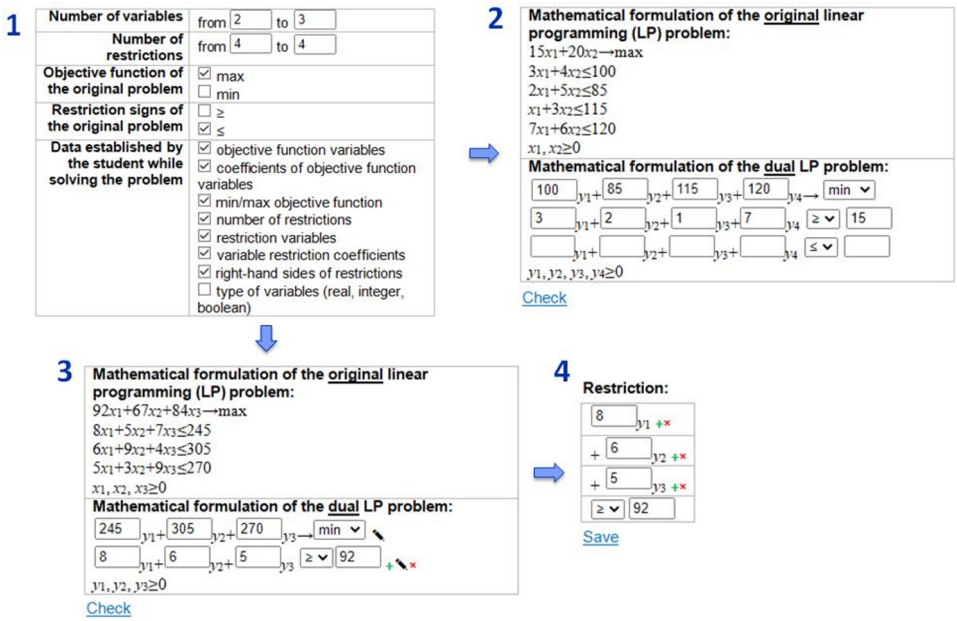

Fig. 2 Configuring and executing the exercise of developing a mathematical model of the dual LP problem

Depending on the instructor's settings of the exercise parameters in Fig. 2(1), different variants of exercises can be automatically generated in terms of complexity. Fig. 2(2) shows the web interface of the exercise for the simpler variant, and Fig. 2(3) and Fig. 2(4) show the more complex variant. While in the example in Fig. 2(2) the number of variables and constraints is known to the learner (automatically determined by the system), in the example in Fig. 2(3) the student must determine the required number of constraints in the model, and in the interface in Fig. 2(4) add the required number of variables.

According to the settings in Fig. 2(1), each student will be generated the same difficulty variant of the exercise. The variants will differ from each other by the values of the coefficients of variables, the number of variables and constraints (within the limits of the minimum and maximum values of parameters set by the teacher).

Example No. 2. Exercise on developing a mathematical model of the Boolean linear programming (BLP) problem for finding min/max path in the initial graph.

The setting of the exercise by the teacher is in many respects similar to the example No.1, but takes into account the specific features of mathematical models of BLP problems. The parameters that determine the structure and properties of the mathematical model of the BLP problem, as shown in Fig. 3(1), include setting the acceptable number of nodes of the initial graph for the subsequent generation of the graph in the individual variant of the exercise. The set of student actions in the exercise also takes into account the distinctive features of the BLP task models.

The instructor's settings allow generating a simplified version of the exercise, an example of which is shown in Fig. 3(2), and a more complex version of the exercise, an example of which is shown in Fig. 3(3) and 3(4).

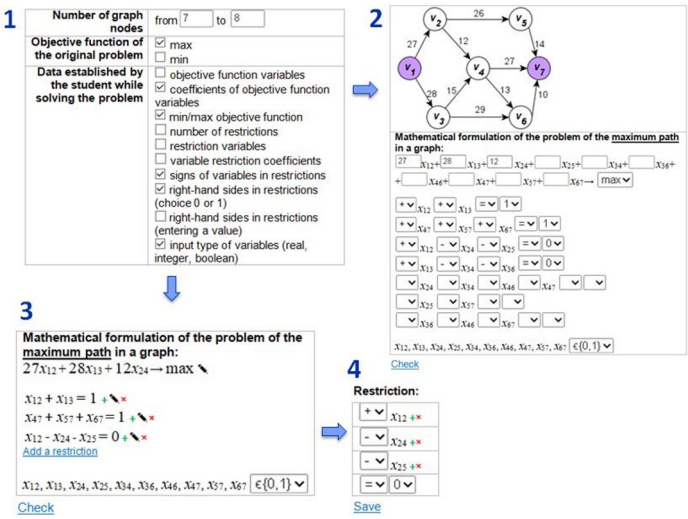

Fig. 3 Configuring and executing an exercise to develop a mathematical model of the BLP problem to find min/max path in the original graph

Example No.3. Exercise on graph construction based on the mathematical model of the BLP problem to find min/max path in the graph.

The distinctive feature of setting up such an exercise when the teacher specifies a set of possible actions is setting in the interface in Fig. 4(1) the ways for the student to specify the nodes and arcs of the graph in a special graphical editor embedded in the web-interface of the exercise.

In the example of an individual variant of the exercise in Fig. 4(2) shows an exercise of medium complexity, where the number of graph nodes is initially defined in the graphical editor, and the values of arc weights are to be set by the student.

