Using System Dynamics Approach to Development of Enrollment Policies in Higher Education: A Case of Teacher Education Faculties in Croatia

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Abstract **- The paper proposes an approach to development of higher education enrollment policies based on system dynamics as an appropriate mathematical modelling method for modelling nonlinearity, time delays and feedback loops. The model of teacher education students' population in Croatia is presented, to enhance forecasting, planning and support the decision-making process. Simulation is conducted for the period from 2016 to 2021 based on historical data for the period from 2010 to 2015. The results show that system dynamics modelling can support decision making regarding enrollment policies by presenting simulated data and providing recommendations to teacher education faculties and education authorities.**

Keywords **– system dynamics, educational system, teacher faculties, mathematical modelling, enrollment policies.**

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1. Introduction

Human resources planning is of utmost importance in every aspect of society, and as such it is crucial part of educational system. The number of students enrolling in higher education has a direct impact on human resources.

As a contrast to faculties management, which interest is to attract and enroll more students, education authorities must balance between educating sufficient number of teachers to prevent shortages in future, as well as prevent too many unemployed teachers. In the Republic of Croatia, the analysis and forecast of labor market demand for individual professions and recommendations for educational enrolment policy is made by the Croatian Employment Service [1]. These recommendations are elaborated with statistical data and static predictions. More complex, dynamic approach is needed, because educational system is, as every aspect of human activity, affected by contemporary technologies and the possibilities that they offer such as online courses, enrollment to different programs globally, home schooling, teleworking, etc. Nowadays preservice teachers find attractive possibilities of implementing social networks in formal education [2], mobile learning environment [3], game based learning and gamification [4] etc., which enhances competitiveness among teacher faculties to enroll quality students.

Preservice teachers' technological self-efficacy and interest toward online education increases as well as students belief that online education is appropriate for their future successful profession [5]. This reflects in enrollment policies complication for teacher faculties, bringing human resources uncertainties.

The pressure of the industry on ICT educated staff should not be neglected either. By offering better working conditions and wages, they could attract students to an industry career, away from the educational system and thus could cause disruption in its functioning.

Abovementioned factors make managing human resources in educational system more unpredictable than ever before. Therefore, there is a need for better understanding of elements of the system, modelling and experimenting in safe environment without making mistakes which will downgrade educational system for years. The application of mathematical modeling in educational system is present in many countries, such as modelling human resources in Portugal schools [6], modelling population of students, staff, and investments in a private university in Syria [7], etc.

This paper is an extension of the theoretical framework for implementing system dynamics (SD) in educational system, presented by Tomljenović et al. [8]. Authors argued SD applicability in education system, as a prerequisite for forecasting and planning.

The aim of this work is to extend theoretical framework and build an operational model of teacher education students' population, as a subset of education system, that could be used for providing useful enrollment policies recommendations. Simulated data obtained by the model can contribute to better understanding of enrollment policies and support planning for higher education management as well for education authorities.

2. Background

2.1. Educational System as a Complex System

Recognizing educational system as a complex system is the first step for qualitative analysis. Qualifications of the complex system are synthesized by Sterman [9] and presented in Table 1. Educational system has all the qualities summarized in Table 1. and therefore is considered as complex system [10].

2.2. System Dynamic Modelling

Depending on the degree of abstraction, complex systems can be modelled through three main approaches, related to its level of aggregation and abstraction. Discrete event modelling as the least abstract, systems dynamic modelling as the most abstract and an agent-based modelling as a balance between these two approaches [11].

System dynamics is one of the numerical mathematical methods introduced by Forrester in1960's [12]. Main characteristics of the method is nonlinear dependencies between parts of the model, feedback loops, time delays and modeling the system as a whole with time dynamics [13]. Method is used in a variety of disciplines [14], [15], [16], including human resources planning [17], [18].

According to Sterman [19], SD simulation modelling is one of the most appropriate and successful scientific approaches to development of complex, nonlinear, natural, technical and organizational systems.

Table 1. Characteristics of a complex system

Characteristic	Description
constantly changing	change in a system is constant at many time scales and levels of representation
tightly coupled	the actors in a system interact with each other and with the environment
governed by feedback	there are feedbacks of actions, altering the system state; dynamic of the system arises from these feedback loops
nonlinear	multiple factors interact
history-dependent	future state of the system depends on present condition
self-organizing	the dynamics of the system arise from their internal structure
adaptive	the capabilities and decision rules of the agents in systems change over time
delays in feedback	time delays mean the long-run response of the system to an intervention
emergent	properties at the micro-level lead to emergent properties at macro-level
policy resistant	complexity of the systems overwhelms our ability to understand them: many seemingly obvious solutions can fail or even worsen the problem

Graphical representation of SD model includes stock variables, flow variables, links between variables, dynamic variables, constant parameters, and links between them. In Figure 1. is the simplest presentation of SD elements.

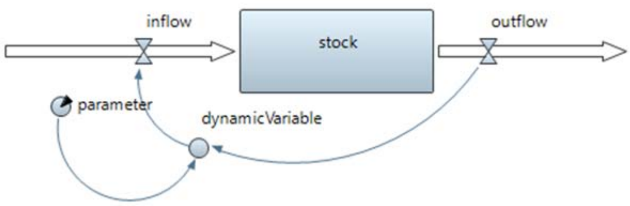

Figure 1. Graphical presentation of general SD model

Variables and constants are related by equations, and links indicate which element is included in equation. General dependencies between stock and flow in unit of time (t) is presented in equation (1):

$$\frac{d(stock)}{dt} = inflow(t) - outflow(t) \quad (1)$$

Model is represented with a system of equations which is difficult to solve. Therefore SD is enhanced with increase of processing power of contemporary ICT, becoming more appropriate method for complex systems, as presented on example of human resources planning in the Croatian educational system [8].

3. Methodology

Applicability of system dynamics modelling of educational system is presented with population of students at teacher education faculties (TF) in Croatia. The population is observed from high school graduates, through enrollment at the TF, to obtaining a diploma degree. The objective of the model is to provide valid number of students' enrollment at TF, as crucial element for administrators of the faculties, as well for predicting possible teacher shortages in future. There are 7 TF in Croatia which educate future teachers for 1st to 4th grade of elementary school (primary education). Data such as enrollment quotas and number of applicants are obtained from relevant sources [20] for all TF in the period 2010-2021. In addition, average duration of study, gender composition of enrolled students, etc., are obtained from the Faculty of Teacher Education in Zagreb. As the biggest faculty with approximately 40% of all teacher education student population in Croatia, such data can be presumed as appropriate for the whole student population.

The concept of the model is adopted from simple Bass diffusion model of innovation of new product [21], extended using system dynamics techniques [19]. Figure 2. presents conceptual design with parameters, connections and causal loops. Based on the concept, the model is designed with 3 stocks, 6 flows, static parameters (constants) and dynamic parameters, as presented in Figure 3. The first stock represents population of high school graduates (*Graduates*), part of them is applying for teacher education faculties (*TF_Applicants*), and after the enrollment process (*enrollment, quota*) part of them become students at teacher faculties (*TF_Students*). Beside flows between stocks, there are flows outside the model: graduates which decided to go to other

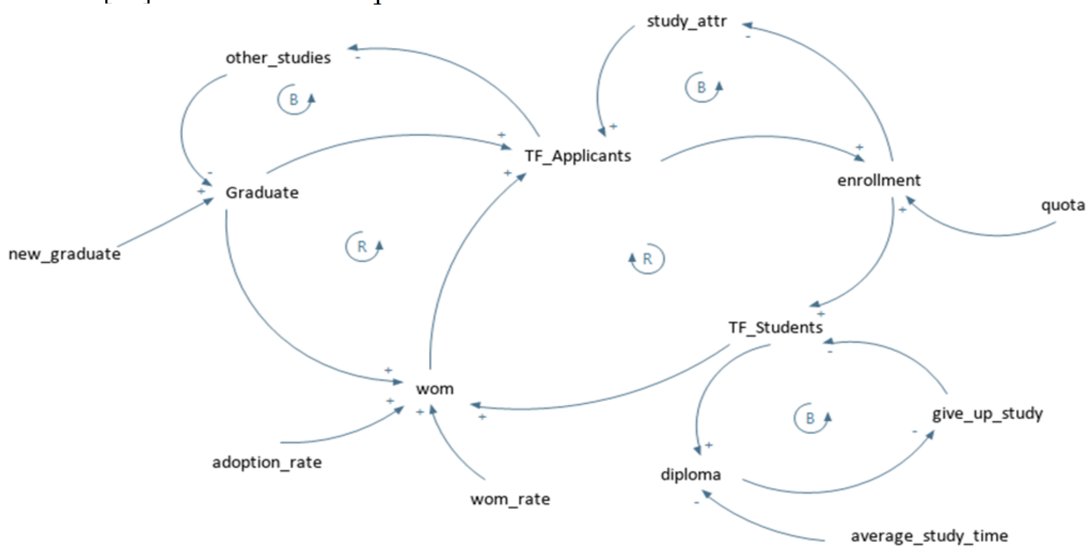

Figure 2. Concept of the model

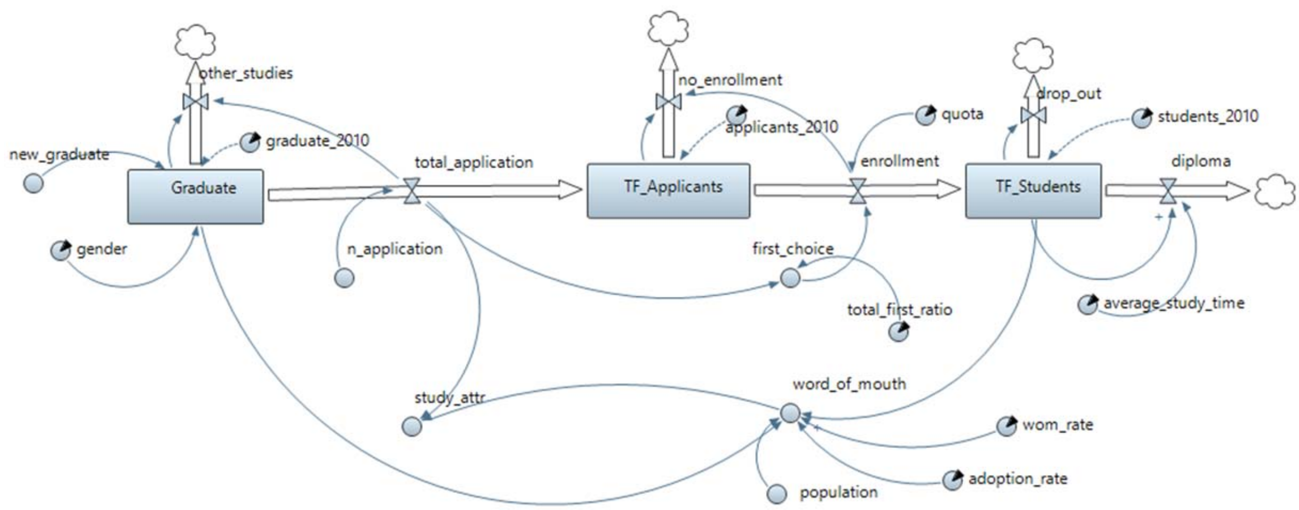

Figure 3. Model design

faculties (*other_studies*), applicants who didn't succeed to enroll TF (*no_enrollment*) and drop-out students (*drop_out*). After average study time (*average_study_time*), students get diploma (*diploma*) and go outside the model. At the same time, new generation of high school graduates (*new_graduate*) enters the model.

