System Dynamics Use in Engineering Education
Development Planning

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Abstract: - The lack of specialists of engineering and precise sciences is no longer a surprise, but already for quite a long time it causes problems to the development of economy of these fields in some countries. The EngiMod model described in the article serves the analysis of possible affecting factors using system dynamics and simulation in STELLA possibilities. It allows easily manipulating with the weight of the significant factors and interactively acquiring the necessary predictions. According to the primary conditions and statistical data, it is possible to model and predict the development of the situation in any time period. EngiMod multilevel model can be adapted to the needs of other sectors.

Key-Words: - Engineering Education, Simulation, System Dynamics, STELLA

1 Introduction

The lack of specialists of engineering and precise sciences is no longer a surprise, but already for quite a long time it causes problems to the development of economy of these fields in some countries.

On 25 May 2007 the Education Council adopted conclusions on a coherent framework of 16 core indicators for monitoring progress towards the Lisbon objectives in education and training. The important indicators are literacy in reading, mathematics and science, and ICT skills [1].

Regular monitoring of performance and progress using indicators and benchmarks is an essential part of the Lisbon process, allowing strengths and weaknesses to be identified with a view to providing strategic guidance for the Education and Training 2010 work programme.

By adopting five European benchmarks in May 2003, the Council set measurable objectives indicating the policy areas in which, in particular, it expected to see clear progress. The benchmark related with the indicators nominated above to be achieved by 2010 were: increase of at least 15% in the number of graduates in Mathematics, Science and Technology (MST). MST cover the following fields: life sciences, physical sciences, mathematics and statistics, computing, engineering and engineering trades, manufacturing and processing, architecture and building.

In 2005 Estonia, Greece, Poland, Austria and Italy showed the strongest growth in the numbers of MST graduates (>10%). Despite the general positive trend, some countries Spain, Cyprus, Belgium, Hungary, Malta, Sweden, Iceland, and Norway showed a considerable decrease in numbers in 2005. Other problem is total growth of MST graduates, which majority of countries as Bulgaria, Czech Republic, Germany, Greece, Cyprus, Latvia, Hungary, Malta, Netherlands, Austria, Slovenia, Croatia, FYR Macedonia, Turkey and Norway are below average EU-27 level [1].

The lack of specialists limits the possibilities to develop and produce science-capacious production with high added value. There are difficulties with introducing technologically complicated systems of management and control whose exploitation requires specific knowledge obtainable in a longer period of time. But the representatives of social sciences, humanities and management sciences often lack the knowledge and skills necessary to take well-grounded decisions which in the information and knowledge society are not possible without the knowledge of mathematics and modelling skills, and not based only on intuitive assumptions.

Not only the lack of new specialists causes problems, but also the necessity to regularly update the technical engineering skills and knowledge in accordance with the rapid changes in the development of technologies.

It must be noted that the solving of the above mentioned problems still is rather unsuccessful because it requires considerable capital investments in the development of material supply and introduction of new training methods.
In order to develop a well-considered state education policy, it is necessary to perform the analysis of affecting factors and create a full cycle model that would allow predicting the development of the situation in a longer time period. It can be done by using the system dynamics approach which gives the possibility to describe the set of significant factors and check the possible results in different conditions and development scenarios.

There exist a number of mathematical methods that can be used for solving differential equations. However, in order to reach the model transparency and sufficiently high level of abstraction, to ensure the possibilities of model usage by people without IT knowledge who should take decisions regarding state policy in the field of education and science, as well as to promote the interactivity of modelling process, the decision was taken to use the possibilities offered by simulation.

Today there is no problem to choose any of the system dynamics modelling tools like Vensim, Powersim, Dynamo, Dymola, STELLA, iThink etc., but it is preferable to have the best possible compliance with the previously defined criteria.

2 STELLA and System Dynamics

To describe the structure and functioning of continuous system in 80’ies, Barry Richmond created STELLA software [2, 3, 4]. STELLA introduced and integrated graphical interface using icons to develop stock-and-flow diagrams, and tying these icons to the underlying equations. STELLA window is divided into four tabbed pages: Interface, Map, Model, and Equation. Each tab represents a distinct layer in the model and each provides a different way of designing and presenting a model. Most important are Model and Equation layers. Model layer is used for transformation the maps into models that can be simulated, but Equation level gives the presentation about all the equations that make up the model [2].

The most significant advantage of STELLA [5, 6] is the possibility to specify very complicated models with minimum alphabet and offer different abstraction levels. In turn, the tools of graphic visualisation provide sufficiently comfortable model verification, validation and control of modelling process.

3 EngiMod – the model for changes management in engineering education

EngiMod can be used to show the processes of training and also decrease of engineering specialists in a particular territory or country. In this particular case it is based on Latvian education system [7]. The quality and the functionality of every model, also EngiMod results depend on the preparation quality of the initial data. During the model development and testing, a set of hypothetical initial data is used.

Model EngiMod consists of seven layers:
- Prediction of the increase in the number of potential engineering students;
- Training of college level specialists;
- Analysis of the increase of engineering bachelor degree holders;
- Engineers training model;
- Training of master’s level specialists;
- Prediction of the increase in the number of Ph.D. holders;
- Tendencies of change of the total number of engineering specialists.