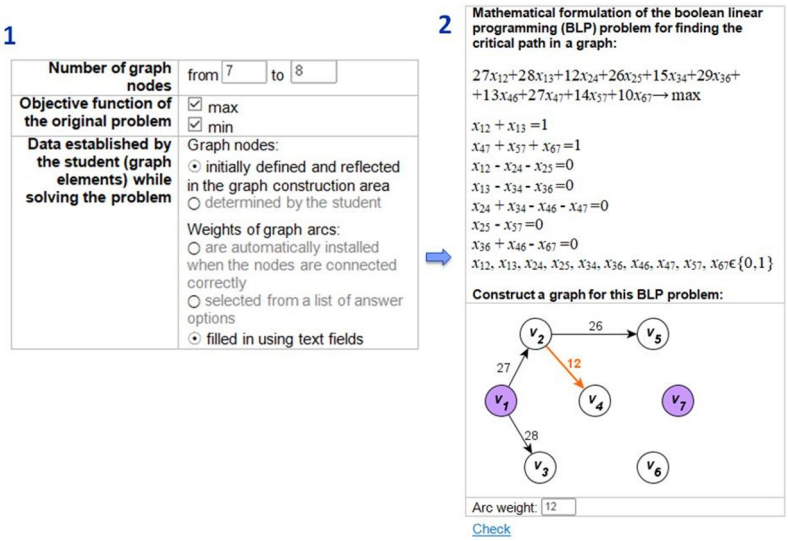

Fig. 4 Set up and execute a graphing exercise based on a mathematical model of the BLP problem to find the min/max path in the graph

3 Configuring and performing exercises on fuzzy control tasks

Exercises in ITC can also include the construction by the trainee of a certain algorithm in the field of solving optimization and production process control problems. We will consider an example of setting up and executing such an exercise, testing the skills of developing fuzzy control systems [8-10].

Example No.4. Exercise on execution of fuzzy inference algorithm based on the system of fuzzy products.

According to Fig. 5(1), the parameters set by the instructor, which determine the structure and properties of the fuzzy productions system for generating its individual variant for a student, are: the number of productions rules, the number of input linguistic variables, the use of one-point sets, and the use of one-point sets. 5(1) are: the number of productions rules, the number of input linguistic variables, the use of one-point sets as output linguistic variables.

An example of the student's individual variant of the fuzzy inference algorithm exercise is shown in Fig. 5(2). According to the difficulty level settings of the exercise in Fig. 5(1), the order of actions in the algorithm is already set for the learner, and for each step of the algorithm, it is necessary to perform the input of required values and the selection of certain actions. For example, when filling in the data for the defuzzification step, we go to the web interface of filling in the numerators and denominator of the fraction in Fig. 5(3).

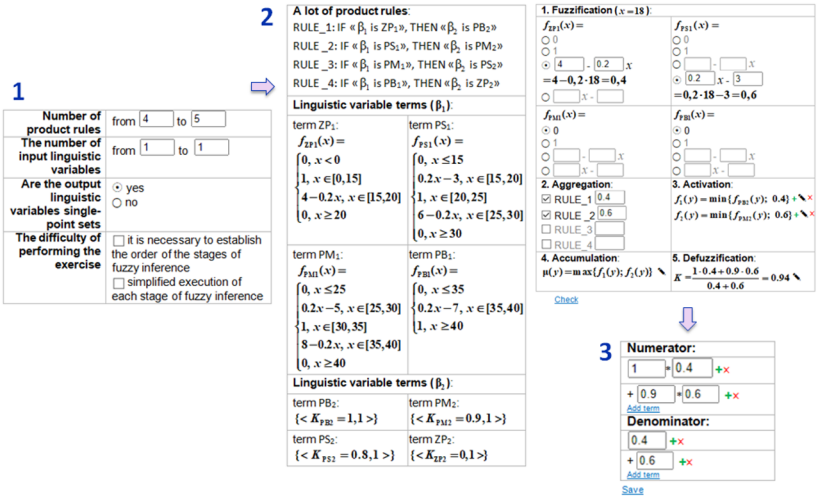

Fig. 5 Configuring and executing the fuzzy inference algorithm exercise

As follows from the above examples of work with the web application, the use of ITC during the current and intermediate control of disciplines in the field of optimization and management (e.g., during the defense of laboratory works, during examinations), provides greater functionality compared to existing software products and teaching methods.

4 Conclusions

1. ITC prototype has been developed for training engineering specialists in knowledge and skills of solving optimization and control problems of production processes. ITC software functioning is based on algorithms that allow modeling typical optimization and control problems in exercises, in particular, the processes of formation and evaluation of individual exercise variants are determined by the properties and structure of this type of problems.

2. The key features and advantages of ITC application in the teaching process of disciplines in the field of optimization and control are:

1) variable adjustment of exercise parameters by the teacher according to the properties of optimization and control problems (instead of manual generation of a large number of individual exercise variants for each student);

2) automatic generation of an individual exercise variant for each student in accordance with the configured parameters;

3) execution of the exercise by the student with the help of a visual user web-interface, automatic complex evaluation of the exercise result (instead of manual checking of the exercise by the instructor and waiting for the result of checking by the student), informational support of the student (comments, recommendations on problem solving);

4) collection, structured storage in the database, visual presentation of information about the dynamics of skills formation in solving optimization and control problems to teachers and students using the web-interface;

5) regulation of the level of complexity of exercises to adapt to the individual characteristics of each student.

3. Implementation of the ITC prototype in the educational process of technological universities (e.g., ROSBIOTECH) to train engineering specialists in the skills of solving optimization and control problems in the practical aspect allows to simplify the creation and evaluation of exercise courses, contributes to better formation of knowledge and skills of a specialist taking into account the specifics of the chosen area of training (in particular, with regard to the professional training of food technologists, specialists in the automation of technological processes at food enterprises).

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