Initial values for stocks are taken for the year 2010. Values for constant parameters are either taken for the year 2010 or calculated as an average for the period 2010-2015. Some parameters which change more dynamically, like number of new graduates every year, are presented with their linear interpolation formula.

Parameters of interest for potential human resource decision maker are how many graduates are interested in application (*total_application* parameter) and indirectly how many applicants are motivated for TF, so they put it as a first choice in their applications (*first_choice* parameter). In this model those are key parameters and their results highlighted.

Model verification is conducted with comparison of historical to simulated data of parameters *total_application* and *first_choice* in years 2016-2021. Relative errors and mean squared errors are calculated:

$$e_t = \frac{|(y_t' - y_t)|}{y_t} \qquad (2)$$

$$\text{MSE} = \sqrt{\frac{\sum_1^n e_t^2}{n}} \qquad (3)$$

Here y_t represents the observed (historical) number in the year t, y_t' represents simulated number in the year t, e is the relative error and MSE is the mean of relative error squares. For model verification MSE<0.1 is acceptable [22].

The systems dynamics model is built with AnyLogic software (AnyLogic PLE ver. 8.7.10, AnyLogic North America, USA). Results are presented and data analyzed with Statistica (Statistica 13.5.0.17, TIBCO Software Inc., USA) and Excel (Office 365, Microsoft Corporation, USA).

4. Results and Discussion

The output of the models' parameter *total_application* is presented with corresponding observed data in Table 2., as well as relative error for each year, and overall mean squared error. MSE<0.1 denotes that the model represents good enough the real behavior of total number of applications to teacher faculties by high school graduates in Croatia.

Data is presented graphically in Figure 4., showing matching of general trends for simulated and observed data.

Table 2. Observed (historical) and simulated data of TF total applicants

Year	Observed	Simulated	Relative error (2)
2016	5446	5926	0.88
2017	4831	5401	0.118
2018	4302	4875	0.133
2019	3996	4350	0.089
2020	3559	3824	0.074
2021	3098	3299	0.065
	MSE (3)		0.097

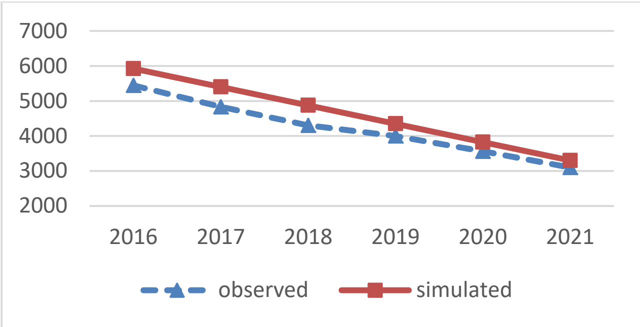

Figure 4. Observed and simulated number of TF total applicants

The first remark imposed from the data is significant decline in interest for the enrollment to teacher education programs. Such results can be explained by frequent reports by Croatian Employment Service which cite a surplus of teachers [1], so high school graduates find it unattractive as a future career path.

Another explanation can be related to low wages of teaching personnel in Croatia, that is the well-known fact, therefore such a drastic decline in freshmen enrollment is unexpected. Future research is needed for relevant explanation of such results. Nevertheless, the results call for revision of the enrollment policies by educational authorities.

The output of the second observed parameter, models' parameter *first_choice*, is presented with corresponding historical data in Table 3., with relative error for each year, and MSE. As MSE<0.1, we conclude that outputs for number of graduates who choose teacher faculties as their first choice is within acceptable accuracy.

Table 3. Observed (historical) and simulated data of TF first-choice applicants

Year	Observed	Simulated	Relative error (2)
2016	1631	1642	0.007
2017	1488	1496	0.005
2018	1354	1350	0.003
2019	1250	1205	0.036
2020	1101	1059	0.038
2021	1187	914	0.230
	MSE (3)		0.096

Corresponding graphical representation is in Figure 5. In year 2021 there is a significant gap from simulated observed data. It should be noted that the real data shows a significant shift from the trend established in the data series.

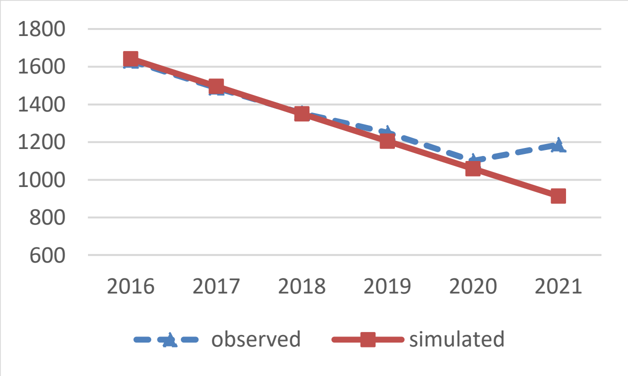

Figure 5. Observed and simulated number of TF first-choice applicants

The behavior of the parameter *first_choice* is expected in the same manner as the *total_application*, as results shows. Number of first-choice applicants are 3-5 time less then total applicants, so change in numbers for couple of hundreds could show as a significant deviation. Explanation of such fluctuations could be in a various reason and is outside the scope of this paper.

After establishing functional model from historical data, the next step is a forecast about future period obtained from simulation. According to the model, by the year 2025 there will be radical down-size of both total applicants and first-choice applicants to TF, as shown in Table 4.

Table 4. Forecast of TF applicants by the year 2025

Year	2022	2023	2024	2025
Simulated TF total applicants	2773	2248	1722	1197
Simulated TF first-choice applicants	768	623	477	331

Nevertheless, such scenario is not to be expected because of the complexity and many causal loops in real education system. This model is reproduction of present conditions and a tool for learning the system how certain parameters change in such environment. The model is made with assumptions the system would not change and didn't consider radical changes in policies which could change the trends. In that case, the model structure is to be redesigned and other parameters added.

Additional parameters are included in the model based on the Bass Diffusion [21] model, which influences a number of applicants: word of mouth (*wom*, *wom-rate*, *adoption_rate*) and attractiveness of study (*study_attr*). Word of mouth is an internal motivation factor of becoming a teacher, and factor of influence of family, friends, personal positive experience with teachers, etc. Attractiveness of the study at TF is external motivation factor and includes salary of the future job, availability of vacant job positions, the difficulty and complexity of the study, conditions at faculty, etc. All these elements together determine the number of applicants at TF. This can be referred as the bottom-to-top approach. In order to determine the numeric value of such inexplicit factors, the top-to-bottom approach can be applied: the model presented in this paper is built on historical data and behavior of added parameters can be observed based on modelled outputs. Additional research can be conducted to determine the value of specific parameters and consequently to refine the model.

5. Conclusion

An estimation of needed faculties capacities to fulfill the demand for number of professionals in the educational system conducted by educational authorities is usually based on static models, statistics, student-teacher ratio etc. There are also efforts to implement more complex analysis for systemic approach to enrollment policies planning and in that manner the system dynamics is appropriate modeling method. In this paper, the model of students' enrollment in teacher education faculties in Croatia is presented. The model is built with historical data from years 2010-2015 and verified with data from years 2016-2021. The purpose of the model is to show the need for more complex analysis and systemic approach to higher education enrollment policies, as a prerequisite for forecasting and planning activities.

Results of this model are showing a significant decline of interest in enrollment at Croatian faculties of teacher education. On the other hand, results stress the importance for serious introspection by educational authorities and how they can support teacher education faculties to make teacher education programs more attractive, with the ultimate goal to prevent possible future shortage of teachers in primary education.

Regarding the model, further research is needed for detailed classification and evaluation of parameters. The results are significant and can support decision-making in the enrollment policy of teacher education faculties. The SD modelling has proven to be useful method for achievement of such support.

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