The first level of EngiMod is the source of data for the rest of model layers. On the first level (see Fig. 1) the development process of the potential engineering students is described based on the data on the change of the number of secondary school students (Grammar_School_Absolvents).

![Fig. 1. The growth of potential engineering students](image-url)
Absolvents with Natural Science will choose engineering science as his or her profession (Engineering_Students_Started). The potential student is concerned with the salary in the future profession (Material_Factor), the possibilities for development and career (Developing_Factor), as well as the prestige of the profession (Prestige_Factor). One of the important factors is state support (State_Factor) in providing study loans, state funded studies and other benefits.

On the second level of EngiMod the training of first level higher education specialists in engineering sciences is described (see Fig. 2).

In the particular model the influence of vocational schools is taken into account (Vocational_Schools_Impact_1), as well as the possibility that a small number of secondary school graduates without formal knowledge in exact sciences will nevertheless risk and choose engineering science studies (Wrong_Choice_Factor_Plus). It must be noted that only part of Engineering_Students_Started choose college level studies (College_Selected), but the majority go to universities. The increase of the number of specialists is affected by academic dropout (Academic_Dropout) that results from the failure to complete study debts, as well as the realisation of the wrong choice of the profession (Wrong_Choice_Factor_Minus).

Third level model of EngiMod (see Fig.3) considers the condition that bachelor studies (Bachelors_Input) are undertaken not only by students that have planned studies for a long time (University_Selected), but also those secondary school students that have not considered that before (Wrong_Choice_Factor_Plus_2). Also part of the specialists who finish college level studies can continue with bachelor’s level studies (Continuing_College). Small part of vocational secondary education graduates (Vocational_Schools_Impact_2) prefer bachelor’s studies instead of college level studies.

Influenced by the above mentioned factors, a number of students can make a conclusion that engineering science studies is not their true call (Wrong_Choice_Factor_Minus_2).

Bachelor studies provide second level higher education; nevertheless, it is possible to continue studies (Engineer_Speciality_Selected) in order to obtain the professional qualification of an engineer (see Fig. 4) or study on a master’s level.

Fig. 3. The increase of engineering bachelor degree holders

The considerable student dropout should be taken into account (Academic_Dropout_2), resulting from the complicated character and the specific study process of engineering science studies (laboratory works, high costs of individual study process). Influenced by the above mentioned factors, a number of students can make a conclusion that engineering science studies is not their true call (Wrong_Choice_Factor_Minus_2).

Fig. 4. Engineers training model

The fourth level of EngiMod takes into account the condition that part of the students that begin
engineering studies, will leave it (Academic_Dropout_3), but the experience shows that for the time being this factor is not an important model component.

It must be noted that a considerable part of bachelor graduates choose to continue studies on a master’s level (Master_Studies_Selected) (see Fig.5). Academic dropout (Academic_Dropout_Masters) is almost equal to bachelor’s studies, and also the wrong choice of study programme has some effect (Wrong_Choice_Factor_Minus_3).

![Fig. 5. Training of master’s level specialists](image)

However, the number of engineering and precise science master’s students can be increased by one very important factor – interdisciplinary study programmes (Interdisciplinary_Programmes), which is a perspective in order to change a rather hopeless situation in specialist training in precise sciences.

Although it is not possible to achieve it in a democratic way that secondary school graduates study engineering sciences, it turns out, however, that in the following years the mood of the social science supporters can change significantly and some social science specialists are willing to study exact subjects with pleasure acquiring lots of things previously ignored or not understood by way of self-instruction. These conclusions can be made due to EU SocSimNet (2004 – 2006) project [8, 9] that was devoted to developing an interdisciplinary master’s study programme in Sociotechnical Systems Modelling.

After the preliminary testing, studies in this programme were undertaken by both IT, management science and humanities bachelor graduates with acquired professional qualification. The new knowledge and skills in knowledge management, simulation and modern technologies allow new master’s not only to work in their specialities more successfully, but also ensure higher mobility in the labour market.

The sixth level of EngiMod (see Fig.6) describes the training process of Ph.D. students. It must be noted that the doctoral studies are undertaken not only by the local students, but also by students that have acquired their master’s degree abroad (Masters_Abroad). It is possible that the doctoral dissertation is prepared individually without attending doctoral studies (External_Doctors).

![Fig. 6. Prediction of the increase in the number of Ph.D. holders](image)

The result of a successful doctoral programme depends not only on material circumstances (Social_Factor), which often serves as a formal reason, but a very significant condition is the lack of qualitative and interested doctoral dissertation advisers (Guidance_Quality).

On the seventh level of EngiMod the total changes in the number of engineering science specialists are described (see Fig.7).
Not only the increase of the total number is enumerated (Engineering_Specialists_Increase), but also the decreasing tendencies are analysed caused by processes of aging (Retired) and migration (Going_Abroad), as well as change of profession (Trained_for_a_New_Occupation) if the person has not managed to find a good and suitable job or if there is a lack of willingness to periodically update the knowledge.

4 Conclusion
The EngiMod model described in the article serves the analysis of possible affecting factors using system dynamics possibilities. It allows easily manipulating with the weight of the significant factors and interactively acquiring the necessary predictions. According to the primary conditions and statistical data, it is possible to model and predict the development of the situation in any time period. EngiMod multilevel model can be adapted to the needs of other sectors.

References: